GEOLOGICAL SURVEY OF CANADA
COMMISSION GÉOLOGIQUE DU CANADA

PAPER 80-35

LATE QUATERNARY GEOLOGY AND GEOCHRONOLOGY OF BRITISH COLUMBIA

Part 2: Summary and Discussion of Radiocarbon-Dated Quaternary History

JOHN J. CLAGUE

Canada

1981

PAPER 80-35

LATE QUATERNARY GEOLOGY AND GEOCHRONOLOGY OF BRITISH COLUMBIA

Part 2: Summary and Discussion of Radiocarbon-Dated Quaternary History

JOHN J. CLAGUE

1981

Available in Canada through

authorized bookstore agents
and other bookstores

or by mail from

Canadian Government Publishing Centre
Supply and Services Canada
Hull, Québec, Canada K1A 0S9

and from

Geological Survey of Canada
601 Booth Street
Ottawa, Canada K1A 0E8

A deposit copy of this publication is also available
for reference in public libraries across Canada

Cat. No. M44-80/35E Canada: $4.00
ISBN – 0-660-10928-X Other countries: $4.80

Price subject to change without notice

Author's Address

Cordilleran Geology Division
100 West Pender Street
Vancouver, B.C. V6B 1R8

Original manuscript submitted: 1979-09-26
Approved for publication: 1980-10-01

CONTENTS

Figures

LATE QUATERNARY GEOLOGY AND GEOCHRONOLOGY OF BRITISH COLUMBIA

Part 2: Summary and Discussion of Radiocarbon-Dated Quaternary History

Abstract

That period of late Quaternary time in British Columbia for which there is radiocarbon dating control is subdivided into three major units: Olympia nonglacial interval (or Olympia Interglaciation), Fraser Glaciation, and the postglacial.

The Olympia nonglacial interval probably began more than 59 000 years ago. It ended with climatic deterioration and glacier growth at the onset of the Fraser Glaciation, perhaps as early as about 29 000 years ago in parts of the Western System and about 25 000 years ago in the Interior System. Glaciers apparently remained confined to the major mountain ranges throughout the Olympia nonglacial interval, and, in general, the sedimentary deposits, geomorphic framework and processes of the Olympia were similar to those of postglacial time.

The Fraser Glaciation began with a build-up of glacier ice in the Coast Mountains. Glacier growth was slow at first, with ice confined to mountainous regions until 20 000 to 25 000 years ago. The Cordilleran glacier complex attained its maximum size about 15 000 years ago. Subsequent deglaciation was rapid -- parts of the coastal lowland of British Columbia were ice free about 13 000 years ago, and the entire province probably was as free of ice as at present before 9000 years ago. During both the growth and decay phases of the Fraser Glaciation, aggradation occurred in valleys and on lowlands, drainage patterns were altered extensively, and networks of glacial lakes developed near glacier termini.

Postglacial includes the time from deglaciation until the present. The deposits of this interval formed in response to factors that generally remain active today. Extensive aggradation in river valleys during late glacial and early postglacial time was followed by degradation in most regions.

In coastal areas late glacial and postglacial time was marked by changes in the level of the sea relative to the land. Along the Vancouver Island and mainland coasts, relative sea levels were high during deglaciation due to glacio-isostatic depression of the crust. Subsequent isostatic uplift resulted in a rapid fall in sea level relative to the land, such that by 8000 to 11 500 years ago, depending on the locality, inner coastal areas became more emergent than they are at present. Although these areas remained emergent until recently, deviations in sea level from the present during the last 5500 years have been relatively minor. In contrast, sea levels on the outer coast (i.e., Queen Charlotte Islands and western Vancouver Island) during middle and late postglacial time were relatively higher than at present. Differences between the sea level histories of the inner and outer coasts are due in part to differential diastrophic effects and in part to differences in the timing and magnitude of the isostatic response to deglaciation.

The climate immediately following the Fraser Glaciation was cool and moist. In some areas there were minor resurgences of remnant Pleistocene glaciers during early postglacial time. The climate gradually ameliorated, however, and probably was as warm as or warmer than the present from 8000 to 10 500 years ago until at least 6600 years ago (and perhaps much later). This warm interval was followed in most regions by a generally cooler moister period which has persisted until present. During this cool interval, advances of alpine glaciers occurred between about 2300 and 3100 years ago, within the last several centuries, and perhaps between 4000 and 5000 years ago.

Seven dated postglacial tephras have been recognized in British Columbia. From oldest to youngest, these are: Mazama, about 6600 years old; St. Helens Yn, 3300 to 3500 years old; Bridge River (older layer), 2300 to 2400 years old; St. Helens P (?), somewhat older than 2100 years; Bridge River (younger layer), 1900 to 2000 years old; Edziza, about 1350 years old; and St. Helens Wn, about 450 years old. In addition, Glacier Peak layer G, approximately 12 750 years old; Edgecumbe (?) tephra, probably 9000 to 11 000 years old; and White River tephra, approximately 1200 years old, may occur in British Columbia, although they have not been identified there.

Résumé

En Colombie-Britannique, la fin du Quaternaire, pour laquelle il existe une datation au radiocarbone, se divise en trois unités principales: l'intervalle interglaciaire d'Olympia (ou interglaciation d'Olympia), la glaciation du Fraser, et période postglaciaire.

L'intervalle interglaciaire d'Olympia a probablement commencé il y a plus de 59 000 ans. Il s'est terminé avec un refroidissement du climat et l'avance des glaciers, au début de la glaciation de Fraser, peut-être il y a 29 000 ans dans les régions occidentales et il y a 25 000 ans environ dans l'intérieur. Les glaciers semblent avoir été confinés aux grandes chaînes de montagnes pendant l'intervalle interglaciaire d'Olympia et, en général, les sédiments, l'encadrement morphologique et les processus de l'Olympia étaient similaires à ceux du temps postglaciaire.

La glaciation Fraser a commencé avec l'accumulation de glace de glacier dans la chaîne côtière. La croissance de glacier a d'abord été lente, la glace étant confinée aux zones montagneuses jusqu'à il y a 20 000 à 25 000 ans. Le complexe glaciaire de la Cordillère a atteint son extension maximale il y a 15 000 ans environ. La déglaciation qui a suivi a été rapide: certaines basses-terres côtières de la Colombie-Britannique étaient peut-être déjà dégagées il y a 13 000 ans et toute la province l'était probablement autant qu'aujourd'hui il y a plus de 9 000 ans. Tant durant l'avance que durant le recul des glaciers de Fraser, des alluvions se sont déposées dans les vallées et les basses-terres, le réseau hydrographique a été boulversé, et des réseaux de lac glaciaires sont apparus près de l'extrémité des glaciers.

Le temps postglaciaire dure depuis le début de la déglaciation. Les sédiments se sont déposés pendant cette période se conformant à des phénomènes qui restent généralement actifs aujourd'hui. D'importants dépôts alluvionnaires ont eu lieu dans les vallées au cours de la dernière glaciation et au début du temps postglaciaire; ils ont été suivis d'une action érosive dans la plupart des régions.

Dans les régions côtières, la fin de la période glaciaire et la période postglaciaire ont été marquées par des changments relatifs du niveau de la mer par rapport à la terre. Le long de l'île de Vancouver et des côtes du continent, le niveau de la mer était plus élevé pendant la déglaciation, à cause de l'abaissement glacio-isostatique de la croûte terrestre. Le soulèvement isostatique ultérieur a entraîné l'abaissement rapide du niveau de la mer par rapport à la terre, au point que certaines côtes continentales émergeaient plus il y a 8 à 11 500 ans qu'à l'heure actuelle. Bien que ces régions soient restées émergées jusqu'à très récemment, le niveau de la mer a assez peu varié depuis 5 500 ans. Par contre, le niveau de la mer des côtes insulaires (archipel de la Reine Charlotte et côte ouest de l'île Vancouver) étaient relativement plus élevés au cours du temps postglaciaire moyen et supérieur qu'aujourd'hui. Les différences entre la variation du niveau de la mer sur les côtes continentales et sur les côtes insulaires sont dues, en partie, aux effets diastrophiques différentiels et en partie aux différences dans le temps et de l'amplitude de la réaction isostatique à la déglaciation.

Le climat qui a suivi immédiatement la glaciation de Fraser était froid et humide. Il y a eu d'abord quelques résurgences des restes de glaciers pléistocènes dans certaines régions, mais le climat s'est réchauffé progressivement et était probablement aussi chaud ou méme plus chaud que maintenant il y a 8 000 ou 10 500 ans jusqu'à 6 600 ans (et peut-être même plus tard). Ce temps chaud était suivi dans la plupart des régions par une période plus froide et plus humide et qui a persisté jusqu'à aujourd'hui. Au cours de cet intervalle froid, les glaciers alpins ont avancé il y a environ 2 300 à 3 100 années, au cours des derniers siècles et, peut-être il y a 4 000 à 5 000 ans.

On a reconnu en Colombie-Britannique sept téphras postglaciaires datés. Du plus ancien au plus récent ce sont: Mazama, il y a environ 6 600 ans; St. Helens Yn, il y a 3 300 à 3 500 ans; Bridge River (couche ancienne) il y a 2 300 à 2 400 ans; St. Helens P (?), il y a un peu plus que 2 100 ans; Bridge River (couche récente), il y a 1 900 à 2 000 ans; Edziza, il y a 1 350 ans environ; et St. Helens Wn, il y a 450 ans environ. De plus, la couche G du Glacier Peak il y a environ 12 750 ans; téphra d'Edgecumbe (?), probablement 9 000 à 11 000 ans; et le téphra de White River, âgé de 1 200 ans environ, peuvent être présents en Colombie-Britannique, bien qu'ils n'aient pas encore été trouvés dans cette région.

INTRODUCTION

The "Radiocarbon Geochronology of Southern British Columbia" (Fulton, 1971) provides a summary of the radiocarbon-dated Quaternary history of southern British Columbia and a compilation of most radiocarbon dates of geologic significance published before 1971. Since the publication of this important paper, much new information has been gathered on the Quaternary of British Columbia. A larger number of radiocarbon determinations is now available, resulting in a corresponding improvement in the chronology of geologic events of late Quaternary age.

In this paper the late Quaternary geology of British Columbia is summarized within a radiocarbon-dated framework consisting of three major geologic-climate units: Olympia nonglacial interval (or Olympia Interglaciation), Fraser Glaciation, and the postglacial. Each unit forms a major section of the paper within which physiographic and geologic-climate subheadings are utilized to simplify discussion and to group geographically and geologically related dates. Physiographic subdivisions used in the text and shown in Figure 1 are those of Holland (1964).

Radiocarbon dates cited in the text, as well as other dates of geologic significance published prior to 1980 are summarized in a series of tables in Clague (1980). All cited age determinations are in radiocarbon years based on the original ('Libby') half life of 5570 ± 30 years. No attempt has been made to change radiocarbon ages to calendar ages because of the questionable appropriateness of doing so and because of uncertainties in available charts relating radiocarbon and calendar age. Readers who wish to correct radiocarbon ages for variations in past atmospheric radiocarbon activity are referred to the calibration charts and tables of Stuiver and Suess (1966), Olsson (1970), Suess (1970), Damon et al. (1972, 1974), Michael and Ralph (1974), and Stuiver (1978). These calibration charts have been prepared by radiocarbon dating large numbers of tree-ring samples of known dendrochronologic age. The accuracy of the radiocarbon method also has been evaluated from dated varved sediments (e.g., Buddemeier, 1969; Stuiver, 1970, 1971; Tauber, 1970; Yang, 1971; Yang and Fairhall, 1972) and by comparison with other radiometric dating techniques (e.g., Peng et al., 1978; Stuiver, 1978). All these studies have shown that the ratio of ^{14}C to ^{12}C in atmospheric CO_2 has undergone significant change in the past, thus radiocarbon ages calculated on the assumption of constancy of this ratio may vary substantially from the 'true' ages of dated materials.

Acknowledgments

Marcia Ruby and Sally Topham assisted in the compilation of radiocarbon dates utilized in this paper, and their help is gratefully acknowledged. R.N.W. DiLabio and R.J. Fulton read and commented on an early version of the paper.

THE FRAMEWORK OF LATE QUATERNARY GEOLOGIC-CLIMATE UNITS IN BRITISH COLUMBIA

The geologic-climate framework employed in this paper is a synthesis of work published by many Quaternary geoscientists over the past 30 years. This framework has evolved over this period and undoubtedly will be refined further as additional information becomes available; however, its basic elements are now well established and thus can be used for grouping and discussing radiocarbon dates. Readers interested in the details of Quaternary stratigraphy and stratigraphic nomenclature in British Columbia should examine many of the papers listed in the Reference section (e.g., Fyles, 1963; Armstrong et al., 1965; Armstrong, 1975a, b, 1976, 1977a, b, 1981; Armstrong and Hicock, 1975, 1976; Clague, 1975c; Fulton, 1975a, b, 1976; Tallman, 1975; Miller, 1976; Rutter, 1976, 1977; Ryder, 1976, in press (a), in press (b); Armstrong and Clague, 1977; Fulton and Smith, 1978; Mathews, 1978; Alley, 1979; Hicock, 1980).

That period of late Quaternary time for which there is radiocarbon dating control is subdivided into: (1) an early interval during which nonglacial conditions prevailed over most of British Columbia, (2) a middle interval dominated by glacial environments and climates, and (3) a late interval during which nonglacial conditions again prevailed. These are respectively the Olympia nonglacial interval*, the Fraser Glaciation, and the postglacial. During each of these intervals, characteristic suites of sediments were deposited and distinctive landforms developed; thus, late Quaternary stratigraphic units in British Columbia are closely tied to the above geologic-climate framework.

Current nomenclature applied to major late Quaternary lithostratigraphic units and to subdivisions of the Fraser Glaciation in various parts of the province and bordering regions is summarized in Figure 2. Although Fraser Glaciation sediments in some areas have been subdivided into lower order stratigraphic units and events of stadial-interstadial rank have been recognized, no attempt yet has been made to formally define lithostratigraphic and geologic-climate subunits of the Olympia nonglacial interval and the postglacial.

DATES BEYOND RADIOCARBON RANGE

"Greater-than" radiocarbon dates range from >11 600 years (I-2244A, Mathews, 1978, p. 17) to >62 000 years (QL-194, Lowdon and Blake, 1978, p. 9). The chronostratigraphic significance of many of these dates is in doubt because they represent only minimum ages of dated materials.

Most of the dates beyond the radiocarbon range are from nonglacial deposits overlain by a single till, the latter presumably deposited during the Fraser Glaciation. In such cases, the dated sediments are thought to have been deposited during the early part of the Olympia nonglacial interval. Support for this supposition is provided by the fact that in the Georgia Depression** of southwestern British Columbia sediments dated at beyond the radiocarbon range lie with apparent conformity beneath sediments containing organic material of finite Olympia age (e.g., Fyles, 1963, p. 38; Dyck et al., 1965, p. 37).

It is possible, however, that some of the dated stratified sediments underlying a single till may have been deposited during an interstade or interglaciation preceding the Olympia. For example, it is conceivable that Fraser Glaciation ice locally may have eroded Olympia-age sediments and juxtaposed across an unconformity Fraser Glaciation drift and pre-Olympia stratified sediments. Alternatively, the single till at these sites may have been deposited during a glaciation preceding the Olympia nonglacial interval. This latter possibility is considered unlikely, however, because the dated sites are in areas known to have been glaciated during the Fraser Glaciation, and because the till is at or near the land surface and is present over large areas without a cover of Olympia-age sediments. Where sediments overlie this till, they invariably are either postglacial or late Fraser Glaciation in age.

The oldest date beyond the radiocarbon range from sediments beneath a single till is >51 000 years (GSC-94-2, Fulton and Halstead, 1972, p. 9). This date was obtained on wood in a marine diamicton on southeastern Vancouver Island. The dated sediments, which likely were deposited during the transition from the penultimate (pre-Fraser) glaciation to the Olympia nonglacial interval (Armstrong and Clague, 1977, p. 1479), are overlain with apparent conformity by Olympia sediments of finite radiocarbon age. The latter, in turn, are overlain progressively by outwash, till, and glaciomarine sediments, all deposited during the Fraser Glaciation. Thus, the stratigraphic relationships at this site indicate that the Olympia nonglacial interval began more than 51 000 years ago. One older radiocarbon date ($58\,800\ ^{+\,2900}_{-\,2100}$ years, QL-195, Clague, 1977a, p. 15), however, has been obtained on what are thought to be sediments of the Olympia nonglacial interval, thus possibly extending the beginning of the Olympia even farther back in time.

* The "climatic episode immediately preceding the last major glaciation" originally was termed the Olympia Interglaciation (Armstrong et al., 1965, p. 324). Later, Hansen and Easterbrook (1974, p. 598) argued on the basis of lithostratigraphic and palynologic evidence from Puget Lowland, Washington, that the Olympia was of insufficient length and its climate too cool to justify the formal appelation "interglaciation". However, in British Columbia at least, the Olympia persisted far longer than the present nonglacial climatic episode which is generally considered to be an interglaciation rather than an interstade.

Perhaps of greater importance is the character of the Olympia climate. An interglaciation is characterized by a climate similar to that of the present, that is, one incompatible with the wide extent of glaciers in North America and Europe as is characteristic of glacial episodes. Although not enough is known of the climate of British Columbia during Olympia time, there is evidence that it was similar to that of the present for at least part of this interval (e.g., Clague, 1978a; Alley, 1979). Furthermore, it appears that at no time during the Olympia did glaciers occupy lowland areas in British Columbia.

On a global scale, however, the climate during Olympia time apparently was sufficiently cool for ice sheets to exist on parts of Scandinavia and northeastern Canada (e.g., Dreimanis and Raukas, 1975; Andrews and Barry, 1978); therefore it can be argued that the Olympia interval should be of interstadial rather than interglacial rank.

In this paper the more informal and perhaps less controversial term "Olympia nonglacial interval" is used in preference to both "Olympia Interglaciation" and "Olympia Interstade". It is possible, however, that as our understanding of Olympia climatic conditions improves, we will be in a better position to decide whether the interval is more appropriately identified as interglacial or interstadial.

** Place names cited in the text are located in Figure 1.

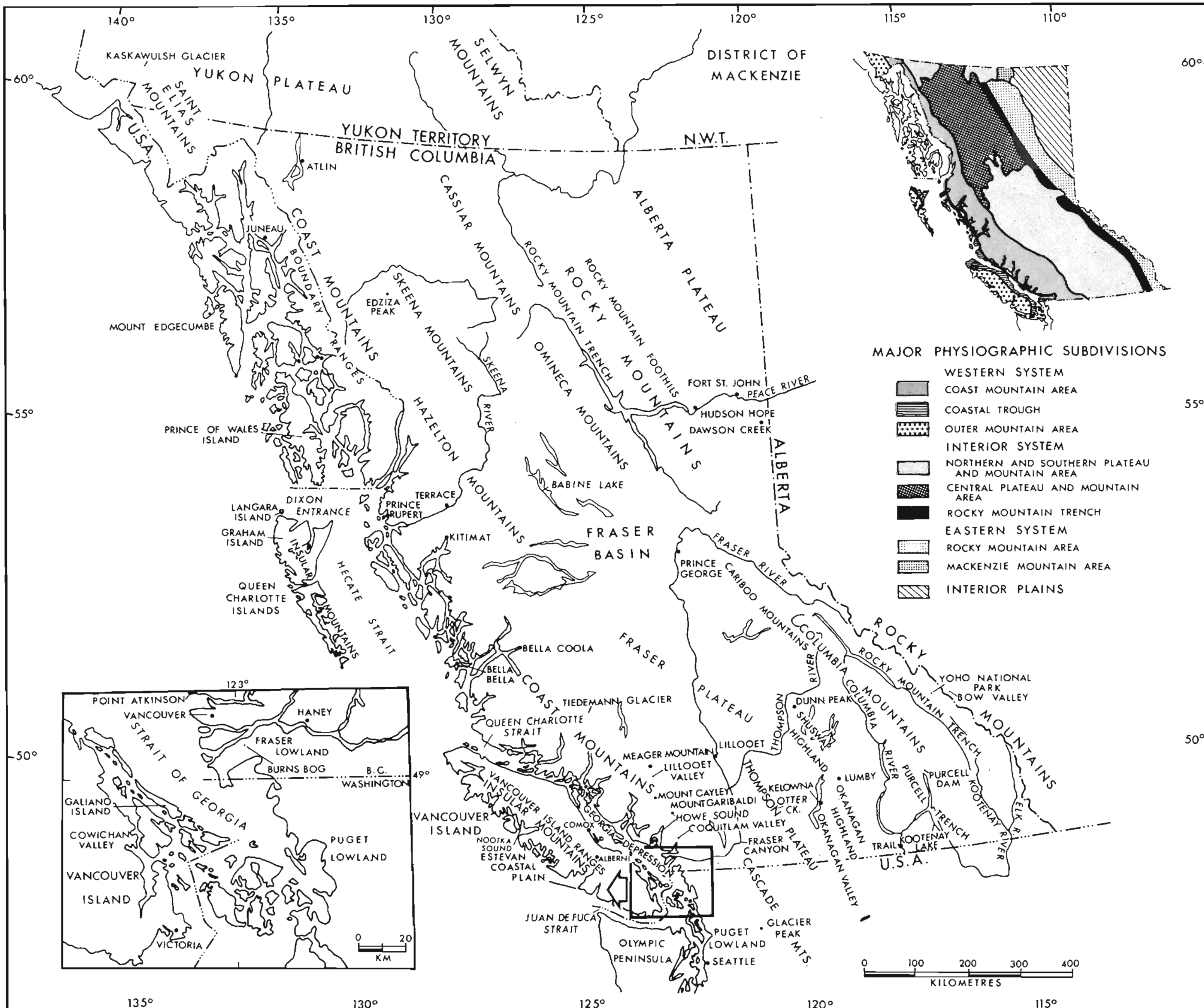

Figure 1. Map of British Columbia and adjacent regions showing place names cited in the text. Major physiographic subdivisions of British Columbia (after Holland, 1964) are delineated on the small-scale inset map.

Dates beyond the radiocarbon dating range also have been obtained on sediments underlying two or more tills. In such cases the dates are of limited value in correlating and identifying stratigraphic units. Because these sediments presently are poorly dated and are exposed in only a fragmentary fashion at scattered localities, little is known of their age, origin, and regional relationships. The little that is known is based on studies of pre-Olympia deposits in the southern Interior System (Fulton, 1975a, b, 1976; Fulton and Smith, 1978) and in the Georgia Depression (Fyles, 1956, 1963; Armstrong, 1975a, b, 1977a, b; Armstrong and Hicock, 1975, 1976; Hicock, 1980).

OLYMPIA NONGLACIAL INTERVAL

The Olympia nonglacial interval is the time preceding the last major glaciation in British Columbia when intermontane valleys, basins, plateaus, and coastal lowlands were largely free of glacier ice. Extensive deposits of Olympia age occur in the lowlands of the Georgia Depression and in many valleys in southern British Columbia. In addition, deposits of limited or unknown areal extent at scattered localities elsewhere in British Columbia have yielded finite Olympia radiocarbon ages.

Western System

Most finite radiocarbon dates on deposits of the Olympia nonglacial interval are from the Georgia Depression, an elongate basin located between the Coast Mountains of mainland British Columbia and the Vancouver Island Ranges. Thick unconsolidated sediments underlie much of the lowlands bordering the Strait of Georgia and provide a detailed record of the late Quaternary environments and geomorphic history of the region.

Cowichan Head Formation

Sediments of the Olympia nonglacial interval in the Georgia Depression are included in the Cowichan Head Formation (Fig. 2; Armstrong and Clague, 1977). Reliable finite radiocarbon dates from this unit range from $23\,600 \pm ^{2100}_{1500}$ to 40 500 ± 1700, and possibly $58\,800 \pm ^{2900}_{2100}$ years (no laboratory number, Anderson, 1968, p. 427; GSC-2167, Armstrong and Clague, 1977, p. 1478; QL-195, Clague, 1977a, p. 15).

The Cowichan Head Formation consists of fluvial, estuarine, and marine silt, sand, and gravel. Armstrong and Clague (1977) subdivided the formation into a lower marine member consisting mainly of clayey silt and sand and an upper estuarine and fluvial member comprising gravel and sandy silt, in general rich in fossil plant remains.

The Cowichan Head Formation commonly is underlain by glaciomarine, glaciolacustrine, and glaciofluvial sediments, which in turn are underlain by till. The sequence apparently is conformable and records the transition from glacial conditions of the penultimate glaciation to nonglacial conditions of the Olympia nonglacial interval. As glaciers retreated from the Georgia Depression at the close of the penultimate glaciation, glaciomarine, glaciolacustrine, and glaciofluvial sediments were deposited on the isostatically depressed lowlands. With the complete disappearance of glacier and drift ice from southwestern British Columbia, glacigene sedimentation was succeeded by marine, estuarine, and fluvial sedimentation in a physiographic setting similar to that characterizing the area at present. Thus, rivers and streams flowed across the isostatically uplifted lowlands and into the sea. Channel and overbank sediments were deposited on floodplains and along stream courses; deltaic, lagoonal, and littoral sediments accumulated in coastal areas; and marine muds were deposited in offshore areas.

These environments changed spatially through time. For example, as the Olympia nonglacial interval progressed, sea areas became progressively more restricted in the Georgia Depression due to isostatic and possibly diastrophic uplift and to the influx of sediments into the basin from the adjacent mountains. Thus, marine sediments were overlain by estuarine and fluvial deposits as terrestrial lowland areas expanded at the expense of the sea. The common occurrence of Olympia-age estuarine and fluvial silt and gravel overlying marine mud and sand is the basis for the subdivision of the Cowichan Head Formation into two members.

The Cowichan Head Formation is overlain by thick, cross-stratified, well sorted sand, termed "Quadra Sand" by Clague (1976a, 1977a). Clague interpreted the sand to be outwash deposited during the transition from nonglacial to glacial conditions at the beginning of the Fraser Glaciation. Fyles (1963) included the sand in his "Quadra sediments", an informal lithostratigraphic unit comprising all sediments deposited during the Olympia nonglacial interval. In contrast, Clague (1976a, 1977a) and Armstrong and Clague (1977) emphasized the glaciofluvial origin of Quadra Sand and thus grouped it with other drift deposits of the Fraser Glaciation. Accordingly, they considered the Cowichan Head Formation to be the only unit deposited during the Olympia nonglacial interval.

Paleoclimate

Published information on climatic conditions during the Olympia nonglacial interval in coastal southwestern British Columbia and northwestern Washington has been summarized by Clague (1978a) and Alley (1979). Fyles (1963, p. 28) concluded that eastern Vancouver Island was forested, at least in part, and that the climate during part of the Olympia interval was somewhat cooler than at present. Gascoyne (1980) and Gascoyne et al. (1980) likewise considered the Olympia climate to be cooler than that of the present. On the basis of oxygen isotope fractionation in speleothems dated by uranium-series methods, they proposed that cave temperatures near Alberni on Vancouver Island decreased 4°C between about 64 000 and 28 000 years ago. This temperature decrease was attributed to gradual climatic deterioration during the Olympia nonglacial interval. Alley (1976a, 1979) examined fossil pollen spectra of the Cowichan Head Formation on eastern and southern Vancouver Island and concluded that lowland vegetation and climates from before 51 000 to about 29 000 years ago were broadly similar to the present. Finally, Armstrong and Clague (1977, p. 1477-1478) reported on fossil beetle and pollen assemblages from the Cowichan Head Formation and stated that the Olympia climate was at times similar to, and at times cooler than the present.

Palynological data obtained from late Quaternary sediments in northwestern Washington State bear on the paleoclimatic conditions in nearby southwestern British Columbia. For example, Florer (1972) and Heusser (1972, 1977) compared modern and radiocarbon-dated fossil pollen assemblages on Olympic Peninsula and concluded that during the Olympia nonglacial interval average July temperatures near the coast were 8 to 13°C – 2 to 7°C colder than at present (e.g., Heusser, 1977, p. 299-301). Heusser argued that the climate fluctuated within the Olympia interval; cold periods with temperatures comparable to those of the Fraser Glaciation maximum alternated with periods of relative warmth during which temperatures approached those of the present. Similar conclusions were reached by Hansen and Easterbrook (1974) on the basis of palynological investigations in Puget Lowland east of the Olympic Mountains and south of the Georgia Depression. Hansen and Easterbrook (1974, p. 593) and Easterbrook (1976a, p. 90; 1976b, p. 447-448) also proposed that Puget Lowland was occupied by glaciers during part of Olympia time.

It is difficult to reconcile the above evidence for the existence of glacial climatic conditions during parts of the Olympia interval in northern Washington both with the palynological evidence that Olympia climates were similar to, or slightly cooler than those present on Vancouver Island and with the absence of coeval glacial events in lowland areas throughout southern British Columbia. It is possible that intervals of extreme cold were too brief to lead to significant glaciation in the Cordillera. There remains an incompatibility, however, between the paleoclimatic interpretations based on palynostratigraphic studies in Washington and British Columbia. It seems probable that the Olympia-age temperature reductions estimated by Heusser (1972, 1977) and Hansen and Easterbrook (1974) are too large and that the lithostratigraphic evidence for glaciation during the Olympia interval in Puget Lowland is invalid (see also Fulton et al., 1976).

Interior System

Radiocarbon-dated sediments of Olympia age occur in several valleys in south-central and southeastern British Columbia and in the northern Rocky Mountain Trench and at Babine Lake in the northern Interior System.

South-Central British Columbia

Bessette Sediments

Sedimentary deposits of the Olympia nonglacial interval in south-central British Columbia are included in the Bessette Sediments (Fulton, 1975a, b, 1976; Fulton and Smith, 1978). Finite radiocarbon dates from this unit range from 19 100 ± 240 to 43 800 ± 800 years (GSC-913, Lowdon and Blake, 1970, p. 72; GSC-740, Lowdon and Blake, 1968, p. 224).

At two sites in southern British Columbia there are radiocarbon-dated exposures of Bessette Sediments that span long periods of time (Fulton, 1968, 1975b; Fulton and Smith, 1978; Alley et al., in press). A sequence exposed at the Duncan Dam borrow pit in the Purcell Trench dates from 25 840 ± 320 to 43 800 ± 800 years old (GSC-715 and GSC-740, Lowdon and Blake, 1968, p. 224-225). This sequence has been correlated by tephrochronology with sediments exposed along Bessette Creek east of Lumby (Westgate and Fulton, 1975). Bessette Sediments at the latter site, the type locality for the unit, range in age from 19 100 ± 240 to more than 31 200 ± 900 years old (GSC-913, Lowdon and Blake, 1970, p. 72; GSC-2031, Westgate and Fulton, 1975, their Table 2). The date of 19 100 ± 240 years is of considerable importance in that it defines the age of the contact between floodplain deposits of the Bessette Sediments and overlying laminated lacustrine sediments of the Kamloops Lake Drift (Fig. 2). The change from a fluvial to a lacustrine environment at Bessette Creek is thought to be due to disruption of the regional drainage pattern by glaciers advancing south across the southern Interior System during the Fraser Glaciation (Fulton, 1971, p. 8).

