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The Quaternary Geologic History of the Canadian Rocky Mountains
Histoire de la géologie du Quaternaire des montagnes Rocheuses du Canada
Die geologische Geschichte der kanadischen Rocky Mountains im Quaternär

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Article abstract

The Canadian Rocky Mountains figured prominently during the glacial history of western Canada. First as a western limit or boundary to the Laurentide Ice Sheet, second as an eastern margin of the Cordilleran Ice Sheet, and finally as a centre of local Montane ice. Throughout the Quaternary, complex interactions of glacier ice from these three ice sources markedly changed the physical form of the Rocky Mountains, Trench and Foothills areas. Investigations into the Quaternary history of this region have been ongoing since the beginning of the last century. Since about 1950, the number of studies performed in this area have increased significantly. This paper briefly reviews the historical accomplishments of Quaternary work in the region up to the period of about 1950. From this time to the present, individual study efforts are examined in detail according to the three geographic regions: 1) the northern Rocky Mountains (from the Liard Plateau south to the McGregor Plateau), 2) the central Rocky Mountains (from the McGregor Plateau south to the Porcupine Hills) and 3) the southern Rocky Mountains (from the Porcupine Hills south to the international border). In the northern region, geologic data suggest a maximum of two Rocky Mountain glaciations and only one Laurentide glaciation and no ice coalescence. In the central region, three of four Rocky Mountain events, and at least two Laurentide events are known. Only in the central region is there good evidence for ice coalescence, but the timing of this event is not clearly established. In the south, at least three Rocky Mountain episodes and a variable number of Laurentide episodes are recognized. There is no evidence for ice coalescence. A number of facts support the proposal that Cordilleran ice crossed the Continental Divide and joined with local Montane ice at several locations. However, this expansion of western ice occurred before the Late Wisconsinan in all areas but Jasper. In general, the chronological data presented suggest that the Late Wisconsinan glaciation in the Rocky Mountains was a short-lived event which started around or after 20 ka years ago and ended before 12 ka ago.

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THE QUATERNARY GEOLOGIC HISTORY OF THE CANADIAN ROCKY MOUNTAINS*

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ABSTRACT The Canadian Rocky Mountains figured prominently during the glacial history of western Canada. First as a western limit or boundary to the Laurentide Ice Sheet, second as an eastern margin of the Cordilleran Ice Sheet, and finally as a centre of local Montane ice. Throughout the Quaternary, complex interactions of glacier ice from these three ice sources markedly changed the physical form of the Rocky Mountains, Trench and Foothills areas. Investigations into the Quaternary history of this region have been ongoing since the beginning of the last century. Since about 1950, the number of studies performed in this area have increased significantly. This paper briefly reviews the historical accomplishments of Quaternary work in the region up to the period of about 1950. From this time to the present, individual study efforts are examined in detail according to the three geographic regions: 1) the northern Rocky Mountains (from the Liard Plateau south to the McGregor Plateau), 2) the central Rocky Mountains (from the McGregor Plateau south to the Porcupine Hills) and 3) the southern Rocky Mountains (from the Porcupine Hills south to the international border). In the northern region, geologic data suggest a maximum of two Rocky Mountain glaciations and only one Laurentide glaciation and no ice coalescence. In the central region, three of four Rocky Mountain events, and at least two Laurentide events are known. Only in the central region is there good evidence for ice coalescence, but the timing of this event is not clearly established. In the south, at least three Rocky Mountain episodes and a variable number of Laurentide episodes are recognized. There is no evidence for ice coalescence. A number of facts support the proposal that Cordilleran ice crossed the Continental Divide and joined with local Montane ice at several locations. However, this expansion of western ice occurred before the Late Wisconsinan in all areas but Jasper. In general, the chronological data presented suggest that the Late Wisconsinan glaciation in the Rocky Mountains was a short-lived event which started around or after 20 ka years ago and ended before 12 ka ago.

RÉSUMÉ *Histoire de la géologie du Quaternaire des montagnes Rocheuses du Canada.* Les montagnes Rocheuses ont constitué un cas particulier au cours de l'évolution glaciaire de l'ouest du Canada. Elles ont d'abord formé la limite occidentale de l'Inlandsis laurentidien, puis la limite orientale de l'Inlandsis de la Cordillère et finalement le centre d'une glaciation alpine locale. Tout au long du Quaternaire, les interactions complexes des glaces à partir de ces trois sources ont modifié de façon sensible l'aspect physique des Rocheuses, du sillon et du piémont. Les études sur l'évolution géologique de la région ont commencé au début du siècle dernier; beaucoup plus nombreuses depuis 1950, elles se sont également diversifiées. On résume d'abord les réalisations jusqu'aux années 50, puis on se penche plus particulièrement sur les travaux accomplis depuis lors dans: 1) la partie septentrionale (du plateau du Liard au plateau du McGregor, au sud); 2) la partie centrale (du plateau du McGregor aux collines Porcupine, au sud); et 3) la partie méridionale (des collines Porcupine à la frontière des É-U., au sud). Dans la partie septentrionale, les données géologiques montrent l'existence d'au plus deux glaciations issues des Rocheuses, une seule glaciation laurentidienne et aucune coalescence des glaces. Dans la partie centrale, on reconnaît l'existence de trois ou quatre glaciations issues des Rocheuses et au moins deux glaciations d'origine laurentidienne. On y observe des indices sur la coalescence des glaces, mais on ne sait pas exactement quand elle s'est produite. Dans le sud, on reconnaît l'existence d'au moins trois glaciations issues des Rocheuses et d'un nombre variable de glaciations d'origine laurentidienne. Il n'y aurait pas eu de coalescence. Un certain nombre de faits appuient l'hypothèse selon laquelle les glaces cordillérennes auraient traversé la ligne de partage des eaux en plusieurs points pour se joindre aux glaces alpines locales. Cependant, cette extension des glaces venant de l'ouest s'est produite avant le Wisconsinien supérieur dans tous les secteurs, sauf à Jasper. De façon générale, les données chronologiques indiquent que la glaciation du Wisconsinien supérieur a été de courte durée dans les Rocheuses (de 20 ka à 12 ka environ).

ZUSAMMENFASSUNG *Die geologische Geschichte der kanadischen Rocky Mountains im Quaternär.* Die kanadischen Rocky Mountains stellen einen Sonderfall in der glazialen Geschichte von Westkanada dar. Zuerst als eine westliche Grenze oder Trennungslinie zur laurentidischen Eisdecke, dann als ein östlicher Rand der Kordilleren-Eisdecke, und schließlich als das Zentrum einer lokalen alpinen Vereisung. Während des ganzen Quaternärs haben komplexe Interaktionen von Gletschereis aus diesen drei Eisquellen die physikalische Form der Rocky Mountains, der Trench und Foothill-Gebiete signifikant verändert. Untersuchungen der Quaternär-Geschichte dieses Gebiets finden seit dem Beginn des letzten Jahrhunderts statt. Dieser Aufsatz gibt einen kurzen Überblick über die historischen Leistungen der Arbeit zum Quaternär in dem Gebiet bis in die 50ger Jahre. Von diesem Zeitpunkt an bis heute werden individuelle Forschungsbemühungen im Detail untersucht und zwar zu drei geographischen Gebieten: nördlichen, zentralen und südlichen Rocky Mountains. Im nördlichen Gebiet weisen die geologischen Daten auf maximal zwei Rocky Mountain-Vereisungen und nur eine laurentidische Vereisung und auf keinen Eiszusammenschluß. Im mittleren Gebiet sind drei von vier Rocky Mountain-Vereisungen und mindesten zwei laurentidische Vereisungen bekannt. Nur im mittleren Gebiet findet man einen klaren Nachweis für Eiszusammenschluß aber die Zeit für diesen Vorgang kann nicht klar bestimmt werden. Im Süden können mindestens drei Rocky Mountain-Vereisungen und eine variable Zahl von laurentidischen Vereisungen erkannt werden. Es gibt keinerlei Hinweis auf Eiszusammenschluß. Eine Reihe von Fakten stützen die These, daß Eis von den Kordilleren die Wasserscheidelinie überquerte und sich an einigen Plätzen mit lokalem alpinem Eis vereinigte. Jedoch geschah diese Ausdehnung westlichen Eises vor dem späten Wisconsinum in allen Gebieten außer in Jasper. Im allgemeinen zeigen die vorgelegten chronologischen Daten, daß die Spät-Wisconsinum-Vereisung in den Rocky Mountains ein kurzlebiges Ereignis war, das vor etwa 20 ka Jahren oder danach begann und vor 12 ka Jahren endete.

* The present article is a follow up to the special issue dedicated to the Cordilleran Ice Sheet (Vol. 45, No. 3)/Cet article constitue la suite du numéro spécial consacré à l'Inlandsis de la Cordillère (vol. 45, n° 3).

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INTRODUCTION

The Canadian Rocky Mountains figured prominently during the glacial history of western Canada. First as a western limit or boundary to the Laurentide Ice Sheet, second as an eastern margin of the Cordilleran Ice Sheet, and finally as a centre of local Montane ice. Throughout the Quaternary, repetitive but punctuated glacial cycles, as well as complex interactions of glacier ice from these three ice sources markedly changed the physical form of the Rocky Mountains, Rocky Mountain Trench and Foothills. Each cycle of glaciation and non-glaciation not only modified the nature of the topography, but also altered the types and abundance of plants and animals which would successfully survive in the area. Changing climates, colonization and extinction of biota, and a continuous cycle of sediment erosion and deposition characterize the Quaternary. Also, the peopling of the Americas is intimately tied to this geologic history. Fortunately, the signature of these past events is fairly well recorded, and the task of deciphering this remarkable history has been, and continues to be, successfully addressed by numerous researchers.

Throughout this paper we employ the terms Rocky Mountain and Montane interchangeably in describing glaciers and ice originating in the Rocky Mountains. We use the term Cordilleran to describe glaciers and ice originating from west of the Rocky Mountain Trench. The only exception to this usage of terms is in our historical discussion, where early authors used the term Cordilleran without properly documenting the origin of the ice.

In many discussions of the glaciations that affected the Rocky Mountains region, a pervasive tendency exists to refer to the local events as a part of the larger Cordilleran glaciation. Indeed, the Cordilleran Ice Sheet is frequently viewed as a sweeping entity which was solely responsible for the history of glacial events in the Rocky Mountains (*e.g.*, Andrews and Barry, 1978). This tendency is based more on historical precedence than fact, since it has long been known that montane ice played a far greater role than Cordilleran ice in the glacial history of the Rocky Mountains. Generalizations concerning Cordilleran glaciations are common, but rarely do they apply to the Rocky Mountains of Canada. For instance, Harris' (1987b:182) contention of "at least eight major glaciations during the Quaternary in the Cordillera" has little merit with respect to the Rocky Mountains and Foothills region.

During the last two decades, several attempts have been made to correlate isolated glacial events within the mountains and Foothills (*e.g.*, Boydell, 1978; Clague, 1981, 1989; Dreimanis *et al.*, 1981; Fulton, 1976, 1977, 1982, 1984a, 1984b, 1986; Fulton, Fenton and Rutter, 1984, 1986; Roed, 1975; Rutter, 1981a, 1984; Shaw, 1972). Harris and Waters (1977) provide a lengthy example of such attempts at correlation. These reviews and syntheses rarely detail the data upon which the various correlations are based. Rather than duplicate these interpretations, this paper itemizes the raw data of the individual studies for which significant observations, discoveries and errors are highlighted. Similarly, given the hazards of correlation, with its concomitant potential for erroneous results, the task of a new correlation is left to the perception of the reader.

The purpose of this paper is to review the Quaternary geology of the Canadian Rocky Mountains, in particular the stratigraphy and sedimentology associated with past glacial and nonglacial events which have affected the region during the Pleistocene. As a consequence of preservation, most of the geologic evidence discussed stems from the final glaciation affecting any one area. The emphasis here is on glacial geology, although reference is made to certain paleoecological (botanical and paleontological) and paleoenvironmenal evidence. By necessity, the discussion of the Rocky Mountains includes the adjoining Rocky Mountain Trench and Foothills. Finally, given the interaction between Rocky Mountain ice and the Laurentide Ice Sheet to the east, mention is also made regarding the relationship of the two ice masses (but see Dyke *et al.*, 1982; Dyke and Prest, 1987; Evans, 1985; Fenton, 1984 for greater detail). It is beyond the scope of this paper to properly discuss the numerous studies that concern the Holocene. However, a brief review of the significant palynologic, paleontologic, archaeologic and geologic accomplishments is provided.

We have arbitrarily divided the study area into three manageable regions: a northern sector ranging from the Yukon/Northwest Territories border south to about McGregor Plateau, a central area from McGregor Plateau south to Crowsnest Pass, and a southern area from Crowsnest Pass to the international border (Fig. 1).

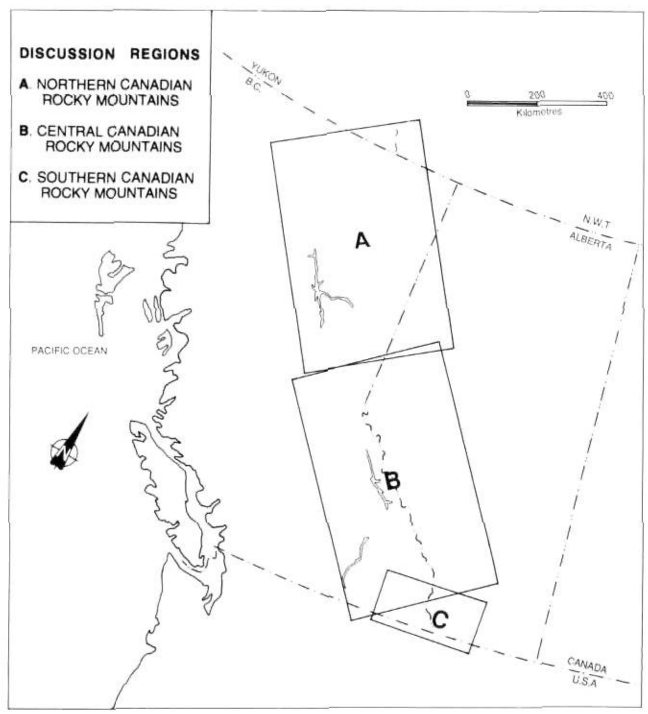

FIGURE 1. Location map of the Canadian Rocky Mountains, including the Rocky Mountains Trench and Foothills regions. Demarcation lines refer to the three geographic regions identified for detailed discussion.

Localisation des montagnes Rocheuses, incluant les régions du sillon et du piémont. Les rectangles correspondent aux trois divisions dont il est question dans le texte.

Although this paper summarizes a number of exceptional Quaternary geological accomplishments, we recognize that there is no alternative to the examination of the actual evidence in the field. At present, several useful field guides on Quaternary geology and paleoecology are available for the Rocky Mountains, Rocky Mountain Trench and Foothills regions. These include Rutter (1971a) and Rutter and Christiansen (1972) for Banff National Park, Fulton and Halstead (1972) for the Trans Canada Highway, Jackson (1981) for the Porcupine Hills to Calgary area, Jackson *et al.* (1984) for the Calgary area, Proudfoot *et al.* (1981) for southwestern Alberta, Proudfoot *et al.* (1982) for Banff and Jasper National Parks, Bobrowsky *et al.* (1987) for the northern Rocky Mountain Trench, Jasper National Park and the Grande Prairie district, Dormaar *et al.* (1987) for the southern Rocky Mountains from Waterton National Park to Jasper National Park, Karlstrom (1987b, 1987c) for Waterton-Glacier Park, and Levson *et al.* (1989) for Jasper National Park and the North Saskatchewan valley.

REGIONAL BEDROCK GEOLOGY, PHYSIOGRAPHY, CLIMATE AND VEGETATION

BEDROCK GEOLOGY

The Canadian Rocky Mountains owe much of their existence to terrane deformation initiated during the Mesozoic. A lengthy tectonic history of oblique terrane/craton accretion between North American and Pacific Ocean lithosphere eventually resulted in a positive northwest-southeast regional bedrock trend to the Cordillera (Tipper *et al.*, 1981; Gabrielse and Yorath, 1989). Several paralleling morphogeological belts comprise the Canadian Cordillera, but only the Foreland Belt is of importance to a discussion of the Canadian Rocky Mountain area. This belt coincides with the ancestral North America craton whose eastern boundary reflects the eastern limit of Cordilleran deformation (Gabrielse and Yorath, 1989). Complex folding and imbricate thrust faulting of sedimentary rocks created the sharp-crested ranges (Madole *et al.*, 1987). Bedrock consists primarily of a westerly thickening wedge of folded and faulted Proterozoic and Jurassic carbonates and clastics including limestone, quartzite, dolomite, chert, shale, slate and sandstone. Cambrian-Devonian rocks are common in the Main Ranges, whereas the Front Ranges host Devonian-Jurassic rocks (Tipper *et al.*, 1981). Steep westward dipping thrust faults typify the Rockies. The Foothills are completely underlain by gently dipping, folded sedimentary rocks ranging in age from the Precambrian to Tertiary, although most of the bedrock is Cretaceous in age (Holland, 1964).

The Muskwa Ranges in the northern Rocky Mountains contain a diverse succession of quartzites, slates, limestone and conglomerates (Irish, 1970). The Hart Ranges predominantly consist of quartzite and limestone, with minor occurrences of schist in the far west. Quartzite, sandstone, shale and limestone comprise the Continental Ranges (Allan, 1914) (Fig. 2). The Border Ranges in the southern Rocky Mountains consist of limestone, argilites, siltstone and sandstone (Alden, 1932).

Initiated in the early Tertiary (possibly Paleocene) by downfaulting, the Rocky Mountain Trench is filled with mid- to late-Tertiary bedrock and a thick accumulation of Quaternary deposits (Leech, 1966). The bedrock within the Trench ranges from Oligocene and Miocene clastics in the south (Clague, 1974; Hopkins *et al.*, 1972) to Cretaceous low-grade metamorphics and Pliocene conglomerates in the north (Bobrowsky, 1989a; Rutter and Taylor, 1968). Detailed bedrock data for the Rocky Mountains can be found in Allan (1914), Bauerman (1884), Beach and Spivak (1943), Daly (1912), Dawson (1877, 1881b, 1890b), Dolmage and Campbell (1963), Gabrielse and Yorath (1989 and references therein), Hedley and Holland (1941), Henderson (1954), Hughes (1967), Irish (1965, 1970), McLearn and Kindle (1950), Monger *et al.* (1972), Mountjoy (1958), Rice (1941) and Selwyn (1877).

FIGURE 2. Oblique air-photograph of the Continental Ranges (Main Ranges) (Province of British Columbia BC896-46).

Photo aérienne oblique de la chaîne Continentale (photo BC896-46).

PHYSIOGRAPHY

The Rocky Mountains, Rocky Mountain Foothills and Rocky Mountain Trench cover an area of approximately 170,000 km² and represent most of the Eastern System and part of the Interior System of the Canadian Cordillera (Fig. 3). True mountain regions cover an area of about 100,000 km², whereas the adjoining Foothills flanking the east side of the mountains cover an area of about 65,000 km² (Slaymaker and McPherson, 1977). The remaining 5,000 km² encompasses the Rocky Mountain Trench along the west side of the study area. All three relief regions trend northwest from the Canada-United States border at 49°N latitude to about 59°N latitude. This area includes the southwest part of the province of Alberta, and most of eastern British Columbia. Differing bedrock geology, tectonic histories and Quaternary cover contribute to the separate physiographic divisions (Bostock, 1947, 1948, 1970b).

Remnants of an old erosional surface or peneplain which formed during the Tertiary is evident in several portions of the

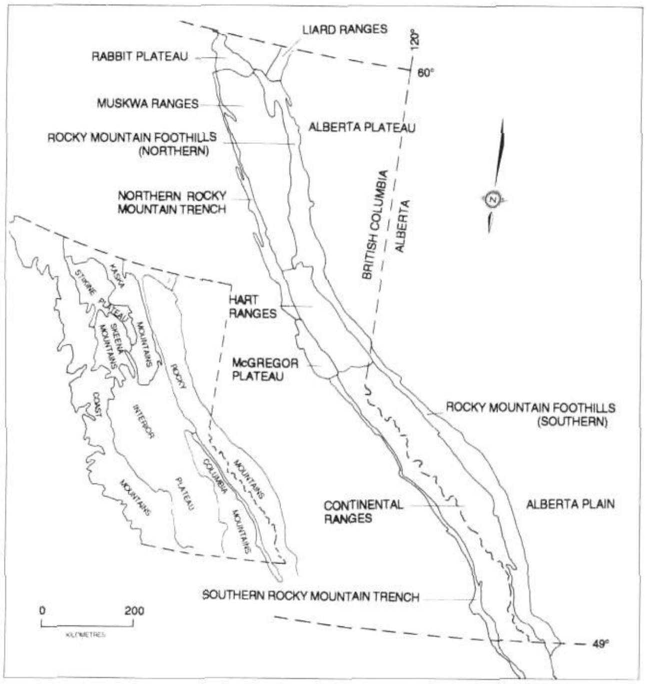

FIGURE: 3. Physiographic regions and details of the Canadian Rocky Mountains (modified from Mathews, 1986).

Régions physiographiques et toponymie des Rocheuses, modifiées à partir de Mathews (1986).

FIGURE 4. Oblique air photograph of the Border Ranges, southeastern British Columbia (Province of British Columbia BC894-21).

Photo aérienne oblique des Border Ranges, dans le sud-ouest de la Colombie-Britannique (photo BC894-21).

study area (Bostock, 1970a). Subsequent uplift, stream entrenchment and glaciation during the Quaternary accentuated the pre-existing Tertiary topography to provide the relief evident today (Madole *et al.* 1987). In northern B.C., Kerr (1936) suggested several periods of Tertiary uplift involving several hundred metres of displacement. The entire region was glaciated at least once during the Pleistocene. Because of this pandemic history of glaciation, glacial features provide a common overprint to the land surface. U-shaped valleys with a relief of up to 2000 m and up to 3 km in width are present (Bostock, 1970a). The valley bottoms support till and outwash plains, eskers, terraces, meltwater channels and drumlins. Cirques, arêtes, and horns are common to the mountains, as are neoglacial moraines. Other common landform features evident throughout much of the glaciated mountains are paraglacial fans which developed post-glacially in many drift covered areas (Ryder, 1971; Church and Ryder, 1972).

The Rocky Mountains are divisible into four divisions, which from south to north consist of the: Border Ranges, Continental Ranges, Hart Ranges and Muskwa Ranges. As the name implies, the Border Ranges straddle the international border and extend north to about latitude 49.3°N. Peaks up to 2600 m and rugged relief characterize these southern ranges (Holland, 1964) (Fig. 4). The Continental Ranges then extend from this point northward to about 54°N latitude. Representing the most spectacular part of the Rocky Mountains, the second highest falls in B.C. (Takakaw Falls-366 m), several prominent passes (Yellowhead-1131 m, Kicking Horse-1622 m, Vermillion-1639 m and Crownest-1357 m), as well as the highest peaks in the Canadian Rockies (Mt. Robson-3954 m, Mt. Columbia-3747 m, and Mt. Assiniboine-3618 m) occur in the

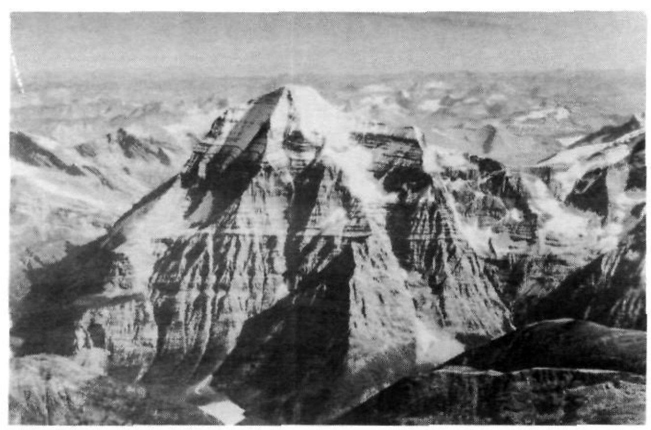

FIGURE 5. Mount Robson (3954 m) in the Continental Ranges (Province of British Columbia BCO-74).

Le mont Robson (3954 m) dans la chaîne Continentale (photo BCO-74).

Continental Ranges (Figs. 2 and 5). The Hart Ranges represent the lowest and least rugged part of the Rocky Mountains and extend from the Continental Ranges north to the Peace River, with summit elevations averaging 2300 m (Holland, 1964) (Fig. 6). The lowest passes in the Canadian Rocky Mountains occur in this area (Pine Pass-869 m and Monkman Pass-1082 m). From the Peace River north to the Rabbit Plateau, summit elevations in the Muskwa Ranges gradually rise from about 2500 m to 3200 m and then drop back down to 1500 m. The highest peaks in this region include Churchill Peak (3200 m) and Mt. Lloyd George (2917 m). In general, the

FIGURE 6. Oblique air photograph of the Hart Ranges, east central British Columbia (Province of British Columbia BC763-69).

Photo aérienne oblique des Hart Ranges, dans le centre est de la Colombie-Britannique (photo BC763-69).

FIGURE: 7. Oblique air photograph of the Canadian Rocky Mountains Foothills (Province of British Columbia BC1206-92).

Photo aérienne oblique du piémont des Rocheuses (photo BC1206-92).

Canadian Rocky Mountains reflect the strong control of the underlying bedrock, which predominantly consists of faulted and folded sedimentary rocks.

The Foothills of western Canada abut the Rocky Mountains along a structural boundary, west of which Paleozoic rocks are thrust over Mesozoic rocks (Holland, 1964). The Foothills exhibit considerable variation in relief along their entire length (700-2350 m), although they do form a continuous topographic feature (Fig. 7). More consistent, however, is the gradual decrease in elevation and relief from west to east. The subdued relief and landforms of the Foothills generally reflect the gently dipping Cretaceous bedrock. Several important rivers originating in the mountains cross the Foothills region including the Oldman, Bow, North Saskatchewan, Wapiti, Peace and Liard rivers.

The Rocky Mountain Trench marks the transition between two larger physiographic systems (Fig. 8). It extends from north of the Yukon border to northern Montana, for a combined length of 1600 km (Slaymaker and McPherson, 1977). This linear feature is offset and breached centrally along its length in the area of the McGregor River (Holland, 1964) (Fig. 9). The southern trench is drained by the Kootenay and Columbia Rivers, the central part by the Fraser River and the north central portion by the Parsnip and Finlay rivers. North of Sifton Pass (998 m), the trench is drained by the Kechika River. Seismic studies have revealed that this broad structural lineament is steep sided, ranging from 1000-200 m in depth and averaging 5-13 km in width (Leech, 1966). Much of the trench is filled with thick deposits of unconsolidated Quaternary sediment.

Modern soils data can be found in several reports such as Hortie *et al.* (1970), Jungen (1980), Kelly and Sprout (1956), Lord (1974), Valentine *et al.* (1978), Wittenben and Lacelle (1978) and Young and Alley (1978).

CLIMATE

The Canadian Rocky Mountains are affected by variable climatic patterns due to significant latitudinal and altitudinal range. Generally, the dominating factors affecting the region are prevailing westerly winds and proximity to the Pacific Ocean. The northwest oriented mountain ranges (Coast Mountains and Rocky Mountains) provide a significant barrier to the westerly air flow, essentially draining weather patterns of moisture as either rain or snow on their western flanks and warming the air masses and dissipating clouds on the lee sides of the mountains. During the winter months, the Rocky Mountains block the westward flow of cold Arctic air masses which develop over the Interior Plains (Schaefer, 1981).

The present day orographic snowline (lower limit of perennial snow) is intimately related to the equilibrium line, both of which increase west to east across the Cordillera (Østrem, 1966). Briefly, the equilibrium line rises from 1300 m near Kitimat and 1600 m on the west side of Vancouver Island to 2300 m on the west side of the Columbia Mountains and 3100 m in the Front Ranges north of Banff (Fig. 10). This trend is an important consideration in the potential affects of ice formation and expansion in the Rocky Mountains during the Pleistocene. High altitude permafrost is known to occur in the Rocky Mountains, at elevations as low as 2347 m in the southern Front Ranges near Snow Creek valley (Ogilvie and Baptie, 1967).

Temperatures are consistent over the region, although precipitation varies significantly. Three locations along a north-

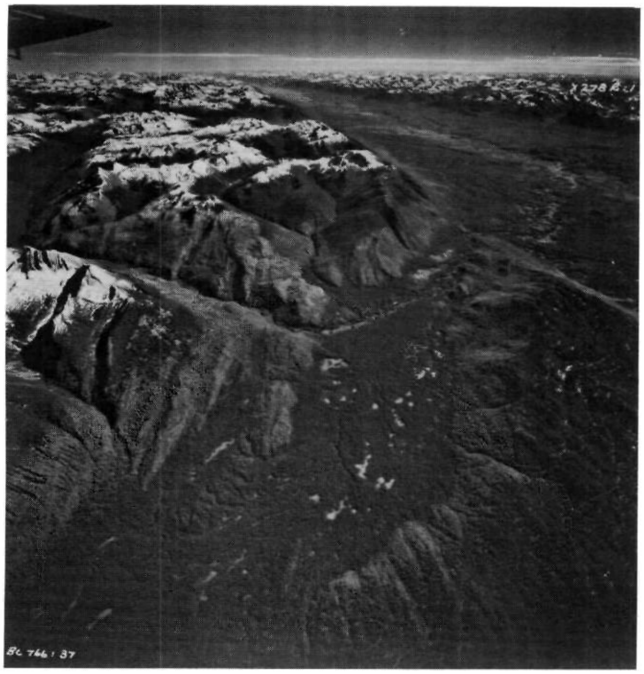

FIGURE 8. Oblique air photograph of the Rocky Mountain Trench (*Province of British Columbia BC766-37*).

Photo aérienne oblique du sillon des Rocheuses (photo BC766-37).

FIGURE 9. Oblique air photograph of the McGregor Plateau, east central British Columbia (*Province of British Columbia BC761-70*).

Photo aérienne oblique du plateau de McGregor, dans le centre-est de la Colombie-Britannique (photo BC761-70).

south transect illustrate these similarities and differences; the first is on the northeast side of the Rockies, at Fort St. John (56°14'N 120°44'W-elevation 695 m), the second on the west-central side of the mountains at Mt. Robson ranch (53°01'N 119°14'W-elevation 869 m), and a third on the southwest side of the mountains at Fernie (49°30'N 115°03'W-elevation 1003 m). Extreme maximum and minimum temperatures for 1978 were 29.8°C and -36.9°C, 31.0°C and -36.0°C, and 33.0°C and -37.0°C, respectively (Air Studies Branch, 1982). Mean annual precipitation for the three areas during 1978 were 325 mm, 610 mm and 1010 mm, respectively (Air Studies Branch, 1982). The precipitation data suggest a trend of increase north to south. The values given are not totally dependent on aspect of the station relative to the mountains, since the community of Ware, located in the Rocky Mountain Trench west of Fort St. John experiences an average of 493 mm of total precipitation.

VEGETATION

The present day vegetation of the Rocky Mountains and Foothills regions is patterned relative to small physiographic zones including the lower Foothills, northern Foothills, upper Foothills, east slope Rockies, interior subalpine and montane forest (Annas, 1977; Rowe, 1977). At lower elevations in the north, lodgepole pine (*Pinus contorta*), trembling aspen (*Populus tremuloides*) and balsam poplar (*Populus balsamifera*) are common, whereas at higher elevations lodgepole pine, white spruce (*Picea glauca*) and black spruce (*Picea mariana*) predominate. Farther south, Engelmann spruce (*Picea engelmannii*) and white spruce occur at higher elevations. The characteristic forest of the Interior Subalpine includes Engelmann spruce, white spruce, alpine fir (*Abies lasiocarpa*), and lodgepole pine. The southern Rocky Mountain Trench supports a montane forest including ponderosa pine (*Pinus ponderosa*) and Douglas-fir (*Pseudotsuga menziesii*).

PREVIOUS WORK

Quaternary geologic investigations in British Columbia and the Rocky Mountains have been going on for over a century, and several individuals stand out as pioneers of Quaternary studies in the Rocky Mountain area. Only in the last few decades have detailed stratigraphic and sedimentologic studies become common practice. The following discussion reviews some of the activities and accomplishments of these early scientists up to 1950. Studies performed after this date are included in the detailed discussion of the three geographical regions. During the late 1800's many Quaternary related studies were ancillary to broader reconnaissance bedrock mapping and as such, much work appeared as either short comments or brief observations in the early journals and reports. Similarly, much of the work performed before 1950 concentrated on single themes, such as limits of glaciation.

THE PERIOD UP TO 1900

The most influential and productive scientist of this early era was George M. Dawson (1879, 1881a, 1888b), who contributed to much of the database on the Cordillera (Jackson and Clague, 1991). In his early work, Dawson (1878, 1891) believed that the inception of glacial ice began in the northwest corner of British Columbia as a result of moisture supply off the warm Japanese current, in conjunction with the prevailing westerlies. Furthermore, he believed that during the Pleistocene, a land depression in excess of 914 m, and up to a maximum of

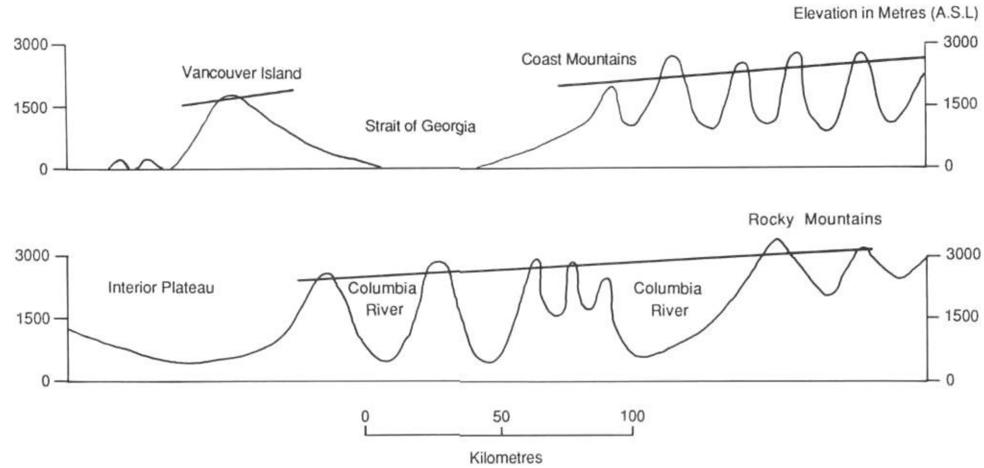

FIGURE 10. East-west cross-section through southern British Columbia illustrating upward rise in the equilibrium line from west to east modified after Østrem (1966).

Coupe d'est en ouest à travers le sud de la Colombie-Britannique illustrant le relèvement de la ligne d'équilibre de l'ouest vers l'est, modifiée à partir de Østrem (1966).

1606 m occurred in the province. This depression permitted the influx of 'prairie ocean water' up the Peace River valley, for instance, thereby both fueling and floating large isolated ice masses. Resultant 'boulder-clay' sediments were thought to represent debris from pan-provincial floating icebergs. Several years later, Dawson (1886) reported on his investigations of the southern Rocky Mountain area. His two major contributions included the observation of striae trending south and southeast in the Foothills southwest of Calgary, and his suggestion that the southern Rocky Mountain Trench was at one time filled with ice. Elaborating on some of his work a few years later, Dawson (1889) reported observing glacial striae at elevations up to 2195 m. This led him to conclude that Pleistocene ice may have been up to 1829 m thick in places, but generally 610-914 m thick west of the Rockies in the interior. Dawson (1888a) formerly proposed and named the existence of two major ice masses: Cordilleran and Laurentide. Seven years later T. C. Chamberlin (1895) formerly adopted the phrase Cordilleran Ice Sheet in a publication.

The end of this period is well marked with an attempt by Dawson (1890a) to correlate Cordilleran and Laurentide events in southwestern Alberta. Ongoing fieldwork during the preceding years had obviously prompted Dawson to modify some of his earlier models. Dawson reiterated his belief in a major northwestern ice centre for the Cordillera, specifically the northern Coast Mountains area; he also acknowledged the existence of local ice centres in the Rocky Mountains, which he suggested may have flowed off their eastern margin onto the Interior Plains. According to Dawson, eastward flowing ice originating in western British Columbia did not flow across the Rocky Mountains and onto the Plains. Dawson (1890b) continued to report on work in southeast B.C., assigning high altitude striae found at 2134 m east of the trench to his "great Cordilleran Glacier". Finally, Dawson's (1890a) major chronologic contribution was his belief in two Cordilleran glacial events; what he saw was an early extensive glaciation and a second minor glaciation. The two-glaciations theory was soon supported with evidence outside of the Rocky Mountains in the Atlin district of B.C. with the work of Gwillim (1902).

Other active individuals during this period included R. G. McConnell (1896), who provided several section descriptions of the Quaternary sediments along the Finlay River in the northern Rocky Mountain Trench during a bedrock mapping expedition. McConnell summarily concluded that the Pleistocene stratigraphic history of the area consisted of stratified sands and gravels overlain by "boulder-clay" which in turn was covered by additional stratified sands and gravels. Also at this time, but in the Bow Valley, McConnell noted that all drift west of Calgary was of a Rocky Mountain provenance and none was of an eastern origin. A joint effort launched by Dawson and McConnell in southwestern Alberta resulted in several significant findings. Laurentide erratics were observed at 1615 m west of the Porcupine Hills, at least three tills were noted farther south in the Oldman River area, and attempts were made to relate these western glacial events with T. C. Chamberlin's Kansan and Iowan intervals in eastern North America (Dawson, 1895; Dawson and McConnell, 1895).