Bessette Sediments are underlain by Okanagan Centre Drift, deposited during the glaciation immediately preceding the Olympia nonglacial interval, and are overlain by Kamloops Lake Drift deposited during the Fraser Glaciation (Fig. 2).

Bessette Sediments formed within a geomorphic framework similar to that in south-central British Columbia today – "large valleys filled in part by sediments and in part by lakes, set between hilly upland or mountain blocks" (Fulton, 1971, p. 5). As they are at present, sedimentation patterns during the Olympia nonglacial interval were complex. A variety of fluvial and organic sediments were deposited in the channels of small streams and on floodplains,

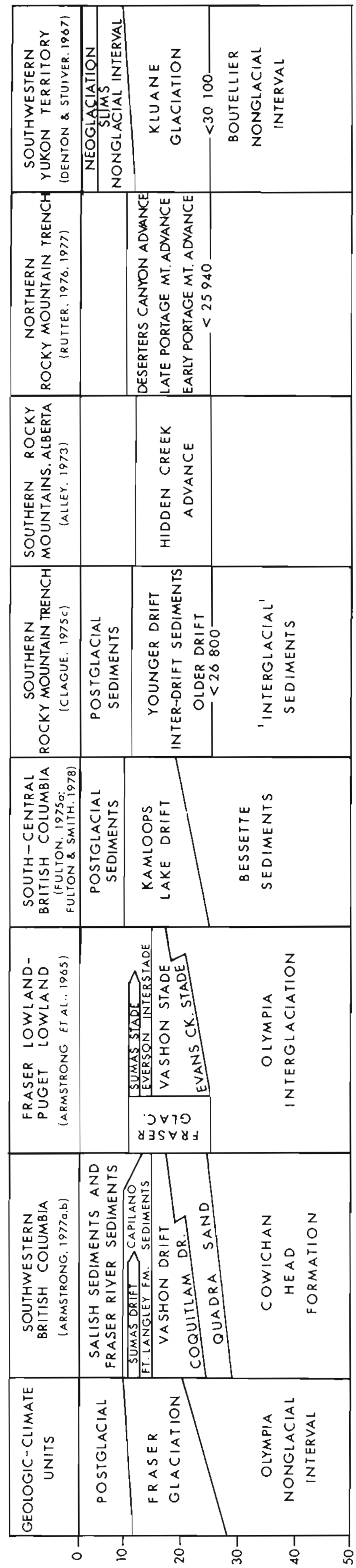

Figure 2. *Subdivisions of late Quaternary deposits and events in British Columbia and adjacent regions.*

and soil and colluvium developed on slopes bordering floodplains. Fans and deltas were built out into valleys and lake basins.

Bessette Sediments from widely separated localities in southern British Columbia have been correlated using tephrochronology (Westgate and Fulton, 1975). Ten distinct thin fine grained rhyolitic tephras have been recognized, and each serves as a valuable isochronous stratigraphic marker. In order of increasing age these tephras are: Rialto Creek, about 20 000 years old; Cherryville, about 25 000 years old; Riggins Road, about 30 000 years old; Duncan Lake, about 34 000 years old; Dufferin Hill and Sweetsbridge, probably close in age to Duncan Lake tephra; Kamloops Lake, slightly older than 34 000 years; Mission Flats, probably older than 35 000 years; and Coutlee, older than 37 000 years; the age of Okanagan Centre tephra is unknown. The source area of all these tephras is the Cascade Mountains of the Pacific Northwest; many probably were derived from Mount St. Helens in Washington (Westgate and Fulton, 1975, p. 500).

Paleoclimate

Fossil animal and plant remains from Bessette Sediments suggest that the climate in south-central British Columbia during much of the Olympia nonglacial interval was not significantly different from that at present (Fulton, 1975a; Alley and Valentine, 1977; Alley et al., in press). For example, during at least part of the Olympia, the climate was sufficiently warm and humid to support large vertebrates such as **Equus** sp., **Equus** cf. **conversidens**, **Bison** sp., and **Mammuthus** cf. **columbi** (Fulton, 1975a, p. 16-17). Leaf impressions, wood fragments, and molluscs also suggest climatic conditions similar to the present. Palynological analyses of Bessette Sediments at the Duncan Dam borrow pit and at the type locality at Bessette Creek suggest that: (1) the climate was similar to or warmer than that at present in south-central British Columbia between about 25 000 and 42 000 years ago; (2) major climatic deterioration accompanying the onset of the Fraser Glaciation began about 25 000 years ago, but a full glacial climate was not attained until about 19 000 years ago (Alley and Valentine, 1977; Alley et al., in press).

Available evidence suggests that, whereas the climate during the Olympia nonglacial interval in south-central British Columbia was for the most part similar to the present, the Olympia climate in coastal southwestern British Columbia and northwestern Washington was somewhat cooler than at present. The reasons for this difference, if indeed it is real, are unknown.

Other Areas in the Interior System

Weathering zones and sediments that formed during the Olympia nonglacial interval also have been identified in the Rocky Mountain Trench, at Babine Lake, and in the Atlin region.

Rocky Mountain Trench

Nonglacial sediments that correlate with Bessette Sediments occur in the southern Rocky Mountain Trench in southeastern British Columbia and have been described by Clague (1973, 1975c). One radiocarbon date has been obtained on these sediments (26 800 ± $^{1200}_{1000}$ years, GX-2032, Clague, 1973, p. 258). Another Olympia date has been obtained from intertill stratified sediments in the northern Rocky Mountain Trench (25 940 ± 380 years, GSC-573, Lowdon et al., 1971, p. 298-299). These latter sediments have been described by Rutter (1976, 1977).

Babine Lake

Wood from organic-rich silt at Babine Lake in central British Columbia has yielded dates of 42 900 ± 1860 and 43 800 ± 1830 years (GSC-1657 and GSC-1687, Harington et al., 1974, p. 287). Mammoth bone in this silt was dated at 34 000 ± 690 years (GSC-1754, Harington et al., 1974, p. 287). On the basis of the palynological analysis of a single sample of the silt, Harington et al. (1974, p. 301) concluded that the site, which is presently covered by boreal forest, was in a shrub-tundra biozone at the time the sediments were accumulating. This indicates a markedly colder climate in this area about 43 000 years ago. However, additional paleobotanical work is required in central and northern British Columbia to substantiate the above conclusion.

Atlin Region

Weathering zones developed in drift in the Atlin region of northwestern British Columbia are thought by Tallman (1975) to have formed during an interstade (the Pine Creek Intraglacial) which may correlate in part with the Olympia nonglacial interval. This correlation is tenuous, however, in that radiocarbon dates of Olympia age that have been reported for the region (Miller, 1976, p. 481) are in an uncertain stratigraphic context. Tallman (1975) also suggested that a glacial event (Atlin I) occurred about 30 000 to 40 000 years ago, immediately before the Pine Creek Intraglacial. This is within the Olympia nonglacial interval as defined for southern British Columbia. Until the deposits of both the Pine Creek Intraglacial and Atlin I are better dated, however, the occurrence of a glacial event in northwestern British Columbia during Olympia time should be viewed with caution.

Interior Plains

Stratified sediments deposited before the Fraser Glaciation climax occur in the Fort St. John area near the western edge of the Interior Plains physiographic province (Mathews, 1963, 1978). A typical succession of these sediments consists of a lower unit of gravel and minor sand, overlain conformably by an upper unit of silt and clay. The sediments occupy a buried interglacial valley system of Peace River (Mathews, 1978, p. 5-6). The time involved in cutting this valley system probably was much greater than that required for Peace River to erode its postglacial trench, because postglacial Peace Valley is much smaller than the interglacial valley.

The gravel within the nonglacial succession in the Fort St. John area is similar in texture and provenance to that on the present Peace River floodplain and was deposited by the ancestral Peace River under aggrading conditions. The fine grained sediments overlying the fluvial gravel were deposited as a result of aggradation and ponding of Peace River by glaciers advancing from the east (Mathews, 1978, p. 8). The contact between these two units thus marks the transition from nonglacial to proglacial conditions accompanying a major expansion of the Laurentide Ice Sheet. The silt and clay of the upper unit are capped by till deposited when the area finally was overriden by glacier ice.

This succession of subtill stratified sediments likely was deposited during the Olympia nonglacial interval and the early part of the Fraser Glaciation. A radiocarbon date of 27 400 ± 580 years (GSC-2034, Mathews, 1978, p. 17) was obtained on a mammoth tooth from nonglacial gravel beneath a postglacial river terrace near Fort St. John. The dated sediments at this site have been correlated with gravel occurring elsewhere in the region beneath silt, clay, and till (Mathews, 1978, p. 8). Recently, however, some doubt has been cast on the validity of this correlation as a result of new radiocarbon determinations in Peace River valley west of Hudson Hope and in west-central Alberta southeast of Fort St. John. These dates, briefly discussed below, raise the possibility, but do not prove, that surface glacial deposits in the Fort St. John region predate both the Fraser Glaciation and the Olympia nonglacial interval.

A mammoth tusk, found about 13 km west of Hudson Hope in a large kame moraine marking the terminus of a major Cordilleran glacial advance or stillstand, yielded a radiocarbon date of >11 600 years* (I-2244A, Mathews, 1978, p. 17). On the basis of this date, both the kame moraine and Cordilleran glacial deposits farther east have been assigned a Fraser Glaciation age. Recently, however, a larger sample of the same tusk was dated at 25 800 ± 320 years (GSC-2859, Lowdon and Blake, 1979, p. 28). This latter date suggests, among other things, the possibility that surface Cordilleran drift east of the kame moraine was deposited during a glaciation preceding the Olympia nonglacial interval, and that parts of the Interior Plains of British Columbia were ice free during the Fraser Glaciation. The date, however, is difficult to reconcile with the nearly contemporaneous date of 25 940 ± 380 years (GSC-573, Lowdon et al., 1971, p. 298-299) from nonglacial sediments 135 km to the west and much closer to the source of Cordilleran ice. This discrepancy raises the possibility that the tusk was contaminated** or redeposited (Lowdon and Blake, 1979, p. 28).

Radiocarbon dates from sediments in a high-level lake in west-central Alberta 120 km southeast of Fort St. John also bear on the age of the last glaciation of the Interior Plains of British Columbia (White et al., 1979). A core of organic mud from this lake yielded four radiocarbon dates spanning the period from 10 740 ± 395 to >30 000 years (WAT-362 and WAT-361, White et al., 1979, p. 1873). These dates raise the possibility that this hilly area and thus, by inference, the Fort St. John region escaped overriding by Laurentide ice during the Fraser Glaciation. This supposition, however, cannot be accepted without additional field and laboratory studies because of: (1) the possibility of contamination of the dated sediments, (2) the possible presence in the core of an unrecognized stratigraphic discontinuity which might indicate a period of ice advance, and (3) the apparent youthfulness of glacial landforms at the date locality (White et al., 1979, p. 1872-1873).

In summary, the age of surface glacial deposits in the Interior Plains of British Columbia is uncertain. This, in turn, introduces doubt as to the age of stratified nonglacial sediments underlying till in the Fort St. John area. These nonglacial sediments must be better dated in order to confirm their Olympia age.

Summary

The Olympia nonglacial interval is that portion of late Quaternary time in British Columbia between the Fraser Glaciation and the penultimate glaciation. During this interval a variety of nonglacial sediments were deposited within a geomorphic framework similar to that of postglacial time. Most of these sediments accumulated in intermontane valleys, on coastal lowlands, and in offshore areas where they are still preserved.

Although there is some uncertainty regarding the climate of the Olympia nonglacial interval, temperatures probably were at times similar to, and at times cooler than those at present. Apparently, alpine glaciers at no time during the Olympia interval expanded into the plateau and lowland areas of southern and central British Columbia.

Climatic deterioration marking the transition from the Olympia nonglacial interval to the Fraser Glaciation probably occurred over a period of several thousand years. This climatic change was accompanied by increased sediment production in mountain areas, leading to aggradation along most rivers and streams. This period of fluvial aggradation at the close of the Olympia nonglacial interval and during the early Fraser Glaciation was preceded by a period during which most fluvial systems in British Columbia were either stable or degrading, much as they are at present.

FRASER GLACIATION

The Fraser Glaciation is the last major glaciation of British Columbia, during which ice covered most of the province. In the Puget Lowland and in the Strait of Georgia region, the Fraser Glaciation is subdivided into several lower order, geologic-climate units, including the Evans Creek Stade, Vashon Stade, Everson Interstade, and Sumas Stade (Armstrong et al., 1965). Several lithostratigraphic units have been established which broadly correlate with these geologic-climate units (Fig. 2)

In south-central British Columbia none of the above units have been recognized. Instead, all deposits of the Fraser Glaciation are included in a single lithostratigraphic unit, Kamloops Lake Drift. At a few localities elsewhere in the Interior System, however, the last glaciation has been subdivided into stades and interstades. For example, Clague (1973, 1975c) proposed three stades and two interstades for the southern Rocky Mountain Trench. Likewise, Rutter (1976, 1977) suggested that there were three glacier advances separated by two intervals of glacier recession in the northern Rocky Mountain Trench. Tipper (1971a, b) presented evidence for a late glacial readvance following the Fraser Glaciation maximum in central British Columbia. Finally, Tallman (1975) outlined for the Atlin region a complicated sequence of "glacials" and "interglacials" characterized by out-of-phase fluctuations of glaciers from different source areas. Two main stades and three lesser ones with intervening interstades were defined. Unfortunately, at none of the above localities in the Interior System are the glacial events which have been recognized adequately dated. Thus, it is not possible at present to correlate these events within the British Columbia interior, nor to deduce their relationships to the better dated geologic-climate units of the Georgia Depression and Puget Lowland.

Sediments and landforms of the Fraser Glaciation occur throughout British Columbia and are particularly prominent and widespread in valleys, plateau areas, and the coastal lowlands. In fact, much of the present landscape of British Columbia is a product of glacial erosion and deposition during the Fraser Glaciation.

At the close of the Olympia nonglacial interval, in response to climatic cooling and perhaps increased precipitation, glaciers in the mountains of British Columbia advanced. With continued growth, they coalesced to form piedmont glaciers and small mountain ice sheets. Eventually, piedmont complexes from separate mountain source areas joined to cover most of the province.

During the glacier advance phase of the Fraser Glaciation, the long-established Olympic drainage system was disrupted and rearranged. Proglacial lakes formed in many areas in front of the advancing glaciers, but eventually were overriden. Ice build-up also was accompanied by aggradation, as outwash flooded into interior and coastal valleys from alpine areas. The details of these changes are not known in most areas because much of the pertinent stratigraphic

* This date was incorrectly reported as 11 600 ± 1000 years by Bryan (1969, p. 340) and Rutter (1976, p. 433; 1977, p. 21).

** The tusk was coated with a hydrocarbon-based preservative (Krylon?) before the sample for GSC-2859 was obtained.

evidence was removed by glacial erosion or was covered by younger drift. In some areas, however, events of the Fraser Glaciation advance phase have been reconstructed, and details are provided in the following section.

As the Cordilleran glacier complex expanded, its nourishment and surface flow patterns became less controlled by ground surface topography and more controlled by ice sheet morphology (Davis and Mathews, 1944). It has been proposed that the ice became sufficiently thick over interior British Columbia for an ice dome to exist, with surface flow radially away from its centre (e.g. Dawson, 1881; Kerr, 1934; Mathews, 1955; Wilson et al., 1958; Fulton, 1967; Flint, 1971). If this indeed happened, it would have been accompanied by a reversal of glacier flow in the Coast Mountains, as the ice divide (i.e., the axis of outflow) shifted from the mountain crest eastward to a position over the Interior Plateau (Flint, 1971, p. 469). A comparable westward shift and reversal of flow would have occurred in the Rocky Mountains.

Tipper (1971a, p. 80; 1971b, p. 749-750), however, questioned the existence of an ice dome over central British Columbia during the Fraser Glaciation. He proposed instead that at the glacial maximum the Cordilleran Ice Sheet consisted of coalescent piedmont glaciers which covered the Interior System, but which were fed entirely from alpine centres. This conclusion was based, in large part, on an analysis of the regional pattern of drumlins, flutings, and striae in the Interior System.

Nevertheless, the possibility must be considered that the pattern of ice flow at the base of the Cordilleran Ice Sheet may have differed from that at the surface. The former was controlled largely by the topography of the terrain over which the ice flowed. For example, most ice flow indicators shown on the Glacial Map of Canada (Prest et al., 1968) indicate basal flow in conformity with major physiographic elements. If the ice was thick enough to cover high elevation terrain, however, surface flow may not have been topographically controlled and thus would not necessarily conform to the basal flow indicators. Reconstruction of the ice flow pattern at the surface of the ice sheet at the peak of the Fraser Glaciation should be made largely by measuring high elevation striae. From the observations that have been made, it appears that Fraser Glaciation ice in some areas indeed was thick enough to overtop high mountain divides, thus suggesting that glacier nourishment and surface flow were controlled, at least for a short time, by the ice sheet itself rather than by substrate topography (Prest et al., 1968).

Fraser Glaciation ice flow patterns were even more complicated than suggested above because flow varied with time in relation to the stage of glaciation. Thus, flow patterns of early Fraser time, when individual glaciers were confined to their valleys, differed from those near the Fraser maximum when glaciers from different source areas coalesced on the plateaus and lowlands. Furthermore, during the Fraser Glaciation, events of stadial-interstadial rank affected the extent of ice cover and complicated flow patterns, at least near the periphery of the ice sheet.

The pattern of glacial recession at the end of the Fraser Glaciation was not everywhere the mirror image of the pattern of glacial advance. In many areas of the Interior System, deglaciation was characterized by widespread stagnation of tongues of ice in valleys after uplands became ice free. This pattern of deglaciation contrasts sharply with a pattern of orderly frontal retreat without stagnation, which would occur if deglaciation was a mirror-image replica of ice build-up in these areas.

As was the case during the advance phase of the Fraser Glaciation, rapid aggradation and extensive drainage changes occurred during deglaciation. Large glacial lakes formed and evolved as glaciers downwasted and retreated over the Interior Plateau. The glacio-isostatically depressed coastal lowlands of the Western System were flooded by the sea and became sites of glaciomarine deposition. Floodplains throughout British Columbia rapidly aggraded because rivers and streams were unable to cope with the large volumes of sediment made available during deglaciation.

The pattern and history of deglaciation in British Columbia are much better understood than are Fraser Glaciation advance events because the sediments and landforms produced during deglaciation in most areas have not been removed by erosion or covered by younger deposits.

Fraser Glaciation Advance Phase

The advance phase of the Fraser Glaciation is defined here as the period from the close of the Olympia nonglacial interval to the maximum of the Fraser Glaciation. During this interval, glaciers advanced from retracted positions in the mountains of British Columbia to cover nearly the entire province (Fig. 3).

Georgia Depression

As mentioned previously, the Fraser Glaciation in the Strait of Georgia region and Puget Lowland has been subdivided into the Evans Creek Stade, Vashon Stade, Everson Interstade, and Sumas Stade. The first two of these geologic-climate units constitute the advance phase of the Fraser Glaciation.

Evans Creek Stade

Evans Creek Stade is "the climatic episode early in the Fraser Glaciation during which alpine glaciers formed and reached their maximum extents..." (Armstrong et al., 1965, p. 326). The episode was recognized in the western Cascade Mountains adjacent to Puget Lowland where alpine drift is overlain by glaciolacustrine sediments deposited in a lake dammed by the Puget lobe of the Cordilleran Ice Sheet. From this stratigraphic succession, Crandell (1963, p. A32-A36) inferred that the alpine glacier had reached its maximum extent and retreated far upvalley prior to the Puget lobe attaining its maximum stand during the Vashon Stade.

The expansion of alpine glaciers in the Cascade Mountains probably was contemporaneous with the initial growth of the Cordilleran glacier complex in the mountains of western British Columbia. Continued expansion of alpine glaciers in British Columbia eventually led to the formation of an ice sheet, whereas in Washington growth of alpine glaciers was arrested and individual glaciers retreated before the Fraser Glaciation climax (Armstrong et al., 1965, p. 327).

At two places in the Georgia Depression deposits of an early Fraser Glaciation advance have been differentiated from those of the Vashon Stade. The lowlands of southeastern Vancouver Island are underlain by thick outwash gravels (Saanichton gravel) which Halstead (1968) attributed to a pre-Vashon glacial advance in nearby Cowichan River valley. He correlated this alpine glacial event with the Evans Creek Stade. Halstead, however, was unable to show conclusively that the Cowichan Valley advance occurred significantly before or was in fact distinct from the main Vashon advance. There is no good evidence for recession of the Cowichan glacier prior to the Vashon Stade; thus it seems possible that the Cowichan Valley and Vashon advances in this area were more or less in-phase. This casts doubt on the correlation of the Cowichan Valley advance with the Evans Creek Stade.

In Coquitlam River valley and the Fraser Lowland east of Vancouver, a Fraser Glaciation drift unit older than the Vashon Drift has been reported by Armstrong and Hicock (1976), Hicock (1976), and Armstrong (1977a, b). This unit, the Coquitlam Drift, apparently was deposited by alpine glaciers advancing out of the Coast Mountains during the early part of the Fraser Glaciation. Radiocarbon dates from Coquitlam Drift and correlative sediments range from 21 500 ± 240 to 21 700 ± 130 years (GSC-2536 and GSC-2416, Lowdon and Blake, 1978, p. 8). At the time of this advance in Coquitlam Valley, glaciers probably already occupied large parts of the Georgia Depression (Clague et al., 1980). However, after the Coquitlam Valley glacier entered the Fraser Lowland and reached its maximum extent, it receded an unknown distance and the lowland became at least partially ice free. Subsequently, the Fraser Lowland was completely inundated by ice during the Vashon Stade. Radiocarbon dates ranging from 18 300 ± 170 to 18 700 ± 170 years (GSC-2322, Lowdon and Blake, 1978, p. 8-9; GSC-2344, Armstrong, 1977a, his Fig. 1) on pre-Vashon organic sediments in the Fraser Lowland east of Vancouver provide chronologic control on deglaciation of this part of the lowland prior to the Vashon advance.

The regional significance of recession following the Coquitlam advance is unknown. Although Heusser (1972, 1973a, 1977), on the basis of palynological evidence from Olympic Peninsula, suggested that there was a brief interval of relative warmth about 18 000 years ago, no stratigraphic evidence has been found of contemporaneous glacier recession in the Georgia Depression outside Coquitlam River valley and the adjacent Fraser Lowland, despite the abundance of well studied exposures of Quaternary sediments in the region. Rather, the record indicates: (1) the slow, but progressive growth of glaciers in the Coast Mountains, accompanied by aggradation in mountain valleys; followed by (2) the advance of glaciers down these valleys and into the

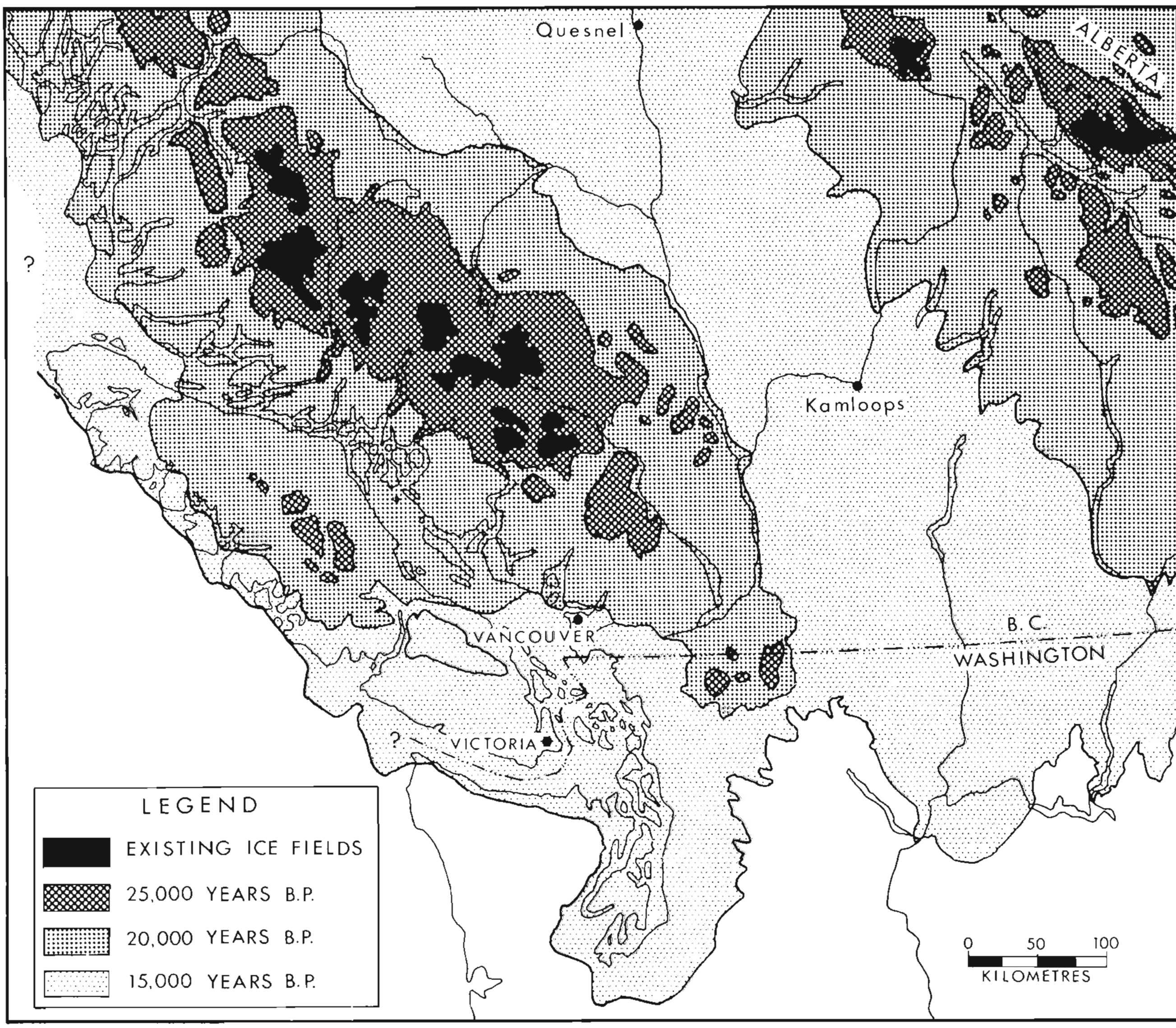

Figure 3. Growth of the Cordilleran Ice Sheet in southern British Columbia and nothern Washington during the Fraser Glaciation. Approximate glacier margins at 25 000, 20 000, and 15 000 years B.P. are shown. These positions have been determined from available radiocarbon dates and physiography and should be considered first approximations, subject to revision as additional data become available. The 15 000 year old margin is, in part, from Crandell (1965b) and Richmond et al. (1965) and is speculative off the west, north, and south coasts of Vancouver Island. Alpine glaciers in the Olympic and Cascade mountains outside the 15 000 year old boundary of the Cordilleran Ice Sheet and unglaciated areas within the confines of the ice sheet are not shown.

lowlands of the Georgia Depression, with aggradation occurring mainly on lowland floodplains; and (3) continued thickening and coalescence of glaciers to form a large piedmont lobe which advanced southeast down the Georgia Depression, outwash being deposited as a proglacial apron or blanket fronting the advancing ice (Clague, 1976a, 1977a). In such a scenario, the Vashon Stade, defined by Armstrong et al. (1965, p. 327) 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 southwestern British Columbia and northwestern Washington", is not clearly separable from an early alpine stade in a regional sense.

Quadra Sand and the Growth of the Cordilleran Ice Sheet

Proglacial outwash deposited in the Georgia Depression and in some adjoining mountain valleys during the Fraser Glaciation advance phase has been termed Quadra Sand by Clague (1976a, 1977a). This prominent lithostratigraphic unit, consisting of horizontally and cross-stratified well sorted sand, minor silt and gravel, is underlain by the Cowichan Head Formation and overlain by till and related glacial sediments (Armstrong and Clague, 1977). Quadra Sand has a wide, although patchy distribution in the Georgia Depression and Puget Lowland*. Fyles (1963, p. 33) and Clague (1976a, 1977a) proposed that the sand formed subaerially on floodplains which extended across or along the margins of what is now the Strait of Georgia. Clague (1977a, p. v) further stated that the initial influx of Quadra Sand into the Georgia Depression:

> "...occurred during a period of climatic deterioration at the onset of the Fraser Glaciation. The sand was deposited, in part, as distal outwash aprons at successive positions in front of, and perhaps along the margins of, glaciers moving from the Coast Mountains into the Georgia Depression and Puget Lowland during late Wisconsin time. After deposition at a site, but before burial by ice, the sand was dissected by meltwater and the eroded detritus was transported farther down the basin to sites where aggradation continued."

Because Quadra Sand was deposited as a prograding apron or blanket down the axis of the Georgia Depression and Puget Lowland from source areas in the Coast Mountains to the north and northeast, it is markedly diachronous, overlapping in age the Cowichan Head Formation. Thus, although Quadra Sand is stratigraphically above the Cowichan Head Formation, deposition of the latter continued in some areas of the Georgia Depression while the former was being deposited in others.

Quadra Sand, in general, decreases in age from north to south in the Georgia Depression. The oldest date that confidently can be assigned to the unit is 28 800 ± 740 years (GSC-95, Dyck and Fyles, 1963, p. 49-50). This date, obtained from the lower part of the sand near Comox in the northern Georgia Depression, indicates that there was enhanced glacial activity in the nearby Coast Mountains many thousands of years before glaciers finally occupied the coastal lowlands and intermontane plateaus. At the south end of the Georgia Depression east of Vancouver, Quadra Sand deposits underlying Vashon till have yielded three dates ranging from 18 300 ± 170 to 18 700 ± 170 years (GSC-2322, Lowdon and Blake, 1978, p. 8-9; GSC-2344, Armstrong, 1977a, his Fig. 1). Finally, in the vicinity of Seattle, Washington near the southern limit of the outwash unit, stratified clay underlying Esperance Sand has yielded radiocarbon dates as young as 15 000 ± 400 years (W-1227, Mullineaux et al., 1965, p. 07).