THE PERIOD OF 1900-1925

A number of the early studies in this period occurred near the international border. For instance, Daly's (1912) classic study along the 49th parallel provided a lengthy discussion of the surficial deposits encountered. Although deposits relating to only one Cordilleran glaciation were observed, Daly did not discount the possibility of earlier events. Earlier work by Coleman (1910) on multiple till sections south-east of Banff National Park provided important information regarding both ice sheets. Coleman suggested that the two ice sheets overlapped in their respective areas of glaciation, but the events were asynchronous; that is, the Cordilleran glaciation preceded the Laurentide glaciation. On the east side of the central Rockies, Malloch (1910) recognized two tills, the earliest originating in the Rocky Mountains and the younger originating in the west. At the same time, south of the international border, Stewart (1913) discussed the effects of Cordilleran glaciation in northern Idaho.

Tyrrell (1919) in his discussion of glaciation south of Quesnel, disputed Dawson's earlier claims of thick and extensive glacial ice. Tyrrell proposed that thin local ice masses existed in the province, none of which reached a 1829 m thickness over valleys. Johnston (1926) supported Tyrrell by citing evidence for glacial ice limits at 1981 m in the Cariboo Mountains, 1676 m in the Dease Lake area, and 1372 m near Williams Lake. As the maximum glaciation had only attained an elevation of 1981 m, ice thickness over valleys would have been in the order of 914 m. Johnston accepted Dawson's hypothesis of two glaciations, but emphasized the existence of a long interglacial between the two glaciations. Finally, a major issue in Johnston's thesis centred on the character of the ice lying between the Cariboo and Cassiar districts. Johnston abandoned the term Cordilleran Glacier in favor of the "Cordilleran system of intermontane, piedmont and valley glaciers" for Pleistocene glacial ice in the province.

THE PERIOD OF 1925-1950

The beginning of this period drew criticism against the Cordilleran Ice Sheet concept by several active researchers who favored a less intense Cordilleran glaciation involving a complex system of coalescing valley and piedmont glaciers (Johnston, 1926; Leverett, 1929). Antevs (1929) provided very little information regarding the Cordilleran glacier complex in his global synthesis of Pleistocene glaciations. From the figure illustrated for North America, it appears that Antevs favored a full ice sheet cover of the Cordillera, as well as coalescence between the Rocky Mountain and Laurentide ice masses. This conflicted with earlier works, as well as subsequent study by Nichols (1931) in southwestern Alberta, in which he found evidence for two Cordilleran and two Laurentide glaciations, which overlapped in their geographic extent but did so during different time intervals. Johnston and Wickenden (1931) followed Antevs' earlier interpretation by suggesting that coalescence of the two ice masses occurred during the later stages of glaciation southwest of Calgary.

Kerr (1934) renewed the hypothesis of a Pleistocene ice centre in the northwest corner of the province. Prevailing westerlies coupled with the high humidity and precipitation in the area were recognized as creating ideal conditions for an ice centre. Additionally, Kerr (1934) created an hierarchical classification of glaciation types based on evidence in the Coast Mountains: 1) Alpine Glaciation; 2) Intense Alpine Glaciation; 3) Mountain Ice Sheet; and, 4) Continental Ice Sheet. He envisioned ice expanding from the ice centre in the northwest through the four types of glaciation. In the process, glacial ice apparently traveled southeast across the Stikine, Finlay and Parsnip rivers. In contrast to Johnston and Tyrrell, but in support of Dawson, Kerr suggested maximum ice heights in excess of 3048 m and an axial ice thickness of 1524 m in the Stikine valley. In the Omineca River valley, several examples of multiple till strata interbedded with sand and gravel were recognized by Kerr (1934), who was uncertain if the tills represented different advances or pulses of a single advance. In contrast, a year earlier, Johnston (1933) had proposed the maximum elevation of Cordilleran glaciation was 2438 m, that this ice did not cross the Rocky Mountains and that an ice-free zone may have existed along the eastern flanks of the mountains. According to Johnston, this ice-free zone may have provided an avenue for early human migrants to expand into the New World.

A few years later, Rice (1936) reported striae at 2355 m in the southern trench. More importantly, Rice argued for very little glacial erosion in the region given the absence of U-shaped and hanging valleys, and the presence of V-shaped valleys and thick deposits of preglacial sediments in the valley bottoms. Based on the abundance of ice contact deposits and kettle topography, Rice suggested deglaciation was essentially one of ice stagnation. For the Foothills area, Rutherford (1941) reviewed glacial evidence, and noted a decreasing trend in the elevations of Laurentide erratics from 1609 m near the international border to 914 m near Edson. He also recognized that Cambrian quartzite erratics overlying Laurentide drift near Waterton are from the Windermere district of British Columbia, and must therefore have been deposited by Cordilleran ice.

A new interpretation for ice accumulation centres was offered by Hedley and Holland (1941), who proposed the main Cordilleran ice centre lay in the Cassiar Mountains. The cyclical nature of the arguments continued later, with Armstrong and Tipper (1948), who believed the main ice centre in B.C. was in the Coast Mountains, but further suggested localized accumulation centres existed in the Cassiar, Cariboo, Selkirk and Rocky Mountains. Observations by these authors indicated maximum ice elevations of 1829 m in the Nechako Plain and less than 1524 m in the Omineca Mountains. Evidence for two Cordilleran advances was recognized in their study area, with the first advance considered the most erosive. The second advance apparently carried less sediment and simply reworked existing glacial sediments. The second advance, as interpreted by the authors, also had a dominant flow to the east, but did not cross the Rocky Mountains; the flow became obstructed by ice moving off the Rocky Mountains resulting in a subsequent diversion north down the Parsnip.

Two papers published in 1943 independently concluded that the extent of ice in the Cordillera was not as great as generally assumed by previous researchers. Flint (1943:327) stated that in the Cordillera, "glaciers expanded into piedmont glaciers that became generally coalescent throughout the broad belt between the Coast Ranges and the Rocky Mountains. It is doubtful whether this glacier complex was more than temporarily an ice sheet in the Greenland sense." Demorest (1943) went further, accepting a piedmont ice apron along the Pacific coast, but very little ice in the eastern Cordillera as a result of a self-imposed "snow shadow". At about the same time, a second review paper by Antevs (1945) questioned the applicability of Kerr's model outside of the southern Rocky Mountains and Coast Mountains. Instead, Antevs argued for a thick ice sheet cover over much of the province, a Rocky Mountain eastern slope origin for Keewatin ice, as well as an "ice-free lane" between the two major ice sheets along the southern Foothills region. Antev's acceptance of an ice-free corridor may have been influenced by Bretz's (1943) detailed study of Laurentide recessional moraines in Alberta which concluded the Laurentide moraines terminated far east of the Foothills in west-central Alberta.

From 1950 to the present, geologic contributions to Rocky Mountain research have increased dramatically. The temporal-historical divisions used in the preceding section are not adequate in the discussion of these modern research accomplishments. Geologic studies completed during the last four decades are therefore examined in detail in relation to three broad geographic zones for the Canadian Rocky Mountains.

NORTHERN ROCKY MOUNTAINS

Within the Canadian Rocky Mountains, the northern most region has received the least amount of Quaternary geologic field research. This results from poor access and difficult terrain. Nonetheless, a moderate amount of written attention has been directed toward this poorly understood region. Modern river sedimentologic data are available for the Beatton River and the Muskwa River (Hicken and Nanson, 1975; Nanson, 1977, 1980a, 1980b; Nanson and Hicken, 1983; Sherstone, 1983), but except for the ancestral Finlay River (Bobrowsky, 1989a), few sedimentologic data are available for Pleistocene deposits. Stratigraphic information is far more abundant, and apart from miscellaneous studies, the locations best studied include the Peace River district extending from the WAC Bennett Dam near Hudson Hope into northwestern Alberta, the area now covered by the Williston Lake reservoir, and the northern Rocky Mountain Trench along the Finlay River (Fig. 11). Quaternary tephras are unknown in this northern mountain region, and Holocene glacial activity and moraines

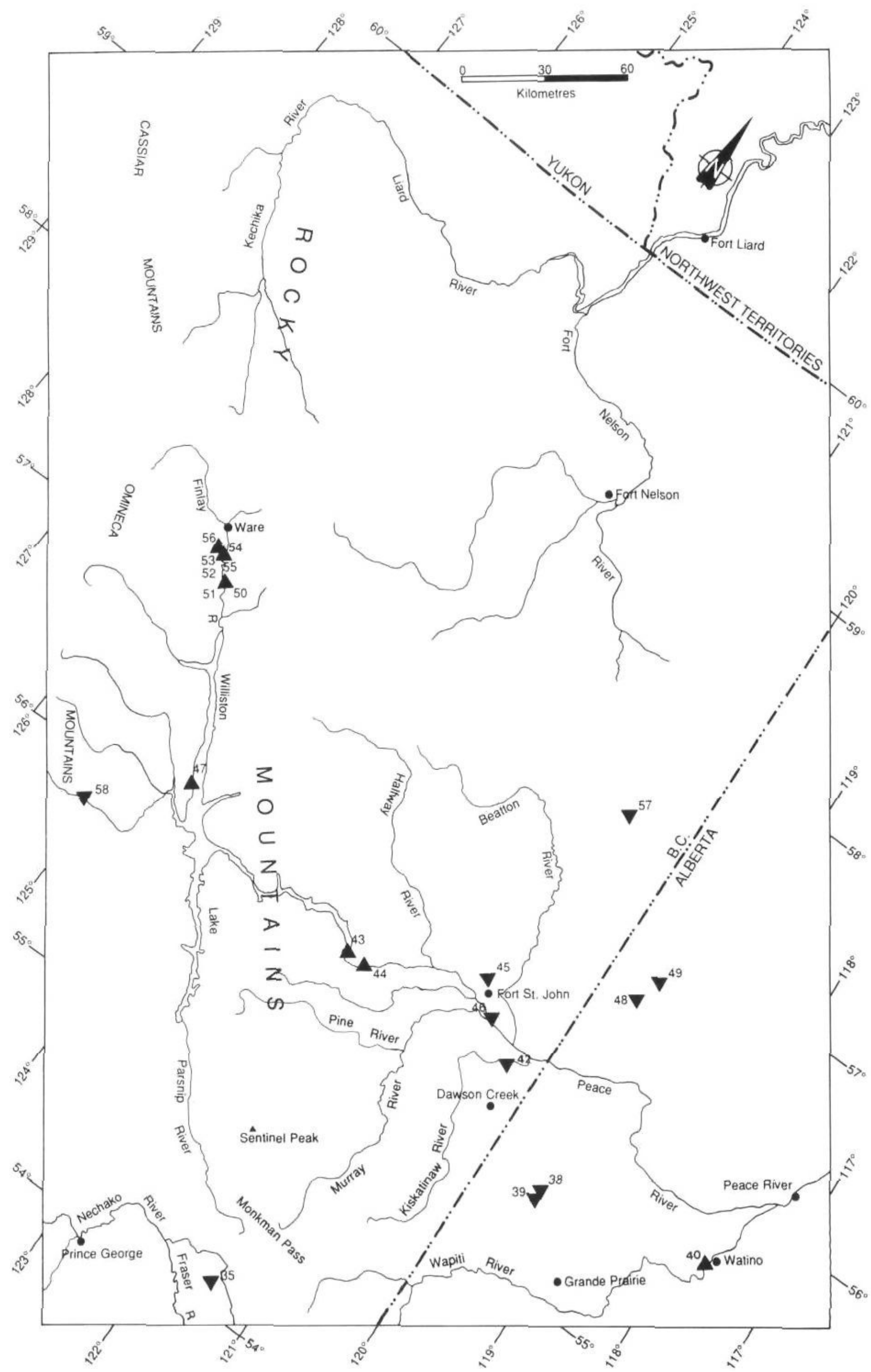

FIGURE 11. Location map of the northern Canadian Rocky Mountain region. Place names discussed in the text are illustrated, including key radiocarbon localities listed in Table I. Triangles pointing up are preglacial localities, whereas upside down triangles are postglacial localities.

Carte de localisation de la région du nord des Rocheuses. Noms de lieux et sites principaux de datation au radiocarbone (tabl. I). Les triangles pointés vers le haut identifient des sites préglaciaires, et ceux pointés vers le bas, les sites postglaciaires.

have yet to be studied at any level. Similarly, except for two isolated studies along the Peace River in B.C. and Alberta, Holocene soils have received little attention.

PEACE RIVER DISTRICT

The earliest substantive contribution to Quaternary geology in the Peace district is that of Mathews (1954), who proposed a twice-repeated package of sediments each beginning with nonglacial gravels and ending with Laurentide till in the Fort St. John area (Fig. 12). Finer sediments interbedded within these end-members were interpreted as proglacial lake deposits. The lower till was assumed to be Early Wisconsinan. At that time, Mathews believed that Rocky Mountain ice had advanced into a proglacial lake environment, to within 25 km west of Fort St. John, thus overriding Early Wisconsinan Laurentide deposits in the process. Exceptionally thick accumulations of unconsolidated sediment in the over-deepened modern and ancestral Peace valley could not be explained by simple stream incision and isostatic rebound. Mathews suggested that the valleys formed by channelized glacial erosion under ice tongues confined within mountain valleys. As the mountain ice entered the plains bordering the Rocky Mountains and Foothills, ice fanning lessened the entrenching capabilities of the ice mass.

Several years later, Mathews (1962) revised the maximum Rocky Mountain ice-front limit to within 15 km west of Fort St. John. The Portage Mountain moraine, located at the WAC Bennett Dam west of Hudson Hope, was interpreted to be a recessional moraine formed by Rocky Mountain ice during the Late Wisconsinan. Finally, Mathews also noted elevations of 838 m, 689 m and 625 m as the major strandlines of Glacial Lake Peace. In a further revision to the basic model, Mathews (1972) noted a single Late Wisconsinan till sheet for the area containing mixed eastern and western lithologies. Clast lithologies increased in abundance in the direction of the respective provenance within outcrops of this till sheet. This was taken as evidence of Rocky Mountain and Laurentide ice coalescence occurring during the Late Wisconsinan (Fig. 12). Continued field work by Mathews (1973) led him to report on the occurrence of a pre-Late Wisconsinan diamicton of Rocky Mountain provenance interbedded in proglacial lake sediments east of Attachie, and pre-Late Wisconsinan gravels of Laurentide provenance occurring west of Attachie (Fig. 12). Postglacial strandline elevations were also redefined at this time at 838 m, 808 m, 701 m and 655 m.

Mathews' (1978a, 1978b) final contribution to the area included the important recognition of three separate ice sources: Laurentide, Cordilleran and Montane. His latest stratigraphy for the area recognized two Laurentide glaciations, Early and Late Wisconsinan in age, as well as three Late Wisconsinan Rocky Mountain events including two of Cordilleran provenance and the final of local Montane origin (Fig. 12). Mathews (1978a) supported his interpretations with dates of 25,800±320 years BP (GSC-2859) at Portage Mtn. and 27,400±580 years BP (GSC-2034) at Taylor (*cf.* Table I). A detailed description of the retreat of the Laurentide Ice Sheet from northeastern B.C. by Mathews (1980) provided a chronologic outline of several phases of Glacial Lake Peace, from the Bessborough stage to the Keg River stage.

South of Dawson Creek, Rutter (1971b) and Reimchen and Rutter (1972) offered a different interpretation concerning the history of glacial events for northeastern B.C. (Fig. 13). The major conclusions of their study included the recognition of three Rocky Mountain and possibly two Laurentide glaciations affecting the region. Like Mathews, they suggested a zone of till containing mixed lithologies of both Rocky Mountain and Laurentide provenance was indicative of a 25 km zone of Pleistocene ice overlap. However, they also observed drumlins of Rocky Mountain origin truncating older Laurentide drumlins, thus "indicating that the maximum mountain ice advance postdates that of continental ice in at least this one area" (Reimchen and Rutter, 1972:92). Proglacial lake strandlines were observed at the following elevations: 838 m, 738 m, 722 m, 710 m, 689 m, 664 m and 655 m.

Recent fieldwork in the Peace River district during the summer of 1990 has resulted in the discovery of 56 bluff and cutbank sections suitable for detailed sedimentologic and strat-

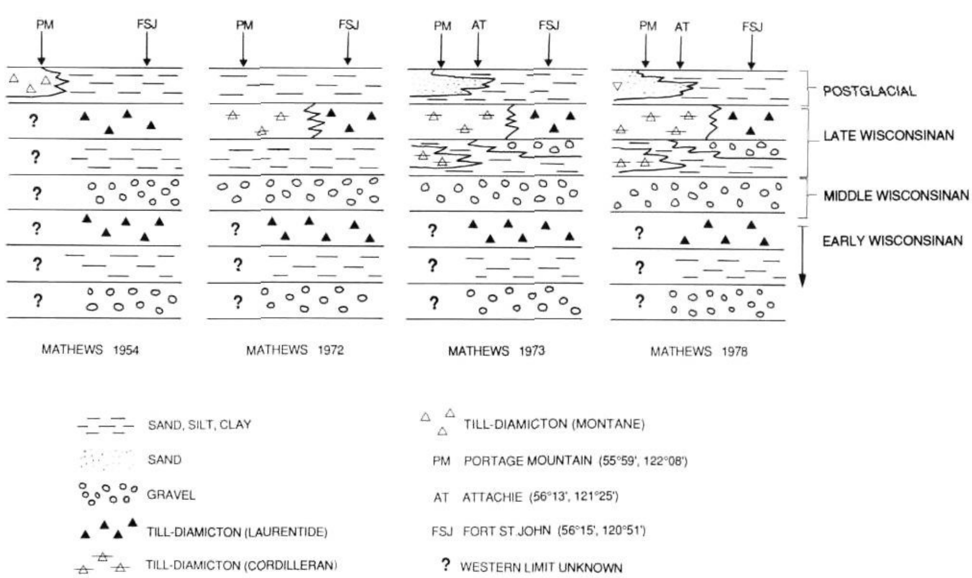

FIGURE 12. Composite stratigraphic columns interpreted from or modified after Mathews (1954, 1972, 1973, 1978) from the Peace River District, northeastern British Columbia. Legend applicable to remaining stratigraphic columns.

Colonnes stratigraphiques interprétées ou modifiées à partir de Mathews (1954, 1972, 1973, 1978) du district de Peace River au nord-est de la Colombie-Britannique. La légende s'applique à toutes les colonnes stratigraphiques qui suivent.

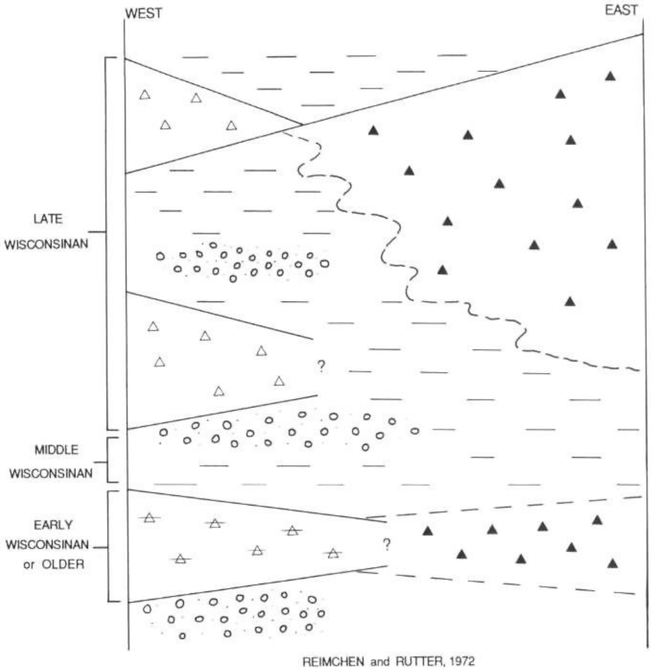

FIGURE 13. Composite stratigraphic history of the Dawson Creek area, modified after Reimchen and Rutter (1972).

Évolution stratigraphique de la région de Dawson Creek, modifiée à partir de Reimchen et Rutter (1972).

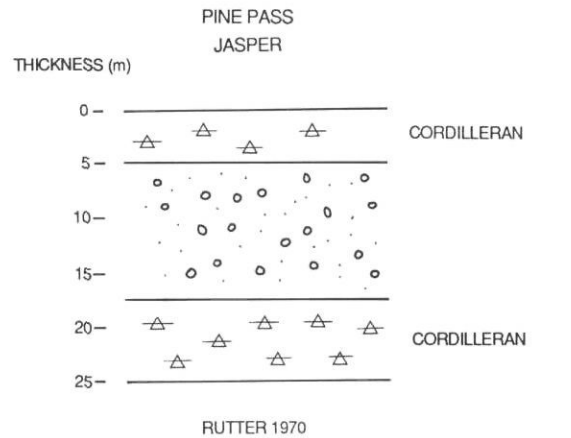

FIGURE 14. Simplified composite stratigraphic history of the Pine Pass (B.C.) — Jasper (Alta.) area as interpreted from Rutter (1970).

Stratigraphie simplifiée de la région de Pine Bass (C.-B.) — Jasper (Alb.) interprétée à partir de Rutter (1970).

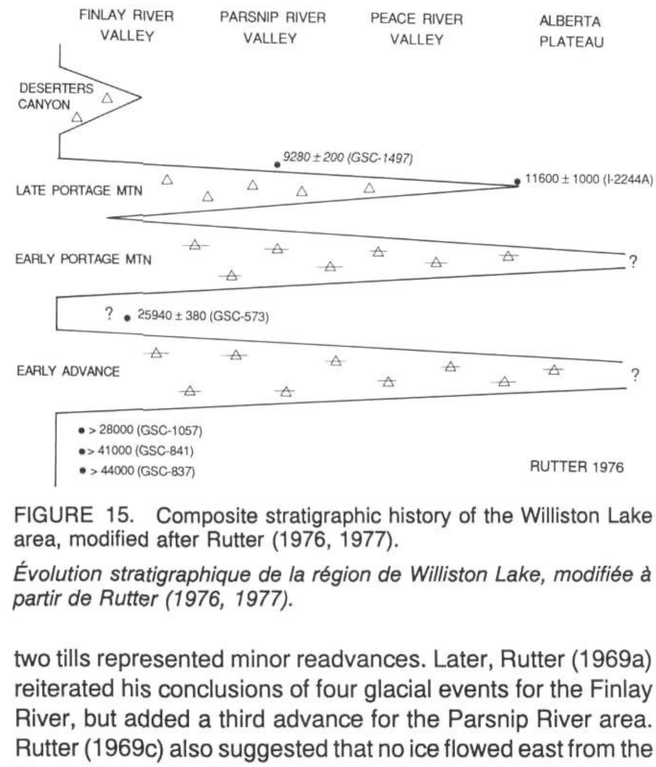

FIGURE 15. Composite stratigraphic history of the Williston Lake area, modified after Rutter (1976, 1977).

Évolution stratigraphique de la région de Williston Lake, modifiée à partir de Rutter (1976, 1977).

igraphic study (Bobrowsky *et al.*, 1991). Ongoing studies are planned, but results to date do not support previous suggestions of multiple Laurentide and Rocky Mountain glaciations, nor do they support the single till sheet-ice coalescence model.

The most southern investigation in this part of the Rocky Mountains consists of a reconnaissance study by Rutter (1970). Lacustrine sediments were observed at elevations between 1067 m and 1219 m. More importantly, good sections along the Murray River led Rutter to conclude that the area was glaciated twice by Cordilleran ice (Montane?) (Fig. 14). Oxidized sand and gravel interbedded between a thick lower till and a thin upper till was tentatively correlated by Rutter (1970) to similar and widely distributed sediments observed in the north in the Williston Lake basin. Neither the timing nor the extent of the two Rocky Mountain glacial events could be established and, moreover, evidence for Laurentide glaciation was not observed.

WILLISTON LAKE

The Williston Lake reservoir now covers significant lengths of the Peace, Parsnip and Finlay rivers. As a mitigative response to the loss of exposures of Quaternary sediments as a result of the construction of the WAC Bennett Dam at Portage Mountain near Hudson Hope, the Geological Survey of Canada undertook research in Quaternary geology for the proposed flood area. The earliest observations by Rutter (1967b, 1968a) led him to recognize deposits representing a minimum of four glacial advances occurring down the Finlay River (*cf.* Del Creek section), and two glaciations along the Parsnip. At the time, he proposed that the oldest and second youngest tills were deposited by widespread ice advances, whereas the remaining two tills represented minor readvances. Later, Rutter (1969a) reiterated his conclusions of four glacial events for the Finlay River, but added a third advance for the Parsnip River area. Rutter (1969c) also suggested that no ice flowed east from the Rocky Mountains across or into the Rocky Mountain Trench, and more importantly, he proposed that the ice that extensively crossed the Rocky Mountains from the west probably did so during an early glaciation (not Late Wisconsinan).

Rutter (1976, 1977) detailed his observations and modified early conclusions only slightly in his subsequent summaries for the area (Fig. 15). Of the four Cordilleran (and Montane?) glaciations, Early Advance, Early Portage Mountain, Late Portage Mountain and Deserter's Canyon Advance, the first and second glaciations were now interpreted as extensive events. Striae oriented to the northeast, at elevations of about 1981 m observed in the mountains directly east of the trench and in the Rocky Mountains were attributed to the early extensive glaciations. Additional support for an extensive early

TABLE I

Pleistocene radiocarbon dates for the Canadian Rocky Mountains and surrounding a d (site sumbers correspond to locations on Figs. 11,21 and 32)

Site	Laboratory Dating No.	Date (yr B P)	Locality	Location lat.	long.	Material	Reference
35	GSC-2964	10000±90	Summit Creek	54°08'	121°31'	wood	Lowdon and Blake 1980
2	GSC-220	10000±130	Blood Indian Res.	49°18'	113°34'	humus	Dyck et al.1965
58	GSC-2036-2	10000±140	Omineca	55°47'	125°05'	marl	Blake 1986
23	GSC-1457	10000±140	Oldman River	51°29'	117°13'	peat	Lowdon and Blake 1976
49	GSC-3544	10000±150	Yesterday Lake	56°46'	119°29'	organics	MacDonald 1987b
26	GSC-1753	10000±160	La Forme Creek	51°14'	118°13'	wood	Lowdon and Blake 1979
22	RIDDL-511	10060±160	Lake O'Hara	51°21'	116°20'	needles	Reasoner and Rutter 1988
59	AECV-124C	10090±130	Vermilion Lakes	51°10'	155°39'	bone	Arnold unpublished
45	RIDDL-392	10100±210	Charlie Lake	56°17'	120°56'	bone	Driver 1988b
22	RIDDL-433	10100±200	Lake O'Hara	51°21'	116°20'	needles	Reasoner and Rutter 1988
58	GSC-2036	10100±90	Omineca	55°47'	125°05'	marl	Alley and Young 1978
13	GX-5998	10125±285	Upper Elk Valley	50°23'	114°56'	wood	Ferguson and Osborn 1981
46	AECV-1206C	10240±160	Taylor	56°09'	120°42'	bone	Bobrowsky et al. 1991
27	I-5675	10250±165	Rocky Mtn House	52°28'	114°32'	shell	Harris and Boydell 1972
34	GSC-2935	10300±220	Mary Gregg Lake	53°07'	117°28'	organics	Blake 1983
45	SFU-378	10380±160	Charlie Lake	56°17'	120°56'	bone	Driver 1988b
17	TO-149	10400±70	Toboggan Lake	50°46'	114°36'	wood	MacDonald 1989
18	GSC-2965	10400±110	Kananaskis	50°52'	115°10'	wood***	Lowdon and Blake 1980
57	GSC-3704	10400±140	Snowshoe Lake	57°27'	120°40'	organics	MacDonald 1987b
42	GSC-1654	10400±170	Dawson Creek	55°59'	120°16'	shell	Rutter 1977
10	GSC-211	10400±200	Cowley	49°40'	113°59'	shell	Trautman and Walton 1962
45	SFU-300	10450±150	Charlie Lake	56°17'	120°56'	bone	Driver 1988b
16	GSC-2162	10600±100	Longview	50°32'	114°27'	shell	Lowdon et al. 1977
7	GSC-161	10620±250	Blood Indian Res	49°32'	112°56'	organics	Dyck and Fyles 1964
48	GSC-3520	10700±140	Lone Fox Lake	56°43'	119°43'	organics	MacDonald 1987b
38	WAT-362	10740±395	Boone Lake	55°35'	119°26'	organics***	White et al. 1979
19	GSC-612	10760±160	Cochrane	51°11'	114°27'	bone	Lowdon et al. 1967
45	SFU-454	10770±120	Charlie Lake	56°17'	120°56'	bone	Driver 1988b
39	SFU-210	10800±180	Spring Lake	55°31'	119°35'	organics***	White and Mathewes 1986
28	BGS-627	10850±300	Maligne Lake	52°44'	117°37'	wood	Kearney 1981
59	SFU-314	10900±270	Vermilion Lakes	51°10'	115°39'	charcoal	Hobson and Nelson 1984
59	SFU-348	11000±480	Vermilion Lakes	51°10'	115°39'	charcoal	Fedje 1985
34	GSC-2997	11000±120	Mary Gregg Lake	53°07'	117°28'	organics	Blake 1983
61	GSC-4284	11000±120	Copper Lake	51°16'	115°55'	organics	McNeely and McCuaig 1991
19	GSC-989	11100±160	Cochrane	51°11'	114°27'	bone	Lowdon et al. 1967
25	TO-572	11110±110	Mitchell Lake	52°13'	115°30'	gyttja	Mandryk 1990
39	WSU-2557	11200±400	Spring Lake	55°31'	119°35'	organics***	White and Mathewes 1986
21	WSU-881	11220±680	Banff	51°42'	115°39'	shell	Harris and Boydell 1972
19	GSC-613	11370±170	Cochrane	51°11'	114°27'	bone	Lowdon et al. 1967
29	GSC-3543	11400±170	Goldeye Lake	52°27'	116°12'	charcoal	McNeely 1989
59	SFU-316	11500±300	Vermilion Lakes	51°10'	115°39'	charcoal	Hobson and Nelson 1984
59	SFU-346	11700±290	Vermilion Lakes	51°10'	115°39'	charcoal	Hobson and Nelson 1984
38	SFU-223	11700±260	Boone Lake	55°35'	119°26'	wood	White et al. 1985
12	GSC-2142	11900±100	Upper Elk valley	50°09'	114°57'	organic detritus	Lowdon and Blake 1976
33	GSC-3885	11900±120	Jasper	53°13'	117°55'	shell	Blake 1986
12	GSC-2275	12200±160	Upper Elk valley	50°09'	114°57'	organic detritus	Lowdon and Blake 1976
62	AECV-430C	12350±440	Lorraine Lake	52°45'	117°40'	organics	Arnold unpublished
38	WAT-408	12650±320	Boone Lake	55°35'	119°26'	organics***	White et al. 1979
13	GX-5599	13430±450	Upper Elk valley	50°23'	114°56'	shell***	Ferguson and Osborn 1981
28	BGS-629	13500±400	Maligne Lake	52°44'	117°37'	wood	Kearney 1981
36	GSC-694	13510±230	Little Smoky River	54°21'	117°01'	shell	Lowdon and Blake 1968
36	GSC-698	13580±260	Little Smoky River	54°21'	117°01'	shell	Lowdon and Blake 1968
4	GX-2034	14000±750	Bull River	49°28'	115°28'	peat ***	Clague 1973
29	GSC-3528	14500±180	Goldeye Lake	52°27'	116°12'	charcoal	McNeely 1989
9	RL-362	14470±610	Crowsnest Pass	49°40'	114°35'	charcoal	Driver 1978
25	TO-573	14740±130	Mitchell Lake	52°13'	115°30'	shell	Mandryk 1990
54	TO-708	15180±100	Finlay	57°17'	125°28'	wood	Bobrowsky 1989a
17	TO-150	16130±80	Toboggan Lake	50°46'	114°36'	aquatic moss***	MacDonald et al. 1987
38	WAT-406	17570±650	Boone Lake	55°35'	119°26'	organics***	White et al. 1979
25	TO-574	17960±160	Mitchell Lake	52°13'	115°30'	shell	Mandryk 1990
14	GSC-2668	18300±380	Chalmer's bog	50°39'	114°33'	aquatic moss***	Lowdon and Blake 1979
14	GSC-2670	18400±1090	Chalmer's bog	50°39'	114°33'	aquatic moss***	Lowdon and Blake 1979
56	TO-709	18750±120	Finlay	57°22'	125°34'	wood	Bobrowsky 1989a
5	GX-2033	19100±850	Jaffray	49°23'	115°18'	peat	Clague 1973
24	GSC-173	21500±300	Boat Encampment	52°06'	118°23'	wood	Dyck et al. 1965
30	GSC-1258	21700±240	Canoe Valley	52°12'	118°27'	wood	Lowdon et al. 1971
60	GSC-4220	21800±570	Strubl Lake	52°12'	115°00'	organics***	McNeely and McCuaig 1991
8	GAK-2336	22700±1000	Eagle Cave	49°37'	114°38'	bone	Kigoshi et al. 1973
24	I-773	22900±1500	Wood River	52°07'	118°24'	wood	Dyck et al. 1966

Site	Laboratory Dating No.	Date (yr B P)	Locality	Location lat.	long.	Material	Reference
15	GAK-5438	23100±860	January Cave	50°11'	114°31'	bone	Burns 1980
53	AECV-351C	23280±750	Finlay	57°16'	125°28'	wood	Bobrowsky 1989a
29	GSC-3662	*23600±260*	*Goldeye Lake*	*52°27'*	*116°12'*	*charcoal****	*McNeely 1989*
24	GSC-1802-3	24800±280	Boat Encampment	52°07'	118°24'	wood	Lowdon and Blake 1979
24	GSC-1802-5	24900±350	Boat Encampment	52°07'	118°24'	wood	Lowdon and Blake 1979
24	QU-153	24980±950	Boat Encampment	52°07'	118°24'	wood	Lowdon and Blake 1979
24	GSC-1802-4	25000±270	Boat Encampment	52°07'	118°24'	wood	Lowdon and Blake 1979
24	GSC-1802-2	25200±260	Boat Encampment	52°07'	118°24'	wood	Lowdon and Blake 1979
24	WAT-199	25320±400	Boat Encampment	52°07'	118°24'	wood	Lowdon and Blake 1979
24	BGS-303	25620±300	Boat Encampment	52°07'	118°24'	wood	Lowdon and Blake 1979
24	GSC-1802	25800±310	Columbia River	52°07'	118°24'	wood	Fulton and Smith 1978
43	GSC-2859	25800±320	Portage Mtn	56°01'	122°07'	tusk collagen	Mathews 1978a
24	DAL-254	25800±1070	Boat Encampment	52°07'	118°24'	wood	Lowdon and Blake 1979
47	GSC-573	25940±380	Finlay	56°18'	124°21'	plants	Rutter 1977
3	GX-2032	26800+1200 -1000	Sand Creek	49°21'	115°17'	wood	Clague 1973
55	AECV-379C	26800±1450	Finlay	57°18'	125°27'	wood	Bobrowsky 1989a
46	GSC-2034	27400±580	Taylor	56°09'	120°42'	mammoth tooth***	Mathews 1978a
40	I-4878	27400±850	Watino	55°43'	117°38'	wood	Clague 1981
31	GSC-3792	29100±560	Jasper	52°53'	118°06'	wood	Levson and Rutter 1987
52	AECV-352C	29280±1230	Finlay	57°11'	125°17'	wood	Bobrowsky 1989a
50	AECV-349C	29880±1680	Finlay	57°09'	125°15'	peat	Bobrowsky 1989a
29	GSC-3517	31300±1100	Goldeye Lake	52°27'	116°12'	charcoal***	McNeely 1989
40	AECV-416C	31530±1440	Watino	55°43'	117°38'	wood	Liverman et al. 1989
15	QL-1738	31900±1400	January Cave	50°11'	114°31'	bone	Burns 1991
29	GSC-3654	32100±820	Goldeye Lake	52°27'	116°12'	charcoal***	McNeely 1989
51	AECV-382C	32750±3180	Finlay	57°10'	125°20'	wood	Bobrowsky 1989a
50	AECV-380C	33490±1780	Finlay	57°09'	125°15'	peat***	Bobrowsky 1989a
15	QL-1737	33500±1100	January Cave	50°11'	114°31'	bone	Burns 1991
40	I-2626	34900+3000 -2000	Watino	55°43'	117°38'	wood	Lowdon and Blake 1970
40	I-2516	35500+2300 -1800	Watino	55°43'	117°38'	wood	Lowdon and Blake 1970
40	I-2615	35500+3300 -2300	Watino	55°43'	117°38'	wood	Lowdon and Blake 1970
40	AECV-415C	36220±2520	Watino	55°43'	117°38'	wood	Liverman et al. 1989
51	AECV-350C	36510±2570	Finlay	57°10'	125°20'	wood	Bobrowsky 1989a
41	AECV-428C	37010±2690	Simonette	55°08'	118°12'	wood	Liverman 1990
53	AECV-353C	37190±2870	Finlay	57°16'	125°28'	wood	Bobrowsky 1989a
40	GSC-1020	43500±620	Watino	55°43'	117°38'	wood	Lowdon and Blake 1970
37	GSC-1687	43800±1830	Babine Lake	55°00'	126°14'	wood	Harington et al. 1974
43	I-2244A	>11600	Portage Mtn	56°01'	122°07'	tusk collagen	Rutter 1977
55	GSC-1057	>28000	Finlay	57°18'	125°27'	wood	Rutter 1977
38	WAT-361	>30000	Boone Lake	55°35'	119°26'	organics***	White et al. 1979
20	S-214	>33000	Red Deer River	51°38'	115°20'	charcoal	McCallum and Wintemberg 1968
8	S-1963	>33000	Eagle Cave	49°37'	114°38'	bone	Burns 1991
1	GX-2031	>36000	Elk River	49°10'	115°13'	wood	Clague 1973
40	GX-1207	>38000	Watino	55°43'	117°38'	wood	Lowdon and Blake 1970
32	AECV-450C	>39750	Jasper	52°47'	117°54'	wood	Levson unpublished
55	AECV-348C	>40000	Finlay	57°18'	125°27'	wood	Bobrowsky 1989a
44	I-2259	>40000	Peace	56°	122°	charcoal	Buckley et al. 1968
55	AECV-386C	>40130	Finlay	57°18'	125°27'	wood	Bobrowsky 1989a
40	AECV-414C	>40170	Watino	55°43'	117°38'	wood	Liverman et al. 1989
51	AECV-385C	>40180	Finlay	57°10'	125°20'	wood	Bobrowsky 1989a
51	AECV-381C	>40330	Finlay	57°10'	125°20'	wood	Bobrowsky 1989a
51	AECV-383C	>40400	Finlay	57°10'	125°20'	wood	Bobrowsky 1989a
63	AECV-434C	>40620	Nordegg Bridge	52°24'	116°05'	charcoal	Arnold unpublished
56	GSC-841	>41000	Finlay	57°22'	125°31'	peat	Rutter 1977
52	GSC-837	>44000	Finlay	57°11'	125°20'	wood	Rutter 1977
32	GSC-4646	>48000	Jasper	52°47'	117°54'	wood	Levson unpublished
41	GSC-4263	>51000	Simonette	55°08'	118°12'	wood	McNeely and McCuaig 1991
11	GSC-237	>54500	Oldman River	49°46'	113°01'	wood	Dyck et al. 1965

Laboratories: GSC-Geological Survey of Canada; S-University of Saskatchewan; I-Teledyne Isotopes; WSU-Washington State University; BGS-Brock University; GX-Geochron Laboratories; WAT-University of Waterloo; AECV-Alberta Environmental Centre, Isotope Laboratory; RL-Radiocarbon Ltd.; RIDDL-RIDDL Laboratory; DAL-Dalhousie University; QU-Ministère des richesses naturelles Québec; GAK-Gakushuin University; TO-Isotrace Laboratory; SFU-Simon Fraser University.