As an interesting aside, it is worth mentioning that the diachroneity of Quadra Sand causes difficulties in defining the age of the boundary between the Olympia nonglacial interval and the Fraser Glaciation (Clague, 1976b, p. 323-324). According to the Code of Stratigraphic Nomenclature, the time boundaries of geologic-climate units such as the Olympia nonglacial interval and the Fraser Glaciation are defined from the dated boundaries of stratigraphic units. In the Georgia Depression there are no isochronous lithostratigraphic units which can be used to establish on a regional basis the age of the Olympia-Fraser boundary. A unique isochronous biostratigraphic boundary, reflecting the regional climatic changes accompanying the onset of the Fraser Glaciation, may yet be discovered and thus provide a suitable time horizon for the end of the Olympia nonglacial interval and the beginning of the Fraser Glaciation. Unfortunately, insufficient work has been done on the fossil plant and animal assemblages of Quadra Sand and the Cowichan Head Formation to know whether or not such a time horizon indeed can be specified.

Vashon Stade and the Fraser Glaciation Climax

Vashon Stade glaciers did not completely cover the southern Georgia Depression until after 17 000 to 18 000 years ago. This conclusion is based on several radiocarbon dates on bone, wood, and peat underlying Vashon till, including 17 000 ± 240 years from the Victoria area (GSC-2829, Keddie, 1979, p. 20); 17 800 ± 150 and 18 000 ± 150 years from Coquitlam River valley (GSC-2297, Lowdon et al., 1977, p. 15; GSC-2371, Lowdon and Blake, 1978, p. 8); 18 300 ± 170, 18 600 ± 190, and 18 700 ± 170 years from western Fraser Lowland (GSC-2322, Lowdon and Blake, 1978, p. 8-9; GSC-2194, Clague, 1977a, p. 15; GSC-2344, Armstrong, 1977a, his Fig. 1); and 19 150 ± 250 years from Cowichan River valley (GSC-210, Dyck et al., 1965, p. 36).

As Vashon ice overrode the Georgia Depression, it split into two lobes near the southeastern end of Vancouver Island. One lobe flowed south into the Puget Lowland and the other west-northwest along Juan de Fuca Strait towards the Pacific Ocean (Alley, 1974; Chatwin, 1974; Alley and Chatwin, 1979). Glaciolacustrine sediments overlain by Vashon till on the south coast of Vancouver Island were deposited in lakes dammed by the advancing Juan de Fuca lobe. At this stage ice in the Strait of Georgia region was not thick enough to overtop the mountains of southern Vancouver Island and flow directly into Juan de Fuca Strait (Alley and Chatwin, 1979).

At the Vashon maximum, according to Mathews et al. (1970, p. 691), the ice surface was 1220 to 1520 m in elevation in the mountains of Vancouver Island, declining to about 1070 m near Victoria and to about 460 m near the west end of Juan de Fuca Strait. Alley and Chatwin (1979), although arguing for somewhat greater thicknesses of ice (e.g., about 1500 m near Victoria and at least 800 m at the west end of Juan de Fuca Strait), reconstructed an ice sheet at the Vashon maximum similar to that proposed by earlier workers (e.g., Wilson et al., 1958; Fyles, 1963; Armstrong et al., 1965; Halstead, 1966; Mathews et al., 1970). These investigators all concluded that, at the climax of the Vashon Stade, ice in the Georgia Depression spilled south and southwest through valleys and across ridge tops of the southern Vancouver Island Ranges. This ice presumably flowed into Juan de Fuca Strait to merge with the Juan de Fuca lobe flowing west-northwest out of the Georgia Depression. It has been assumed that the Juan de Fuca lobe terminated on the continental shelf off the west end of Juan de Fuca Strait, although a glacial limit has not been identified.

*The unit is called Esperance Sand in Washington (Mullineaux et al., 1965).

Anderson (1967, 1968), on the basis of stratigraphic analysis of radiocarbon-dated cores from the seafloor of western Juan de Fuca Strait, disputed this generally accepted view, stating that "there is no sedimentary evidence that the Vashon 'Juan de Fuca' ice lobe penetrated to the Pacific Ocean" (1968, p. 419). Instead, he suggested that Vashon ice occupied only the eastern part of Juan de Fuca Strait, east of the vicinity of Victoria. This appears unlikely, however, in that the Puget lobe at the Vashon maximum terminated about 80 km south of Seattle (that is, about 280 km south of Vancouver). In order for the Puget lobe to have reached this far south, ice must have been quite thick in the vicinity of Victoria and, consequently, would have extended far to the west of that city. Futhermore, the geomorphic and stratigraphic work of Bretz (1920) and Alley and Chatwin (1979), among others, suggests that western Juan de Fuca Strait was occupied by Vashon ice at the Fraser Glaciation climax. This ice, however, may not have been as thick as previous workers have suggested; if Anderson's data are valid, it is conceivable that the Juan de Fuca lobe was not grounded in westernmost Juan de Fuca Strait at the Fraser climax.

Paleoclimate

Palynological investigations of early Fraser Glaciation sediments in the Georgia Depression have been conducted by Alley (1979) and Mathewes (1979). Alley examined Quadra Sand and related sediments on eastern and southern Vancouver Island. He concluded that between about 29 000 and 21 000 years ago there was a gradual deterioration in climate marked by the progressive replacement in lowland areas of temperate plant species with subalpine, and finally alpine or tundra vegetation. This supports the conclusions of Clague (1976a, 1977a) regarding the genesis and paleoclimatic significance of Quadra Sand. It also is in agreement with the finding of Mathewes (1979) at Vancouver; there, pollen assemblages in Quadra Sand dating 24 000 to 25 000 years include significant subalpine and minor alpine components, indicating a colder climate than at present.

Palynological investigations on Olympic Peninsula (Florer, 1972; Heusser, 1972, 1977, 1978) and in the northern Puget Lowland (Hansen and Easterbrook, 1974) have important implications for early Fraser Glaciation events and paleoclimates in the Georgia Depression. On Olympic Peninsula climatic deterioration associated with the Fraser Glaciation is interpreted to have begun about 28 000 years ago. Between about 28 000 and 22 000 years ago, treeline in the area fell, and the dominant plant community on the coastal lowlands changed from closed temperate forest to subalpine forest. Towards the end of this interval, nonarboreal species became dominant in lowland areas. Heusser (e.g., 1972, p. 197; 1977, p. 294) thought that this was due to incursion of tundra vegetation into the coastal lowlands. Hansen and Easterbrook (1974, p. 598), however, have commented that fossil pollen assemblages dominated by nonarboreal pollen may also result from a lowering of sea level, with the resultant expansion of grasses, sedges, and herbs onto a former seafloor exposed during marine regression.

A less complete pollen record from the northern Puget Lowland suggests that, as on Olympic Peninsula, a cool moist climate prevailed during the early stages of the Fraser Glaciation. Between about 28 000 and 23 000 years ago an open forest containing both lowland and subalpine species was gradually replaced by what Hansen and Easterbrook (1974, p. 598) interpreted to be tundra vegetation.

Other Areas in the Western System

In the Western System outside of the Georgia Depression relatively little is known of the ice build-up phase of the Fraser Glaciation. However, one date of 16 700 ± 150 years (GSC-2768, Clague et al., 1980) closely delimits Vashon Stade glacial occupation of the Estevan Coastal Plain on westernmost Vancouver Island. Another date of 17 250 $\pm\,^{2600}_{1900}$ years (no laboratory dating number, Anderson, 1968, p. 427) probably predates the Vashon advance into Juan de Fuca Strait.

It is likely that climatic deterioration at the beginning of the Fraser Glaciation produced similar effects throughout the Coast Mountains. Thus, valley glaciers advanced and mountain ice caps grew along the entire length of the Western System. Glaciers flowing west off the Coast Mountains advanced down fiords and spilled onto the continental shelf. With continued thickening, the valley glaciers overtopped divides and formed coalescent ice masses covering much of the mainland coast.

Glaciers also grew on the mountains of Vancouver Island and the Queen Charlotte Islands. For example, glaciers flowing east and northeast off northern Vancouver Island coalesced with Coast Mountains glaciers to form an ice stream which flowed northwest along Queen Charlotte Strait. At the Vashon maximum, however, mainland ice possibly overrode northern Vancouver Island (Flint, 1971, p. 469; Howes, 1981, p. 10-11). At the Fraser climax, a small independent ice cap existed on the Queen Charlotte Islands. The eastern fringe of this ice cap may have coalesced briefly with mainland ice flowing west off the Coast Mountains. The resulting piedmont complex perhaps covered what is now Hecate Strait and flowed north and northwest into Dixon Entrance and southeast into Queen Charlotte Sound (Sutherland Brown and Nasmith, 1962; Sutherland Brown, 1968).

Fladmark (1975, 1978, 1979) has argued for less extensive ice cover on the outer coast during the Fraser Glaciation. Specifically, he suggested that Hecate Strait was not glaciated at the Fraser climax and that ice from the mainland and Queen Charlotte Islands last coalesced prior to the Olympia nonglacial interval. He further proposed that much of the outer continental shelf and the western fringe of Vancouver Island were free of ice during the Fraser Glaciation. This contradicts the generally held view (e.g., Prest, 1969) that the Cordilleran Ice Sheet extended to the outer edge of the continental shelf at the Vashon Stade maximum.

The controversy surrounding the extent of Vashon ice on the continental shelf and along the outer coast cannot be satisfactorily resolved until the youngest drift sheet in these areas is dated. However, early postglacial bog-bottom dates from Langara Island at the nothern end of the Queen Charlotte group (Sutherland Brown, 1968, p. 34) and from the uplands of southern Vancouver Island (Alley and Chatwin, 1979, p. 1651-1652) support the concept of fairly widespread Vashon ice along at least some parts of the outer coast (see section entitled "Fraser Glaciation Recessional Phase" for details).

Interior System

The initial response to climatic deterioration at the onset of the Fraser Glaciation was the growth of alpine glaciers and mountain ice caps in the Coast, Skeena, Hazelton, Cassiar, Omineca, Columbia, and Rocky mountains. As in the Western System, this was accompanied by aggradation in valleys draining these mountain ranges. For example, thick gravel underlying Fraser Glaciation till in the

Fraser and Thompson river valleys in the southwestern Interior System probably was deposited during the early part of the Fraser Glaciation. Aggradation here followed an interval of valley deepening (Ryder, 1976, p. 13), which likely coincided in part or wholly with the Olympia nonglacial interval.

Glaciers eventually advanced beyond the mountains and coalesced over the Interior Plateau. As mentioned previously, it is possible that at the Fraser Glaciation maximum one or more ice domes existed over the Interior Plateau; however, during much of the Fraser Glaciation the ice sheet was a large piedmont complex nourished by glaciers flowing from the high mountains.

The ice sheet was hemmed in by the Coast Mountains to the west and the Rocky Mountains to the east and was at least 2300 m thick over valleys of the Interior Plateau (Flint, 1971, p. 469). Ice from this complex flowed out of the Interior System through valleys transecting the mountain barriers. It also flowed south into northern Washington, Idaho, and Montana, and north into Yukon Territory (Wilson et al., 1958; Richmond et al., 1965; Hughes et al., 1969; Prest, 1969). Ice flowing north out of British Columbia was in contact with a lobe flowing west from the Selwyn Mountains (Hughes et al., 1969).

Several radiocarbon dates provide control on the timing of glacial invasion of south-central and southeastern British Columbia during the Fraser Glaciation. A date of 19 100 ± 240 years (GSC-913, Lowdon and Blake, 1970, p. 72) at the type section of the Bessette Sediments near Lumby is closely related to initial glacial occupation of that region (Fulton, 1971, p. 8). Dates of 17 240 ± 330 and 17 440 ± 330 years (I-10,022 and I-10,021, Clague et al., 1980) from proglacial outwash near Trail further define the Fraser advance. Five additional dates ranging from 19 900 ± 230 to 21 700 ± 240 years (GSC-1188 and GSC-1258, Lowdon et al., 1971, p. 293-294) have been obtained on subtill sediments at other sites in south-central and southeastern British Columbia, providing additional evidence that the southern Interior Plateau was invaded relatively late by glaciers. One of these dates (21 500 ± 300 years, GSC-173, Dyck et al., 1965, p. 32) is from sediments at a site only 35 km from one of the largest existing ice fields in the Rocky Mountains. This suggests that alpine glaciers did not advance beyond the western front of the Rocky Mountains until after about 21 500 years ago. Finally, a date of 19 100 ± 850 years (GX-2033, Clague, 1973, p. 258) was obtained on a peat clast within Fraser Glaciation recessional outwash. The clast apparently was redeposited from sediments predating the last glacial advance, and therefore its age is limiting for this advance.

The only radiocarbon date bearing on the Fraser (Portage Mountain) advance in the northern Interior System is 25 940 ± 380 years (GSC-573, Lowdon et al., 1971, p. 298-299). This is a maximum limiting date, and the actual advance may have occurred up to several thousand years later.

Eastern System

The chronology and characteristics of the Fraser Glaciation advance phase in the Rocky Mountains of British Columbia are poorly known. It is noteworthy, however, that valley glaciers probably did not advance beyond the Rocky Mountain front until some time after about 21 500 years ago, even though the initial climatic deterioration marking the onset of the Fraser Glaciation in nearby south-central British Columbia occurred a few thousand years earlier (Alley and Valentine, 1977; Alley et al., in press). It is likely that glaciers in the Rocky Mountains advanced during the early phase of the Fraser Glaciation but remained confined to the mountain belt for several thousand years before spilling into the Interior System.

Interior Plains

The Interior Plains physiographic province in British Columbia probably was affected both by Cordilleran and Laurentide glaciers during the Fraser Glaciation. Nonglacial gravel in the Fort St. John area is overlain by sand, silt, and clay deposited when Peace River was blocked by advancing Laurentide glaciers (Mathews, 1978, p. 8). Laurentide ice flowed southwest into the area, but apparently was deflected in a broad sweeping curve south and then southeast by Cordilleran glaciers flowing east and northeast.

The Laurentide and Cordilleran advances occurred approximately contemporaneously and are thought to be of Fraser Glaciation age. The evidence for this is that drift deposited during these advances overlies nonglacial sediments that have been correlated with gravel near Fort St. John dated at 27 400 ± 580 years (GSC-2034, Mathews, 1978, p. 17). Unfortunately, this correlation is somewhat tenuous because the dated sediments are unconformably overlain by postglacial river gravel, rather than drift. Thus, the age of the most recent coalescence of Laurentide and Cordilleran ice in the area remains somewhat uncertain, and the possibility that coalescence last occurred prior to the Fraser Glaciation cannot be denied at present (see section entitled "Interior Plains" in "Olympia Nonglacial Interval"). The last Cordilleran advance on the Plains may correlate with the Early Portage Mountain advance in the Rocky Mountain Trench to the west (Fig. 2; Rutter, 1976, 1977).

A better-dated succession of nonglacial sediments overlain by Laurentide drift occurs at Watino, Alberta, 200 km east of Fort St. John. Wood and peat from this sequence have yielded radiocarbon dates from 27 400 ± 850 to 43 500 ± 620 and >38 000 years (I-4878, GSC-1020, and GX-1207; Lowdon and Blake, 1970, p. 69; Westgate et al., 1972, p. 380); thus, at this site the last Laurentide advance clearly is of Fraser age.

In addition to the main Laurentide and Cordilleran glacial advances discussed above, Mathews (1978, p. 7-8, 14) suggested that there may have been a less extensive Cordilleran advance of presumed early Fraser Glaciation age to the front of the Rocky Mountains. Sediments attributed to this glacial event, however, were found at only two sites, and because Mathews could not definitely prove that these sediments were indeed of glacial origin, he was reluctant to state unequivocally that the advance had occurred.

Summary

The Fraser Glaciation advance phase began with climatic deterioration at the end of the Olympia nonglacial interval and ended when the Cordilleran Ice Sheet attained its maximum size. Initially, glacier growth was slow, and many thousands of years elapsed before glaciers reached the lowland and plateau areas outside the major mountain systems. Thus, although the initial climatic deterioration of the Fraser Glaciation may have occurred as early as 29 000 years ago on the Pacific coast, most lowland and plateau areas, at least in southern British Columbia, were ice free until after 21 500 years B.P., and some areas were not covered by the Cordilleran Ice Sheet until about 17 000 years ago (Fig. 3).

Climatic deterioration and glacier growth were accompanied by widespread rapid aggradation within river valleys. Also, as glaciers advanced across the Interior Plateau, there were major drainage disruptions – many rivers and streams changed courses and large ice-dammed lakes formed.

Brief intervals of glacier recession occurred during the Fraser Glaciation advance phase. Although these recessional events are known from several different areas in British Columbia, their ages, climatic significance, and relationships to one another are not well established.

Fraser Glaciation Recessional Phase

The recessional phase of the Fraser Glaciation encompasses the time during which the Cordilleran Ice Sheet disintegrated after attaining its maximum size (Fig. 4). Climatic amelioration resulted in down-wasting, stagnation, and frontal retreat. Locally, recession was interrupted by glacier stillstands and minor readvances.

Georgia Depression

The Cordilleran Ice Sheet reached its maximum extent in the Puget Lowland between 14 460 ± 200 and 15 000 ± 400 years ago (Y-2452, Heusser, 1973b, p. 289; W-1227, Mullineaux et al., 1965, p. O7). Northward retreat of the glacier lobe was accompanied initially by the development of proglacial lakes in the southern Puget Lowland and later, as Juan de Fuca Strait became deglaciated, by the incursion of marine waters into the area (Thorson, 1979, 1980). The Puget lobe had retreated to a position north of Seattle by 13 650 ± 550 years ago (L-346A, Rigg and Gould, 1957, p. 357). Radiocarbon dates from glaciomarine sediments deposited on the isostatically depressed lowlands of the Georgia Depression indicate that deglaciation was in progress there about 13 000 years ago (e.g., 12 900 ± 170 years, GSC-2193, Lowdon et al., 1977, p. 14; 12 800 ± 175 years, I(GSC)-248, Trautman and Walton, 1962, p. 36; 12 750 ± 170 years, GSC-418, Dyck et al., 1966, p. 113).

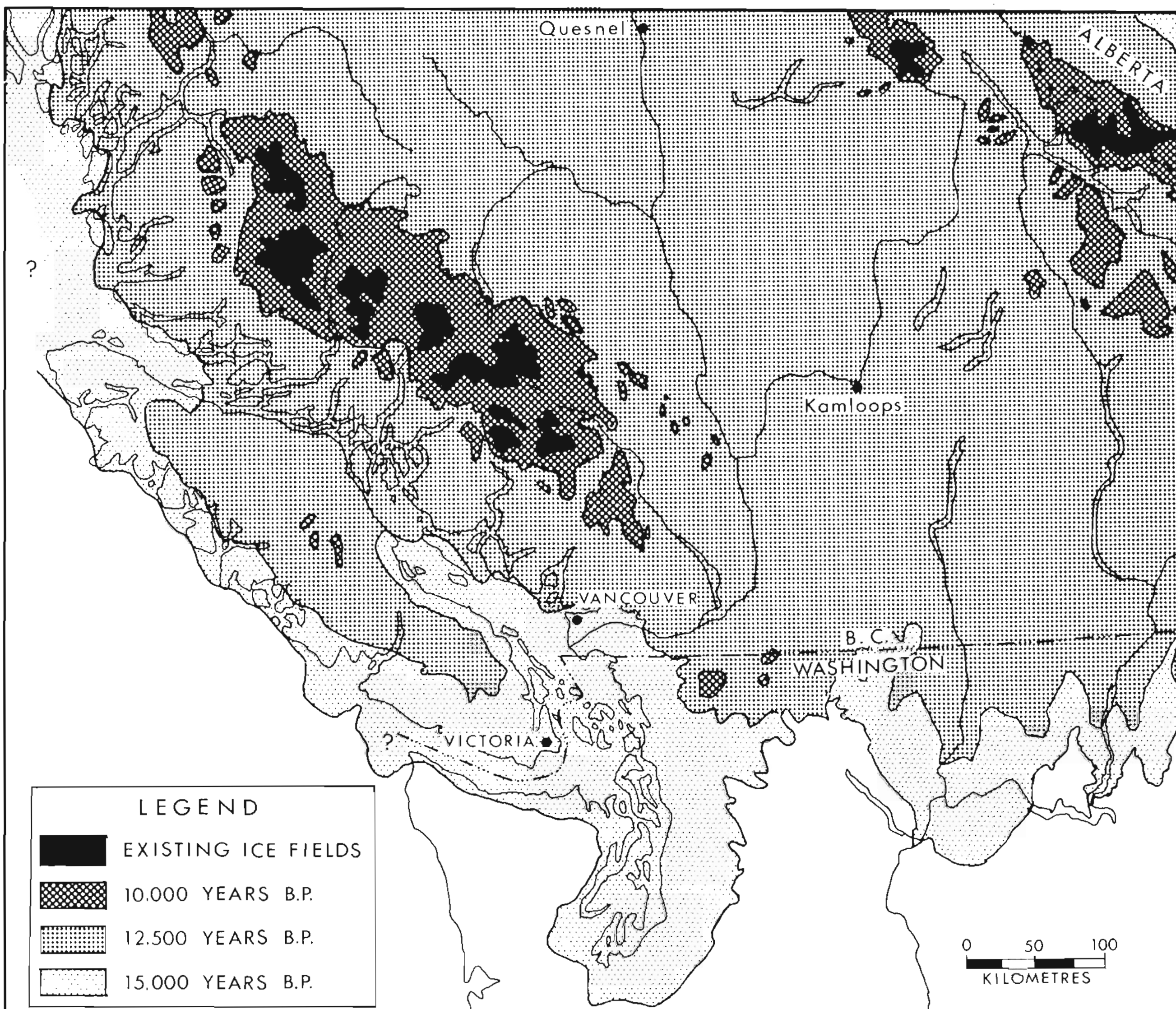

Figure 4. Decay of the Cordilleran Ice Sheet in southern British Columbia and northern Washington during the terminal phase of the Fraser Glaciation. Approximate glacier margins at 15 000, 12 500, and 10 000 years B.P. are shown. These positions have been determined from available radiocarbon dates and physiography and should be considered first approximations, subject to revision as additional data become available. The 15 000 year old margin is, in part, from Crandell (1965b) and Richmond et al. (1965) and is speculative off the west, north, and south coasts of Vancouver Island. Alpine glaciers in the Olympic and Cascade mountains outside the 15 000 year old boundary of the Cordilleran Ice Sheet and unglaciated areas within the confines of the ice sheet are not shown.

Everson Interstade

In coastal northwestern Washington and southwestern British Columbia the interval of glacier recession between the Fraser Glaciation maximum and the Sumas advance is termed the Everson Interstade (Armstrong et al., 1965; Armstrong, 1981). In practice, this interval is defined as beginning when marine waters invaded the area, and as ending in the eastern half of the Fraser Lowland with the advance of Sumas glaciers, and elsewhere with the withdrawal of the sea from lowland areas and the disappearance of floating ice. Accordingly, the Everson Interstade began about 13 000 years ago and ended in the eastern Fraser Lowland about 11 300 ± 100 years ago (GSC-2523, Lowdon and Blake, 1978, p. 7-8), the latter date being the approximate time of the Sumas advance. The Everson Interstade ended in the western Fraser Lowland and on eastern Vancouver Island between about 10 000 and 11 300 years ago, when lowland areas became emergent (Mathews et al., 1970; see also section entitled "Late Glacial and Postglacial Sea Levels").

During the Everson Interstade, a variety of sediments, including glaciomarine diamicton, marine silt and clay, subaqueous outwash, and deltaic sand and gravel, was deposited on submerged coastal lowlands in the Georgia Depression (e.g., Armstrong and Brown, 1954; Fyles, 1963; Armstrong, 1981). These sediments exhibit complex facies changes due to spatial differences in sediment supply during deposition and to differences in the rate and nature of glacier recession within the area. These complexities preclude subdivision of Everson Interstade deposits, which collectively are referred to both as the Fort Langley Formation and Capilano Sediments (Armstrong and Brown, 1953; Fyles, 1963; Armstrong, 1976, 1977a, b, 1981).

Sumas Stade

The Everson Interstade ended in the eastern Fraser Lowland with a readvance of glaciers. Armstrong et al. (1965) attributed this readvance to a climatic episode which they called the Sumas Stade. Sumas Drift overlies the Fort Langley Formation over an area of about 650 km^2 in the eastern Fraser Lowland (Armstrong et al., 1965, p. 329). Because the drift is not overlain by marine sediments, much of the Fraser Lowland had emerged by isostatic rebound prior to the end of the Sumas Stade.

The climax of the Sumas Stade was about 11 300 ± 100 years ago (GSC-2523, Lowdon and Blake, 1978, p. 7-8). This date was obtained on wood embedded in Sumas till. Radiocarbon dates on wood and shells from the underlying Fort Langley Formation substantiate this age assignment.

Several radiocarbon dates bear on the timing of retreat of Sumas glaciers. A date of 9920 ± 760 years (I-2280, Easterbrook, 1969, p. 2285) was obtained on peat at the base of a bog developed on Sumas outwash in Washington State just south of the International Boundary. Sumas ice had withdrawn from its maximum position, and the outwash surface became inactive before this date. Three radiocarbon dates from postglacial sediments beneath two lakes in the lower Fraser Canyon suggest earlier recession of Sumas ice. Dates of 11 430 ± 150 and 11 000 ± 170 years (I-6057 and I-5346, Mathewes et al., 1972, p. 1057) were obtained on basal organic sediments in two cores from one lake at an elevation of approximately 320 m. A third date of 11 140 ± 260 years (I-6058, Mathewes et al., 1972, p. 1057) was obtained on organic sediments in another lake at an elevation of about 205 m, less than 160 m above the bedrock floor of the Fraser Canyon. Together, the dates indicate that the Canyon contained little or no ice after 11 000 years ago.

The above dates from the Fraser Canyon are at the centre of a controversy concerning both the source of the Sumas piedmont glaciers and the timing of the Sumas Stade (Mathewes et al., 1972). The following is a discussion and attempted resolution of this controversy.

The Fraser Canyon during each major glaciation was an important outlet for ice flowing into the Fraser Lowland from the Coast Mountains and southern Interior Plateau. It seems likely that the Sumas piedmont glacier in the Fraser Lowland was fed in part by ice flowing down this canyon. Yet the three dates from the Fraser Canyon cited above bracket the date for the Sumas maximum in the Fraser Lowland (11 300 ± 100 years, GSC-2523, Lowdon and Blake, 1978, p. 7-8), suggesting, at first glance, that the Sumas piedmont glacier did not flow through the canyon. If the error terms of the radiocarbon dates at two standard deviations from the mean are taken into account, however, it is possible that the Sumas maximum in the lowland was attained up to about 300 years before sedimentation began in the higher lake, and up to about 800 years before sedimentation commenced in the lower lake in the Fraser Canyon*. The dates also allow for the possibility that there was up to 250 m of ice in Fraser Canyon at 11 430 ± 150 years B.P. and up to 150 m of ice at 11 140 ± 260 years B.P. Nevertheless, if the Fraser Canyon was an important supplier of Sumas ice, the Sumas piedmont glacier must have receded extremely rapidly, on the order of 50 to 100 km in no more than 300 years, even if residual ice persisted at low elevations in the canyon until about 11 000 years ago.

An alternative explanation is that the piedmont glacier was not nourished by Fraser Canyon ice. Alternative sources include valleys entering the Fraser Lowland from the Cascade Mountains and one or two major valleys entering the eastern Fraser Lowland from the Coast Mountains. However, at least the former are precluded because their lower reaches were deglaciated while the adjacent Fraser Lowland was buried by ice. In one such valley, for example, deltaic sediments were deposited in a lake dammed by ice in the Fraser Lowland about 11 800 ± 100 years ago (GSC-2966). The lower part of this valley remained ice free at the climax of the Sumas Stade and thus did not supply ice to the Sumas piedmont glacier in the Fraser Lowland. Another argument against such alternative sources of Sumas ice is that it is unlikely that the Fraser Canyon was ice free at a time when nearby valleys supported large active glaciers.

In conclusion, with evidence presently available, it appears that the Sumas piedmont glacier receded rapidly out of the Fraser Lowland immediately after it reached its climax position. By 11 000 years ago, the lowland probably was completely free of glacier ice.

Several investigators have identified sediments and landforms of probable Sumas age outside the Fraser Lowland, although, in most cases, the lack of radiocarbon dates precludes their definite assignment to the Sumas Stade. Mathews et al. (1970, p. 696) stated that a large submarine moraine in Howe Sound north of Vancouver marks a maximum stand of Sumas ice. Halstead (1968, p. 1413) proposed that ice-contact sediments in Cowichan River valley were deposited during a glacier stillstand resulting from climatic cooling of the Sumas Stade. Crandell (1965b, p. 347) correlated the climatic episode responsible for the rejuvenation of small glaciers in the Cascade Mountains of Washington at the end of the Fraser Glaciation with the Sumas Stade. Finally, Porter (1976, p. 73) dated the Hyak advance in the North Cascade Range as no more than several centuries older than 11 050 ± 50 years (UW-321), and, on this basis, tentatively correlated it with the Sumas Stade.

* Error terms for Teledyne Isotopes' dates, including I-6057, I-6058, and I-5346, are 1σ; the error term for GSC-2523 is 2σ.

In some areas readvances at the end of the Fraser Glaciation do not correlate with the Sumas, thus raising some doubt concerning the climatic significance of the latter. Alley and Chatwin (1979) presented evidence for resurgence of ice in Juan de Fuca Strait and in upland areas of southern Vancouver Island prior to the Sumas advance in the Fraser Lowland. In contrast, Armstrong (1966b) found evidence for a local readvance in the Coast Mountains near Terrace between 10 420 ± 160 and 10 790 ± 180 years B.P. (GSC-535 and GSC-523, Lowdon et al., 1967, p. 174), well after the Sumas advance in southwestern British Columbia. Finally, Sutherland Brown (1968, p. 34) proposed that final disengagement and recession of mainland and insular ice on the Queen Charlotte Islands was followed by a readvance on the lowlands of northeastern Graham Island near the end of the Fraser Glaciation*. This readvance occurred before 13 700 ± 100 years B.P. (GSC-3222), which is a minimum deglaciation date for Graham Island, and thus is substantially older than the Sumas Stade.