*****Samples probably contaminated.**

glaciation included erratics of western provenance (*e.g.*, pegmatites) in the Rocky Mountains northeast of Williston Lake at elevations near 1829 m. Ice from the Late Portage Mountain advance apparently did not exceed an elevation of about 1067 m along both the Finlay and Parsnip rivers. This latter limit of glaciation is in agreement with that proposed by Tipper (1971a, 1971b) and Armstrong and Tipper (1948) to the southwest near Prince George. Furthermore, the eastern limit of this advance is assumed to be marked by deltaic and ice contact deposits of the Portage Mountain moraine (855 m) which Mathews (1978a, 1980) interpreted as a recessional feature. Finally, Rutter (1976) suggested a short-lived glacial event of limited extent occurred along the Finlay River after 9280±200 years BP (GSC-1497). Rutter (1976) based his stratigraphy on the presence of one sub-till date of 25940±380 years BP (GSC-573) and a few infinite dates (*cf.* Table I).

FINLAY RIVER

Directly north of Rutter's study area, surficial mapping (Leslie, 1988) and sedimentologic/stratigraphic (Bobrowsky, 1984, 1989a) studies were undertaken along the Finlay River, in the area from the community of Ware south to the head of Williston Lake in the Rocky Mountain Trench (Fig. 16). Following preliminary fieldwork in 1984, evidence for three Cordilleran glacial advances was described (Fig. 17). The terms adopted for the glaciations (Early Advance Till, Early Portage Mountain and Late Portage Mountain) corresponded to the earlier terms provided by Rutter (1977). Stages assigned to the events included pre-Sangamonian, Early Wisconsinan and Late Wisconsinan (Bobrowsky *et al.*, 1987).

FIGURE 16. Glaciodeltaic sediments over till and outwash on the Finlay River, British Columbia.

Sédiments glaciodeltaïques sus-jacents à un till et à un épandage fluvio-glaciaire (Finley River, Colombie-Britannique).

Continued fieldwork and improved chronologic resolution from several sub-till radiocarbon dates necessitated a redefinition of the Quaternary stratigraphy history of the northern Rocky Mountain Trench (Fig. 18) (Bobrowsky, 1987, 1988; Bobrowsky and Rutter, 1989). The final stratigraphic interpretation proposed for the area indicates only two Rocky Mountain glaciations affected the region (termed Early Portage Mountain and Late Portage Mountain) (Bobrowsky, 1989a). Facies analysis of the diamictons provided a means of distinguishing sediment gravity flow deposits from till (Bobrowsky, 1989b), and thus permitted the elimination of 'debris flow' sediments from earlier proposed models with three to four tills. More importantly, the suggested Quaternary history recognized that the earliest advance (pre-Middle Wisconsinan but not necessarily Early Wisconsinan) was extensive, and consisted of far-western derived ice crossing the Rocky Mountain Trench in an eastward direction. This interpretation helps explain the presence of unique erratic lithologies at high elevations in the Rocky Mountains. The second and final glaciation was a valley-controlled, short-lived (~5 ka) Late Wisconsinan event, which most likely terminated near Portage Mountain moraine and did not coalesce with Laurentide ice to the east (Bobrowsky, 1989a). This Late Wisconsinan, Montane glaciation was probably restricted to the Peace River valley, since there is no evidence of such an event farther north along the Foothills (*cf.* Denny, 1952).

The above stratigraphic history is well supported with a series of finite radiocarbon dates obtained on wood in sub-till positions in the trench. Ages range from 37,190±2870 years BP (AECV-353C) and 36,510±2570 years BP (AECV-350C) to 15,280±100 years BP (TO-708) and 18,750±120 years BP (TO-709) (*cf.* Table I). Postglacial dates of 10,100±90 years BP (GSC-2036) and 10,000±140 years BP (GSC-2036-2) in this area, further support the contention for a short-lived Late Wisconsinan glaciation (*cf.* Table I).

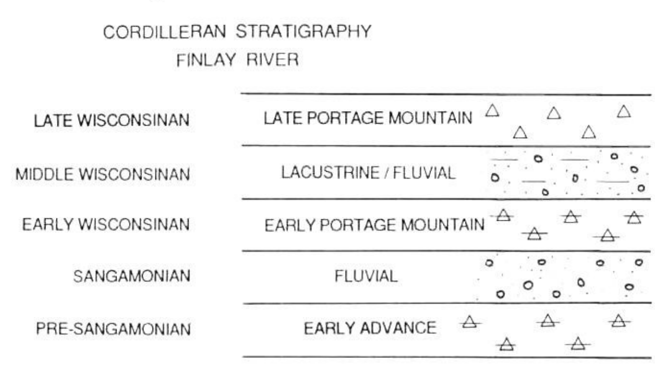

FIGURE 17. Simplified composite stratigraphic history of the northern Rocky Mountain Trench area as interpreted from Bobrowsky *et al.* (1987).

Stratigraphie simplifiée de la région du nord du sillon des Rocheuses interprétée à partir de Bobrowsky et al. *(1987).*

In northwestern Alberta, stratigraphic evidence for a single Laurentide glaciation is now available (Liverman, 1990; Liverman *et al.*, 1988, 1989) adding support to the model (Fig. 19). Chronologic control at Watino and Simonette in Alberta suggests a pre-glacial period starting as early as 43,500±620 years BP (GSC-1020) and ending sometime after 31,530±1440 year BP (AECV-416C) thus indicating the Laurentide glaciation was clearly Late Wisconsinan (*cf.* Table I). North of Watino, near High Level, a mammoth tusk dated at 22,020±450 years BP (AECV-719C) technically extends the Middle Wisconsinan by an additional ten thousand years. Directly south of Watino, radiocarbon dates of 13,580±260 years BP (GSC-698) and 13,510±230 (GSC-694) have been obtained from shells in silts overlying Late Wisconsinan deposits (St-Onge, 1972). Collectively, this indicates that Late Wisconsinan Laurentide ice traveled through northwestern Alberta sometime after about 22 ka and into the Foothills of northeastern B.C., and then retreated back into Alberta before about 13.5 ka, thereby reducing the period of the Laurentide Late Wisconsinan in this region to at least 8.5 ka. These chronologic data support the proposed model for asynchronous glaciation (Fig. 18).

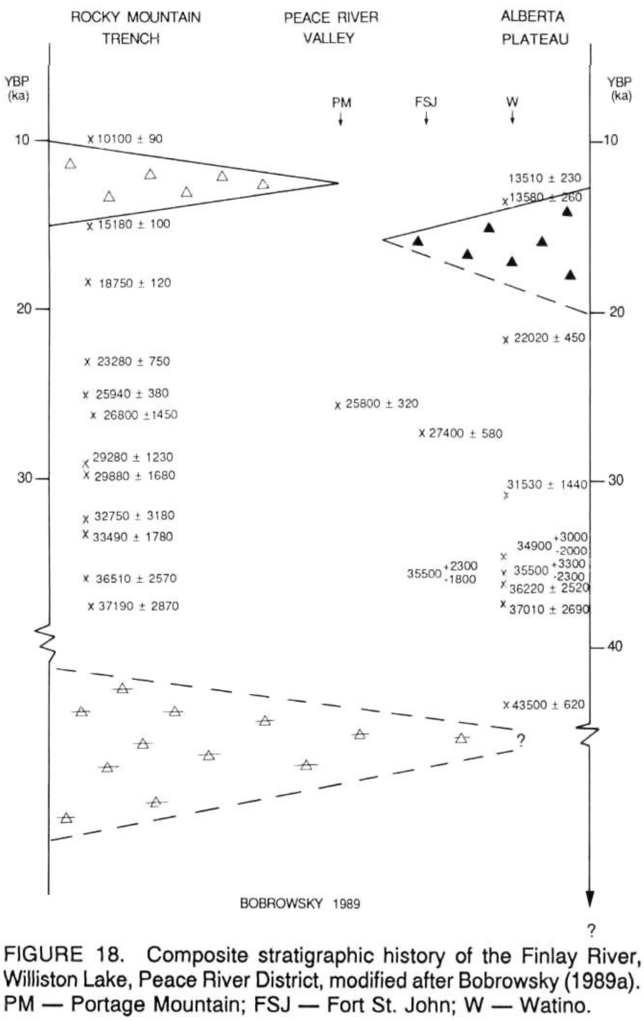

FIGURE 18. Composite stratigraphic history of the Finlay River, Williston Lake, Peace River District, modified after Bobrowsky (1989a). PM — Portage Mountain; FSJ — Fort St. John; W — Watino.

Évolution stratigraphique de la région de Finlay River, Williston Lake, district de Peace River, modifiée à partir de Bobrowsky (1989a). PM — Portage Mountain; FSJ — Fort St. John; W — Watino.

SURROUNDING AREAS

West of the Rocky Mountains, work in the area of Prince George confirmed that Late Wisconsinan ice flow was to the northeast across the McGregor Plateau and down the Parsnip, as well as southeast up the Fraser River. This work, however, also complicated issues by raising the number of Cordilleran glacial advances to three or four (Armstrong and Leaming 1968; Tipper 1971a, 1971b). Ice of the last glaciation apparently thinned from maximum limits of 1371 m near Prince George to 1066 m on the Parsnip River (Tipper, 1971b), data which are in agreement with that presented by Rutter (1976) to the north. Tipper (1971b), therefore concluded glacial ice limits of 1676 m in the Rocky Mountains near Peace River must be related to an earlier glaciation. Recent work at Mt. Milligan, 80 km west of the Parsnip River and 160 km northwest of Prince George, indicates a minimum of two glaciations (*ad modum* Armstrong and Tipper, 1948) affected the region (Kerr and Bobrowsky, 1991). Basalt overlying till of the older glaciation has yet to be dated using K/Ar dating. Based on the 34-43.8 ka age of nonglacial deposits at Babine Lake 250 km west of Prince George (Harington *et al.*, 1974), the last glaciation directly west of the Parsnip is probably also Late Wisconsinan.

A few studies in the Peace country of northwestern Alberta have figured prominently in the study of Quaternary geologic history of northeastern British Columbia. Hastily published radiocarbon dates (*cf.* Table I) from Boone Lake (White *et al.* 1979) were subsequently often cited as good evidence of a long history of ice free conditions in the area and used as firm evidence for an extended ice-free corridor. Re-evaluation of the dated material and a realization by the authors that the materials dated were likely contaminated with dead carbon now restricts the utility of the data (White *et al.*, 1985). To the east, at Watino, reference has already been made to the significant findings of Liverman (1987, 1989, 1990) and Liverman *et al.* (1988, 1989). Earlier work at Watino by Westgate *et al.* (1971, 1972) contributed to both the chronologic resolution and paleoecologic understanding of the Middle Wisconsinan.

Directly north of the Rocky Mountains in the Liard Plain, R. W. Klassen reported on four spectacular Quaternary

FIGURE 19. Watino section on the Smoky River, Alberta.

La coupe de Watino sur la Smoky River, en Alberta.

sections. Originally, up to five tills were recognized and proposed in a composite stratigraphic history of the region (Klassen, 1978), but the number was subsequently modified to only four tills in a later summary (Klassen, 1987). Although dated basalts were not found overlying any of the tills, correlations by Klassen suggest one till to be older than ~545 ka and another till to be older than ~232 ka. Pollen was retrieved from Middle Wisconsinan silts. An early study along the Alaska highway of northeastern B.C. by Denny (1952) provides several key observations and conclusions. From Beatton River to Summit Lake (west of Fort Nelson), Denny (1952) and others observed a lower till of Rocky Mountain provenance covered by lake sediments which in turn are covered by till of Laurentide provenance. The western limit of the latter advance is recognized as occurring within 5 km of the mountain front. Since the Laurentide advance had to be Late Wisconsinan (see earlier comments), this suggests that the northern Foothills were not glaciated with local Rocky Mountain ice during the Late Wisconsinan (Fig. 20).

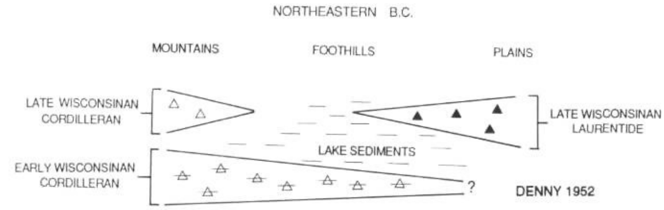

FIGURE 20. Composite stratigraphic history of northeastern British Columbia between Fort St. John and Fort Nelson, adapted from Denny (1952).

Évolution stratigraphique du nord-est de la Colombie-Britannique, entre Fort St. John et Fort Nelson, adaptée de Denny (1952).

CENTRAL ROCKY MOUNTAINS

Without question, much of the Quaternary work in the Rocky Mountains has been generally directed to the eastern side. This is well illustrated in the central Rocky Mountains where all the work known has been concentrated along the major river valleys along the eastern slope or near the divide and virtually none has been attempted along the western margin. The Quaternary geology of the central Rockies is discussed relative to three major river basins: Athabasca, North Saskatchewan and Bow river valleys, although adjacent valley studies are included in these headings (*e.g.*, Brazeau River under the North Saskatchewan River Valley) (Fig. 21). In contrast to the northern mountain area, sedimentologic research on modern environments has been ongoing for several years. The Kicking Horse River, for instance, has been examined in terms of modern bar evolution (Hein, 1974; Hein and Walker, 1977; Smith, 1974) and recent catastrophic flooding (Jackson, 1979a; Jackson *et al.*, 1990). Additionally, data on the sedimentology of outwash sediments from both the Kicking Horse valley (Bement, 1972) and Peyto glacier (McDonald and Banerjee, 1970) are available. Quaternary sedimentology includes work on alluvial fan and debris flow deposits (Eyles *et al.*, 1988; Levson and Rutter, 1988a, 1988b; Osborn and Luckman, 1981), deltaic sediments (Kostaschuk and Smith, 1983; Smith, 1975), as well as lake environments (Leonard, 1980, 1982a, 1982b, 1982c, 1984, 1985, 1986a, 1986b, 1987; Levson and Rutter, 1989a; Reasoner and Rutter, 1988).

ATHABASCA VALLEY REGION

From about Dawson Creek south to the north end of Jasper National Park, very little detailed work is known except for Rutter's (1970) brief reconnaissance study of the region (see above). Airphoto interpretation of part of this area indicates that the low elevation area of McGregor Plateau was breached at least once by eastward flowing ice from the Cordillera, probably during the Late Wisconsinan (Tipper, 1971a, 1971b), ice which may or may not have coalesced with Late Wisconsinan Laurentide ice (Fig. 9).

Two early investigations in different parts of the Athabasca valley provide discrepant results on the number of Quaternary glaciations in this area. An early geomorphic study in the Sunwapta Pass area by Jennings (1951) concluded a single Pleistocene glaciation affected the area, whereas farther northeast in the Foothills area of the Athabasca valley, Stene (1966) provided evidence (two tills) that the region was glaciated twice by Rocky Mountain ice. Research since that time has resulted in conclusions which differ from both early interpretations.

A landmark contribution to Quaternary geology in this area were the definitive results of Mountjoy (1958) on the Foothills Erratics Train. Mountjoy proposed the source of erratics to be the Lower Cambrian Cavell formation (equivalent to the Lower Cambrian Gog near Lake Louise) in the Central Ranges. Grey to pink quartzite erratics comprising the train are known to be distributed from just east of Jasper at 2438 m, then south along the Foothills to the international border (Fig. 22). According to Mountjoy (1958), Rocky Mountain ice, possibly of Late Wisconsinan age probably transported the quartzite erratics eastward down the Athabasca valley and was then deflected southeast in the vicinity of Hinton and Edson by the Laurentide Ice Sheet. Later, Roed *et al.* (1967) argued that the metamorphic erratics of the Athabasca Valley Erratics Train near Hinton were also transported on the ice mass which transported the Gog quartzites. The most probable source of the metamorphic rocks occurs west of the Rocky Mountain Trench, thus indicating that Cordilleran ice must have crossed the Continental Divide at the time of transport. Shortly thereafter, Tharin (1969) refined the actual distribution of erratics along the Foothills noting elevations of 1981 m west of Hinton and 1074 m near the international border, a total length of approximately 600 km and an average width of about 30 km.