It is apparent that glacier stillstands and minor readvances occurred at many different times during the recessional phase of the Fraser Glaciation and likely were controlled more by local conditions than by global or regional climatic change. The Sumas advance, for example, may have been caused by a change in glacier regimen due to isostatic uplift of lowland areas. As the sea regressed from the Fraser Lowland, glaciers which formerly calved into the sea became grounded on land. This situation would favour a readvance similar to the Sumas which would not be climatically controlled. If the Sumas advance indeed occurred without climatic cooling, the terms "Sumas Stade" and "Everson Interstade" would have to be abandoned as geologic-climate units.

Paleoclimate

Climatic conditions in the Georgia Depression and adjacent regions during the recessional phase of the Fraser Glaciation have been reconstructed from palynological data by Heusser (1973a, b, 1974, 1977), Mathewes (1973a, b), Hansen and Easterbrook (1974), and Mathewes and Rouse (1975). Some amelioration of climate must have occurred from about 15 000 years ago onward to promote the rapid retreat of glaciers and to encourage the revegetation of freshly exposed terrain. Heusser (1977, p. 300-301) proposed that mean July temperatures on Olympic Peninsula during the recessional phase of the Fraser Glaciation were about 2 to 5°C lower than present. According to Heusser, minor climatic amelioration during the Everson Interstade, when mean July temperatures reached to within 2°C of the present, was followed by cooling during the Sumas Stade. About 10 500 years ago, closed temperate forest communities became established in lowland areas, subordinating or replacing pioneer species and those adapted to cooler, more moist conditions (Mathewes, 1973a, p. 2099).

Other Areas in the Western System

Studies of deglaciation in areas of the Western System outside the Georgia Depression include those of: (1) the southern Vancouver Island Ranges (Alley, 1974; Chatwin, 1974; Alley and Chatwin, 1979); (2) the Queen Charlotte Islands (Sutherland Brown and Nasmith, 1962; Sutherland Brown, 1968; Nasmith, 1970; Alley and Thomson, 1978); (3) the Bella Bella – Bella Coola region of the central British Columbia coast (Retherford, 1972; Andrews and Retherford, 1978); and (4) the Terrace-Kitimat-Prince Rupert region of the Coast Mountains (Duffell and Souther, 1964; Armstrong, 1966a, b; Clague and Hicock, 1976; Clague, 1977b).

Vancouver Island Ranges

On southern Vancouver Island deglaciation proceeded mainly by downwasting. Most upland areas were free of ice down to an elevation of 400 m before 13 000 years ago (Alley and Chatwin, 1979, p. 1652). As mentioned previously, a minor resurgence of glaciers occurred in this area before deglaciation was complete. Following this readvance, downwasting continued, and glacier-dammed lakes formed in most major valleys. With melting of residual ice, these lakes drained and the postglacial drainage pattern quickly became established.

Queen Charlotte Islands

An extensive outwash plain was constructed adjacent to a fairly stable ice front on northeastern Graham Island during a glacial advance or stillstand thought to be of late Fraser age (Sutherland Brown, 1968, p. 34; however, see Fladmark, 1975, p. 125-126, for a different interpretation of the age of this feature). Following construction of this sandur, glaciers on the Queen Charlotte Islands downwasted and receded. Lowland areas were ice free before 13 700 ± 100 years B.P. (GSC-3222), which is the age of mosses underlying a peat bed and postglacial marine sediments on northeastern Graham Island.

Northern and Central Mainland Coast

Minimum dates for deglaciation of the mainland coast east of the Queen Charlotte Islands are 12 700 ± 120 years (GSC-2290; Lowdon and Blake, 1979, p. 25) at Prince Rupert and 12 210 ± 330 years (GSC-1651, Lowdon and Blake, 1973, p. 27) near Bella Bella. Deglaciation occurred later, however, at the heads of fiords extending into the Coast Mountains. For example, the major mountain valley between Terrace and Kitimat became ice free between about 10 500 and 11 000 years ago (Armstrong, 1966b). The northward retreat of the tongue of ice in this valley was interrupted several times by stillstands or minor readvances which probably had little or no regional climatic significance. During these stillstands, large volumes of gravel and sand were deposited as ice-contact and proglacial deltas in an arm of the sea extending inland from the present fiord head at Kitimat. Also, thick marine and glaciomarine muds were deposited under lower energy conditions on the floor of this submerged valley (Duffell and Souther, 1964, p. 8-10; Armstrong, 1966a, b; Clague and Hicock, 1976). Although the pattern of deglaciation in the Terrace-Kitimat area was similar to that in the Fraser Lowland, the timing of events differed in the two areas, and there is no evidence at Terrace-Kitimat for a climatic episode equivalent to or even comparable with the Sumas Stade.

Interior System

Style and Pattern of Deglaciation

The style of deglaciation in areas of moderate relief in the Interior System has been summarized by Fulton (1963, 1967, 1971). He proposed that deglaciation at the close of the Pleistocene occurred largely by downwasting, accompanied by stagnation and complex frontal retreat from the southern and probably northern sectors of the Interior System. Fulton (1967, p. 28) further suggested that deglaciation proceeded through four stages: (1) active-ice phase – regional flow continued but diminished as the ice thinned; (2) transitional upland phase – highest uplands appeared through the ice sheet, but regional flow continued in major valleys; (3) stagnant-ice phase – ice was confined to valleys but was still thick enough to flow; and (4) dead-ice phase – valley tongues thinned to the point where plasticity was lost. This model, which is based on deglacial deposits

* Fladmark (e.g., 1975, p. 125-126), however, argued that this "readvance" did not occur during the recessional phase of the Fraser of the Fraser Glaciation, but rather represents the Fraser climax.

and landforms in south-central British Columbia, has been used with minor modifications to describe deglaciation of parts of the southwestern Interior System (Ryder, 1976) and the central Interior Plateau (Heginbottom, 1972; Tipper, 1971a, b; Howes, 1977).

On a regional scale, ice receded from hilly uplands while stagnant, climatically dead ice remained in the major valleys and basins. In the southern Interior System, for example, the southern Columbia Mountains appeared above the surface of the ice sheet before the lower Okanagan Highland to the west; the Okanagan Highland was deglaciated while an ice tongue remained in adjacent Okanagan Valley; and the hilly Thompson Plateau became free of ice while the lower Fraser Plateau to the north remained covered (Fulton, 1971, p. 16). Likewise, as the ice sheet thinned over the central Interior Plateau, it "lost its mobility over wide areas, broke up into blocks lying in small valleys, stagnated, and decayed" (Tipper, 1971b, p. 750). As stagnation and decay replaced active flow over more and more of the central Interior Plateau, the active ice sheet probably degenerated to a piedmont apron skirting the Coast and Cariboo mountains.

In summary, at the close of the Fraser Glaciation, the Cordilleran Ice Sheet in the Interior System thinned and receded in a complex and irregular manner. In areas of low and moderate relief frontal retreat was accompanied by stagnation, with uplands appearing through the ice cover and dividing the ice sheet into a series of valley tongues which retreated in response to local conditions. Active ice eventually became restricted to the major mountain systems, locally as piedmont complexes, but in most areas as valley glaciers. These glaciers continued to recede, such that by early postglacial time, ice cover in British Columbia was about the same as, or less extensive than it is today.

During deglaciation, as during the Fraser advance, there were, at least locally, glacier stillstands and readvances. Tipper (1971a, b) proposed a late Fraser resurgence of ice in the Coast and Cariboo mountains, during which glaciers reoccupied part of the central Interior Plateau but did not join to form a single ice sheet. Late Pleistocene readvances also have been proposed for the southern Rocky Mountain Trench ("late stade" of Clague, 1973, 1975c), the northern Rocky Mountain Trench ("Late Portage Mountain" advance of Rutter, 1976, 1977), and the Atlin area of northwestern British Columbia ("Atlin III, IV, V" and "Gladys III" of Tallman, 1975). Because these events, in general, are not adequately dated, their relationships to one another and to the Sumas advance are not known.

Glacial Lakes

In many parts of the Interior System deglaciation was accompanied by the formation of glacial lakes in which large quantities of silt and clay were deposited. The most extensive lakes formed on the central Interior Plateau (Armstrong and Tipper, 1948; Tipper, 1971a) and in valleys of south-central British Columbia (Mathews, 1944; Nasmith, 1962; Fulton, 1965, 1969). Those on the central Interior Plateau were dammed behind ice receding south out of the Fraser Basin. Lakes in south-central British Columbia, on the other hand, were ponded behind stagnant and dead ice and drift left as the active ice front receded north towards the Fraser Plateau. The evolution of the glacial lakes in south-central British Columbia has been documented in considerable detail by studying shorelines, outlet channels, lacustrine deposits, and ice-marginal features (e.g., see Mathews, 1944; Fulton, 1969).

Glacial lakes also formed in tributary valleys to the southern Rocky Mountain Trench during deglaciation (Clague, 1973, 1975a). Although small in comparison to those in central and south-central British Columbia, these lakes are of considerable importance because they provide evidence that valley glaciers in the Rocky and Columbia mountains in southeastern British Columbia receded prior to the trunk glacier in the adjacent Rocky Mountain Trench. Ice in the Rocky Mountain Trench blocked the drainage in the tributary valleys and thus impounded the lakes. The glacier dams repeatedly failed, producing floods which swept south down the trench into Montana.

There were lakes in the northern Rocky Mountain Trench during the recessional phases of both the Early and Late Portage Mountain advances*. The older (Early Portage Mountain) lake was overriden by ice during the Late Portage Mountain advance. The younger (Late Portage Mountain) lake perhaps was continuous for a short time with Lake Peace on the Interior Plains (Rutter, 1976, 1977; Mathews, 1978); however, as the former expanded during the westward retreat of Cordilleran ice, the level of the latter dropped due to the eastward retreat of the Laurentide Ice Sheet. Lacustrine conditions apparently persisted in the Rocky Mountain Trench after Lake Peace disappeared from the Interior Plains of British Columbia, perhaps because of blockage of Peace River valley at the eastern front of the Rocky Mountains by morainal or colluvial deposits (Rutter, 1977, p. 21) or because of regional differential isostatic uplift. The final drainage of lakes in the trench and the establishment of the postglacial drainage system of Peace River may not have occurred until after 9280 ± 200 years B.P. (GSC-1497, Rutter, 1976, p. 431).

Chronology of Deglaciation

The chronology of deglaciation of parts of the Interior System is known with some assurance. At its southern margin in north-central and northeastern Washington, the Cordilleran Ice Sheet began to retreat before 13 000 years ago, the time when floodwaters of glacial Lake Misoula last poured across the Channeled Scabland and through the canyon of the Columbia River (Mullineaux et al., 1978). The Okanagan lobe on the Columbia Plateau in Washington had retreated at least 80 km from its maximum stand by the time Glacier Peak tephra layer G was deposited approximately 12 750 ± 350 years ago (W-1664, Ives et al., 1967, p. 517; Porter, 1978, p. 38-39). However, the absence of layer G from a substantial area of northern Washington within the projected zone of tephra fallout indicates that the margin of the ice sheet in most areas was south of the International Boundary about 12 750 years ago.

Harrison (1976a) suggested that the southern Rocky Mountain Trench near the International Boundary was deglaciated before about 12 200 years ago. The basis for this suggestion is two radiocarbon dates of 11 900 ± 100 and 12 200 ± 160 years (GSC-2142 and GSC-2275, Lowdon and Blake, 1976, p. 9) on postglacial sediments in Elk River valley, which is tributary to the Rocky Mountain Trench. Harrison thought that the dated sediments were deposited after the final drainage of glacial Lake Elk, which had been dammed by Rocky Mountain Trench ice. Thus, in order for the lake to drain, the southernmost trench would have to have been ice free.

Although there is no reason to question the above evidence for initial deglaciation of some lowland areas in interior British Columbia prior to 12 000 years B.P., the oldest reliable postglacial radiocarbon age obtained to date in the Interior System north of the International Boundary is 11 000 ± 180 years (GSC-909, Lowdon and Blake, 1970, p. 71). Bog-bottom dates in the Interior System, in general, become younger towards the west (Fulton, 1971, p. 17), perhaps reflecting later deglaciation of the Coast Mountains.

* Both advances have been assigned to the time period of the Fraser Glaciation (Rutter, 1976, 1977).

By 9500 to 10 000 years ago, the plateaus and valleys of the interior were completely deglaciated, and ice was restricted to the major mountain ranges. Bog-bottom sediments immediately outside the terminus of present-day Tiedemann Glacier in the southern Coast Mountains dated 9510 ± 160 years (GSC-939, Lowdon et al., 1971, p. 300), indicating that the mountains in that area were as free of ice then as they are now. A date of 9315 ± 540 years (GX-2695, Reeburgh and Young, 1976, p. 12) from the Atlin area is a minimum for deglaciation of the northern Interior System near the front of the Coast Mountains.

Rutter et al. (1972) and Rutter (1976, 1977) concluded that there still was ice in part of the northern Rocky Mountain Trench after 9280 ± 200 years B.P. (GSC-1497, Rutter, 1976, p. 431). This date was obtained from a bighorn sheep skull in what were interpreted to be ice-contact gravels. If the stratigraphic interpretation is correct and the radiocarbon date valid, ice lingered in this area after it had disappeared from other interior localities. Nevertheless, it seems improbable that glaciers occupied areas far distant from their sources in the Cassiar, Omineca, and northern Rocky mountains at a time when glaciers in the Coast and southern Rocky mountains were not much larger than they are at present. It thus is concluded that the chronology of deglaciation in the northern Rocky Mountain Trench proposed by Rutter may require revision.

Eastern System

Although considerable work has been done on deglacial sediments and landforms in the Rocky Mountains of Alberta (e.g., Jennings, 1951; Horberg, 1954; McPherson, 1963, 1970; Nelson, 1963; Rutter, 1966a, b, c, 1969, 1972; Stene, 1966; Wagner, 1966; Roed, 1968, 1975; Boydell, 1970, 1972, 1978; Walker, 1971, 1973; Alley, 1972, 1973; Harris and Boydell, 1972; Shaw, 1972; Stalker, 1973; Alley and Harris, 1974; Waters, 1975; Harrison, 1976b; Harris and Waters, 1977; Jackson, 1977, 1980; Stalker and Harrison, 1977), relatively little is known of deglacial events in that portion of the Rocky Mountains in British Columbia. Geomorphic and Quaternary stratigraphic studies, however, have been conducted in Peace River valley (Rutter, 1976, 1977), Yoho National Park and vicinity (Bement, 1972; Fox, 1974), and Elk River valley (Harrison, 1976a).

Harrison's work in Elk River valley is of particular importance in terms of the timing of deglaciation in the southern Rocky Mountains. Radiocarbon dates of 11 900 ± 100 and 12 200 ± 160 years (GSC-2142 and GSC-2275, Lowdon and Blake, 1976, p. 9) from postglacial sediments in this valley near the centre of the southern Rocky Mountains indicate deglaciation before about 12 000 years ago. The site from which these radiocarbon dates were obtained is less than 50 km downstream from existing glaciers of some of the highest peaks in the southern Rockies. If these dates are valid, late Pleistocene glaciers in this region must have retreated back to within a few tens of kilometres of the Continental Divide prior to about 12 000 years ago. The location of the samples, however, does not rule out a later, limited alpine readvance in Elk River valley upstream of the sample site, and, in fact, such a late glacial event has been recognized in valleys elsewhere in the Rocky Mountains (e.g., the Eisenhower Junction advance in Bow River valley, Alberta; Rutter, 1969, 1972).

Interior Plains

A series of glacier-dammed lakes (Lake Peace) were impounded by decaying Laurentide ice in the Peace River region of the Interior Plains physiographic province (Taylor, 1960; Mathews, 1963; 1978, 1980). Four stages of glacial Lake Peace were recognized by Mathews. During each successive stage, lake levels were tied to lower outlets controlled by the Laurentide Ice Sheet which was downwasting and retreating to the east.

From a study of strandlines and associated glacial features, Mathews related the evolution of Lake Peace to recession of Cordilleran and Laurentide glaciers. During the earliest stage of Lake Peace, the Cordilleran glacier in Peace River valley terminated at the Rocky Mountain front west of Hudson Hope and built an end moraine consisting of deltaic deposits into the lake. During a later stage, when the Laurentide glacier dam was east of the British Columbia – Alberta boundary, the Cordilleran glacier probably terminated in Peace River valley about 40 km west of the Rocky Mountian front (Mathews, 1978, p. 16). After Lake Peace drained, there was a minor late glacial readvance in the Rocky Mountains; however, glaciers did not extend beyond the mountain front.

A few radiocarbon dates help fix the termination of glaciation in the Peace River region. A date of >11 600 years (I-2244A), determined on the collagen fraction of a mammoth tusk recovered from the end moraine near Hudson Hope, was interpreted by Mathews (1978, p. 17) to be a minimum for retreat of Cordilleran ice westward into the Rocky Mountains*. A corrected date of 9960 ± 170 years (GSC-1548, Lowdon and Blake, 1973, p. 28), previously incorrectly reported as 16 300 ± 180 years (Reimchen and Rutter, 1972, p. 177), and another of 10 400 ± 170 years (GSC-1654, Lowdon and Blake, 1973, p. 28) were obtained near Dawson Creek on shells from silts deposited either in a late stage of Lake Peace or in local ponds which postdate the lake. Other dates from bog and lake bottoms, proglacial lacustrine sediments, and younger fossiliferous silts in the Swan Hills area about 240 km southeast of Fort St. John indicate that much of north-central Alberta was deglaciated before about 11 500 years ago, with some areas ice free perhaps as early as 13 500 years B.P. (St-Onge, 1972, p. 8).

Summary

Deglaciation in British Columbia proceeded by downwasting accompanied by stagnation and frontal retreat. Topography controlled the pattern of deglaciation in each region, and hilly uplands became ice free prior to major valleys and basins. As downwasting progressed, terminal zones of the ice sheet became divided into a series of valley tongues which retreated in response to local conditions.

Retreat occurred first along the southern, eastern, and western margins of the Cordilleran Ice Sheet in British Columbia about 13 000 years ago. Although there were short-lived stillstands and minor readvances, deglaciation progressed rapidly, for by about 9500 years ago glaciers were little more extensive than they are today.

Deglaciation was accompanied by marine inundation of coastal lowlands, by the growth and decay of ice- and drift-dammed lakes, by widespread aggradation in valleys, and by the establishment of the present drainage network.

POSTGLACIAL

Postglacial includes the time since the disappearance of ice of the Fraser Glaciation. The deposits of this interval formed in response to processes that, in general, remain active in British Columbia today, although erosion and sedimentation in most areas presently are occurring at much slower rates than during late glacial and early postglacial time.

* This tusk recently has been redated at 25 800 ± 320 years (GSC-2859), indicating either that the end moraine is older than previously thought, that the sample was contaminated, or that the tusk was recycled from Olympia-age sediments (Lowdon and Blake, 1979, p. 28).

Patterns of Sedimentation and Erosion

During and immediately following deglaciation, and before vegetation became firmly established, rapid aggradation occurred in river valleys and on lowlands. In coastal areas thick marine and glaciomarine sediments were deposited on isostatically depressed lowlands vacated by retreating glaciers and covered by the sea. Throughout the province, freshly deglaciated drift was eroded from uplands and valley walls and was transported to lower elevations to be deposited in fans and deltas and on floodplains (Church and Ryder, 1972). It is probable that the bulk of postglacial deposits, except in lake basins and at the mouths of major rivers, were laid down within a few hundred years following deglaciation. Deltaic progradation of the Fraser, Skeena, and other large rivers occurred throughout postglacial time and continues today on a large scale (e.g., Johnston, 1921; Mathews and Shepard, 1962; Luternauer and Murray, 1973).

As slopes stabilized and vegetation became established, sediment supply to streams and rivers decreased. Together with a fall in base level due to glacio-isostatic uplift and resultant changes in land-sea positions, this led to entrenchment and terracing of late glacial and older deposits.

This pattern of aggradation in late glacial and early postglacial time, followed by degradation, occurred in most regions of the province. For example, the Fraser and Thompson rivers in south-central and southwestern British Columbia locally are incised up to 300 m below late glacial, lacustrine, and outwash surfaces (Ryder, 1971a, p. 1254-1255; see also Anderton, 1970, p. 69-70). Likewise, Peace River and its tributaries on the Interior Plains flow in deep postglacial valleys (Beach and Spivak, 1943; Mathews, 1963, 1978).

Eolian sedimentation, like fluvial aggradation, occurred mainly during late glacial and early postglacial time (Fulton, 1975a, p. 38). During deglaciation, dust was blown from unvegetated surfaces and deposited in protected areas as loess. At the same time, wherever there was an abundant source of sand, dunes were constructed by wind. As bare surfaces became stabilized by vegetation, there was a marked reduction in loess deposition and dune formation. On some modern floodplains, however, wind still sweeps dust from unvegetated flats and blows sand into small active dunes.

Sediment Types and Their Distribution

Postglacial sediments are widely distributed in British Columbia. Fluvial sediments underlie floodplains, terraces, deltas, and some fans, and generally occur in association with present-day rivers and streams. Likewise, eolian deposits, including loess and dune sand, are most extensive in and adjacent to major river valleys, but thin loess veneers much of the Interior Plateau.

Postglacial marine sediments occur in most offshore areas of British Columbia but are thickest adjacent to the deltas of large rivers. Marine sediments also were deposited on coastal lowlands and at the heads of some fiords during late glacial and early postglacial time.

Organic deposits occur in shallow closed depressions, at the shallow margins of lakes, and on gently sloping, poorly drained surfaces. Most deep basins occupied by organic deposits previously contained lakes; in these, peaty surface sediments commonly overlie marl, which, in turn, overlies lacustrine silt and clay. In contrast, bogs in meltwater channels, in abandoned floodplain channels, and on subaerial deltas generally overlie fluvial sand and silt, whereas bogs on coastal lowlands below the late glacial and early postglacial marine limit commonly overlie marine silt and clay. Organic deposits of bogs situated on floodplains and at the toes of alluvial fans generally contain interbeds of mineral detritus.

Colluvial sediments, including talus, slopewash, and landslide material, are found throughout British Columbia but are most common in areas of moderate and high relief. A wide variety of landslide types occurs in the province, of which many have been described and discussed. Among these are various rockfalls and rock topples (e.g., Piteau, 1977; Mathews, 1979); rockslides and rockfall avalanches (e.g., Mathews and McTaggart, 1969, 1978; Eisbacher, 1971; Moore, 1976; Mokievsky-Zubok, 1977; Alley and Young, 1978; Moore and Mathews, 1978); "sackung" (sags) and gravitational spreading features (e.g., Piteau et al., 1978; Psutka, 1978; Brown and Psutka, 1980); debris flows (e.g., Ryder, 1970, 1971a, b; O'Loughlin, 1972, 1973; Alley and Thomson, 1978; Clague, 1978b; Jackson, 1979; Nasmith and Mercer, 1979); earthflows (e.g., Stanton, 1898; VanDine, 1974, 1980; Skermer, 1976; Clague, 1978b; Luternauer and Swan, 1978; Swan, 1978; Swan and Luternauer, 1978); and earth and rock slumps.

Eisbacher (1979) has shown that the landslide characteristics of each major physiographic region of British Columbia are unique, due to differences in topography, climate, and, possibly, seismicity. Landslides in the Coast and Insular mountains are mainly rockfalls, rockslides, debris flows, and earthflows; those on the Interior Plateau are chiefly slumps, debris flows, and earthflows; deep-seated slope sagging and gravitational spreading are dominant in the mountain ranges of the Interior System; landslides in the Rocky Mountains are mainly rockfall avalanches and debris flows; finally, most landslides in the Interior Plains are softrock slumps and earthflows.

Volumetrically small, but stratigraphically important beds of tephra occur in many parts of British Columbia. Tephra is preserved only where erosion was not ocurring during a volcanic eruption. Where tephra was deposited on a flat surface far from the vent and was not subsequently reworked (for example, in large bogs), it forms a uniform layer a few millimetres to several centimetres in thickness. Where deposited on irregular surfaces and then reworked (for example, on fans), the tephra is discontinuous and may be several tens of centimetres thick in local lenses. Tephra units of several postglacial volcanic eruptions have been recognized in British Columbia, and these are discussed individually in the section "Postglacial Lava Flows and Tephras".

Late Glacial and Postglacial Sea Levels

Changes in land-sea positions in British Columbia and adjacent regions during late Quaternary time have resulted from a combination of eustatic, glacio-isostatic, and diastrophic adjustments (Easterbrook, 1962, 1963; Mathews et al., 1970; Miller, 1973; Clague, 1975b; Fladmark, 1975; Andrews and Retherford, 1978; Thorson, 1979, 1980). Because these changes may occur independently or semi-independently of one another, it is generally difficult to assess the contribution of each to past sea level stands. It is possible, however, to date former shorelines and sediments deposited during transgressions and regressions, and thus determine the net effect on sea level of eustatic, isostatic, and diastrophic adjustments through time.

Vancouver Island and the Mainland

Early Postglacial Sea Levels

Most areas near the periphery of the Cordilleran Ice Sheet were covered by the sea during and immediately following deglaciation (Fig. 5); this was due to isostatic depression of the crust by glacier ice. Along the mainland coast, where the ice sheet approached its greatest thickness, glacio-isostatic depression more than compensated for lower eustatic water levels, and here postglacial marine limits are highest. Southwest and west of these areas, marine limits decrease in elevation due to the reduced importance of glacio-isostasy relative to eustacy. Thus, whereas the marine limit is 200 m or higher at Vancouver (Armstrong, 1981) and in the Terrace-Kitimat area, and is at least 150 m near Bella Coola (Andrews and Retherford, 1978, p. 345-346), it decreases to about 90 to 100 m near Alberni (Fyles, 1963, p. 91) and 75 m at Victoria (Mathews et al., 1970, p. 693), and is less than 50 m on the west coast of Vancouver Island (Valentine, 1971, p. 9; D.E. Howes, personal communication, 1979).

Maximum marine limits were attained on the mainland coast and on much of Vancouver Island immediately following ice retreat. Because deglaciation was a diachronous event, however, the limits were not reached at the same time in these areas. For example, near Vancouver the marine limit was attained before 12 900 ± 170 years ago (GSC-2193, Lowdon et al., 1977, p. 14), whereas in the Terrace-Kitimat area, where deglaciation occurred later, the marine limit was reached about 10 790 ± 180 years ago (GSC-523, Lowdon et al., 1967, p. 174).

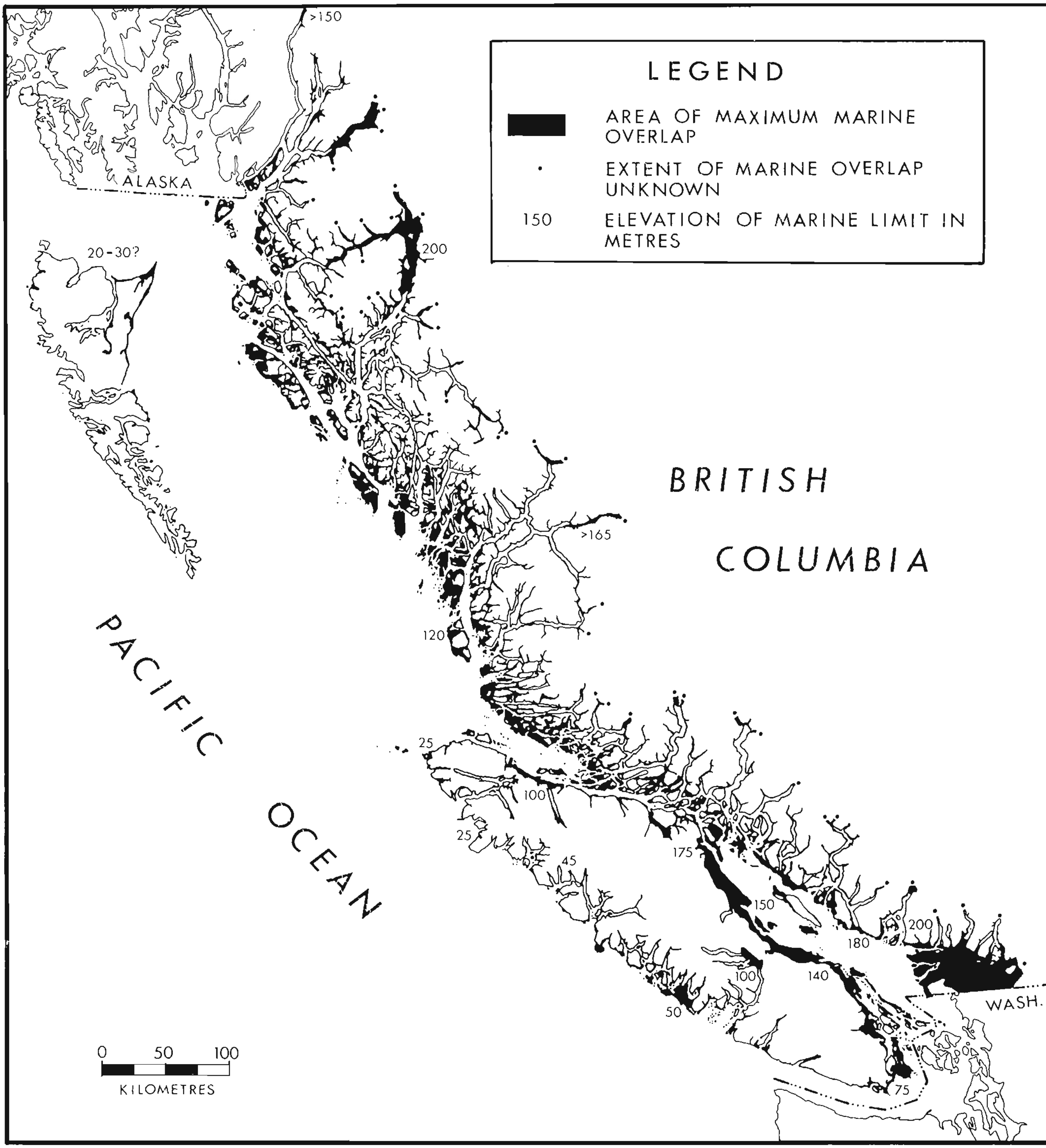

Figure 5. Maximum late Quaternary marine overlap in British Columbia. Extent of overlap inland from the heads of most mainland fiords is unknown.

Emergence of the isostatically depressed coastal lowlands of Vancouver Island and mainland British Columbia was rapid. Present sea level was attained perhaps as early as 11 700 ± 170 years B.P. at Victoria (I-3675, Buckley and Willis, 1970, p. 101-102), between 10 000 and 11 000 years ago on eastern Vancouver Island and in the Fraser Lowland (Mathews et al., 1970, p. 694), and between 8000 and 9000 years ago near Bella Coola (Andrews and Retherford, 1978, p. 341).

Emergence may not have proceeded in a uniform fashion. Mathews et al. (1970, p. 695-696) proposed that, in the Fraser Lowland and on eastern Vancouver Island, emergence was interrupted by a strong, but short-lived resubmergence about 11 500 to 12 000 years ago. The main evidence for this resubmergence is the presence in the Georgia Depression and Puget Lowland of radiocarbon-dated fossiliferous marine sediments overlying post-Vashon "terrestrial" deposits (Mathews et al., 1970, p. 695). Many deposits formerly thought to be terrestrial are now known to be marine or deltaic, thus weakening the argument for a second post-Vashon marine transgression (e.g., Croll, 1980). Nevertheless, an organic horizon containing what appear to be in situ stumps occurs between two late Pleistocene glaciomarine units in northern Puget Lowland 80 km southeast of Vancouver. Assuming the stumps indeed are in situ and both glaciomarine units are post-Vashon in age*, this stratigraphic sequence provides good evidence for two transgressions and an intervening regression at the close of the Pleistocene.

A quite different early postglacial sea level history has been reconstructed for southeastern Vancouver Island (Mathews et al., 1970). Here, there is no evidence for the second marine transgression postulated for nearby Puget Lowland. At Victoria, following deglaciation about 13 000 years ago, isostatic uplift caused a rapid relative fall in sea level from the marine limit at about 75 m. The sea attained its present level about 11 700 ± 170 years ago (I-3675, Buckley and Willis, 1970, p. 101-102) and probably was no higher than at present during the remainder of postglacial time. An interval of relative sea level stability from about 11 700 ± 170 to 9250 ± 140 years B.P. (I-3675 and I-3676, Buckley and Willis, 1970, p. 101-102) may reflect a balance between the eustatically rising sea and the isostatically rebounding land. What is possibly a coeval slowing or halt in emergence also has been proposed for the Juneau area of southeastern Alaska (Miller, 1973, p. C17).

There presently is no satisfactory explanation for the second post-Vashon transgression proposed for parts of the Georgia Depression and Puget Lowland. It is unlikely that this transgression was caused by localized tectonic movements because of the regularity in the slope of the marine limit throughout the region and the absence of subsequent comparable tectonism. Isostatic depression due to a build-up of ice during the Sumas Stade likewise seems unlikely in view of the small volumetric changes in ice loads during Sumas time and the apparent nonsynchroneity of the Sumas advance and the second post-Vashon transgression. Finally, the magnitude of the transgression (100 to 150 m in the Fraser Lowland according to Mathews et al., 1970, p. 700) cannot be accounted for solely by a rapid eustatic rise in sea level. The apparent inexplicability of the postulated crustal movements casts some doubt on their validity. This problem cannot be resolved without additional field studies, but it is probable that the second post-Vashon marine transgression, if indeed real, is much smaller than previously thought. Limited resubmergence perhaps was caused by a rapid eustatic sea level rise acting in concert with as yet poorly understood, complex isostatic adjustments in the crust and mantle.

Middle Postglacial Sea Levels

During middle postglacial time, many mainland and eastern Vancouver Island coastal sites were more emergent than at present (Mathews et al., 1970, p. 696-697; Andrews and Retherford, 1978, p. 348). Terrestrial sediments dated 7300 ± 120, 7600 ± 100, 8290 ± 140, and 8360 ± 170 years old (S-99, McCallum and Wittenberg, 1962, p. 73-74; GSC-2, Dyck and Fyles, 1962, p. 15; GSC-229 and GSC-225, Dyck et al., 1965, p. 35) occur up to 11 m below mean sea level in the Fraser Lowland. Sea level was several metres lower than present at Comox on eastern Vancouver Island between 6820 ± 200 and 8680 ± 140 years B.P. (I-1227, Mathews et al., 1970, p. 696; GSC-265, Dyck et al., 1966, p. 113-114), but was at about its present position by 5680 ± 130 years B.P. (GSC-424, Mathews et al., 1970, p. 696). At Victoria the sea was lower than at present from before 9250 ± 140 to after 5470 ± 115 years B.P. (I-3676 and I-3673, Buckley and Willis, 1970, p. 101).

Late Postglacial Sea Levels

During the past 5000 years, sea levels have not fluctuated significantly on the inner coast but apparently were up to a few metres below present level during much of this interval. Hebda (1977) studied the paleoecology of Burns Bog, which is situated near present sea level on the Fraser River delta, and concluded that the sea was no higher than at present during the past 5000 years. A tree stump exposed on a beach north of Victoria and protruding through a peat bed 1.5 m below high tide has been dated at 2040 ± 130 years (GSC-252, Mathews et al., 1970, p. 697). Another peat bed, 4350 ± 100 years old (GX-0781, Kellerhals and Murray, 1969, p. 83) occurs 1.8 m below high tide on the Fraser River delta. Finally, numerous coastal archeological sites occupied during middle and late postglacial time are now partially or completely submerged, indicating former lower sea levels (e.g., Mitchell 1971, p. 67). For example, a site on Galiano Island now partially inundated at high tide, contains material 730 ± 130 to 3160 ± 130 years old (GSC-436 and GSC-437, Lowdon et al., 1969, p. 34-35). In the Bella Bella – Bella Coola area, middens located below high tide and presently being eroded by waves range in age from 50 ± 80 to 3400 ± 100 years old (GaK-3717 and GaK-2715, Andrews and Retherford, 1978, p. 347). Finally, in the vicinity of Prince Rupert several archeological sites presently are waterlogged and partly eroded by the sea. These sites were occupied by man nearly continuously for the past 5000 years, indicating that sea levels were similar to or lower than that at present at Prince Rupert throughout this period.

Whereas late postglacial sea levels were lower than that at present along most or all of the inner coast, they were higher along many parts of the west coast of Vancouver Island. For example, on the north side of Nootka Sound littoral sediments deposited when the sea was at least 4 m above present high tide have yielded radiocarbon dates ranging from 3590 ± 190 to 4230 ± 90 years (GSC-1767 and GaK-2183, Lowdon et al., 1974, p. 7; Dewhirst, 1978, p. 8-9). A series of younger radiocarbon dates from a site about 20 km to the southeast are associated with former sea levels up to a few metres higher than present (Hebda and Rouse, 1979; D.E. Howes, personal communication, 1980).

Contemporary Sea Level Fluctuations

Tide-gauge records and geodetic measurements indicate that the sea is rising relative to the land on the mainland coast (Mathews et al., 1970, p. 697-699; de Jong and Siebenhuener, 1972; Riddihough, 1979, p. 358-359). De Jong and Siebenhuener (1972, p. 4) concluded from tide-gauge records for the period 1943 to 1968 at Vancouver, Point Atkinson, and Prince Rupert that this rise is 2 to 3 mm/a. Part of this may be due to a worldwide eustatic rise in sea level, but most is caused by crustal subsidence.

* A sample from one of the stumps at this site recently has been radiocarbon-dated at 11 455 ± 125 years (Beta-1324; D.P. Dethier, personal communication, 1980).

Comparison of computed elevations of bench marks in the Fraser Lowland, which were surveyed between 1914 and 1924 and resurveyed between 1958 and 1967, indicates downward movement of almost all stations, with an increase in the rate of displacement southward across the International Boundary (Mathews et al., 1970, p. 699). Maximum subsidence rates are about 1.5 mm/a. Apparently, this sinking is not related to loading of the crust by deltaic sediments of Fraser River because maximum subsidence is not centred over the Fraser River delta; rather, the sinking is likely due to tectonic movements (Riddihough, 1979). Whatever its cause, historical subsidence in this area appears to be substantially greater than the long-term average inferred from submergence of terrestrial features 4000 to 8000 years old.

Queen Charlotte Islands

Early Postglacial Sea Levels

On the Queen Charlotte Islands, far from the centre of the Cordilleran Ice Sheet, postglacial marine submergence occurred to at least 15 to 18 m elevation (Sutherland Brown, 1968, p. 34-35; Alley and Thomson, 1978, p. 18-19).* The postglacial transgression on these islands not only was much less extensive than the transgression in coastal areas of eastern Vancouver Island and mainland British Columbia, but it also occurred later (Clague, 1975b, p. 18). In fact, Sutherland Brown (1968, p. 34-35), Nasmith (1970, p. 7), and Fladmark (1975, p. 154-157) all argued that sea levels on the Queen Charlotte Islands during late glacial and early postglacial time were lower than at present, the main evidence being what they interpreted to be drowned, outwash-filled channels graded to below present sea level and submerged wave-cut scarps. Support for relatively low sea levels on the Queen Charlotte Islands during late glacial time is provided by a terrestrial peat dating 12 400 ± 100 years old (GSC-3112) at its base and extending to below mean sea level on northeastern Graham Island. On the basis of this date, it seems probable that sea levels in the vicinity of the Queen Charlotte Islands were lower than that at present at a time when maximum marine limits, locally 200 m or more, were achieved on the mainland coast to the east. If this is correct, the gradient of vertical displacements caused by glacio-isostatic depression of the crust must have been very steep between the Coast Mountains and the Queen Charlotte Islands during and shortly after the Fraser Glaciation. Implicit in this is the possibility that ice cover on the Queen Charlotte Islands during the Fraser Glaciation was not extensive.

Middle Postglacial Sea Levels

The transgression from the low sea stand of late glacial time on the Queen Charlotte Islands began before 9000 years ago, which is the approximate age of shells of marine molluscs living when sea level was at least several metres higher than that at present (e.g., 9040 ± 80 years, GSC-2867; 8850 ± 90 years, GSC-2534, Alley and Thomson, 1978, p. 18). This conclusion is supported by a radiocarbon date of 9510 ± 280 years (I-1621, Swanston, 1969, p. 31) on molluscan shells in beach deposits at about 10 m elevation on Prince of Wales Island, southeastern Alaska.

Dated archeological and geological materials associated with raised beaches on the Queen Charlotte Islands indicate that the sea had fallen from the marine limit by 5460 ± 70 years ago (GSC-2963), but likely remained fairly high until about 4500 years ago (e.g., 4290 ± 130 years, GSC-1554, Lowdon et al., 1972, p. 21; 4445 ± 90 years, I-9169, Alley and Thomson, 1978, p. 19).

Late Postglacial Sea Levels

Sea levels continued to fall on the Queen Charlotte Islands during late postglacial time. On northeastern Graham Island, for example, the sea was perhaps 9 m higher than at present 5460 ± 70 years ago (GSC-2963), but had fallen to below 6 m between 3280 ± 210 and 4150 ± 90 years ago (GaK-5439, Severs, 1975, p. 15; S-936, Rutherford et al., 1979, p. 75), and to about 2 m by 940 ± 60 years ago (GSC-2815, Harper, 1980, p. 15). These dates support Fladmark's (1975, p. 158) contention that the highest (>10 m) of the shoreline complexes recognized by Sutherland Brown (1968, p. 35-36) dates from 4000 to 9500 years ago, whereas the middle complex (3 to 8 m) is about 2000 to 3000 years old. The lowest shoreline feature recognized by Sutherland Brown is a wave-cut bench at present high tide which has not been directly dated.

Summary

Sea levels on the mainland and Vancouver Island coasts were high during and shortly after deglaciation. Glacio-isostatic uplift resulted in rapid emergence, with the sea reaching its present level relative to the land 1000 to 4000 years after deglaciation, depending on the locality. The sea continued to fall relative to the land and was up to 12 m or more below present when emergence culminated about 6000 to 9000 years ago. During most of the remainder of postglacial time, sea levels have been lower than at present. A late postglacial marine transgression has resulted in erosion of many coastal middens and inundation of low-lying terrestrial vegetation.

In contrast to the above pattern of sea level variations, which is characteristic of inner coastal areas, sea levels on the Queen Charlotte Islands were relatively low during early postglacial time and were higher than at present during middle and late postglacial time.

The differences between the sea level histories of the inner and outer coasts during middle and late postglacial time probably are due to diastrophism. Coastal areas of British Columbia are situated near the junction of major crustal plates. Although the tectonics in this region are complex (see Riddihough, 1979, for a recent review and summary), present plate interactions involve both strike-slip displacement along major transform faults and compression and crustal thickening in the vicinity of subduction zones. As a result, seismicity is high in most coastal areas and differential tectonic movements are to be expected. Although the pattern of sea level fluctuations in British Columbia cannot be related in detail to the tectonic framework of the region, it does appear that most of the outer coast is being uplifted, while the inner coast is subsiding.

Paleoclimate

The character of fossil pollen spectra, the position and age of post-Pleistocene moraines, and inferred positions of former treelines all provide evidence of postglacial climatic fluctuations in British Columbia.

Early and Middle Postglacial Climates

Southern British Columbia

The earliest major work on postglacial climates in southern British Columbia and adjacent areas in the United States is that of Hansen (1937, 1938, 1939a, b, c 1940a, b, 1941a, b, 1943, 1944, 1947a, b, 1948, 1950, 1955, 1967). Hansen postulated the existence of a postglacial interval of maximum warmth and dryness (i.e., the "Altithermal" of Antevs, 1948, p. 176), which was preceded and followed by

* N.F. Alley (personal communication, 1979) has identified a possible strandline at about 30 m elevation on northwestern Graham Island; however, the age of this feature is unknown, and it has not been proven to be of marine origin.

cooler wetter periods. The strongest evidence for a postglacial xerothermic interval comes from the dry Columbia Plateau in eastern Washington where Hansen found that pollen of xerophytes consistently reaches maximum values around the 6600 year old Mazama tephra layer in several bogs.

Hansen (1955) placed the xerothermic interval in south-central British Columbia between 3500 and 7500 years ago, with a "thermal maximum" around 6600 years ago. The climatic interpretation there, however, relied heavily on an inferred abundance of **Pinus ponderosa**, an important floristic element of the semi-arid zone in western North America. Mack (1971) has shown that the size-range method which Hansen used to distinguish **Pinus ponderosa** from **Pinus contorta** is unreliable. Because the latter species is tolerant of a wide range of climatic conditions and occurs in a variety of environments, Hansen's paleoclimatic reconstruction for south-central British Columbia might be disputed. Recent palynological and geomorphic work in the Okanagan Valley of southern British Columbia, however, has confirmed the existence of a warm dry interval from about 8400 years ago to about 6600 years ago, after which there was a shift to cooler, more moist conditions (Alley, 1976c). Likewise, recent palynological investigations in eastern Washington and northern Idaho indicate dry and warm conditions during much of middle postglacial time, although the proposed time boundaries of this xerothermic interval differ at the various studied sites (Mack et al., 1976, 1978a, b, c, 1979).

In the Fraser Canyon area in southwestern British Columbia, cool moist conditions which prevailed during deglaciation were followed about 10 400 years ago by a dry warm climate (Mathewes, 1973a, b; Mathewes and Rouse, 1975). Dry warm conditions persisted in that area until about 6600 years ago, when there was a return to a cooler wetter climate. The timing of the xerothermic interval there is similar to that in the Puget Lowland (Hansen and Easterbrook, 1974, p. 600-601).

Palynological work in the Georgia Depression has not yet provided evidence of a xerothermic interval during postglacial time. Mathewes (1973a, b) studied postglacial lake sediments in the Fraser Lowland near Haney and concluded that a humid coastal climate has prevailed in that area since about 10 500 years ago. Likewise, Hansen (1950) found no evidence of a pronounced warm dry interval on the lowlands of southeastern Vancouver Island. Rather, he attributed changes in pollen assemblages there to normal forest succession in response to a general amelioration of climate and soil maturation.

The lack of evidence for a postglacial xerothermic interval in southwestern British Columbia may reflect a lower degree of climatic change in coastal areas as compared to the interior. Furthermore, any effects of a warming and drying climatic trend likely would be masked in coastal areas where precipitation is not a limiting factor on plant growth. In contrast, in semiarid areas of the southern Interior Plateau where precipitation is limiting, a minor reduction in precipitation or an increase in temperature would lead to marked vegetation changes.

In the wet temperate Puget Lowland and on Olympic Peninsula the xerothermic interval also was less strongly expressed than in dry interior regions (Hansen, 1947b). Both Hansen (1947a) and Heusser (1960, 1964, 1973b, 1974, 1977, 1978), however, still postulated the existence in these areas of a period of increased warmth, preceded and followed by cooler and wetter conditions. Hansen and Easterbrook (1974, p. 599-600) described pollen assemblages in a bog in the Puget Lowland and concluded from them that a climate somewhat warmer and drier than the present characterized that area from before 9920 ± 760 years B.P., (I-2280, Easterbrook, 1969, p. 2285) to about 7000 years ago.

Additional evidence for a postglacial xerothermic interval is provided by dead wood occurring above present treeline in the mountains of southern British Columbia (e.g., Lowdon and Blake, 1968, p. 226). The wood has been found on the surface and beneath snow, ice, and glacial deposits, indicating a past climate warmer than the present (Mathews, 1951, p. 366). Radiocarbon dates on this wood from three widely separated sites include 5260 ± 200, 5300 ± 70, 5470 ± 140, 5950 ± 140, 6170 ± 150, and 7640 ± 80 years (Y-140bis, Stuiver et al., 1960, p. 58; GSC-2027, Lowdon and Blake, 1975, p. 20; GSC-197, Dyck et al., 1966, p. 109; GSC-760, Lowdon and Blake, 1968, p. 226; GSC-1477, Lowdon and Blake, 1973, p. 26; GSC-1993, Lowdon and Blake, 1975, p. 20). In addition, a date of 9120 ± 540 years (GSC-1390, Lowdon et al., 1971, p. 295-296) was obtained on charcoal above present treeline in the Cascade Mountains in southern British Columbia (see also van Ryswyk, 1969, 1971; van Ryswyk and Okazaki, 1979). These dates suggest that there was an interval during postglacial time when the climate was warmer than it is today and that in parts of southern British Columbia this interval terminated after 5200 years B.P.

Atlin Region

Paleoclimatic information for early and middle postglacial time in northern British Columbia is presently available only for the Atlin region. Dated palynological profiles of kettle-hole bogs in this area have been described by Anderson (1970) and Miller and Anderson (1974a, b). They postulated a postglacial thermal maximum between about 2500 and 8000 years ago. During this interval, mean July temperatures are thought to have been up to 1°C higher than at present, and precipitation was at today's level or somewhat higher (e.g., Miller and Anderson, 1974a, p. 46, 48-50). Glaciers in the nearby Boundary Ranges of the Coast Mountains were in retreat, except near the end of the interval.

The thermal maximum in the Atlin region was preceded by a cooler drier period during which Atlin Valley and other valleys draining the Boundary Ranges were becoming deglaciated. Deglaciation proceeded in an irregular fashion, with stillstands and readvances occurring during cooler parts of this period. Mean July temperatures were more than 2°C below present ca. 10 500 to 11 000 years ago, about 2°C below present ca. 10 000 to 10 500 years ago, about 3°C below present ca. 9000 to 10 000 years ago, and 0 to 2°C below present ca. 8000 to 9000 years ago (Miller and Anderson, 1974a, p. 46, 50-52). Shrub tundra grew in areas now covered by spruce forest during the coldest parts of this period (i.e., 9000 to 10 000 and 10 500 to 11 000 years ago).

Miller and Anderson (1974a, b) also proposed that the climatic fluctuations in the Atlin region were out-of-phase with those on the opposite side of the Coast Mountains in southeastern Alaska (Heusser, 1952a, b, 1954, 1960, 1965, 1967; Heusser et al., 1954). In general, when cool moist conditions prevailed in the Alaskan coastal zone, cool and slightly drier climatic conditions characterized the northwestern British Columbia interior. Warm, relatively dry coastal climates were contemporaneous with warm wet interior climates.

Atlin area paleoclimates differed not only from those of southeastern Alaska, but also from those of southern British Columbia. For example, during the warmest part of postglacial time at Atlin, precipitation equalled or exceeded present values, whereas at the same time in south-central British Columbia, precipitation was lower than at present.

Such differences perhaps are to be expected, in that temperature and precipitation responses to global climatic changes probably have differed from one region to another.

This may be particularly true for northwestern North America where there are complex interactions of continental and maritime air masses, and strong topographic controls on climate. For example, Miller and Anderson (1974b, p. 218-220) attributed the opposing climatic characteristics of Atlin and coastal southeastern Alaska to shifts of the Arctic Front and related storm tracks across the Boundary Ranges and to concomitant vertical changes in freezing levels during Quaternary time.

Early Holocene Glacial Advances in the Cordillera

Although early postglacial climates in many parts of British Columbia at times were as warm as or warmer than the present, there probably were short-lived cold intervals during which alpine glaciers advanced. Duford (1976) and Duford and Osborn (1978) documented a cirque glaciation older than 7400 years in the Shuswap Highland, south-central British Columbia. Luckman and Osborn (1979) presented evidence for an early Holocene or late Pleistocene advance in the central Canadian Rocky Mountains. Both advances were of limited extent (less than 2 km beyond present ice margins) and, in general, were smaller than those of the last several centuries. Early postglacial or late Pleistocene glacial events also have been proposed for the United States Rocky Mountains (e.g., Benedict, 1968a, b, 1973; Graf, 1971); the Brooks Range, Alaska (e.g., Porter, 1964, 1966); and the Wallowa Mountains, Oregon (Kiver, 1974).

Extensive early Holocene glacial advances in the Canadian Rocky Mountains have been postulated by several workers (e.g., Stalker, 1969; Reeves and Dormaar, 1972; Fox, 1974; Reeves, 1975; Rutter, 1976, 1977; Harris and Howell, 1977); however, these glacial events are not adequately dated and likely are of late Pleistocene, rather than Holocene age (for a detailed discussion, see Luckman and Osborn, 1979, p. 71-73). For example, Rutter (1977, p. 19-21) proposed that the Deserters Canyon advance, during which glaciers expanded from the Omineca and Cassiar mountains into the northern Rocky Mountain Trench, occurred between 7470 ± 140 and 9280 ± 200 years ago (GSC-1069, Lowdon et al., 1971, p. 298; GSC-1497, Rutter, 1976, p. 431). Unfortunately, neither limiting date is directly associated with Deserters Canyon deposits; thus a Holocene age for the advance has not been proved (Luckman and Osborn, 1979, p. 73).

Late Postglacial Climates

Southern British Columbia

Although the timing of the xerothermic interval in southern British Columbia is uncertain, it is clear that the climate of late postglacial time, in general, was colder and wetter than that of middle and much of early postglacial time. Post-Altithermal cooling caused alpine glaciers to advance from retracted positions. Such advances occurred in the Cordillera of western North America about 4000 to 5000, 2300 to 3100, and 1050 to 1250 radiocarbon years ago, and within the last several centuries (Denton and Karlén, 1973).

The oldest interval of post-Altithermal glacier expansion is not well documented and probably involved relatively minor growth of glaciers. South Cascade Glacier in Washington, however, is known to have advanced 4700 to 4900 radiocarbon years ago (Miller, 1967, 1969; Denton and Karlén, 1973, p. 162). Glacier growth after 5200 years B.P. in British Columbia is indicated by a tree stump dated 5260 ± 200 years (Y-140bis, Stuiver et al., 1960, p. 58) and rooted on a nunatak well above present treeline on Mount Garibaldi in the southern Coast Mountains. The tree was part of a forest destroyed during a glacier advance. The date on the stump, however, is only a maximum limiting date for this advance. Alley (1976b) postulated a glacial advance (Dunn Peak advance) between 4000 to 5000 years ago in the mountains of south-central British Columbia. Subsequent work at Dunn Peak by Duford (1976) and Duford and Osborn (1978), however, has shown that this advance is substantially older than originally thought, being either late Pleistocene or early Holocene in age. The evidence for this is the occurrence of both 6600 year old Mazama ash and charcoal dated 7360 ± 250 years old (GX-4039, Duford and Osborn, 1978, p. 87) on the moraine deposited during the Dunn Peak advance.

A well documented period of glacier expansion occurred throughout the Cordillera of western North America 2300 to 3100 radiocarbon years ago (e.g., Goldthwait, 1963; Crandell and Miller, 1964; Porter, 1964; Crandell, 1965a; Haselton, 1965, 1967; Borns and Goldthwait, 1966; Denton and Stuiver, 1966; Porter and Denton, 1967; Curry, 1968, 1969; Rampton, 1970; Denton and Karlén, 1973, 1977). Tiedemann Glacier in the southern Coast Mountains reached its maximum postglacial position 2940 ± 130 years ago and began to retreat 2250 ± 130 years ago (GSC-938 and GSC-948, Lowdon et al., 1971, p. 300; Fulton, 1971, p. 24). Alley (1976b) recognized a glacial advance (Battle Mountain advance) within the time interval 2400 to 3300 years ago in the mountains of south-central British Columbia.

Supporting evidence for cooling and glacier expansion during this interval is provided by the postglacial pollen record of Kelowna Bog in the semiarid Okanagan Valley. Pollen assemblages from this bog indicate alternating moist and dry conditions on the valley floor. Alley (1976c) attributed these changes in moisture regime to variations in runoff from adjacent uplands, which in turn were caused by fluctuations in temperature and precipitation. Intervals of increased moisture were thought to be contemporaneous with periods when glaciers in alpine areas were in advanced positions. Alley (1976c, p. 1141) thus suggested that a moist phase between about 2000 and 3200 years ago in Okanagan Valley correlates with an interval of glacier expansion recognized elsewhere in the Cordillera.

A short-lived advance occurred locally in western North America 1050 to 1250 years ago (Rampton, 1970; Denton and Karlén, 1973). Although this event has not been documented in British Columbia, Alley (1976c, p. 1141) proposed that the present moist phase at Kelowna Bog began about 1500 years ago.

In many parts of British Columbia alpine glaciers reached their postglacial maxima during the last several centuries (e.g., Munday, 1936; Mathews, 1951), destroying or burying evidence of earlier, less extensive advances. This interval of glacier expansion has been referred to as the "Little Ice Age" and is recognized in mountain ranges throughout the world (for summary and references, see Porter and Denton, 1967; Denton and Karlén, 1973). Within this and earlier postglacial cold intervals, there undoubtedly were minor glacier fluctuations. For example, Little Ice Age advances in the European Alps culminated about A.D. 1500 to 1640, 1710, 1780, 1850, 1890, and 1916 (Denton and Karlén, 1973, p. 155).

Atlin Region

Although air temperatures in British Columbia, in general, were lower in late postglacial time than during middle postglacial time, precipitation responded to global temperature changes in a complex fashion. Thus, whereas cooling in southern British Columbia and in coastal southeastern Alaska apparently was accompanied by increased precipitation, cool intervals in the Atlin region were marked by reduced precipitation (Anderson, 1970; Miller and Anderson, 1974a, b). At Atlin there was a cool dry period from about 750 to 2500 years ago, during which glaciers expanded in the nearby Boundary Ranges (Miller and Anderson, 1974a, p. 48). Within the last 750 years, precipitation and temperatures in the Atlin region have increased to values comparable to those prevailing prior to 2500 years ago.

Summary

During postglacial time there were alternating intervals of glacier expansion and contraction superimposed on broader climatic trends. The climate of British Columbia was cool and wet during and immediately following deglaciation at the close of the Pleistocene Epoch. At this time there probably were localized resurgences of remnant Pleistocene glaciers. These resurgences, however, were not everywhere contemporaneous and probably were caused as much by local factors as by global cooling.

In southern British Columbia arboreal vegetation became established shortly after deglaciation (e.g., Hansen, 1955; Mathewes and Rouse, 1975), indicating a rapid transition to a nonglacial climate without an intervening stage of tundra vegetation. This is supported by the occurrence of a skull of **Bison** cf. **occidentalis** in a glacial-lake delta in south-central British Columbia (Fulton, 1971, p. 19). However, shrub tundra did become established in presently forested valleys in the Atlin area during deglaciation (e.g., Anderson, 1970, p. 286-292; Miller and Anderson, 1974a, p. 50-52).

Within a few thousand years after deglaciation, the climate in most areas was as warm as, or warmer than the present. Generally warm and locally dry conditions persisted until about 6600 years ago in south-central British Columbia, after which the climate gradually became cooler and wetter. In the southern Coast Mountains and perhaps in other mountain ranges, treeline and, therefore, temperatures were higher than at present until after 5200 years ago. In northwestern British Columbia, air temperatures remained slightly higher than at present until about 2500 years ago, and there was no reduction in precipitation during the postglacial interval of maximum warmth as there apparently was in south-central British Columbia.

These observations suggest that postglacial climatic changes did not occur everywhere in British Columbia at the same time. Some caution is required here, however, because most late Quaternary paleoclimatic inferences, including many of those mentioned above, are based on the assumption that floras are sensitive to temperature and precipitation changes. Floras in some areas of British Columbia probably were relatively insensitive to the relatively small climatic changes of postglacial time. For example, fossil pollen assemblages from several bogs and lakes in the lowlands of southwestern British Columbia provide no indication of the climatic changes which produced treeline shifts and glacier fluctuations in nearby mountains. Microfossil assemblages from the coastal lowlands thus may be of limited value in reconstructing postglacial climates. Variations in pollen spectra through time in such areas may be due more to local soil factors, rather than to climatic factors (e.g., Hebda, 1977).

The xerothermic interval in British Columbia was followed by a generally cooler moister period punctuated by sharp climatic fluctuations. Two well documented intervals of post-Altithermal glacier expansion occurred in British Columbia, one between 2300 and 3100 radiocarbon years ago and the other within the last several centuries. In most areas glaciers were more extensive during the latter interval. In addition, there is some evidence for a third glacial event between 4000 and 5000 radiocarbon years ago, although it has not yet been adequately documented. It is probable that, with continued research, additional glacial events will be recognized and the Holocene glacial chronology of the province will be refined. This will lead to a better understanding of the nature and magnitude of the climatic changes responsible for observed glacier fluctuations. It should be remembered, however, that alpine glaciers may respond differently to world-wide changes in climate because of the variable effects of topography, geographic location, and glacier regimen. Thus, glacier expansion or recession in one area may be out-of-phase with that in another area. It is for this reason that the concept of world-wide synchroneity of glacial events, which has been proposed by several scientists (e.g., Porter and Denton, 1967, p. 200; Curry, 1969, p. 41; Kind, 1972, p. 59-61), is probably an oversimplification. That this is indeed the case is suggested by the fact that the Holocene glacial chronology for the southern Rocky Mountains is strikingly dissimilar to that for mountain systems farther west, except for the period fo the last few hundred years (Benedict, 1973, p. 596-597).

Postglacial Lava Flows and Tephras

Most postglacial volcanic activity in British Columbia has been concentrated in three linear volcanic belts (Fig. 6) that appear to be related to crustal plate boundaries (Souther, 1976, p. 260-261). From south to north, these are the Garibaldi volcanic belt, the Anahim volcanic belt, and the Stikine volcanic belt.