In a surficial and stratigraphic investigation from the Jasper National Park boundary to about 20 km east of Edson, Roed (1968, 1975) proposed that evidence existed for four to five glacial advances which are represented by seven tills (Fig. 23). Roed also recognized three preglacial (Tertiary-Quaternary) gravel deposits: Tableland, Lowland, and Buried Valley. Inferential evidence for an 'Early' Cordilleran (?) advance was interpreted by Roed as indicating that this event preceded the most extensive Laurentide glaciation (Marsh Creek) in the region. Both events were assumed to be Early Wisconsinan in age (no absolute dating control). The Late Wisconsinan is first marked by a coalescence of Cordilleran (Marlboro and Raven Creek) and Laurentide (Edson and Mayberne) ice directly west of Edson, and later marked by an additional two Montane (Obed and Drystone Creek) events (Roed, 1975). West of the Rocky Mountain Trench, in the Premier Range, evidence of Pleistocene glaciation limits between 2286 m and 2743 m can be found (Roed *et al.*, 1967). This prompted Roed (1975) to conclude that the first phase of the Late Wisconsinan glaciation was responsible for the erratics train.

Much of Roed's contribution to the glacial history was based on the interpretation of surficial geomorphology, although subsurface evidence was also examined. As presented by Roed (1975) some sections with two tills are present, but the only evidence for more than two tills comes from a single borehole near Hinton (Hole #188 of his Figure 7). Heavy mineral analysis by Roed (1968) allowed him to differentiate Laurentide till (presence of hornblende, kyanite, and hypersthene) from Rocky Mountain till (presence of epidote, chlorite and chloritoid).

Recent work in Jasper National Park by Levson (1986) has neither refuted nor supported stratigraphic claims of others. However, a finite wood date of 29,100±560 years BP (GSC-3792) in basal gravels indicates that the overlying suite of diamictons (representing two glacial events) are all Late Wisconsinan in age (Levson and Rutter, 1987, 1989b). Ice retreated rapidly sometime before 11,900±120 years BP (GSC-3885) based on a shell sample in terrace gravels. The most significant contribution of this study is the illustration of the importance of a sedimentologic approach (*i.e.*, facies analysis) in solving regional geologic problems (Levson and Rutter,

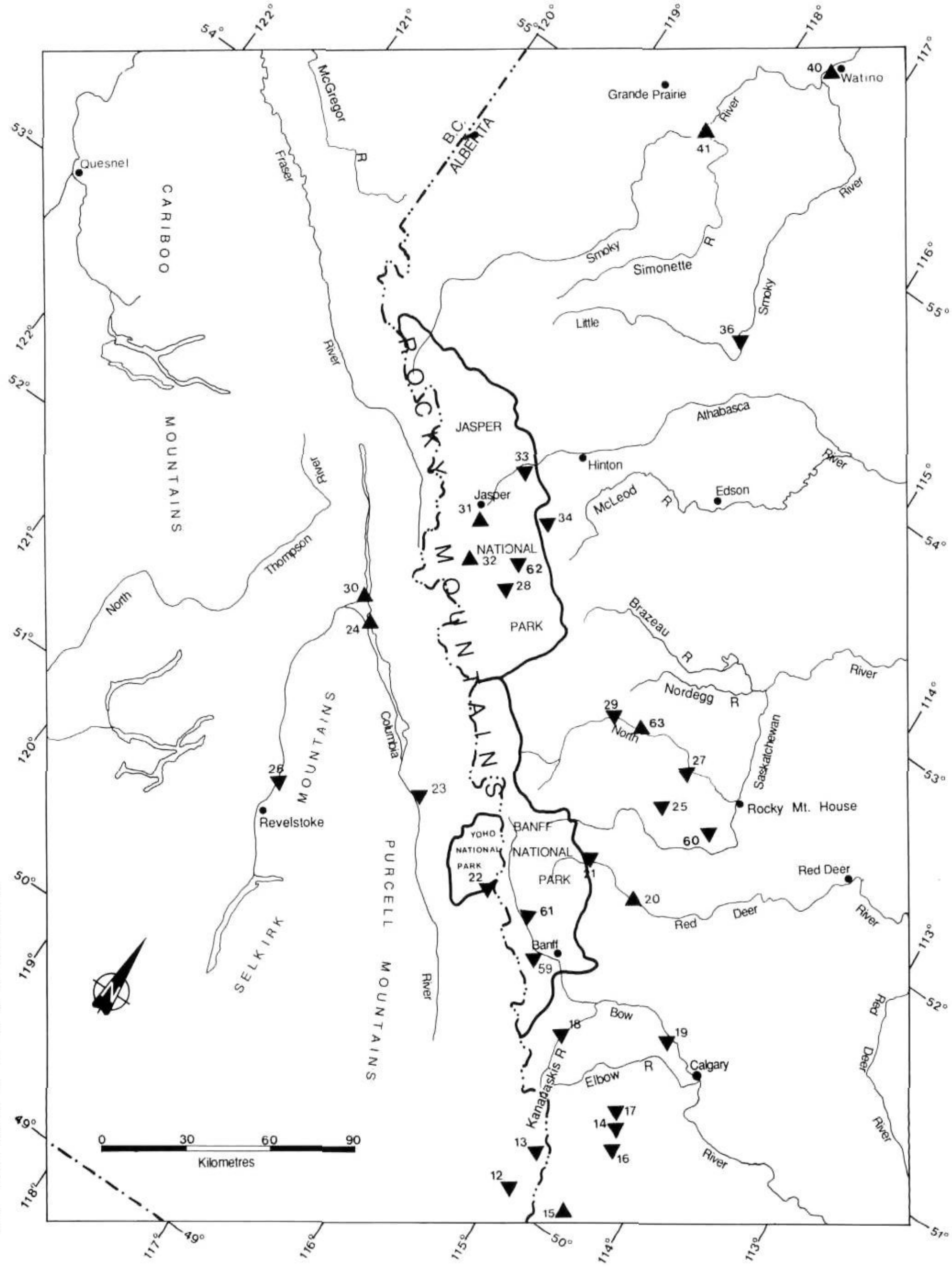

FIGURE 21. Location map of the central Canadian Rocky Mountain region. Place names discussed in the text are illustrated, including key radiocarbon localities listed in Table I. Triangles pointing up are preglacial localities, whereas upside down triangles are postglacial localities.

Carte de localisation de la région du centre des Rocheuses. Noms de lieux et sites principaux de datations au radiocarbone (tabl. I). Les triangles pointés vers le haut identifient des sites préglaciaires, et ceux pointés vers le bas, les sites postglaciaires.

1989b) (Fig. 24). The number of diamicton facies, types and subtypes identified and used by the researchers in this area has varied from eight (Levson and Rutter, 1986b) to twelve (Levson and Rutter, 1988a) to fourteen (Levson and Rutter, 1986a).

NORTH SASKATCHEWAN VALLEY REGION

Geologic study by Kvill (1978, 1984) in the Brazeau River area, directly north of the North Saskatchewan River valley emphasized the interpretation of surficial landforms in determining regional glacial history. Kvill (1978) suggested that the area provides good evidence of ice coalescence and deflection of three separate, but interacting ice lobes: the Brazeau lobe from the west, the Athabasca lobe from the north and the Laurentide lobe from the northeast. Lithologic variation in the sediments and widespread drumlinoid features provide convincing evidence supporting his arguments. The age of this coalescence cannot be established, so that the event may have occurred during pre-Late Wisconsinan or during an early part of the Late Wisconsinan, which would be in agreement with Roed's work to the north and Boydell's work to the south.

Glacial sediments in the upper North Saskatchewan River valley were examined in the early 1960's. Pleistocene ice limits adjacent to the valley were documented to be between 2499 m and 2134 m (McPherson, 1963). Pebble lithologies obtained from till outcrops suggest that the ice which flowed down the North Saskatchewan valley accumulated on the east side of the divide, since exotic erratics from the far west side of the Rocky Mountains were not observed (McPherson, 1970). A comparable conclusion was drawn by Rutter (1966a, 1972) in the Bow River valley to the south (see below). The composite stratigraphic history for the upper North Saskatchewan valley consists of two mountain glaciations (Big Horn advance and a later Main advance) separated by a thick sequence of stratified sand and gravel deposits (McPherson, 1970) (Fig. 25). Unfortunately, the timing and extent of these two events could not be established. Very little detailed information on either the stratigraphy or sedimentology of the observed outcrops is presented by McPherson, who apparently relied considerably on surficial landforms in determining much of the local glacial history.

Shortly thereafter, Boydell (1972) began an investigation directly east of McPherson's study area, in the North Saskatchewan valley and surrounding Foothills area near Rocky Mountain House. Relying extensively on carbonate content (higher in Rocky Mountain tills), and heavy mineral

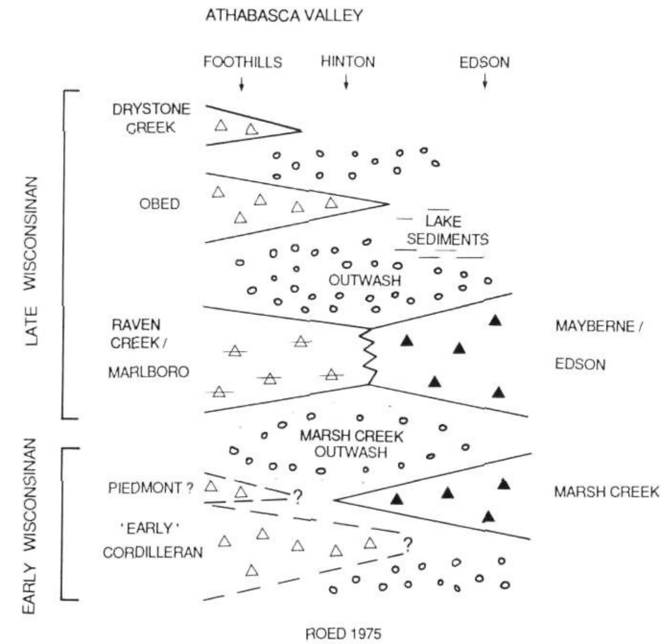

FIGURE 23. Composite stratigraphic history of lower Athabasca River valley modified after Roed (1975).

Évolution stratigraphique de la région de la vallée du cours inférieur de la rivière Athabasca, modifiée à partir de Roed (1975).

FIGURE 22. Large erratic of the Foothills Erratics Train near Fort MacLeod, Alberta.

Gros bloc erratique de la région du piémont des Rocheuses, près de Fort MacLeod, en Alberta.

FIGURE 24. Quaternary fan sediments in Jasper National Park, Alberta (photo courtesy of V. Levson).

Sédiments quaternaires de cône alluvial, dans le parc national de Jasper, en Alberta (photo de V. Levson).

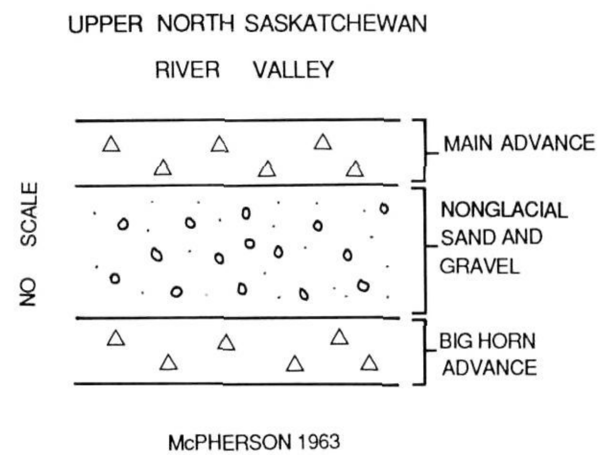

FIGURE 25. Simplified composite stratigraphic history of the upper North Saskatchewan valley as interpreted from McPherson (1963).

Stratigraphie simplifiée de la vallée du cours supérieur de la rivière Saskatchewan Nord interprétée à partir de McPherson (1963).

analysis (presence of hornblende, aegirine and augite in Laurentide till), and supplementing this information with detailed surficial mapping and borehole data from 16 holes, Boydell (1978) recognized four glacial events (Fig. 26). Till, glaciolacustrine sediments and outwash sand and gravel deposits are associated with each of the major events. The earliest glaciation in the area, locally termed the Hummingbird-Baseline advance, was interpreted by Boydell (1978) as being the most extensive Rocky Mountain event (crossed the Brazeau and Ram Ranges). Although supportive radiometric data were not available, Boydell considered the advance to be possibly Early Wisconsinan in age. Apparently during the Late Wisconsinan, two Rocky Mountain events (Lamoral and Jackfish Creek) coalesced with a Laurentide ice mass (Athabasca-Sylvan Lake) near Rocky Mountain House. These Rocky Mountain advances were interpreted by Boydell as being restricted to the main valley of the North Saskatchewan, thus leaving surrounding upland areas ice free during the Late Wisconsinan.

In the upper Red Deer valley, an early study by Pheasant (1968) concluded the area was subjected to a single mountain glaciation. Subsequent work by Boydell (1970) in the Sundre-Red Deer valley supported the conclusions of Pheasant. Besides the Rocky Mountain event, Boydell identified a separate Laurentide glaciation in the area and named the two events Elkton Creek (Rocky Mountain) and Sundre (Laurentide). He further concluded that the two ice advances were most likely asynchronous and therefore never coalesced, a conclusion at odds with his own work to the north. Boydell suggested that the Elkton advance was a short-lived event which preceded the Laurentide glaciation, based on stratigraphic evidence for superimposed till (Boydell, 1971). These conclusions contrasted with the two mountain advances in the upper North Saskatchewan and four advances in the upper Bow River valleys documented by others at about that time. A more significant contrast is the contention by Stalker (1960) that three Laurentide tills can be identified in the Red Deer region. Finally, Boydell (1970) suggested that since many of the boulders associated with the Foothills Erratics Train rest

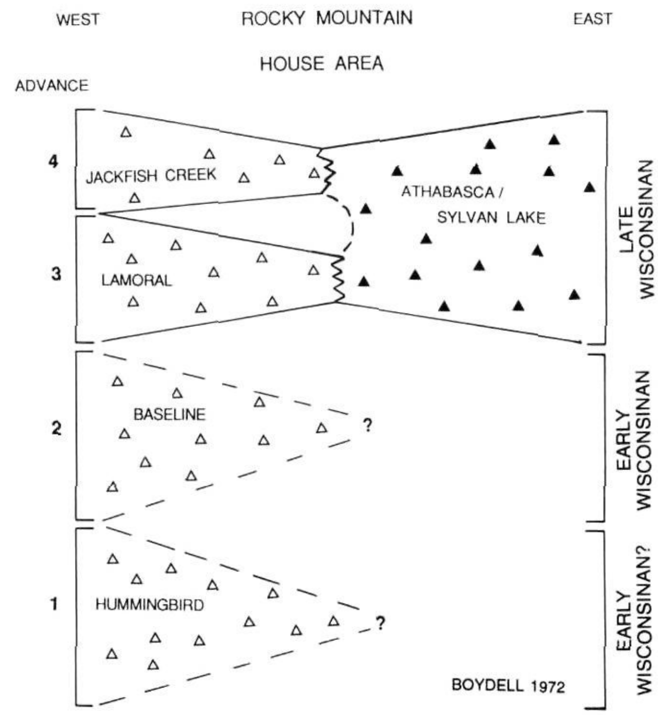

FIGURE 26. Composite stratigraphic column of Rocky Mountain House area, modified after Boydell (1972).

Colonne stratigraphique composite de la région de Rocky Mountain House, modifiée à partir de Boydell (1972).

on glaciolacustrine sediments, deposition by ice-rafting in ice marginal proglacial lakes during deglaciation seems probable.

BOW VALLEY REGION

The first comprehensive study of the glacial history of the Canadian Rockies was by Rutter in the Banff area, beginning in the early 1960's. Conclusions by Rutter (1965, 1966b, 1969b, 1971a, 1972) included the observation that Cordilleran ice from the west side of the Rocky Mountains never crossed the Continental Divide during the Pleistocene, and that four glacial events occurred in the region, which he named Pre-Bow Valley advance, Bow Valley advance, Canmore advance (earlier named Bow Valley re-advance) and Eisenhower Junction advance (Fig. 27). Evidence for his first glaciation was based on the presence of stratified drift occurring below a till which was assigned to the Bow Valley advance (Fig. 28). Admittedly, the stratified sediments could represent outwash of the Bow Valley advance (Rutter, 1966a). According to Rutter (1967a), ice retreated after the Bow Valley advance to about the vicinity of the Banff townsite and then re-advanced for an indeterminate distance during the Canmore advance. Finally, the Eisenhower Junction advance was a short lived, glacial event, which terminated in the upper Bow Valley some 40 km west of Banff. Unfortunately, only one multiple till (two-till) section (near the Kananaskis River) is recorded for the entire valley (Rutter, 1967a), and none of the sections provided materials suitable for absolute dating. Rutter (1972) however, correlated his Bow Valley, Canmore and Eisenhower Junction advances with the three stades of the Pinedale Glaciation in the U.S. Rockies which were considered Late Wisconsinan in age. Glaciation

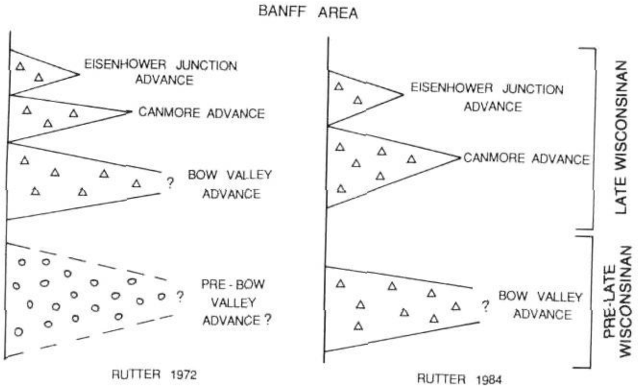

FIGURE 27. Composite stratigraphic column of the Bow Valley from the Continental Divide to Kananaskis River, modified after Rutter (1972, 1984).

Colonne stratigraphique composite de la vallée de Bow River, à partir de la ligne de partage des eaux jusqu'à la Kananaskis River, modifiée à partir de Boydell (1972).

FIGURE 28. Bow Valley till over outwash in Banff National Park, Alberta.

Till de Bow Valley sur épandage fluvio-glaciaire, au parc national de Banff, en Alberta.

limits for the most extensive event (Bow Valley advance) provided Rutter with an ice thickness estimate of approximately 792 m.

Side wall sampling and electro-logs derived from a borehole drilled near Canmore after Rutter's initial results, confirmed the presence of Bow Valley till below Canmore outwash and the presence of distinct "black" till found below the Bow Valley till and stratified drift assigned to the Pre-Bow Valley advance (Rutter and Christensen, 1972).

McLaren (1971) documented and extended the area affected by Eisenhower Junction advance by his cirque analysis in the area of the Continental Divide (McLaren and Hills, 1973). Later, G. B. Mandryk (1986) carried out a detailed study Fon glacigenic deposits in the Banff townsite area and among other things confirmed Rutter's original interpretation of deposits representing the Bow Valley and Canmore advances.