The Garibaldi volcanic belt includes approximately 32 Quaternary eruptive centres of which three, Mount Garibaldi, Mount Cayley, and Meager Mountains, are major dacitic domes. Mount Garibaldi was last active about 10 000 years ago. The youngest activity in the belt occurred about 2000 years ago from a vent near Meager Mountain.

The Anahim volcanic belt includes about 37 Quaternary volcanic centres, all of which have produced alkali olivine basalt magmas. Many of the small pyroclastic cones and thin blocky intra-valley flows associated with these centres are postglacial in age.

The Stikine volcanic belt includes more than 50 postglacial eruptive centres plus at least as many of late Miocene to late Pleistocene age. The largest volcanic centre in the Stikine belt is the Edziza Peak – Spectrum Range complex which was last active about 1350 years ago (Souther, 1976, p. 261) and has had a long, nearly continuous record of activity spanning most of post-Miocene time. Most eruptive centres in the belt, however, have been the locus of a single pulse of activity during which one or more small pyroclastic cones were built and a small volume of alkali olivine basalt extruded to form thin blocky flows. The youngest eruption of this type issued from fissures in the Coast Mountains near the south end of the Stikine belt less than 150 years ago (E.W.T. Grove, personal communication, 1978). The Aiyansh flow (0.45 km^3), in the same region, has been dated at 250 ± 130 years (GSC-1124, Lowdon et al., 1971, p. 300-301; Sutherland Brown, 1969). It issued from a cinder cone which was built inside an older cone about 625 ± 70 years old (S-1046, Wuorinen, 1978, p. 1037).

Several volcanoes in western North America have erupted explosively in postglacial time to produce widespread tephra deposits in British Columbia (Fig. 6). Two of these volcanoes are located in British Columbia, one in the Meager Mountain area and the other in the Edziza Peak – Spectrum Range complex. Volcanoes in the Cascade Mountains of Washington and Oregon are the source of many tephra units in the province, including some of the most useful from a stratigraphic point of view. For example, tephras derived from Mount St. Helens in Washington and Mount Mazama (Crater Lake) in Oregon are widespread in southern British Columbia and serve as excellent marker beds. In addition,

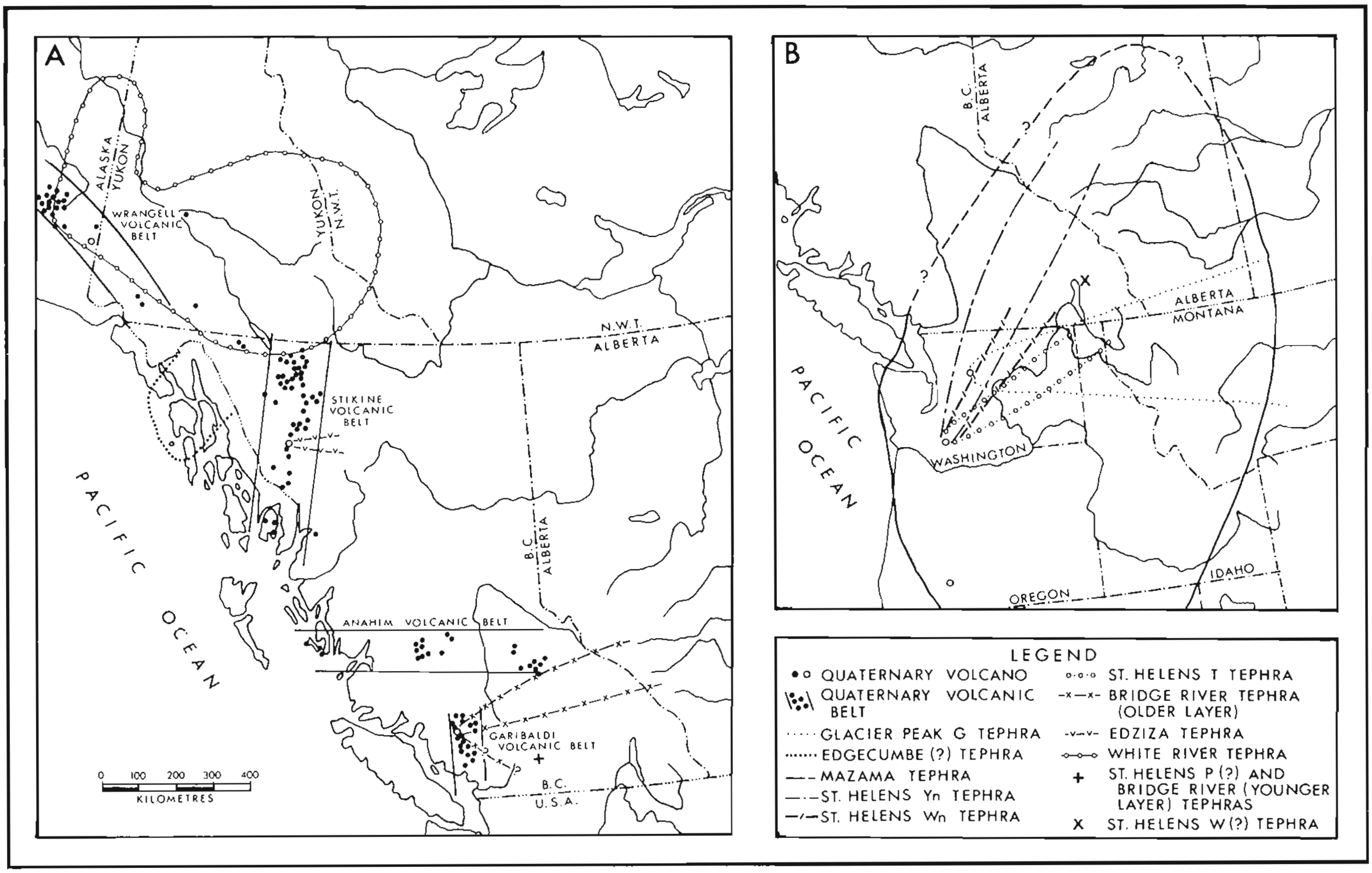

Figure 6. *Late glacial and postglacial tephras in and near British Columbia. A. Distribution of Quaternary volcanic centres in western Canada and eastern Alaska and minimum inferred extent of tephras derived from these centres. B. Inferred distribution of tephras in and adjacent to southern British Columbia which were erupted from Cascade volcanoes in Washington and Oregon. Tephra distributions from Bostock (1952), Nasmith et al. (1967), Westgate et al. (1970), Fulton (1971), Okazaki et al. (1972), Sneddon (1974), Mullineaux et al. (1975), Souther (1976), Smith et al. (1977a), Westgate (1977), Porter (1978), and Mathewes and Westgate (1980).*

Glacier Peak in Washington erupted repeatedly in late glacial and early postglacial time, and tephra of one of these eruptions has been found in western Canada, although not yet in British Columbia. Finally, volcanoes in eastern Alaska have erupted in late Quaternary time to produce air-fall tephras which may be present in northernmost British Columbia. Among these are Mount Edgecumbe in coastal southeastern Alaska and a vent in the St. Elias Mountains near the Alaska-Yukon boundary from which the White River tephra was derived.

Tephras such as those cited above are differentiated largely on the basis of their mineralogical and chemical attributes, which are determined by detailed laboratory studies. Field characteristics, such as colour, degree of weathering, grain size, thickness, and stratigraphic position, are also helpful, but generally do not permit the positive identification of tephra units far from their source vents.

Glacier Peak Tephra

Glacier Peak erupted repeatedly between about 11 250 and 12 750 years ago, spreading pumiceous tephra east and southeast from the vent (Fryxell, 1965; Wilcox, 1965; Westgate et al., 1970; Lemke et al., 1975; Smith et al., 1977b; Porter, 1978; Westgate and Evans, 1978). As many as nine tephra units have been identified within about 25 km of the source (Porter, 1978). Of these, two (layers B and G) are widespread outside of Washington, but only layer G has been identified in Canada.

Layer G occurs in a band east of the source in eastern Washington, northern Idaho, Montana, and southern Canada (Fig. 6). It has been found at one site in southeastern Alberta (Westgate, 1968, p. 75; Westgate et al., 1970, p. 16), and known occurrences lie as near as about 32 km south of the British Columbia – Washington boundary (Powers and Wilcox, 1964, p. 1335). Molluscan shells associated with layer G at Diversion Lake in Montana have a radiocarbon age of 12 750 ± 350 years (W-1644, Ives et al., 1967, p. 517). At this time, glaciers still covered much of southern British Columbia (Prest, 1969; Porter, 1978, p. 38-39), thus precluding preservation of the tephra in most areas. However, layer G may yet be found in favourable geologic situations in the southeastern corner of the province, where some areas perhaps were ice free prior to the eruption (see section entitled "Chronology of Deglaciation" in "Fraser Glaciation Recessional Phase, Interior System").

Edgecumbe(?) Tephra

Tephra, possibly derived from the Mount Edgecumbe area in the Boundary Ranges, occurs in southeastern Alaska (Fig. 6) and has been provisionally dated at between 9000 and

11 000 years (Heusser, 1960, p. 184; McKenzie, 1970). This tephra has not yet been reported in British Columbia, although its known distribution in Alaska indicates that it is likely present in the northwestern corner of the province.

Mazama Tephra

Mazama tephra, the most widespread of the postglacial pyroclastic deposits, is found in Canada from Victoria to Saskatchewan (Fig. 6; Westgate et al., 1970). The source of the tephra is a volcano at the present site of Crater Lake in southwestern Oregon.

A date of 6640 ± 250 years (W-858, Rubin and Alexander, 1960, p. 161) on charcoal buried in pumice at Crater Lake has been accepted as the age of Mazama tephra. Charcoal collected from the tephra in Columbia River valley yielded a date of 6560 ± 115 years (I-3809, Fulton, 1971, p. 21), which is in good agreement with the date from the source area.

Although only a single Mazama tephra unit has been found in British Columbia, multiple layers of Mazama ash have been reported in other areas (e.g., Borchardt et al., 1971, 1973; Davis, 1977; Mack et al., 1979). For example, two layers of Mazama ash occur in a bog in northeastern Washington only 5 km south of the International Boundary (Mack et al., 1979, p. 221). The uppermost ash in this bog is bracketed by radiocarbon dates of 6810 ± 190 and 6870 ± 110 years (TX-2882 and TX-2881), and the lower is associated with a date of 6930 ± 110 years (TX-2883, Mack et al., 1979, p. 217-218). The eruptions which produced these two tephra units probably occurred within a few hundred years of each other.

St. Helens Tephra

Mount St. Helens has been an intermittent but prolific source of tephra for more than 35 000 years (Mullineaux and Crandell, 1962; Crandell and Mullineaux, 1973; Crandell et al., 1975; Mullineaux et al., 1975). Individual tephra layers have been grouped in eight discrete sets, of which six (J, Y, P, B, W, and T) are postglacial in age (Mullineaux et al., 1975). Sets Y and W and possibly set P have been identified in Canada and are discussed separately below. Set B is of local extent around the vent and likely is not present in British Columbia. Set J, comprising tephra layers from slightly more than 8000 years old to slightly less than 12 000 years old (Mullineaux et al., 1975, p. 331-332), is thicker and more extensive than set B and may be present in British Columbia, although it has not yet been found there. Likewise, set T, approximately 150 to 200 years old, has not been identified in the province, although it includes one moderately extensive tephra layer which extends east-northeast from Mount St. Helens to near the International Boundary (Fig. 6; Smith et al., 1968, 1975; Okazaki et al., 1972).

Set Y

Set Y, the thickest and coarsest of the Mount St. Helens tephra units, includes more than a dozen layers of pumice, two of which (Yn and Ye) have been found hundreds of kilometres from the source. Layer Ye does not occur in Canada, but layer Yn extends in a long narrow lobe north-northwest from Mount St. Helens across Washington and southern British Columbia into west-central Alberta (Fig. 6; Westgate et al., 1970; Mullineaux et al., 1975).

Crandell et al. (1962, p. D67) assigned an approximate age of 3200 years to layer Yn on the basis of two limiting radiocarbon dates of about 3000 and 3500 years. Near Mount St. Helens, layer Yn is bracketed by radiocarbon dates of 3350 ± 250 and 3510 ± 230 years (W-2549 and W-1752, Mullineaux et al., 1975, p. 332). Limiting dates from British Columbia, including one above the ash layer of 3460 ± 140 years (GSC-1461, Lowdon and Blake, 1976, p. 9) and five below the ash ranging from 3220 ± 70 to 3640 ± 70 years (GSC-1946, Westgate, 1977, p. 2598; GSC-1868, Lowdon and Blake, 1978, p. 7), are in agreement with dates cited above and suggest that layer Yn is 3300 to 3500 radiocarbon years old.

Set P

Tephra of set P has been identified tentatively at one locality in Canada, the Otter Creek Bog in southern British Columbia (Westgate, 1977). There, a thin tephra that has chemical and mineralogical affinities with set P tephra is bracketed by radiocarbon dates of 2070 ± 80 and 3220 ± 70 years (GSC-1939 and GSC-1946, Westgate, 1977, p. 2594-2595). Set P tephra in Washington ranges in age from 2580 ± 250 to 2930 ± 250 years B.P. (W-2539 and W-2829, Mullineaux et al., 1975, p. 331).

Set W

Set W consists of at least six layers, the coarsest and thickest of which (layer Wn) extends northeast from the volcano in a narrow band towards British Columbia (Fig. 6; Smith et al., 1977a). Smith et al. (1977a, p. 209) documented the presence of layer Wn at two localities in southern British Columbia within 30 km of the International Boundary. Fulton (1971, p. 19) noted a thin, widely dispersed ash farther north in south-central British Columbia and correlated it with St. Helens W tephra.

Charcoal from the basal bed of set W near Mount St. Helens has been dated at 1150 ± 200 years (W-2993, Mullineaux et al., 1975, p. 334). Layer Wn, which overlies this basal bed, has been dendrochronologically dated at about 450 years old (Crandell, 1971, p. 12). A piece of wood 5 cm below St. Helens W tephra near Kootenay Lake has yielded a radiocarbon age of 1220 ± 130 years (GSC-832, Lowdon and Blake, 1970, p. 70).

Bridge River Tephra

Explosive eruption of dacitic pumice from a vent near Meager Mountain produced a thick welded ash-flow tuff in upper Lillooet River valley and at least two layers of air-fall pumice over a large area of southern British Columbia (Stevenson, 1947; Wilcox, 1965; Nasmith et al., 1967; Westgate and Dreimanis, 1967; Westgate et al., 1970; Westgate, 1977; Mathewes and Westgate, 1980).

Tephra of two eruptions has been identified to date. During the earlier main eruptive event, tephra was deposited in a relatively narrow strip extending east from Meager Mountain into Alberta (Fig. 6; Nasmith et al., 1967; Westgate et al., 1970). A burnt wood sample from the centre of an 80-cm diameter tree stump enclosed by this tephra near the vent yielded a date of 2500 ± 50 years (GSC-2571, Lowdon and Blake, 1978, p. 10). The tree was about 150 years old when it was engulfed by the tephra, thus the eruption probably occurred about 2350 ± 50 years ago. In the same general area a date of 2480 ± 60 years (GSC-2587, Lowdon and Blake, 1978, p. 10) was obtained on charcoal within fluvially redeposited tephra. These dates are consistent with limiting dates on Bridge River tephra at other sites in southern British Columbia, including maxima of 2440 ± 140 and 2450 ± 130 years (GSC-529, Lowdon and Blake, 1968, p. 226-227; GSC-1532, Lowdon and Blake, 1976, p. 10-11) and a minimum of 2240 ± 130 years (GSC-1520, Lowdon and Blake, 1976, p. 10-11).

Tephra of a younger weaker eruption from the Meager Mountain area has been found in the Otter Creek Bog (Westgate, 1977). The eruption apparently spread pumice southeast from the vent along a different trajectory from the earlier eruption. Peat directly above and below the tephra in the Otter Creek Bog dates 1860 ± 70 and 2070 ± 80 years old, respectively (GSC-1950 and GSC-1939, Westgate, 1977, p. 2594-2595).

Edziza Tephra

Late postglacial tephra surrounds a young vent on Edziza Peak and likely extends eastward in a narrow belt across north-central British Columbia (Fig. 6; Souther, 1976). This tephra has not been studied in detail, but it is a potentially useful stratigraphic marker horizon in a part of the province where no other tephras are known to occur. A single radiocarbon date of 1340 ± 130 years (GSC-566, Lowdon et al., 1967, p. 174) from charred wood covered by cinders on Edziza Peak provides an age for the tephra.

White River Tephra

Tephra erupted from a vent in the St. Elias Mountains covers a large area of southern Yukon Territory and eastern Alaska and also may occur in westernmost District of Mackenzie and northernmost British Columbia (Fig. 6; Capps, 1916; Bostock, 1952; Berger, 1960; Stuiver et al., 1964; Lerbekmo and Campbell, 1969; Rampton, 1969; Hughes et al., 1972). The tephra consists of two layers, the older extending north from the source and the younger east.

The younger layer, which is the only one likely to occur in British Columbia, was deposited approximately 1200 years ago. Dates on wood and charcoal beneath the tephra range from 1190 ± 130 to 1300 ± 130 years (GSC-956, Lowdon et al., 1970, p. 481; GSC-1000, Lowdon and Blake, 1970, p. 80). Radiocarbon dates of 1390 ± 70 and 1460 ± 70 years (Y-1364 and Y-1363, Stuiver et al., 1964, p. 260), obtained, respectively, from peat above and below White River ash near Kaskawulsh Glacier, seem anomalous.

The older White River tephra layer is about 1500 to 1800 years old. Dates on organic material immediately underlying this layer range from 1750 ± 130 to 1990 ± 130 years (GSC-1564, Lowdon and Blake, 1973, p. 29-30; GSC-400, Lowdon and Blake, 1968, p. 229). Peat just above the tephra dated 1520 ± 100 years old (I-275, Fernald, 1962, p. B30).

Summary

Non-explosive volcanic activity has occurred at more than 100 sites in British Columbia during Quaternary time. Thin intra-valley flows of alkali olivine basalt are the dominant products of this eruptive activity. The youngest flow is less than 150 years old.

Postglacial tephras deposited in British Columbia, and derived from eruptive centres both within and outside the province, include: Mazama, about 6600 years old; St. Helens Yn, 3300 to 3500 years old; St. Helens P (?), somewhat older than 2100 years; St. Helens Wn, about 450 years old; Bridge River (older layer), 2300 to 2400 years old; Bridge River (younger layer), 1900 to 2000 years old; and Edziza, 1350 years old. In addition, Glacier Peak layer G, approximately 12 750 years old, Edgecumbe (?) tephra, provisionally dated between 9000 and 11 000 years old, and White River tephra, about 1200 years old, may occur in British Columbia, although none has yet been found there.

CONCLUDING REMARKS

The chronology of late Quaternary geologic and climatic events in British Columbia has been determined from radiocarbon dates on organic materials associated with sundry sedimentary, volcanic, and archeological deposits. Although at present there are hundreds of published radiocarbon dates in British Columbia, most are concentrated in a few areas, thus the chronology of late Quaternary events for many parts of the province is poorly known. For example, there are few radiocarbon dates from northern British Columbia, and the late Quaternary history of most of this region is virtually unknown.

Even in those parts of the province where there is an abundance of radiocarbon dates, there are differences of opinion over the timing and climatic significance of some events; in large part, this is due to differing interpretations concerning the genesis, stratigraphic position, and palynology of certain sedimentary deposits. Although these differences will not be resolved without detailed field investigations and, in most cases, additional radiocarbon dates, it is likely that the basic late Quaternary geologic-climatic framework outlined in this paper will remain unchanged.

REFERENCES

Alley, N.F.

1972: The Quaternary history of part of the Rocky Mountains, Foothills, Plains and western Porcupine Hills, southwestern Alberta; unpublished Ph.D. thesis, University of Calgary, Alberta, 201 p.

1973: Glacial stratigraphy and the limits of the Rocky Mountain and Laurentide ice sheets in southwestern Alberta, Canada; Bulletin of Canadian Petroleum Geology, v. 21, no. 2, p. 153-177.

1974: Terrain mapping and Quaternary geology, southern Vancouver Island, British Columbia; in Report of Activities, Part B; Geological Survey of Canada, Paper 74-1B, p. 209-211.

1976a: Late Quaternary stratigraphy and palaeoclimatology, southern Vancouver Island and Strait of Juan de Fuca, British Columbia, Canada [abstract]; in Abstracts; 25th International Geological Congress (Sydney), v. 2, sec. 12, p. 487.

1976b: Post Pleistocene glaciations in the interior of British Columbia [abstract]; in Geomorphology of the Canadian Cordillera and Its Bearing on Mineral Deposits; Geological Association of Canada, Cordilleran Section, Vancouver, p. 6-7.

1976c: The palynology and palaeoclimatic significance of a dated core of Holocene peat, Okanagan Valley, southern British Columbia; Canadian Journal of Earth Sciences, v. 13, no. 8, p. 1131-1144.

1979: Middle Wisconsin stratigraphy and climatic reconstruction, southern Vancouver Island, British Columbia; Quaternary Research, v. 11, no. 2, p. 213-237.

Alley, N.F. and Chatwin, S.C.

1979: Late Pleistocene history and geomorphology, southwestern Vancouver Island, British Columbia; Canadian Journal of Earth Sciences, v. 16, no. 9, p. 1645-1657.

Alley, N.F. and Harris, S.A.

1974: Pleistocene glacial lake sequences in the Foothills, southwestern Alberta, Canada; Canadian Journal of Earth Sciences, v. 11, no. 9, p. 1220-1235.

Alley, N.F. and Thomson, B.
1978: Aspects of environmental geology, parts of Graham Island, Queen Charlotte Islands; British Columbia Ministry of the Environment, Resource Analysis Branch, Bulletin no. 2, 65 p.

Alley, N.F. and Valentine, K.W.G.
1977: Palaeoenvironments of the Olympia Interglacial (mid-Wisconsin) in southeastern British Columbia, Canada [abstract]; in Abstracts; International Union for Quaternary Research, 10th Congress (Birmingham, England), p. 12.

Alley, N.F. and Young, G.K.
1978: Environmental significance of geomorphic processes in the northern Skeena Mountains and southern Stikine Plateau; British Columbia Ministry of the Environment, Resource Analysis Branch, Bulletin no. 3, 83 p.

Alley, N.F., Valentine, K.W.G., and Fulton, R.J.
Paleoenvironments of the middle Wisconsin, southcentral British Columbia; Canadian Journal of Earth Sciences. (in press).

Anderson, F.E.
1967: Stratigraphy of late Pleistocene and Holocene sediments from the Strait of Juan de Fuca; unpublished Ph.D. thesis, University of Washington, Seattle, 179 p.

1968: Seaward terminus of the Vashon continental glacier in the Strait of Juan de Fuca; Marine Geology, v. 6, no. 6, p. 419-438.

Anderson, J.H.
1970: A geobotanical study in the Atlin region in northwestern British Columbia and south-central Yukon Territory; unpublished Ph.D. thesis, Michigan State University, East Lansing, 380 p.

Anderton, L.J.
1970: Quaternary stratigraphy and geomorphology of the lower Thompson Valley, British Columbia; unpublished M.A. thesis, University of British Columbia, Vancouver, 100 p.

Andrews, J.T. and Barry, R.G.
1978: Glacial inception and disintegration during the last glaciation; Annual Review of Earth and Planetary Sciences, v. 6, p. 205-228.

Andrews, J.T. and Retherford, R.M.
1978: A reconnaissance survey of late Quaternary sea levels, Bella Bella/Bella Coola region, central British Columbia coast; Canadian Journal of Earth Sciences, v. 15, no. 3, p. 341-350.

Antevs, E.V.
1948: Climatic changes and pre-white man; University of Utah, Bulletin, v. 38, no. 20, p. 168-191.

Armstrong, J.E.
1966a: Glacial studies, Kitimat-Terrace area; in Report of Activities, May to October, 1965; Geological Survey of Canada, Paper 66-1, p. 50.

1966b: Glaciation along a major fiord valley in the Coast Mountains of British Columbia, Canada [abstract]; in Program, 1966 Annual Meetings; Geological Society of America, 79th Annual Meeting (San Francisco), p. 7.

1975a: Fraser Lowland – Canada; in The Last Glaciation; IUGS-UNESCO International Geological Correlation Programme, Project 73-1-24, Western Washington State College, Department of Geology, Bellingham, Washington, Guidebook for Field Conference, p. 74-97.

Armstrong, J.E. (cont.)
1975b: Quaternary geology, stratigraphic studies and revaluation of terrain inventory maps, Fraser Lowland, British Columbia (92G/1, 2, and parts of 92 G/3, 6, 7, and H/4); in Report of Activities, Part A; Geological Survey of Canada, Paper 75-1A, p. 377-380.

1976: Post-Vashon Wisconsin glaciation, Fraser Lowland British Columbia, Canada; in Quaternary Glaciations in the Northern Hemisphere, ed. D.J. Easterbrook and V. Sibrava; IUGS-UNESCO International Geological Correlation Programme, Project 73-1-24, Report no. 3, p. 13-27.

1977a: Quaternary stratigraphy of the Fraser Lowland; Geological Association of Canada, Mineralogical Association of Canada, Society of Economic Geologists, Canadian Geophysical Union, Joint Annual Meetings (Vancouver), Fieldtrip Guidebook, Trip 10, 20 p.

1977b: Quaternary geology of the Fraser Lowland (Field Trip no. 6); in Geological Excursions in the Pacific Northwest, ed. E.H. Brown and R.C. Ellis; Western Washington University, Department of Geology, Bellingham, Washington, p. 204-226.

1981: Post-Vashon Wisconsin glaciation, Fraser Lowland, British Columbia; Geological Survey of Canada, Bulletin 322, 34 p.

Armstrong, J.E. and Brown, W.L.
1953: Ground-water resources of Surrey Municipality, British Columbia; Geological Survey of Canada, Water Supply Paper no. 322, 48 p.

1954: Late Wisconsin marine drift and associated sediments of the lower Fraser Valley, British Columbia, Canada; Geological Society of America, Bulletin, v. 65, no. 4, p. 349-364.

Armstrong, J.E. and Clague, J.J.
1977: Two major Wisconsin lithostratigraphic units in southwest British Columbia; Canadian Journal of Earth Sciences, v. 14, no. 7, p. 1471-1480.

Armstrong, J.E. and Hicock, S.R.
1975: Quaternary landscapes: present and past – at Mary Hill, Coquitlam, British Columbia (92G/2f); in Report of Activities, Part B; Geological Survey of Canada, Paper 75-1B, p. 99-103.

1976: Quaternary multiple valley development of the lower Coquitlam Valley, Coquitlam, British Columbia (92G/7c); in Report of Activities, Part B; Geological Survey of Canada, Paper 76-1B, p. 197-200.

Armstrong, J.E. and Tipper, H.W.
1948: Glaciation in north central British Columbia; American Journal of Science, v. 246, no. 5, p. 283-310.

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, v. 76, no. 3, p. 321-330.

Beach, H.H. and Spivak, J.
1943: The origin of Peace River canyon, British Columbia; American Journal of Science, v. 241, no. 6, p. 366-376.

Bement, W.O.
1972: The sedimentologic and paleogeographic history of the lower Kicking Horse River valley, southeast British Columbia, during deglaciation; unpublished M.Sc. thesis, University of Illinois, Chicago, 103 p.

Benedict, J.B., Jr.
1968a: Neoglacial history of the Colorado Front Range; unpublished Ph.D. thesis, University of Wisconsin, Madison, 84 p.

1968b: Recent glacial history of an alpine area in the Colorado Front Range, U.S.A. II. Dating the glacial deposits; Journal of Glaciology, v. 7, no. 49, p. 77-87.

1973: Chronology of cirque glaciation, Colorado Front Range; Quaternary Research, v. 3, no. 4, p. 584-599.

Berger, A.R.
1960: On a recent volcanic ash deposit, Yukon Territory; Geological Association of Canada, Proceedings, v. 12, p. 117-118.

Borchardt, G.A., Harward, M.E., and Schmitt, R.A.
1971: Correlation of volcanic ash deposits by activation analysis of glass separates; Quaternary Research, v. 1, no. 2, p. 247-260.

Borchardt, G.A., Norgren, J.A., and Harward, M.E.
1973: Correlation of ash layers in peat bogs of eastern Oregon; Geological Society of America, Bulletin, v. 84, no. 9, p. 3101-3108.

Borns, H.W., Jr. and Goldthwait, R.P.
1966: Late-Pleistocene fluctuations of Kaskawulsh Glacier, southwestern Yukon Territory, Canada; American Journal of Science, v. 264, no. 8, p. 600-619. Reprinted (1969) in Icefield Ranges Research Project Scientific Results, Volume 1, ed. V.C. Bushnell and R.H. Ragle; American Geographical Society, New York, New York, Arctic Institute of North America, Montreal, Quebec, p. 187-196.

Bostock, H.S.
1952: Geology of northwest Shakwak Valley, Yukon Territory; Geological Survey of Canada, Memoir 267, 54 p.

Boydell, A.N.
1970: Relationship of late-Wisconsin Rocky Mountain and Laurentide ice in the vicinity of Sundre, Alberta; unpublished M.Sc. thesis, University of Calgary, Alberta, 130 p.

1972: Multiple glaciation in the Foothills, Rocky Mountain House area, Alberta; unpublished Ph.D. thesis, University of Calgary, Alberta, 128 p.

1978: Multiple glaciation in the Foothills, Rocky Mountain House area, Alberta; Alberta Research Council, Bulletin 36, 35 p.

Bretz, J.H.
1920: The Juan de Fuca lobe of the Cordilleran Ice Sheet; Journal of Geology, v. 28, no. 4, p. 333-339.

Brown, R.L. and Psutka, J.F.
1980: Structural and stratigraphic setting of the Downie slide, Columbia River valley, British Columbia; Canadian Journal of Earth Sciences, v. 17, no. 6, p. 698-709.

Bryan, A.L.
1969: Early man in America and the late Pleistocene chronology of western Canada and Alaska; Current Anthropology, v. 10, no. 4, p. 339-365.

Buckley, J.D. and Willis, E.H.
1970: Isotopes' radiocarbon measurements VIII; Radiocarbon, v. 12, no. 1, p. 87-129.

Buddemeier, R.W.
1969: A radiocarbon study of the varved marine sediments of Saanich Inlet, British Columbia; unpublished Ph.D. thesis, University of Washington, Seattle, 125 p.

Capps, S.R.
1916: An ancient volcanic eruption in the upper Yukon basin; in Shorter Contributions to General Geology, 1915; United States Geological Survey, Professional Paper 95, p. 59-64.

Chatwin, S.C.
1974: Glacial movements and surficial deposits on southwestern Vancouver Island; unpublished B.Sc. thesis, University of British Columbia, Department of Geological Sciences, Vancouver, 77 p.

Church, M. and Ryder, J.M.
1972: Paraglacial sedimentation: a consideration of fluvial processes controlled by glaciation; Geological Society of America, Bulletin, v. 83, no. 10, p. 3059-3072.

Clague, J.J.
1973: Late Cenozoic geology of the southern Rocky Mountain Trench, British Columbia; unpublished Ph.D. thesis, University of British Columbia, Vancouver, 274 p.

1975a: Glacier-flow patterns and the origin of late Wisconsinan till in the southern Rocky Mountain Trench, British Columbia; Geological Society of America, Bulletin, v. 86, no. 6, p. 721-731.

1975b: Late Quaternary sea-level fluctuations, Pacific coast of Canada and adjacent areas; in Report of Activities, Part C; Geological Survey of Canada, Paper 75-1C, p. 17-21.

1975c: Late Quaternary sediments and geomorphic history of the southern Rocky Mountain Trench, British Columbia; Canadian Journal of Earth Sciences, v. 12, no. 4, p. 595-605.

1976a: Quadra Sand and its relation to the late Wisconsin glaciation of southwest British Columbia; Canadian Journal of Earth Sciences, v. 13, no. 6, p. 803-815.

1976b: Quadra Sand and the timing of the late Wisconsin glacial advance in southwest British Columbia; in Quaternary Glaciations in the Northern Hemisphere, ed. D.J. Easterbrook and V. Sibrava; IUGS-UNESCO International Geological Correlation Programme, Project 73-1-24, Report no. 3, p. 315-326.

1977a: 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 p.

1977b: Surficial geology, Kitimat, British Columbia; Geological Survey of Canada, Open File 470.

Clague, J.J. (cont.)
1978a: Mid-Wisconsinan climates of the Pacific Northwest; in Current Research, Part B; Geological Survey of Canada, Paper 78-1B, p. 95-100.

1978b: Terrain hazards in the Skeena and Kitimat river basins, British Columbia; in Current Research, Part A; Geological Survey of Canada, Paper 78-1A, p. 183-188.

1980: Late Quaternary geology and geochronology of British Columbia. Part 1: Radiocarbon dates; Geological Survey of Canada, Paper 80-13, 28 p.

Clague, J.J. and Hicock, S.R.
1976: Sand and gravel resources of Kitimat, Terrace, and Prince Rupert, British Columbia; in Report of Activities, Part A; Geological Survey of Canada, Paper 76-1A, p. 273-276.

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, v. 13, no. 3, p. 322-326.

Crandell, D.R.
1963: Surficial geology and geomorphology of the Lake Tapps quadrangle, Washington; United States Geological Survey, Professional Paper 388-A, 84 p.

1965a: Alpine glaciers at Mount Rainier, Washington, during late Pleistocene and Recent time [abstract]; in Abstracts for 1964; Geological Society of America, Special Paper 82, p. 34-35.

1965b: The glacial history of western Washington and Oregon; in The Quaternary of the United States, ed. H.E. Wright, Jr. and D.G. Frey; Princeton University Press, Princeton, New Jersey, p. 341-353.

1971: Postglacial lahars from Mount Rainier volcano, Washington; United States Geological Survey, Professional Paper 677, 75 p.

Crandell, D.R. and Miller, R.D.
1964: Post-Hypsithermal glacier advances at Mount Rainier, Washington; in Geological Survey Research 1964, Chapter D; United States Geological Survey, Professional Paper 501-D, p. D110-D114.

Crandell, D.R. and Mullineaux, D.R.
1973: Pine Creek volcanic assemblage at Mount St. Helens, Washington; United States Geological Survey, Bulletin 1383-A, 23 p.

Crandell, D.R., Mullineaux, D.R., Miller, R.D., and Rubin, M.
1962: Pyroclastic deposits of Recent age at Mount Rainier, Washington; in Short Papers in Geology, Hydrology, and Topography, Articles 120-179, Geological Survey Research 1962; United States Geological Survey, Professional Paper 450-D, p. D64-D68.

Crandell, D.R., Mullineaux, D.R., and Rubin, M.
1975: Mount St. Helens volcano: recent and future behavior; Science, v. 187, no. 4175, p. 438-441.

Croll, T.C.
1980: Stratigraphy and depositional history of the Deming Sand in northwestern Washington; unpublished M.Sc. thesis, University of Washington, Seattle, 57 p.

Curry, R.R.
1968: Quaternary climatic and glacial history of the Sierra Nevada, California; unpublished Ph.D. thesis, University of California, Berkely, 238 p.

1969: Holocene climatic and glacial history of the central Sierra Nevada, California; in United States Contributions to Quaternary Research, ed. S.A. Schumm and W.C. Bradley; Geological Society of America, Special Paper 123, p. 1-47.

Damon, P.E., Ferguson, C.W., Long, A., and Wallick, E.I.
1974: Dendrochronologic calibration of the radiocarbon time scale; American Antiquity, v. 39, no. 2, p. 350-366.

Damon, P.E., Long, A., and Wallick, E.I.
1972: Dendrochronologic calibration of the carbon-14 time scale; in Proceedings of the Eighth International Radiocarbon Dating Conference; Royal Society of New Zealand, Lower Hutt, New Zealand, v. 1, p. A29-A43.

Davis, J.O.
1977: Quaternary tephrochronology of the Lake Lahontan area, Nevada and California; unpublished Ph.D. thesis, University of Idaho, Moscow, Idaho, 168 p.

Davis, N.F.G. and Mathews, W.H.
1944: Four phases of glaciation with illustrations from southwestern British Columbia; Journal of Geology, v. 52, no. 6, p. 403-413.

Dawson, G.M.
1881: Additional observations on the superficial geology of British Columbia and adjacent regions; Quarterly Journal of the Geological Society of London, v. 37, p. 272-285.

Denton, G.H. and Karlén, W.
1973: Holocene climatic variations – their pattern and possible cause; Quaternary Research, v. 3, no. 2, p. 155-205.

1977: Holocene glacial and tree-line variations in the White River valley and Skolai Pass, Alaska and Yukon Territory; Quaternary Research, v. 7, no. 1, p. 63-111.

Denton, G.H. and Stuiver, M.
1966: Neoglacial chronology, northeastern St. Elias Mountains, Canada; American Journal of Science, v. 264, no. 8, p. 577-599. Reprinted (1969) in Icefield Ranges Research Project Scientific Results, Volume 1, ed. V.C. Bushnell and R.H. Ragle; American Geographical Society, New York, New York, Arctic Institute of North America, Montreal, Quebec, p. 173-186.

1967: Late Pleistocene glacial stratigraphy and chronology, northeastern St. Elias Mountains, Yukon Territory, Canada; Geological Society of America, Bulletin, v. 78, no. 4, p. 485-510. Reprinted (1969) in Icefield Ranges Research Project Scientific Results, Volume 1, ed. V.C. Bushnell and R.H. Ragle; American Geographical Society, New York, New York, Arctic Institute of North America, Montreal, Quebec, p. 197-217.

Dewhirst, J.
1978: Nootka Sound: a 4,000 year perspective; in Nu•tka• – the History and Survival of Nootkan Culture, ed. B.S. Efrat and W.J. Langlois; Sound Heritage, v. 7, no. 2, p. 1-30.

Dreimanis, A. and Raukas, A.
1975: Did Middle Wisconsin, Middle Weichselian, and their equivalents represent an interglacial, or an interstadial complex in the Northern Hemisphere?; Royal Society of New Zealand, Bulletin, v. 13, p. 109-120.

Duffell, S. and Souther, J.G.
1964: Geology of Terrace map-area, British Columbia (102I E1/2); Geological Survey of Canada, Memoir 329, 117 p.

Duford, J.M.
1976: Late Pleistocene and Holocene cirque glaciations in the Shuswap Highland area, British Columbia; unpublished M.Sc. thesis, University of Calgary, Alberta, 100 p.

Duford, J.M. and Osborn, G.D.
1978: Holocene and latest Pleistocene cirque glaciations in the Shuswap Highland, British Columbia; Canadian Journal of Earth Sciences, v. 15, no. 6, p. 865-873. Discussion by N.F. Alley and reply by J.M. Duford and G.D. Osborn (1980) in Canadian Journal of Earth Sciences, v. 17, no. 6, p. 797-800.

Dyck, W. and Fyles, J.G.
1962: Geological Survey of Canada radiocarbon dates I; Radiocarbon, v. 4, p. 13-26. Reprinted (1963) in Geological Survey of Canada Radiocarbon Dates I and II; Geological Survey of Canada, Paper 63-21, p. 1-14.

1963: Geological Survey of Canada radiocarbon dates II; Radiocarbon, v. 5, p. 39-55. Reprinted (1963) in Geological Survey of Canada Radiocarbon Dates I and II; Geological Survey of Canada, Paper 63-21, p. 15-31.

Dyck, W., Fyles, J.G., and Blake, W., Jr.
1965: Geological Survey of Canada radiocarbon dates IV; Radiocarbon, v. 7, p. 24-46. Reprinted (1965) as Geological Survey of Canada, Paper 65-4, 23 p.

Dyck, W., Lowdon, J.A., Fyles, J.G., and Blake, W., Jr.
1966: Geological Survey of Canada radiocarbon dates V; Radiocarbon, v. 8, p. 96-127. Reprinted (1966) as Geological Survey of Canada, Paper 66-48, 32 p.

Easterbrook, D.J.
1962: Pleistocene geology of the northern part of the Puget Lowland, Washington; unpublished Ph.D. thesis, University of Washington, Seattle, 160 p.

1963: Late Pleistocene glacial events and relative sea-level changes in the northern Puget Lowland, Washington; Geological Society of America, Bulletin, v. 74, no. 12, p. 1465-1484.

1969: Pleistocene chronology of the Puget Lowland and San Juan Islands, Washington; Geological Society of America, Bulletin, v. 80, no. 11, p. 2273-2286.

1976a: Middle and early Wisconsin chronology in the Pacific Northwest; in Quaternary Glaciations in the Northern Hemisphere, ed. D.J. Easterbrook and V. Sibrava; IUGS-UNESCO International Geological Correlation Programme, Project 73-1-24, Report no. 3, p. 90-98.

1976b: Quaternary geology of the Pacific Northwest; in Quaternary Stratigraphy of North America, ed. W.C. Mahaney; Dowden, Hutchinson & Ross, Inc., Stroudsburg, Pennsylvania, p. 441-462.

Eisbacher, G.H.
1971: Natural slope failure, northeastern Skeena Mountains; Canadian Geotechnical Journal, v. 8, no. 3, p. 384-390.

Eisbacher, G.H. (cont.)
1979: First-order regionalization of landslide characteristics in the Canadian Cordillera; Geoscience Canada, v. 6, no. 2, p. 69-79.

Fernald, A.T.
1962: Radiocarbon dates relating to a widespread volcanic ash deposit, eastern Alaska; in Short Papers in Geology, Hydrology, and Topography, Articles 1-59, Geological Survey Research 1962; United States Geological Survey, Professional Paper 450-B, p. B29-B30.

Fladmark, K.R.
1975: A paleoecological model for Northwest Coast prehistory; National Museum of Man, Mercury Series, Archaeological Survey of Canada, Paper no. 43, 328 p. Also (1974) Ph.D. thesis, University of Calgary, Alberta, 319 p.

1978: The feasibility of the Northwest Coast as a migration route for early man; in Early Man in America from a Circum-Pacific Perspective, ed. A.L. Bryan; University of Alberta, Department of Anthropology, Occasional Papers, no. 1, p. 119-128.

1979: Routes: alternate migration corridors for early man in North America; American Antiquity, v. 44, no. 1, p. 55-69.

Flint, R.F.
1971: Glacial and Quaternary geology; John Wiley and Sons, Inc., New York, New York, 892 p.

Florer, L.E.
1972: Quaternary paleoecology and stratigraphy of the sea cliffs, western Olympic Peninsula, Washington; Quaternary Research, v. 2, no. 2, p. 202-216.

Fox, J.C.
1974: Glacial geomorphology of the Cataract Brook valley, Yoho National Park, British Columbia; unpublished M.Sc. thesis, University of Alberta, Edmonton, 148 p.

Fryxell, R.
1965: Mazama and Glacier Peak volcanic ash layers: relative ages; Science, v. 147, no. 3663, p. 1288-1290.

Fulton, R.J.
1963: Deglaciation of the Kamloops region, British Columbia; unpublished Ph.D. thesis, Northwestern University, Evanston, Illinois, 125 p.

1965: Silt deposition in late-glacial lakes of southern British Columbia; American Journal of Science, v. 263, no. 7, p. 553-570.

1967: Deglaciation studies in Kamloops region, an area of moderate relief, British Columbia; Geological Survey of Canada, Bulletin 154, 36 p.

1968: Olympia Interglaciation, Purcell Trench, British Columbia; Geological Society of America, Bulletin, v. 79, no. 8, p. 1075-1080.

1969: Glacial lake history, southern Interior Plateau, British Columbia; Geological Survey of Canada, Paper 69-37, 14 p.

1971: Radiocarbon geochronology of southern British Columbia; Geological Survey of Canada, Paper 71-37, 28 p.

1975a: Quaternary geology and geomorphology, Nicola-Vernon area, British Columbia (82L W1/2 and 92I E1/2); Geological Survey of Canada, Memoir 380, 50 p.

Fulton, R.J. (cont.)
1975b: Quaternary stratigraphy south central British Columbia; in The Last Glaciation; IUGS-UNESCO International Geological Correlation Programme, Project 73-1-24, Western Washington State College, Department of Geology, Bellingham, Washington, Guidebook for Field Conference, p. 98-124.

1976: Quaternary history south-central British Columbia and correlations with adjacent areas; in Quaternary Glaciations in the Northern Hemisphere, ed. D.J. Easterbrook and V. Sibrava; IUGS-UNESCO International Geological Correlation Programme, Project 73-1-24, Report no. 3, p. 62-89.

Fulton, R.J. and Halstead, E.C.
1972: Quaternary geology of the southern Canadian Cordillera; 24th International Geological Congress (Montreal), Guidebook, Field Excursion A02, 49 p.

Fulton, R.J. and Smith, G.W.
1978: Late Pleistocene stratigraphy of south-central British Columbia; Canadian Journal of Earth Sciences, v. 15, no. 6, p. 971-980.

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, v. 87, no. 1, 153-155.

Fyles, J.G.
1956: Surficial geology of the Horne Lake and Parksville map-areas, Vancouver Island, British Columbia; unpublished Ph.D. thesis, Ohio State University, Columbus, 283 p.

1963: Surficial geology of Horne Lake and Parksville map-areas, Vancouver Island, British Columbia; Geological Survey of Canada, Memoir 318, 142 p.

Gascoyne, M.
1980: Pleistocene climate determined from stable isotope and geochronologic studies of speleothem; unpublished Ph.D. thesis, McMaster University, Hamilton, 467 p.

Gascoyne, M., Schwarcz, H.P., and Ford, D.C.
1980: A palaeotemperature record for the mid-Wisconsin in Vancouver Island; Nature, v. 285, no. 5765, p. 474-476.

Goldthwait, R.P.
1963: Dating the Little Ice Age in Glacier Bay, Alaska; in Report of the Twenty-First Session, Norden; 21st International Geological Congress (Copenhagen), pt. 27, p. 37-47.

Graf, W.L.
1971: Quantitative analysis of Pinedale landforms, Beartooth Mountains, Montana and Wyoming; Arctic and Alpine Research, v. 3, no. 3, p. 253-261.

Halstead, E.C.
1966: Surficial geology of Duncan and Shawnigan map-areas, British Columbia; Geological Survey of Canada, Paper 65-24, 3 p.

1968: The Cowichan ice tongue, Vancouver Island; Canadian Journal of Earth Sciences, v. 5, no. 6, p. 1409-1415.

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, v. 85, no. 4, p. 587-602.

Hansen, H.P.
1937: Postglacial forest succession and climate in the Puget Sound region; unpublished Ph.D. thesis, University of Washington, Seattle, 43 p.

1938: Postglacial forest succession and climate in the Puget Sound region; Ecology, v. 19, no. 4, p. 528-542.

1939a: Paleoecology of a central Washington bog; Ecology, v. 20, no. 4, p. 563-568.

1939b: Pollen analysis of a bog in northern Idaho; American Journal of Botany, v. 26, no. 4, p. 225-228.

1939c: Pollen analysis of a bog near Spokane, Washington; Torrey Botanical Club, Bulletin, v. 66, no. 4, p. 215-220.

1940a: Paleoecology of a montane peat deposit at Bonaparte Lake, Washington; Northwest Science, v. 14, no. 3, p. 60-68.

1940b: Paleoecology of two peat bogs in southwestern British Columbia; American Journal of Botany, v. 27, no. 3, p. 144-149.

1941a: Further pollen studies of post Pleistocene bogs in the Puget Lowland of Washington; Torrey Botanical Club, Bulletin, v. 68, no. 3, p. 133-148.

1941b: Paleoecology of a bog in the spruce-hemlock climax of the Olympic Peninsula; American Midland Naturalist, v. 25, no. 2, p. 290-297.

1943: A pollen study of two bogs on Orcas Island, of the San Juan Islands, Washington; Torrey Botanical Club, Bulletin, v. 70, no. 3, p. 236-243.

1944: Postglacial vegetation of eastern Washington; Northwest Science, v. 18, no. 4, p. 79-87.

1947a: Postglacial forest succession, climate, and chronology in the Pacific Northwest; American Philosophical Society, Transactions, new ser., v. 37, pt. 1, p. 1-130.

1947b: Climate versus fire and soil as factors in postglacial forest succession in the Puget Lowland of Washington; American Journal of Science, v. 245, no. 5, p. 265-286.

1948: Postglacial forests of the Glacier National Park region; Ecology, v. 29, no. 2, p. 146-152.

1950: Pollen analysis of three bogs on Vancouver Island, Canada; Journal of Ecology, v. 38, no. 2, p. 270-276.

1955: Postglacial forests in south-central and central British Columbia; American Journal of Science, v. 253, no. 11, p. 640-658.

1967: Chronology of postglacial pollen profiles in the Pacific Northwest (U.S.A.); Reviews of Palaeobotany and Palynology, v. 4, no. 1-4, p. 103-105.

Harington, C.R., Tipper, H.W., and Mott, R.J.
1974: Mammoth from Babine Lake, British Columbia; Canadian Journal of Earth Sciences, v. 11, no. 2, p. 285-303.

Harper, J.R.
1980: Coastal processes on Graham Island, Queen Charlotte Islands, British Columbia; in Current Research, Part A; Geological Survey of Canada, Paper 80-1A, p. 13-18.

Harris, S.A. and Boydell, A.N.
1972: Glacial history of the Bow River and Red Deer River areas and the adjacent Foothills; in Mountain Geomorphology: Geomorphological Processes in the Canadian Cordillera, ed. H.O. Slaymaker and H.J. McPherson; Tantalus Research Limited, Vancouver, British Columbia, p. 47-53.

Harris, S.A. and Howell, J.
1977: Chateau Lake Louise moraines – evidence for a new Holocene glacial event in southwest Alberta; Bulletin of Canadian Petroleum Geology, v. 25, no. 3, p. 441-455.

Harris, S.A. and Waters, R.R.
1977: Late Quaternary history of southwest Alberta, a progress report; Bulletin of Canadian Petroleum Geology, v. 25, no. 1, p. 35-62.

Harrison, J.E.
1976a: Dated organic material below Mazama(?) tephra: Elk Valley, British Columbia; in Report of Activities, Part C; Geological Survey of Canada, Paper 76-1C, p. 169-170.

1976b: Evolution of a landscape: the Quaternary Period in Waterton Lakes National Park; Geological Survey of Canada, Miscellaneous Report 26, 33 p.

Haselton, G.M.
1965: Glacier geology of Muir Inlet, southeastern Alaska; Ohio State University, Institute of Polar Studies, Report no. 18, 34 p.

1967: Glacial geology of Muir Inlet, southeastern Alaska; unpublished Ph.D. thesis, Ohio State University, Columbus, 242 p.

Hebda, R.J.
1977: The paleoecology of a raised bog and associated deltaic sediments of the Fraser River delta; unpublished Ph.D. thesis, University of British Columbia, Vancouver 202 p.

Hebda, R.J. and Rouse, G.E.
1979: Palynology of two Holocene cores from the Hesquiat Peninsula, Vancouver Island, British Columbia; Syesis, v. 12, p. 121-130.

Heginbottom, J.A.
1972: Surficial geology of Taseko Lakes map-area (92-0) British Columbia; Geological Survey of Canada, Paper 72-14, 9 p.

Heusser, C.J.
1952a: Pollen profiles from southeastern Alaska; Ecological Monographs, v. 22, no. 4, p. 331-352.

1952b: Pollen profiles from southeastern Alaska; unpublished Ph.D. thesis, Oregon State University, Corvallis, 150 p.

1954: Additional pollen profiles from southeastern Alaska; American Journal of Science, v. 252, no. 2, p. 106-119.

1960: Late-Pleistocene environments of North Pacific North America; American Geographical Society, Special Publication no. 35, 308 p.

1964: Palynology of four bog sections from the western Olympic Peninsula, Washington; Ecology, v. 45, no. 1, p. 23-40.

1965: A Pleistocene phytogeographical sketch of the Pacific Northwest and Alaska; in The Quaternary of the United States, ed. H.E. Wright, Jr. and D.G. Frey; Princeton University Press, Princeton, New Jersey, p. 469-483.

Heusser, C.J. (cont.)
1967: Pleistocene and postglacial vegetation of Alaska and the Yukon Territory; in Arctic Biology, Proceedings of the Biology Colloquium, ed. H.P. Hansen; Oregon State University Press, Corvallis, Oregon, p. 131-151.

1972: Palynology and phytogeographical significance of a late-Pleistocene refugium near Kalaloch, Washington; Quaternary Research, v. 2, no. 2, p. 189-201.

1973a: Age and environment of allochthonous peat clasts from the Bogachiel River valley, Washington; Geological Society of America, Bulletin, v. 84, no. 3, p. 797-804.

1973b: Environmental sequence following the Fraser advance of the Juan de Fuca lobe, Washington; Quaternary Research, v. 3, no. 2, p. 284-306.

1974: Quaternary vegetation, climate, and glaciation of the Hoh River valley, Washington; Geological Society of America, Bulletin, v. 85, no. 10, p. 1547-1560.

1977: Quaternary palynology of the Pacific slope of Washington; Quaternary Research, v. 8, no. 3, p. 282-306.

1978: Palynology of Quaternary deposits of the lower Bogachiel River area, Olympic Peninsula, Washington; Canadian Journal of Earth Sciences, v. 15, no. 10, p. 1568-1578.

Heusser, C.J., Schuster, R.L., and Gilkey, A.K.
1954: Geobotanical studies on the Taku Glacier anomaly; Geographical Review, v. 44, no. 2, p. 224-236.

Hicock, S.R
1976: Quaternary geology: Coquitlam-Port Moody area, British Columbia; unpublished M.Sc. thesis, University of British Columbia, Vancouver, 114 p.

1980: Pre-Fraser Pleistocene stratigraphy, geochronology, and paleoecology of the Georgia Depression, British Columbia; unpublished Ph.D. thesis, University of Western Ontario, London, 231 p.

Holland, S.S.
1964: Landforms of British Columbia, a physiographic outline; British Columbia Department of Mines and Petroleum Resources, Bulletin no. 48, 138 p. Reprinted 1976.

Horberg, L.
1954: Rocky Mountain and continental Pleistocene deposits in the Waterton region, Alberta, Canada; Geological Society of America, Bulletin, v. 65, no. 11, p. 1093-1150.

Howes, D.E.
1977: Terrain inventory and late Pleistocene history of the southern part of the Nechako Plateau; British Columbia Ministry of the Environment, Resource Analysis Branch, Bulletin no. 1, 27 p.

1981: Late Quaternary sediments and geomorphic history of north-central Vancouver Island; Canadian Journal of Earth Sciences, v. 18, no. 1, p. 1-12.

Hughes, O.L., Campbell, R.B., Muller, J.E., and Wheeler, J.O.
1969: Glacial limits and flow patterns, Yukon Territory, south of 65 degrees north latitude; Geological Survey of Canada, Paper 68-34, 9 p.

Hughes, O.L., Rampton, V.N., and Rutter, N.W.
1972: Quaternary geology and geomorphology, southern and central Yukon (northern Canada); 24th International Geological Congress (Montreal), Guidebook, Field Excursion A11, 59 p.

Ives, P.C., Levin, B., Oman, C.L., and Rubin, M.
1967: U.S. Geological Survey radiocarbon dates IX; Radiocarbon, v. 9, p. 505-529.

Jackson, L.E., Jr.
1977: Quaternary stratigraphy and terrain inventory of the Alberta portion of the Kananaskis Lakes 1:250 000 sheet (82-J); unpublished Ph.D. thesis, University of Calgary, Alberta, 478 p.

1979: A catastrophic glacial outburst flood (jokulhlaup) mechanism for debris flow generation at the Spiral Tunnels, Kicking Horse River basin, British Columbia; Canadian Geotechnical Journal, v. 16, no. 4, p. 806-813.

1980: Glacial history and stratigraphy of the Alberta portion of the Kananaskis Lakes map area; Canadian Journal of Earth Sciences, v. 17, no. 4, p. 459-477.

Jennings, A.H.
1951: The glacial geomorphology of the Sunwapta Pass area, Jasper National Park, Alberta, Canada; unpublished M.Sc. thesis, University of Iowa, Iowa City.

Johnston, W.A.
1921: Sedimentation of the Fraser River delta; Geological Survey of Canada, Memoir 125, 46 p.

de Jong, S.H. and Siebenhuener, H.F.W.
1972: Seasonal and secular variations of sea level on the Pacific coast of Canada; Canadian Surveyor, v. 26, no. 1, p. 4-19.

Keddie, G.R.
1979: The late ice age of southern Vancouver Island; Midden (Archaeological Society of British Columbia), v. 11, no. 4, p. 16-22.

Kellerhals, P. and Murray, J.W.
1969: Tidal flats at Boundary Bay, Fraser River delta, British Columbia; Bulletin of Canadian Petroleum Geology, v. 17, no. 1, p. 67-91. Reprinted (1976) in Holocene Tidal Sedimentation, ed. G. deV. Klein; Dowden, Hutchinson & Ross, Inc., Stroudsburg, Pennsylvania, p. 118-142.

Kerr, F.A.
1934: Glaciation in northern British Columbia; Royal Society of Canada, Transactions, ser. 3, v. 28, sec. 4, p. 17-31.

Kind, N.V.
1972: Late Quaternary climatic changes and glacial events in the old and new world – radiocarbon chronology; in Section 12, Quaternary Geology; 24th International Geological Congress (Montreal), p. 55-61.

Kiver, E.P.
1974: Holocene glaciation in the Wallowa Mountains, Oregon; in Quaternary Environments: Proceedings of a Symposium, ed. W.C. Mahaney; York University, Geographical Monographs, no. 5, p. 169-195.

Lemke, R.W., Mudge, M.R., Wilcox, R.E., and Powers, H.A.
1975: Geological setting of the Glacier Peak and Mazama ash-bed markers in west-central Montana; United States Geological Survey, Bulletin 1395-H, 31 p.

Lerbekmo, J.F. and Campbell, F.A.
1969: Distribution, composition, and source of the White River ash, Yukon Territory; Canadian Journal of Earth Sciences, v. 6, no. 1, p. 109-116.

Lowdon, J.A. and Blake, W., Jr.
1968: Geological Survey of Canada radiocarbon dates VII; Radiocarbon, v. 10, no. 2, p. 207-245. Reprinted (1968) as Geological Survey of Canada, Paper 68-2B, 39 p.

1970: Geological Survey of Canada radiocarbon dates IX; Radiocarbon, v. 12, no. 1, p. 46-86. Reprinted (1970) as Geological Survey of Canada, Paper 70-2B, 41 p.

1973: Geological Survey of Canada radiocarbon dates XIII; Geological Survey of Canada, Paper 73-7, 61 p.

1975: Geological Survey of Canada radiocarbon dates XV; Geological Survey of Canada, Paper 75-7, 32 p.

1976: Geological Survey of Canada radiocarbon dates XVI; Geological Survey of Canada, Paper 76-7, 21 p.

1978: Geological Survey of Canada radiocarbon dates XVIII; Geological Survey of Canada, Paper78-7, 20 p.

1979: Geological Survey of Canada radiocarbon dates XIX; Geological Survey of Canada, Paper 79-7, 57 p.

Lowdon, J.A., Fyles, J.G., and Blake, W., Jr.
1967: Geological Survey of Canada radiocarbon dates VI; Radiocarbon, v. 9, p. 156-197. Reprinted (1967) as Geological Survey of Canada, Paper 67-2B, 42 p.

Lowdon, J.A., Robertson, I.M., and Blake, W., Jr.
1971: Geological Survey of Canada radiocarbon dates XI; Radiocarbon, v. 13, no. 2, p. 255-324. Reprinted (1971) as Geological Survey of Canada, Paper 71-7, 70 p.

1977: Geological Survey of Canada radiocarbon dates XVII; Geological Survey of Canada, Paper 77-7, 25 p.

Lowdon, J.A., Wilmeth, R., and Blake, W., Jr.
1969: Geological Survey of Canada radiocarbon dates VIII; Radiocarbon, v. 11, no. 1, p. 22-42. Reprinted (1969) as Geological Survey of Canada, Paper 69-2B, 21 p.

1970: Geological Survey of Canada radiocarbon dates X; Radiocarbon, v. 12, no. 2, p. 472-485. Reprinted (1970) as Geological Survey of Canada, Paper 70-2B (second report), 14 p.

1972: Geological Survey of Canada radiocarbon dates XII; Geological Survey of Canada, Paper 72-7, 26 p.

1974: Geological Survey of Canada radiocarbon dates XIV; Geological Survey of Canada, Paper 74-7, 11 p.

Luckman, B.H. and Osborn, G.D.
1979: Holocene glacier fluctuations in the middle Canadian Rocky Mountains; Quaternary Research, v. 11, no. 1, p. 52-77.

Luternauer, J.L. and Murray, J.W.
1973: Sedimentation on the western delta-front of the Fraser River, British Columbia; Canadian Journal of Earth Sciences, v. 10, no. 11, p. 1642-1663.