In his latest interpretation of age estimates, Rutter (1980, 1984) reassigned the Bow Valley advance to a period preceding the Late Wisconsinan (Fig. 27), based mainly on evidence from other areas, suggesting that Late Wisconsinan ice did not flow much beyond the mountain front (Stalker, 1980; Stalker and Harrison, 1977). However the question is still open for the age of the Bow Valley advance. Evidence is shifting once again to the original interpretation that the Bow Valley advance is Late Wisconsinan in age (Clague, 1989).

Tharin (1969) proposed a stratigraphic history for the area between Banff and Calgary based on his fieldwork in the region, as well as improved knowledge about the Foothills Erratics Train following the work of others (*e.g.* Morgan, 1966, 1969) (Fig. 29). The essential features of his model include two Rocky Mountain and Laurentide glaciations, asynchronous Early Wisconsinan events, and synchronous Late Wisconsinan glacial events with no ice coalescence in the south, but ice coalescence north of the Bow Valley (Fig. 29). Rutter (1968b) extended the western limits of Laurentide glaciation (erratics) from that originally mapped by Tharin in the early 1960's, whereas Harris and Boydell (1972) proposed a complicated and unsubstantiated version of a time distance diagram for the same area (Fig. 30). Other work east along the Bow valley

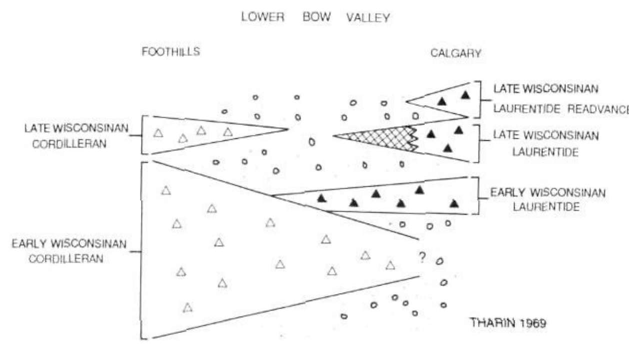

FIGURE 29. Generalized stratigraphy in the Bow Valley between the Foothills and Calgary modified after Tharin (1969). Cross-hatched area denotes Foothill Erratics Train deposits.

Stratigraphie généralisée de la vallée de Bow River entre le piémont et Calgary, modifiée à partir de Tharin (1969). La section hachurée représente les dépôts de la traînée d'erratiques de Foothills.

between Banff and Calgary include Glendinning (1974), Harris (1985, 1987a), Harris and Ciccone (1983, 1986), Kostaschuk (1980), McLaren and Rutter (1972) and Walker (1971a, 1971b).

Southeast of Rutter's study area, Stalker (1973a) reported on the Quaternary geology of the Kananaskis Research Forest and Marmot Creek Basin. Following his fieldwork in 1965, Stalker (1973a) concluded that the area was glaciated four times by Rocky Mountain ice which flowed down the Kananaskis River toward Seebe. He named his events, from oldest to youngest: Glacier I, Glacier II, Glacier III and Glacier IV, and argued that each successive event had a lower glaciation limit in the main valley (*cf.* Stalker's Figure 5). Stalker concluded that his Glacier IV event is correlative to Rutter's Canmore advance to the north, and his Glacier III event is probably correlative to an event as yet unrecorded in Rutter's area which would have occurred between the Bow Valley and Canmore advances. The remaining events were not correlated by Stalker.

West of Stalker's area and south of Rutter's area, Hawes (1977, 1978) went further in defining both local and regional glacial events. Of his eight episodes, the first four represented glacial advances, whereas the remaining four represented stillstands of a retreating ice mass (Table II). Hawes' (1978) four glaciations which he named oldest to youngest: "Oldest Glaciation", Rocky Creek episode, Mount Wintour episode and Limestone Mountain episode, and four standstill positions, each had successively lower glaciation limits. Hawes (1978) also proposed a regional correlation with adjacent field areas, a proposal which has yet to be substantiated spatially and chronologically.

A detailed surficial, sedimentologic and stratigraphic study of the Kananaskis Lakes map area from 51° N latitude south to 50° N latitude and from the B.C. border east to 114° W longitude was performed by Jackson (1975, 1976, 1977, 1978, 1979b, 1980b). Glaciolacustrine and glaciofluvial deposits, as well as five till sheets collectively representing four glaciations, were recognized (Fig. 31). The earliest event in the area is represented by a sporadic distribution of shield and Rocky Mountain erratics near the Porcupine Hills. Based on stratigraphic evidence farther south, Jackson proposed the Rocky Mountain event preceded the Laurentide glaciation. The second glacial episode involved a coalescence of Rocky Mountain and Laurentide ice somewhere east of 114° W, and a combined flow to the south. A second coalescence of Rocky Mountain and Laurentide glaciers occurred during the third episode. It is during this stage that Jackson envisioned the Athabasca Valley glacier coalescing with the Laurentide Ice Sheet in the north, and then coalescing with Bow Valley ice farther south as it deposited the Foothills Erratics Train along its path. The

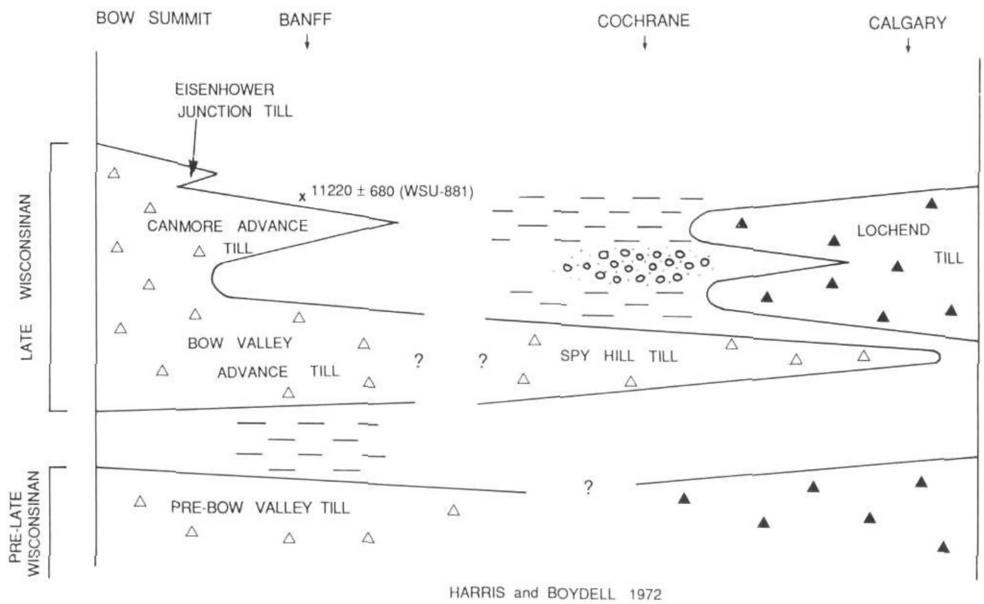

FIGURE 30. Composite stratigraphic history of the lower Bow Valley from Bow Summit to Calgary, modified after Harris and Boydell (1972).

Évolution stratigraphique de la vallée inférieure de Bow River, à partir Bow Summit jusqu'à Calgary, modifiée à partir de Harris et Boydell (1972).

TABLE II

Attempt by Hawes (1978) to correlate Pleistocene events in the Kananaskis valley with those in the Bow valley

Kananaskis Valley episodes (Hawes, 1978)	*Ice Depth (m)* Kananaskis Valley	*Lower Kananaskis* Valley Glaciers (Stalker, 1973)	*Bow Valley Glaciers* Tharin, 1960 (T), Rutter, 1972 (R), Harris and Howell, 1977b (H), Stalker, 1973 (S)
Boulton Creek standstill	120	—	Chateau Lake Louise Phases I and II (H)
Power Plant standstill	150	—	Eisenhower Junction (R)
Galatea Creek standstill	150	—	nothing yet identified
Marmot Creek standstill	150	—	Canmore (R); Seebe standstill (S)
Limestone Mountain episode	150	IV	Canmore (R); Ghost Dam max (S)
Mount Wintour episode	400	III	Morley (T); no corresponding ice height identified in Bow valley
Rocky Creek episode	610	II	Spy Hill (T); Bow valley max (R)
"Oldest Glaciation"	700-800	I	Pre-Bow Valley (R)

final glaciation in this area consisted of a Laurentide advance which terminated east of 114°W, and two short-lived alpine advances which terminated within the Rocky Mountains.

Jackson (1980a) cited a number of radiocarbon dates to support his proposed stratigraphic history. For instance, a wood date of 49,400±400 years BP (GSC-2409) from an exposure of the Erratics Train till, southeast of Calgary, should be treated as a greater than date according to Jackson (1980a), and therefore indicates at least an Early Wisconsinan age for episode three. Additionally, dates of 18,400±380 years BP (GSC-2668) and 18,500±1090 years BP (GSC-2670) from Chalmer's Bog suggested ice-free conditions during the Late Wisconsinan glaciation of the final episode, however, the subsequent illustration that the above two dates are unreliable as a result of contamination with dead carbon puts into question the timing of ice-free conditions.

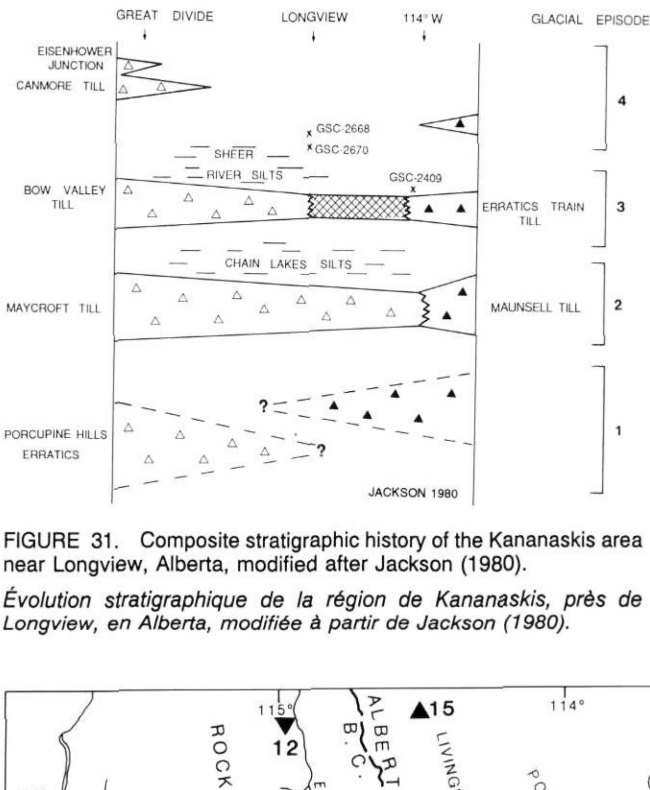

FIGURE 31. Composite stratigraphic history of the Kananaskis area near Longview, Alberta, modified after Jackson (1980).

Évolution stratigraphique de la région de Kananaskis, près de Longview, en Alberta, modifiée à partir de Jackson (1980).

A detailed study of the Calgary area by Moran (1986) simplified the stratigraphic relationships for that area. The earliest glacial sediment recognized by Moran is a pre-Late Wisconsinan till deposited by ice originating in the Rocky Mountains (pre-Spy Hill Formation). About 25,000 years ago, Late Wisconsinan ice originating in the Bow Valley, deposited sediments identified as the Spy Hill Formation. During retreat of the Montane glaciers, Laurentide ice apparently overrode the Calgary area and deposited till of the upper Spy Hill Formation as well as the Lochend Formation. Overlying these older units Moran recognized tills of two additional formations (Balzac and Crossfield) deposited by the Late Wisconsinan Laurentide glacier.

Day (1971a, 1971b) recognized only two Laurentide tills in the Porcupine Hills area directly north of Fort MacLeod. He argued that the tills can be easily distinguished on the basis of texture and heavy mineral content. Moreover, he suggested that the Foothills Erratics Train was associated with the final Laurentide advance into the area, and that there is no evidence to support ice-rafting in proglacial lake environments as a probable depositional mechanism for the erratics.

SOUTHERN ROCKY MOUNTAINS

In this paper, the southern part of the Canadian Rocky Mountains covers the area from the Porcupine Hills, south to the international border (Fig. 32). This region cannot be easily divided into major river valleys for review, but instead is examined on a provincial basis for studies completed either in British Columbia or Alberta. Furthermore, restricting discussion to the area north of the international border is unavoidable given the primary objectives of this paper. Several studies in Quaternary research are known for the Rocky Mountains south of the border and should be consulted (*e.g.*, Carrara, 1986; Carrara and Wilcox, 1984; Richmond, 1965; Richmond *et al.*, 1965; Ross, 1959).

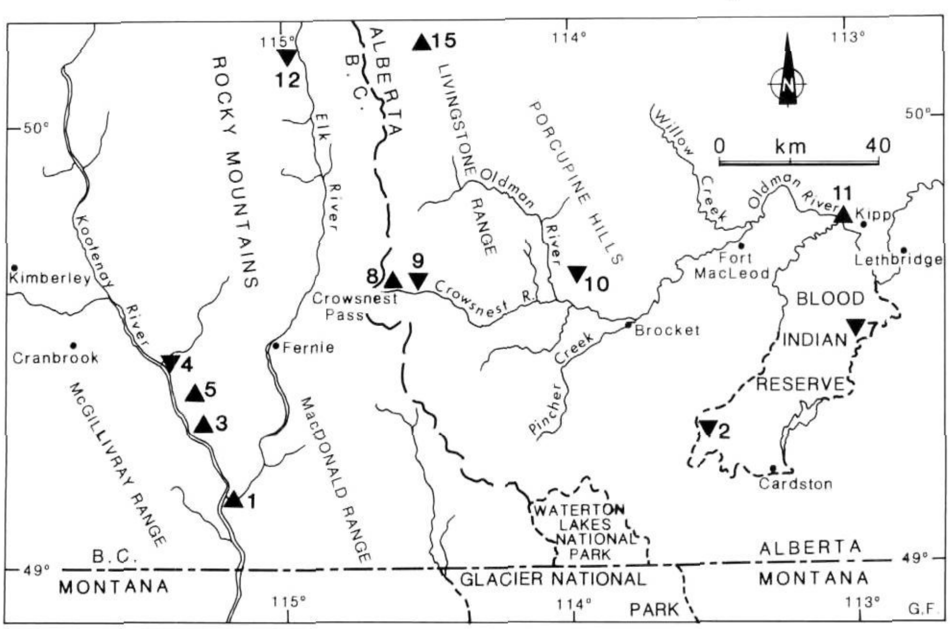

FIGURE 32. Location map of the southern Canadian Rocky Mountain region. Place names discussed in the text are illustrated, including key radiocarbon localities listed in Table I. Triangles pointing up are preglacial localities, whereas upside down triangles are postglacial localities.

Carte de localisation de la région du sud des Rocheuses. Noms de lieux et sites principaux de datations au radiocarbone (tabl. I). Les triangles pointés vers le haut identifient des sites préglaciaires, et ceux pointés vers le bas, les sites postglaciaires.

ALBERTA

A number of studies have been completed in the southwestern part of Alberta (Eschman, 1970). In the Waterton Park area, Horberg (1954) proposed a complex stratigraphy based on his own field work and that of several predecessors (*e.g.*, Bretz 1943). Although his time stratigraphic interpretations which he extended to "Kansan" were unsupported at the time, the extended age of his interpretations has some support from recent work by Karlstrom (1987a) who documented a lengthy history as far back as 4.9 Ma. Holocene glacial activity in the area is summarized by Osborn (1978).

Various parts of southern Alberta have been studied in some manner by Stalker since the 1950's (*e.g.*, 1953a, 1953b). Early work included a review of the distribution of erratics in the Foothills Erratics Train (Stalker, 1956, 1976b), and brief publications of field observations such as the Kipp Section on the Oldman River (Stalker, 1958a, 1958b). The first major compilation of detailed field descriptions for the stratigraphy of southwestern Alberta appeared shortly thereafter (Stalker, 1963a). At the time, Stalker formerly recognized several distinct Cordilleran (?) and Laurentide events (tills), which he discussed at length in later publications (Stalker, 1973a, 1976b). This generalized stratigraphy was modified and summarized in a composite stratigraphy in a subsequent publication (Fig. 33). With some variation, the proposed stratigraphic relationships have been used repeatedly by Stalker for all of his localized studies in the southern part of the province (Stalker, 1963b, 1963c, 1969a), although the number of Laurentide events east of the Foothills and the number of Montane events to the west recognized by Stalker have varied. An early Holocene glacial advance in the Castle River valley proposed by Stalker (1969b, 1970a) is questionable according to others (Wagner, 1966; Wagner and Eschman, 1970). Nonetheless, his observations of Rocky Mountain till underlying Laurentide till and his interpretation for non-coalescence of ice masses during the Quaternary have influenced all researchers working in this region of the Rocky Mountains and Foothills.

The latest chronology presented for the area by Stalker and Harrison (1977) includes four definite Montane and five definite Laurentide events as well as a number of tentative events (Fig. 34). The earliest episode was apparently the most extensive, and consisted of Montane ice advancing and retreating prior to a subsequent Laurentide ice advance. This was followed by a number of possibly non-coalescing events before the Early Wisconsinan. Less extensive Rocky Mountain and Laurentide glaciations then occurred during the Early Wisconsinan, with both sources experiencing a second prominent advance and retreat cycle. It is during this period that Stalker suggests transportation of the Foothills Erratics Train occurred. During the Late Wisconsinan, Rocky Mountain ice and Laurentide ice advanced into the region but were sufficiently separated geographically to maintain an ice free corridor

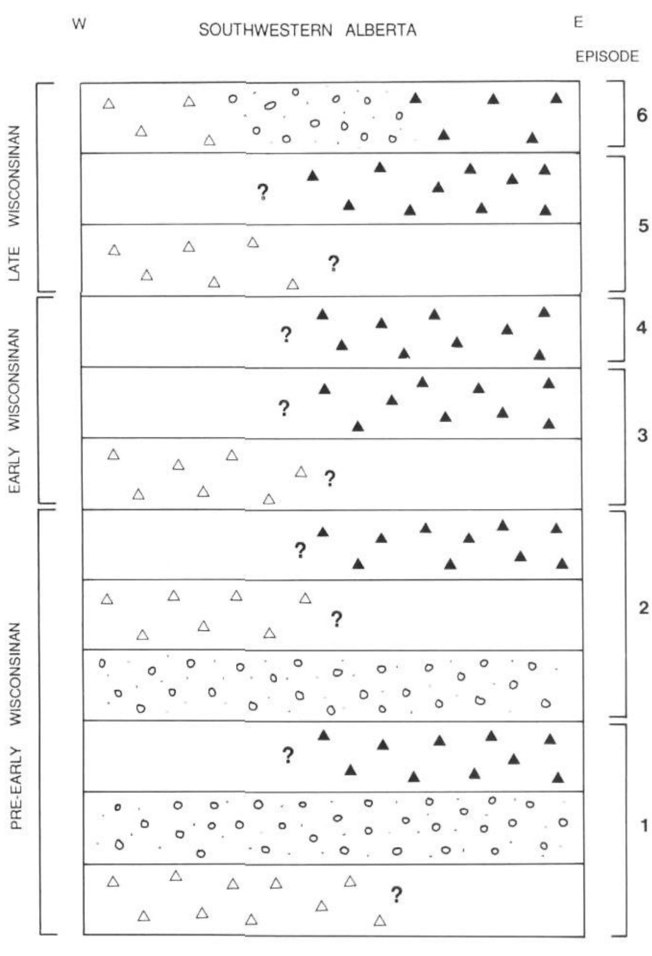

FIGURE 33. Generalized stratigraphy of southwestern Alberta as interpreted from Stalker (1976a).