Luternauer, J.L. and Swan, D.
1978: Kitimat submarine slump deposit(s): a preliminary report; in Current Research, Part A; Geological Survey of Canada, Paper 78-1A, p. 327-332.

Mack, R.N.
1971: Pollen size variation in some western North American pines as related to fossil pollen identification; Northwest Science, v. 45, no. 4, p. 257-269.

Mack, R.N., Bryant, V.M., Jr., and Fryxell, R.
1976: Pollen sequence from the Columbia Basin, Washington: reappraisal of postglacial vegetation; American Midlands Naturalist, v. 95, no. 2, p. 390-397.

Mack, R.N., Rutter, N.W., Bryant, V.M., Jr., and Valastro, S.
1978a: Late Quaternary pollen record from Big Meadow, Pend Oreille County, Washington; Ecology, v. 59, no. 5, p. 956-965.

1978b: Reexamination of postglacial vegetation history in northern Idaho: Hager Pond, Bonner Co.; Quaternary Research, v. 10, no. 2, p. 241-255.

Mack, R.N., Rutter, N.W., and Valastro, S.
1978c: Late Quaternary pollen record from the Sanpoil River valley, Washington; Canadian Journal of Botany, v. 56, no. 14, p. 1642-1650.

1979: Holocene vegetation history of the Okanogan Valley, Washington; Quaternary Research, v. 12, no. 2, p. 212-225.

Mathewes, R.W.
1973a: A palynological study of postglacial vegetation changes in the University Research Forest, southwestern British Columbia; Canadian Journal of Botany, v. 51, no. 11, p. 2085-2103.

1973b: Paleoecology of postglacial sediments in the Fraser Lowland region of British Columbia; unpublished Ph.D. thesis, University of British Columbia, Vancouver, 77 p.

1979: A paleoecological analysis of Quadra Sand at Point Grey, British Columbia, based on indicator pollen; Canadian Journal of Earth Sciences, v. 16, no. 4, p. 847-858.

Mathewes, R.W. and Rouse, G.E.
1975: Palynology and paleoecology of postglacial sediments from the lower Fraser River canyon of British Columbia; Canadian Journal of Earth Sciences, v. 12, no. 5, p. 745-756.

Mathewes, R.W. and Westgate, J.A.
1980: Bridge River tephra: revised distribution and significance for detecting old carbon errors of limnic sediments in southern British Columbia; Canadian Journal of Earth Sciences, v. 17, no. 11, p. 1454-1461.

Mathewes, 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, v. 9, no. 8, p. 1055-1057.

Mathews, W.H.
1944: Glacial lakes and ice retreat in south-central British Columbia; Royal Society of Canada, Transactions, ser. 3, v. 38, sec. 4, p. 39-57.

1951: Historic and prehistoric fluctuations of alpine glaciers in the Mount Garibaldi map-area, southwestern British Columbia; Journal of Geology, v. 59, no. 4, p. 357-380.

Mathews, W.H. (cont.)
1955: Late Pleistocene divide of the Cordilleran Ice Sheet [abstract]; Geological Society of America, Bulletin, v. 66, no. 12, pt. 2, p. 1657.

1963: Quaternary stratigraphy and geomorphology of the Fort St. John area, northeastern British Columbia; British Columbia Department of Mines and Petroleum Resources, Victoria, 22 p.

1978: Quaternary stratigraphy and geomorphology of Charlie Lake (94A) map-area, British Columbia; Geological Survey of Canada, Paper 76-20, 25 p.

1979: Landslides of central Vancouver Island and the 1946 earthquake; Seismological Society of America, Bulletin, v. 69, no. 2, p. 445-450.

1980: Retreat of the last ice sheets in northeastern British Columbia and adjacent Alberta; Geological Survey of Canada, Bulletin 331, 22 p.

Mathews, W.H. and McTaggart, K.C.
1969: The Hope landslide, British Columbia; Geological Association of Canada, Proceedings, v. 20, p. 65-75.

1978: Hope rockslides, British Columbia, Canada; in Rockslides and Avalanches, 1, Natural Phenomena, ed. B. Voight; Elsevier Scientific Publishing Company, New York, New York, p. 259-275.

Mathews, W.H. and Shepard, F.P.
1962: Sedimentation of Fraser River delta, British Columbia [includes Discussion by K. Terzaghi]; American Association of Petroleum Geologists, Bulletin, v. 46, no. 8, p. 1416-1443. Reprinted (1976) in Modern Deltas; American Association of Petroleum Geologists, Reprint Series, no. 18, p. 94-116.

Mathews, W.H., Fyles, J.G., and Nasmith, H.W.
1970: Postglacial crustal movements in southwestern British Columbia and adjacent Washington State; Canadian Journal of Earth Sciences, v. 7, no. 2, pt. 2, p. 690-702.

McCallum, K.J. and Wittenberg, J.
1962: University of Saskatchewan radiocarbon dates III; Radiocarbon, v. 4, p. 71-80.

McKenzie, G.D.
1970: Some properties and age of volcanic ash in Glacier Bay National Monument; Arctic, v. 23, no. 1, p. 46-49.

McPherson, H.J.
1963: The glacial geomorphology of the upper Red Deer River valley, Alberta; unpublished M.Sc. thesis, University of Calgary, Alberta, 41 p.

1970: Landforms and glacial history of the upper North Saskatchewan Valley, Alberta, Canada; Canadian Geographer, v. 14, no. 1, p. 10-26.

Michael, H.N. and Ralph, E.K.
1974: University of Pennsylvania radiocarbon dates XVI; Radiocarbon, v. 16, no. 2, p. 198-218.

Miller, C.D.
1967: Chronology of Neoglacial moraines in the Dome Peak area, North Cascade Range, Washington; unpublished M.Sc. thesis, University of Washington, Seattle, 37 p.

1969: Chronology of Neoglacial moraines in the Dome Peak area, North Cascade Range, Washington; Arctic and Alpine Research, v. 1, no. 1, p. 49-65.

Miller, M.M.
1976: Quaternary erosional and stratigraphic sequences in the Alaska-Canada Boundary Range; in Quaternary Stratigraphy of North America, ed. W.C. Mahaney; Dowden, Hutchinson & Ross, Inc., Stroudsburg, Pennsylvania, p. 463-492.

Miller, M.M. and Anderson, J.H.
1974a: Out-of-phase Holocene climatic trends in the maritime and continental sectors of the Alaska-Canada Boundary Range; in Quaternary Environments: Proceedings of a Symposium, ed. W.C. Mahaney; York University, Geographical Monographs, no. 5, p. 33-58.

1974b: Alaskan Glacier Commemorative Project, Phase IV: Pleistocene-Holocene sequences in the Alaska-Canada Boundary Range; in National Geographic Society Research Reports, Abstracts and Reviews of Research and Exploration Authorized under Grants from the National Geographic Society during the Year 1967, ed. P.H. Oehser; National Geographic Society, Washington, D.C., p. 197-223.

Miller, R.D.
1973: Gastineau Channel Formation, a composite glaciomarine deposit near Juneau, Alaska; United States Geological Survey, Bulletin 1394-C, 20 p.

Mitchell, D.H.
1971: Archaeology of the Gulf of Georgia area, a natural region and its culture types; Syesis, v. 4, supplement 1, 228 p.

Mokievsky-Zubok, O.
1977: Glacier-caused slide near Pylon Peak, British Columbia; Canadian Journal of Earth Sciences, v. 14, no. 11, p. 2657-2662.

Moore, D.P.
1976: The Rubble Creek landslide, Garibaldi, British Columbia; unpublished M.A.Sc. thesis, University of British Columbia, Vancouver, 84 p.

Moore, D.P. and Mathews, W.H.
1978: The Rubble Creek landslide, southwestern British Columbia; Canadian Journal of Earth Sciences, v. 15, no. 7, p. 1039-1052.

Mullineaux, D.R. and Crandell, D.R.
1962: Recent lahars from Mount St. Helens, Washington; Geological Society of America, Bulletin, v. 73, no. 7, p. 855-870.

Mullineaux, D.R., Hyde, J.H., and Rubin, M.
1975: Widespread late glacial and postglacial tephra deposits from Mount St. Helens volcano, Washington; United States Geological Survey, Journal of Research, v. 3, no. 3, p. 329-335.

Mullineaux, D.R., Waldron, H.H., and Rubin, M.
1965: Stratigraphy and chronology of late interglacial and early Vashon glacial time in the Seattle area, Washington; United States Geological Survey, Bulletin 1194-0, 10 p.

Mullineaux, D.R., Wilcox, R.E., Ebaugh, W.F., Fryxell, R., and Rubin, M.
1978: Age of the last major scabland flood of the Columbia Plateau in eastern Washington; Quaternary Research, v. 10, no. 2, p. 171-180.

Munday, W.A.D.
1936: Glaciers of Mt. Waddington region; Canadian Alpine Journal, v. 23, p. 68-75.

Nasmith, H.
1962: Late glacial history and surficial deposits of the Okanagan Valley, British Columbia; British Columbia Department of Mines and Petroleum Resources, Bulletin no. 46, 46 p.

1970: Pleistocene geology of the Queen Charlotte Islands and southern British Columbia; in Early Man and Environments in Northwest North America, ed. R.A. Smith and J.W. Smith; University of Calgary, Archaeological Association, Calgary, Alberta, p. 5-9.

Nasmith, H.W. and Mercer, A.G.
1979: Design of dykes to protect against debris flows at Port Alice, British Columbia; Canadian Geotechnical Journal, v. 16, no. 4, p. 748-757.

Nasmith, H., Mathews, W.H., and Rouse, G.E.
1967: Bridge River ash and some other Recent ash beds in British Columbia; Canadian Journal of Earth Sciences, v. 4, no. 1, p. 163-170.

Nelson, J.G.
1963: The origin and geomorphological significance of the Morley Flats, Alberta; Bulletin of Canadian Petroleum Geology, v. 11, no. 2, p. 169-177.

Okazaki, R., Smith, H.W., Gilkeson, R.A., and Franklin, J.
1972: Correlation of West Blacktail ash with pyroclastic layer T from the 1800 A.D. eruption of Mount St. Helens; Northwest Science, v. 46, no. 2, p. 77-89.

O'Loughlin, C.L.
1972: A preliminary study of landslides in the Coast Mountains of southwestern British Columbia; in Mountain Geomorphology: Geomorphological Processes in the Canadian Cordillera, ed. H.O. Slaymaker and H.J. McPherson; Tantalus Research Limited, Vancouver, British Columbia, p. 101-111.

1973: An investigation of the stability of the steepland forest soils in the Coast Mountains, southwest British Columbia; unpublished Ph.D. thesis, University of British Columbia, Vancouver, 147 p.

Olsson, I.U.
1970: Explanation of Plate IV; in Radiocarbon Variations and Absolute Chronology, ed. I.U. Olsson; Wiley Interscience Division, New York, New York, Almqvist and Wiksell, Stockholm, Sweden, p. 625-626.

Peng, T.-H., Goddard, J.G., and Broecker, W.S.
1978: A direct comparison of ^{14}C and ^{230}Th ages at Searles Lake, California; Quaternary Research, v. 9, no. 3, p. 319-329.

Piteau, D.R.
1977: Regional slope-stability controls and engineering geology of the Fraser Canyon, British Columbia; in Landslides, ed. D.R. Coates; Geological Society of America, Reviews in Engineering Geology, v. 3, p. 85-111.

Piteau, D.R., Mylrea, F.H., and Blown, I.G.
1978: Downie slide, Columbia River, British Columbia, Canada; in Rockslides and Avalanches, 1, Natural Phenomena, ed. B. Voight; Elsevier Scientific Publishing Company, New York, New York, p. 365-392.

Porter, S.C.
1964: Late Pleistocene glacial chronology of north-central Brooks Range, Alaska; American Journal of Science, v. 262, no. 4, p. 446-460.

Porter, S.C. (cont.)
1966: Pleistocene geology of Anaktuvuk Pass, central Brooks Range, Alaska; Arctic Institute of North America, Technical Paper no. 18, 100 p.

1976: Pleistocene glaciation in the southern part of the North Cascade Range, Washington; Geological Society of America, Bulletin, v. 87, no. 1, p. 61-75.

1978: Glacier Peak tephra in the North Cascade Range, Washington: stratigraphy, distribution, and relationship to late-glacial events; Quaternary Research, v. 10, no. 1, p. 30-41.

Porter, S.C. and Denton, G.H.
1967: Chronology of Neoglaciation in the North American Cordillera; American Journal of Science, v. 265, no. 3, p. 177-210.

Powers, H.A. and Wilcox, R.E.
1964: Volcanic ash from Mount Mazama (Crater Lake) and from Glacier Peak; Science, v. 144, no. 3624, p. 1334-1336.

Prest, V.K.
1969: Retreat of Wisconsin and Recent ice in North America; Geological Survey of Canada, Map 1257A.

Prest, V.K., Grant, D.R., and Rampton, V.N.
1968: Glacial map of Canada; Geological Survey of Canada, Map 1253A.

Psutka, J.F.
1978: Structural setting of the Downie slide, northeast flank of Frenchman Cap gneiss dome, Shuswap Complex, southeastern British Columbia; unpublished M.Sc. thesis, Carleton University, Ottawa, 70 p.

Rampton, V.N.
1969: Pleistocene geology of the Snag-Klutlan area, southwestern Yukon, Canada; unpublished Ph.D. thesis, University of Minnesota, Minneapolis, 237 p.

1970: Neoglacial fluctuations of the Natazhat and Klutlan glaciers, Yukon Territory, Canada; Canadian Journal of Earth Sciences, v. 7, no. 5, p. 1236-1263.

Reeburgh, W.S. and Young, M.S.
1976: University of Alaska radiocarbon dates I; Radiocarbon, v. 18, no. 1, p. 1-15.

Reeves, B.O.K.
1975: Early Holocene (ca. 8000 to 5500 B.C.) prehistoric land/resource utilization patterns in Waterton Lakes National Park, Alberta; Arctic and Alpine Research, v. 7, no. 3, p. 237-248.

Reeves, B.O.K. and Dormaar, J.F.
1972: A partial Holocene pedological and archaeological record from the southern Alberta Rocky Mountains; Arctic and Alpine Research, v. 4, no. 4, p. 325-336.

Reimchen, T.H.F. and Rutter, N.W.
1972: Quaternary geology, Dawson Creek, British Columbia (93P); in Report of Activities, Part A; Geological Survey of Canada, Paper 72-1A, p. 176-177.

Retherford, R.M.
1972: Late Quaternary geologic environments and their relation to archaeological studies in the Bella Bella – Bella Coola region of the British Columbia coast; unpublished M.Sc. thesis, University of Colorado, Boulder, 128 p.

Richmond, G.M., Fryxell, R., Neff, G.E., and Weis, P.L.
1965: The Cordilleran Ice Sheet of the northern Rocky Mountains, and related Quaternary history of the Columbia Plateau; in The Quaternary of the United States, ed. H.E. Wright, Jr. and D.G. Frey; Princeton University Press, Princeton, New Jersey, p. 231-242.

Riddihough, R.P.
1979: Gravity and structure of an active margin – British Columbia and Washington; Canadian Journal of Earth Sciences, v. 16, no. 2, p. 350-363.

Rigg, G.B. and Gould, H.R.
1957: Age of Glacier Peak eruption and chronology of post-glacial peat deposits in Washington and surrounding areas; American Journal of Science, v. 255, no. 5, p. 341-363.

Roed, M.A.
1968: Surficial geology of the Edson-Hinton area, Alberta; unpublished Ph.D. thesis, University of Alberta, Edmonton, 200 p.

1975: Cordilleran and Laurentide multiple glaciation, west central Alberta; Canadian Journal of Earth Sciences, v. 12, no. 9, p. 1493-1515.

Rubin, M. and Alexander, C.
1960: U.S. Geological Survey radiocarbon dates V; Radiocarbon, v. 2, p. 129-185.

Rutherford, A.A., Wittenberg, J., and Wilmeth, R.
1979: University of Saskatchewan radiocarbon dates VIII; Radiocarbon, v. 21, no. 1, p. 48-94.

Rutter, N.W.
1966a: Glacial history of the Bow River valley, Banff area, Alberta; Canadian Alpine Journal, v. 49, p. 157-173.

1966b: Multiple glaciation in the Banff area, Alberta; Bulletin of Canadian Petroleum Geology, v. 14, no. 4, p. 620-626.

1966c: Surficial geology of the Banff area, Alberta; unpublished Ph.D. thesis, University of Alberta, Edmonton, Alberta, 105 p.

1969: A late-Pleistocene glacial advance, Bow River valley, Alberta, Canada; in Quaternary Geology and Climate; International Association for Quaternary Research, 7th Congress, Proceedings, v. 16, p. 104-109.

1972: Geomorphology and multiple glaciation in the area of Banff, Alberta; Geological Survey of Canada, Bulletin 206, 54 p.

1976: Multiple glaciation in the Canadian Rocky Mountains with special emphasis on northeastern British Columbia; in Quaternary Stratigraphy of North America, ed. W.C. Mahaney; Dowden, Hutchinson & Ross, Inc., Stroudsburg, Pennsylvania, p. 409-440.

1977: Multiple glaciation in the area of Williston Lake, British Columbia; Geological Survey of Canada, Bulletin 273, 31 p.

Rutter, N.W., Geist, V., and Shackelton, D.M.
1972: A bighorn sheep skull 9280 years old from British Columbia; Journal of Mammalogy, v. 53, no. 3, p. 641-644.

Ryder, J.M.
1970: Alluvial fans of post-glacial environments within British Columbia; unpublished Ph.D. thesis, University of British Columbia, Vancouver, 435 p.

Ryder, J.M. (cont.)
1971a: Some aspects of the morphometry of paraglacial alluvial fans in south-central British Columbia; Canadian Journal of Earth Sciences, v. 8, no. 10, p. 1252-1264.

1971b: The stratigraphy and morphology of para-glacial alluvial fans in south-central British Columbia; Canadian Journal of Earth Sciences, v. 8, no. 2, p. 279-298.

1976: Terrain inventory and Quaternary geology Ashcroft, British Columbia (92-I NW); Geological Survey of Canada, Paper 74-49, 17 p.

Quaternary stratigraphy and chronology of Fraser and Thompson valleys near Lytton, British Columbia; Syesis. (in press (a)).

Terrain inventory and Quaternary geology, Lytton, British Columbia; Geological Survey of Canada, Paper 79-25. (in press (b)).

Severs, P.
1975: Recent research into the prehistory of the Queen Charlotte Islands; Midden (Archaeological Society of British Columbia), v. 7, no. 2, p. 15-17.

Shaw, J.
1972: Pleistocene chronology and geomorphology of the Rocky Mountains in south and central Alberta; in Mountain Geomorphology: Geomorphological Processes in the Canadian Cordillera, ed. H.O. Slaymaker and H.J. McPherson; Tantalus Research Limited, Vancouver, British Columbia, p. 37-45.

Skermer, N.A.
1976: Earthquakes, avalanches, landslides; B.C. Professional Engineer, v. 27, no. 1, p. 5-8.

Smith, H.W., Okazaki, R., and Aarstad, J.
1968: Recent volcanic ash in soils of northeastern Washington and northern Idaho; Northwest Science, v. 42, no. 4, p. 150-160.

Smith, H.W., Okazaki, R., and Knowles, C.R.
1975: Electron microprobe analysis as a test of the correlation of West Blacktail ash with Mount St. Helens pyroclastic layer T; Northwest Science, v. 49, no. 4, p. 209-215.

1977a: Electron microprobe analysis of glass shards from tephra assigned to set W, Mount St. Helens, Washington; Quaternary Research, v. 7, no. 2, p. 207-217.

1977b: Electron microprobe data for tephra attributed to Glacier Peak, Washington; Quaternary Research, v. 7, no. 2, p. 197-206.

Sneddon, J.I.
1974: A study of two soils derived from volcanic ash in southwestern British Columbia and a review and determination of ash distribution in western Canada; unpublished Ph.D. thesis, University of British Columbia, Vancouver, 149 p.

Souther, J.G.
1976: Geothermal potential of western Canada; in Proceedings, 2nd United Nations Symposium on the Development and Use of Geothermal Resources, San Francisco, California (1975), v. 1, p. 259-267.

Stalker, A. MacS.
1969: A probable late Pinedale terminal moraine in Castle River valley, Alberta; Geological Society of America, Bulletin, v. 80, no. 10, p. 2115-2122.

Stalker, A. MacS. (cont.)
1973: Surficial geology of the Kananaskis Research Forest and Marmot Creek basin region of Alberta; Geological Survey of Canada, Paper 72-51, 25 p.

Stalker, A. MacS. and Harrison, J.E.
1977: Quaternary glaciation of the Waterton-Castle River region of Alberta; Bulletin of Canadian Petroleum Geology, v. 25, no. 4, p. 882-906.

Stanton, R.B.
1898: The great land-slides of the Canadian Pacific Railway in British Columbia; Institution of Civil Engineers, Proceedings, v. 132, pt. 2, p. 3-48.

Stene, L.P.
1966: Pleistocene valley train terraces along the Athabasca River in the Hinton area, Alberta; unpublished M.Sc. thesis, University of Alberta, Edmonton, 58 p.

Stevenson, L.S.
1947: Pumice from Haylmore, Bridge River, British Columbia; American Mineralogist, v. 32, no. 9-10, p. 547-552.

St-Onge, D.A.
1972: Sequence of glacial lakes in north-central Alberta; Geological Survey of Canada, Bulletin 213, 16 p.

Stuiver, M.
1970: Long-term ^{14}C variations; in Radiocarbon Variations and Absolute Chronology, ed. I.U. Olsson; Wiley Interscience Division, New York, New York, Almqvist and Wiksell, Stockholm, Sweden, p. 197-213.

1971: Evidence for the variation of atmospheric ^{14}C content in the late Quaternary; in The Late Cenozoic Glacial Ages, ed. K.K. Turekian; Yale University Press, New Haven, Connecticut, p. 57-70.

1978: Radiocarbon timescale tested against magnetic and other dating methods; Nature, v. 273, no. 5660, p. 271-274.

Stuiver, M. and Suess, H.E.
1966: On the relationship between radiocarbon dates and true sample ages; Radiocarbon, v. 8, p. 534-540.

Stuiver, M., Borns, H.W., Jr., and Denton, G.H.
1964: Age of a widespread layer of volcanic ash in the southwestern Yukon Territory; Arctic, v. 17, no. 4, p. 259-260. Reprinted (1969) in Icefield Ranges Research Project Scientific Results, Volume 1, ed. V.C. Bushnell and R.H. Ragle; American Geographical Society, New York, New York, Arctic Institute of North America, Montreal, Quebec, p. 219-220.

Stuiver, M., Deevey, E.S., and Gralenski, L.J.
1960: Yale natural radiocarbon measurements V; Radiocarbon, v. 2, p. 49-61.

Suess, H.E.
1970; Bristlecone-pine calibration of the radiocarbon time-scale 5200 B.C. to the present; in Radiocarbon Variations and Absolute Chronology, ed. I.U. Olsson; Wiley Interscience Division, New York, New York, Almqvist and Wiksell, Stockholm, Sweden, p. 303-311.

Sutherland Brown, A.
1968: Geology of the Queen Charlotte Islands, British Columbia; British Columbia Department of Mines and Petroleum Resources, Bulletin no. 54, 226 p.

Sutherland Brown, A. (cont.)
1969: Aiyansh lava flow, British Columbia; Canadian Journal of Earth Sciences, v. 6, no. 6, p. 1460-1468.

Sutherland Brown, A. and Nasmith, H.
1962: The glaciation of the Queen Charlotte Islands; Canadian Field Naturalist, v. 76, no. 4, p. 209-219.

Swan, D.
1978: Acoustic imaging of the seabed in northern Kitimat Arm, B.C.; unpublished B.Sc. thesis, University of British Columbia, Department of Geophysics and Astronomy, Vancouver, 72 p.

Swan, D. and Luternauer, J.L.
1978: Mosaic of side scan sonar records, northern Kitimat Arm, B.C.; Geological Survey of Canada, Open file 579.

Swanston, D.N.
1969: A late-Pleistocene glacial sequence from Prince of Wales Island, Alaska; Arctic, v. 22, no. 1, p. 25-33.

Tallman, A.M.
1975: The glacial and periglacial geomorphology of the Fourth of July Creek valley, Atlin region, Cassiar District, northwestern British Columbia; unpublished Ph.D. thesis, Michigan State University, East Lansing, 178 p.

Tauber, H.
1970: The Scandinavian varve chronology and ^{14}C dating; in Radiocarbon Variations and Absolute Chronology, ed. I.U. Olsson; Wiley Interscience Division, New York, New York, Almqvist and Wiksell, Stockholm, Sweden, p. 173-196.

Taylor, R.S.
1960: Some Pleistocene lakes of northern Alberta and adjacent areas: revised; Alberta Society of Petroleum Geologists, Journal, v. 8, no. 6, p. 167-178, 185. Originally published (1958) in Edmonton Geological Society Quarterly, v. 2, no. 4, p. 1-9.

Thorson, R.M.
1979: Isostatic effects of the last glaciation in the Puget Lowland, Washington; unpublished Ph.D. thesis, University of Washington, Seattle, 154 p.

1980: Ice-sheet glaciation of the Puget Lowland, Washington, during the Vashon Stade (late Pleistocene); Quaternary Research, v. 13, no. 3, p. 303-321.

Tipper, H.W.
1971a: Glacial geomorphology and Pleistocene history of central British Columbia; Geological Survey of Canada, Bulletin 196, 89 p.

1971b: Multiple glaciation in central British Columbia; Canadian Journal of Earth Sciences, v. 8, no. 7, p. 743-752.

Trautman, M.A. and Walton, A.
1962: Isotopes, Inc. radiocarbon measurements II; Radiocarbon, v. 4, p. 35-42.

Valentine, K.W.G.
1971: Soils of the Tofino-Ucluelet lowland of British Columbia; Canada Department of Agriculture, British Columbia Soil Survey, Report no. 11, 29 p.

VanDine, D.F.
1974: Geotechnical and geological engineering study of Drynoch landslide, British Columbia; unpublished M.Sc. thesis, Queen's University, Kingston, Ontario, 122 p.

1980: Engineering geology and geotechnical study of Drynoch landslide, British Columbia; Geological Survey of Canada, Paper 79-31, 34 p.

van Ryswyk, A.L.
1969: Forest and alpine soils of south-central British Columbia; unpublished Ph.D. thesis, Washington State University, Pullman, 178 p.

1971: Radiocarbon date for a cryoturbated alpine regosol in south central British Columbia; Canadian Journal of Soil Science, v. 51, no. 3, p. 513-515.

van Ryswyk, A.L. and Okazaki, R.
1979: Genesis and classification of modal subalpine and alpine soil pedons of south-central British Columbia, Canada; Arctic and Alpine Research, v. 11, no. 1, p. 53-67.

Wagner, W.P.
1966: Correlation of Rocky Mountain and Laurentide glacial chronologies in southwestern Alberta, Canada; unpublished Ph.D. thesis, University of Michigan, Ann Arbor, 169 p.

Walker, M.J.C.
1971: Late-Wisconsin ice in the Morely Flats area of the Bow Valley and adjacent areas of the Kananaskis Valley, Alberta; unpublished M.Sc. thesis, University of Calgary, Alberta, 114 p.

1973: The nature and origin of a series of elongated ridges in the Morley Flats area of the Bow Valley, Alberta; Canadian Journal of Earth Sciences, v. 10, no. 8, p. 1340-1346.

Waters, R.R.
1975: The glacial geomorphology of the Pekisko Creek – Happy Valley area, Alberta; unpublished M.Sc. thesis, University of Calgary, Alberta.

Westgate, J.A.
1968: Surficial geology of the Foremost-Cypress Hills area, Alberta; Alberta Research Council, Bulletin 22, 122 p.

1977: Identification and significance of late Holocene tephra from Otter Creek, southern British Columbia, and localities in west-central Alberta; Canadian Journal of Earth Sciences, v. 14, no. 11, p. 2593-2600.

Westgate, J.A. and Dreimanis, A.
1967: Volcanic ash layers of Recent age at Banff National Park, Alberta, Canada; Canadian Journal of Earth Sciences, v. 4, no. 1, p. 155-162.

Westgate, J.A. and Evans, M.E.
1978: Compositional variability of Glacier Peak tephra and its stratigraphic significance; Canadian Journal of Earth Sciences, v. 15, no. 10, p. 1554-1567.

Westgate, J.A. and Fulton, R.J.
1975: Tephrostratigraphy of Olympia Interglacial sediments in south-central British Columbia, Canada; Canadian Journal of Earth Sciences, v. 12, no. 3, p. 489-502.

Westgate, J.A., Fritz, P., Matthews, J.V., Jr., Kalas, L., Delorme, L.D., Green, R., and Aario, R.
1972: Geochronology and palaeoecology of mid-Wisconsin sediments in west-central Alberta, Canada [abstract]; in Abstracts; 24th International Geological Congress (Montreal), p. 380.

Westgate, J.A., Smith, D.G.W., and Tomlinson, M.
1970: Late Quaternary tephra layers in southwestern Canada; in Early Man and Environments in Northwest North America, ed. R.A. Smith and J.W. Smith; University of Calgary, Archaeological Association, Calgary, Alberta, p. 13-33.

White, J.M., Mathewes, R.W., and Mathews, W.H.
1979: Radiocarbon dates from Boone Lake and their relation to the 'Ice-free Corridor' in the Peace River District of Alberta, Canada; Canadian Journal of Earth Sciences, v. 16, no. 9, p. 1870-1874.

Wilcox, R.E.
1965: Volcanic-ash chronology; in The Quaternary of the United States, ed. H.E. Wright, Jr. and D.G. Frey; Princeton University Press, Princeton, New Jersey, p. 807-816.

Wilson, J.T., Falconer, G., Mathews, W.H., and Prest, V.K. (compilers)
1958: Glacial map of Canada; Geological Association of Canada, Toronto, Ontario.

Wuorinen, V.
1978: Age of Aiyansh volcano, British Columbia; Canadian Journal of Earth Sciences, v. 15, no. 6, p. 1037-1038.

Yang, A.I.C.
1971: Variations of natural radiocarbon during the last 11 millenia and geophysical mechanisms for producing them; unpublished Ph.D. thesis, University of Washington, Seattle, 118 p.

Yang, A.I.C. and Fairhall, A.W.
1972: Variations of natural radiocarbon during the last 11 millenia and geophysical mechanisms for producing them; in Proceedings of the Eighth International Radiocarbon Dating Conference; Royal Society of New Zealand, Lower Hutt, New Zealand, v. 1, p. A44-A57.

Energy, Mines and Resources Canada
Énergie, Mines et Ressources Canada