Stratigraphie généralisée du sud-ouest de l'Alberta, interprétée à partir de Stalker (1976a).

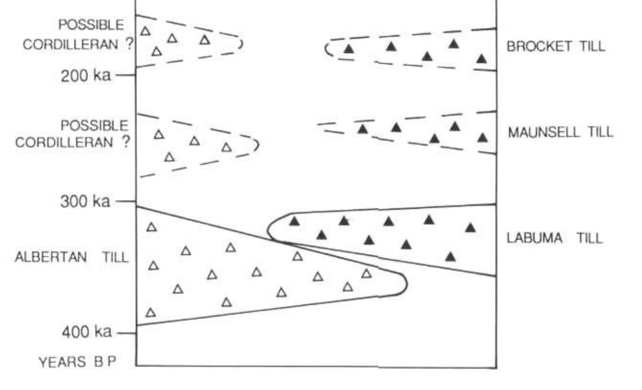

FIGURE 34. Composite stratigraphic column of the Waterton-Castle region, modified after Stalker and Harrison (1977).

Colonne stratigraphique composite de la région de Waterton-Castle, modifiée à partir de Stalker et Harrison (1977).

along the Foothills. All of the authors' interpreted events, however, lack direct chronologic control.

In the Porcupine Hills area of southwestern Alberta, Alley (1971, 1972) examined the chronology of events recorded in multiple till sections, determined the direction and extent of Rocky Mountain and Laurentide ice flow and established the degree of synchroneity between the ice masses during maximum glacial advances. Texture, carbonate content and pebble lithologies proved useful for differentiating tills of separate and similar provenance. One section on the Castle River contains five superposed tills and intervening nonglacial sediments (Figure 10 of Alley, 1973). The stratigraphic history proposed for the region by Alley (1973) depends to a considerable extent on the work of Stalker (1963a, 1963b) to the west (Fig. 35). Three major glacial episodes were identified by Alley (1973; Alley and Harris, 1974), each consisting of a Rocky Mountain or Cordilleran advance and a Laurentide advance. Each episode involved an advance and retreat of ice originating in the mountains before the Laurentide advance, hence, there is no evidence for coalescence of the two ice masses occurring during the Quaternary. Successive glaciations were of decreasing magnitude and extent. More importantly, Alley (1973) proposed a minimum of two streams of Cordilleran ice crossed the Continental Divide into the Crowsnest valley during the Albertan advance. Love (1977) subsequently re-examined part of the area studied by Alley earlier, but offered little in the way of additional insights.

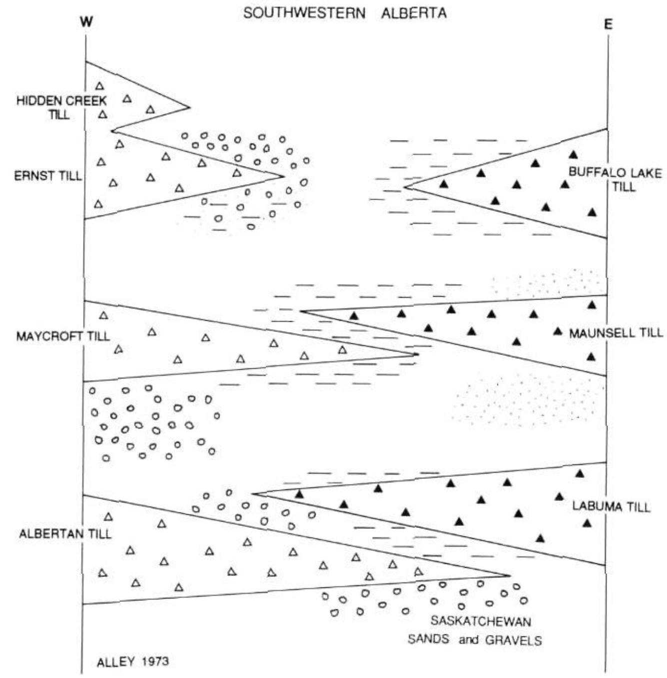

FIGURE 35. Composite stratigraphic column of the Porcupine Hills region, Alberta modified after Alley (1973).

Colonne stratigraphique composite de la région des collines Porcupine, en Alberta, modifiée à partir de Alley (1973).

Alley (1973) relied on a date of 22,700±1000 years BP (GAK-2336) which was obtained from bone recovered from outwash sediments in the Crowsnest Pass area (January Cave), to refine his chronology of glaciation. Further support to his chronology was based on the correlation and presumed accuracy of Stalker's (1963a) Laurentide stratigraphy to the east. In short, Alley proposed that the Hidden Creek advance was Late Wisconsinan, the Ernst advance was Early Wisconsinan and the remaining advances were all pre-Wisconsinan in age.

BRITISH COLUMBIA

The only part of southwestern British Columbia studied in detail is the Southern Rocky Mountain Trench (Clague, 1973, 1975c; Harrison, 1976a). Field work by Clague (1973) has clarified our understanding of the regional Quaternary history, and in particular, the history and behavior of the distal limits of the Cordilleran Ice Sheet. In general, the trunk glacier responsible for the primary flow during each glaciation in this area trended to the south and southeast parallel to the Kootenay River, with minor variations from confluent tributary glaciers which originated in the adjacent Purcell Mountains and Rocky Mountains (Clague, 1975b).

Based on a wood date of 26,800±1000 years BP (GX-2032) obtained directly under till, the area was first glaciated during the Late Wisconsinan (Fig. 36). The latter part of the Late Wisconsinan correlates to the Fraser Glaciation (Clague, 1973). According to Clague (1975a, 1975c), the Late Wisconsinan events in this region consisted of three short-lived glacial episodes and several associated periods of glaciolacustrine and glaciofluvial sedimentation. Striations on the east side of the Kootenay River at elevations as high as 2260 m (Clague, 1975a) indicate ice thickness in excess of 1500 m during the Pleistocene. The maximum frontal position of the ice lobe which passed through the area extended approximately 150 km south of the international border. Recent work in northern Idaho and Montana confirms the extent and style of penetration of Cordilleran ice from the north (Locke *et al.*, 1989). Deglaciation in the southern trench may have occurred before 13.5 ka years ago if a date of 13,430±450 years BP (GX-5599) from the upper Elk River valley is acceptable (Table I). Ferguson and Osborn (1981, 1982) consider the date valid and further propose the date provides a minimum age for the Canmore advance in the Bow River valley; however, Clague (1982) suggests the sample was contaminated. Additional geologic information on the Elk River valley is provided by George (1983; George *et al.*, 1987).

STYLE OF GLACIATION/DEGLACIATION

A casual look at airphotos of the Canadian Rocky Mountains and Foothills reveals an array of stream-lined landforms in the major drainage systems such as the North Saskatchewan (McPherson, 1970) Athabasca (Roed, 1968; Levson, 1986), Bow (Rutter, 1972), Brazeau (Kvill, 1989) valleys and the Rocky Mountain Trench (Leslie, 1988). These include drumlinoid features constructed in drift in the lower parts of the valleys and similar features modifying bedrock on valley sides. The landforms mark the direction of glacial flow during the last glaciation. Commonly, relief is only a few metres within the mountains, whereas outside the mountain front, drumlin relief may be 10 to 15 m, such as in the area of Morley in the Bow River valley and near Hinton in the Athabasca River valley.

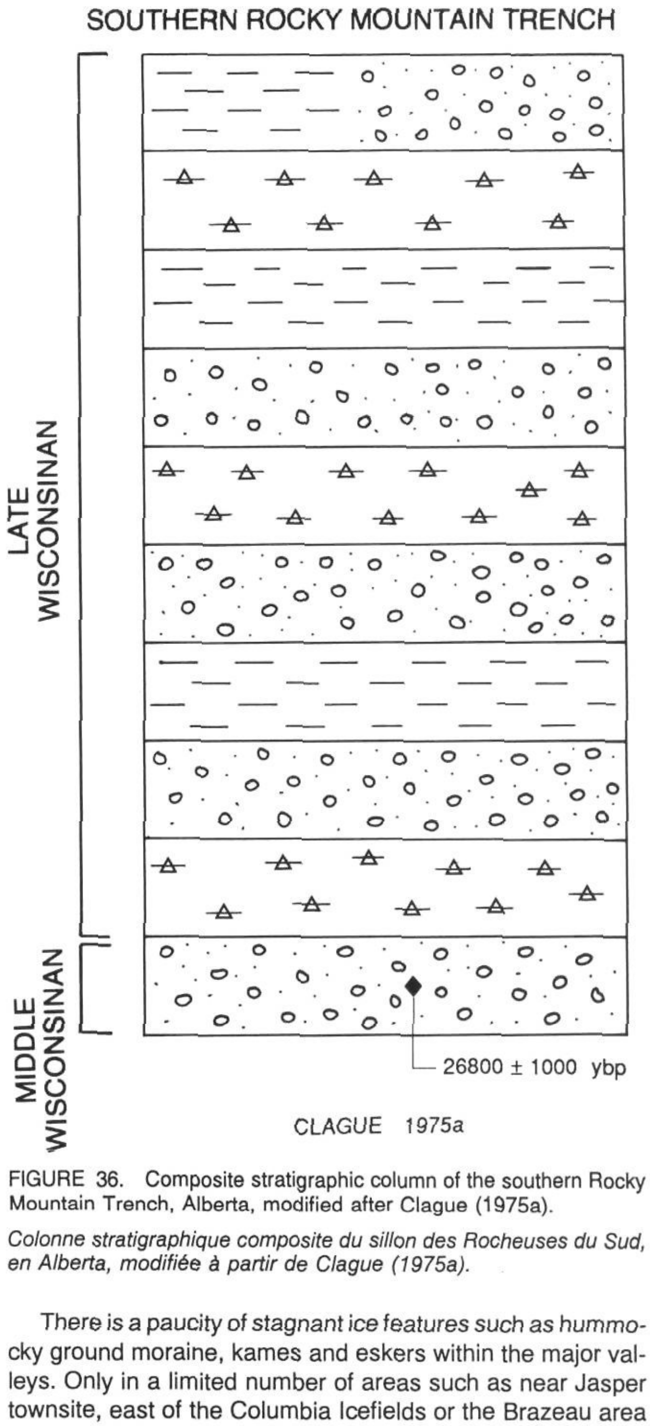

FIGURE 36. Composite stratigraphic column of the southern Rocky Mountain Trench, Alberta, modified after Clague (1975a).

Colonne stratigraphique composite du sillon des Rocheuses du Sud, en Alberta, modifiée à partir de Clague (1975a).

There is a paucity of stagnant ice features such as hummocky ground moraine, kames and eskers within the major valleys. Only in a limited number of areas such as near Jasper townsite, east of the Columbia Icefields or the Brazeau area are these features observed. Although there are faint suggestions of arcuate-shaped (including end and recessional) and lateral moraines in some of the lower valleys, the most prominent ones are restricted to the upper reaches of valleys, near cirques, or associated with present day glaciers. These features are assigned to younger glacier activity than those with mostly streamlined features.

The streamline features that dominate the valley systems reflect the glacier dynamics involved in their origin and the mode of deposition of the underlying sediments. Unfortunately, there have been very few detailed analyses of glacial deposits in the Rocky Mountains. Exceptions to this are facies investigations carried out by Mandryk (1986) in the Banff area, Levson (1986) in the Jasper area and Bobrowsky (1989a) in the northern Rocky Mountain Trench. These studies conclude that by far the most common type of glacial diamicton is the result of subsurface processes, a large part having been deposited by active ice as demonstrated by the presence of a large amount of lodgement till, (for an alternative explanation see Eyles *et al.*, 1988, 1990), and by the streamlined surface features. Very little supraglacial till is recognized except on or near valley walls and in the upper reaches of some valleys. Prominent, well defined arcuate-shaped and lateral moraines in the higher elevations most likely consist of a high percentage of supraglacial debris. The ice contact features such as eskers and kames that are found in restricted areas throughout the Canadian Rockies and Foothills represent the final stages of stagnant ice cover.

As noted elsewhere, the beginning of the postglacial period was marked by the widespread development of unique features called paraglacial fans (Ryder, 1971). Indeed, these and other types of fans characterize much of the mountain and foothill regions throughout the Holocene (Jackson *et al.*, 1982; Kostaschuk *et al.*, 1982, 1987).

PALEOECOLOGY

Paleoecological studies in or near the Canadian Rocky Mountains have attracted a far greater number of Quaternary researchers as compared to stratigraphic and sedimentologic research. Most of this work deals with palynology, and to a lesser degree with vertebrate paleontology. Moreover, much of the information available concerns the changing environmental conditions of the Holocene or postglacial period. Very few data are available on the paleoenvironmental conditions of nonglacial periods preceding the Late Wisconsinan in or near the Rocky Mountains (Figs. 37 and 38). Botanical data include macro-specimens and pollen samples, whereas vertebrate data consists of either isolated finds or larger assemblages.

PALYNOLOGY

Two interglacial pollen assemblages have been described for the northern Rocky Mountain Trench. Rutter (1976) listed the following pollen assemblage from lake sediments on the Parsnip River: *Pinus* (64%), *Picea* (21%), *Abies* (9%), *Alnus* (1%), *Betula* (0.5%), Polypodiaceae (3%), Lycopodium (0.5%), Cyperaceae (0.5%) and Gramineae (0.5%). He correlated this deposit to oxidized gravels on the Finlay and thus suggested an interglacial age for the described pollen suite. Bobrowsky and Rutter (1990) listed the following pollen taxa for interglacial alluvium on the Finlay River: *Picea* (88.3%), *Pinus* (4.1%), *Abies* (3.7%), *Alnus* (1.1%), Cyperaceae (1.4%) and the remainder indeterminate (1.4%). This deposit provided a basal date of 37,190±2870 years BP (AECV-353C) and an upper date of 23,280±1230 years BP (AECV-351C). All macro-botanical specimens recovered on the Finlay have been identified as *Picea* sp. (Bobrowsky, 1989a). West of the discussion area, in the Babine Lake region, a mammoth skeleton and pollen sample were recovered from organic silts underlying Late Wisconsinan till (Harington *et al.*, 1974). The Middle Wisconsinan pollen assemblage consisted predominantly of dwarf birch (*Betula* 32.2%), grasses (Gramineae 16%), *Artemisia* (12%) and Tubuliflorae (9.4%). A number of aquatic taxa (location is an old lake deposit), other herbs and a few more trees were also identified, indicating a shrub or alpine tundra environment. East of the Foothills, near Watino, Liverman *et al.* (1989) collected fragments of *Picea* sp. and *Salix* sp. in interglacial deposits. In the south, a Middle Wisconsinan occurrence is known west of the Rocky Mountains at Meadow Creek in the Purcell Trench. Here a detailed pollen assemblage is complemented with macro-botanical specimens of *Alnus, Salix, Picea, Tsuga* and *Thuja* (Alley and Valentine, 1977; Alley *et al.*, 1986).

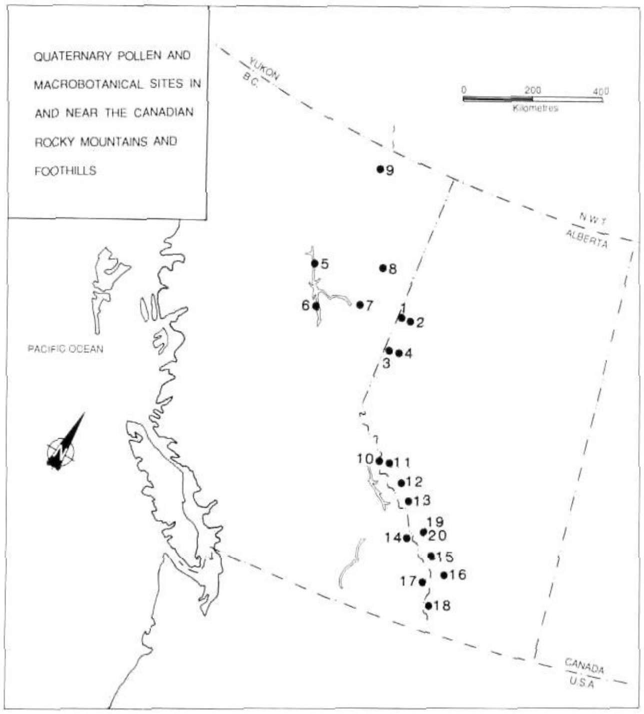

FIGURE 37. Location map of nonglacial and postglacial paleobotanical/pollen sites near the Rocky Mountains and Foothills. Site numbers: 1) Lone Fox Lake (MacDonald, 1987a); 2) Yesterday Lake (MacDonald, 1987a); 3) Spring Lake (White and Mathewes, 1986); 4) Boone Lake (White and Mathewes, 1986); 5) Finlay River (Bobrowsky, 1989a); 6) Parsnip River (Rutter, 1976); 7) Fiddler's Pond (White and Mathewes, 1982); 8) Snowshoe Lake (MacDonald, 1987a); 9) Lac Ciel Blanc (MacDonald, 1984); 10) Tonquin Pass (Kearney and Luckman, 1983b); 11) Watchtower Basin/Excelsior Basin (Luckman and Kaerny, 1986); 12) Maligne Lake (Kearny and Luckman, 1987); 13) Wilcox Pass/Sunwapta Pass (Beaudoin, 1983; Beaudoin and King, 1990); 14) Lake O'Hara (Reasoner, 1988; Reasoner and Hickman, 1989); 15) Yamnuska Bog/Wedge Lake (MacDonald, 1989); 17) Elk Valley (Ferguson and Hills, 1985; Harrison, 1976a); 18) Crowsnest Lake (Driver, 1978); 19) Mitchell Lake (Mandryk, 1990); 20) Goldeye Lake (Schweger, 1989).

Carte de localisation des sites polliniques et paléobotaniques non glaciaires et postglaciaires près des Rocheuses et du piémont. Numéros des sites: 1) Lone Fox Lake (MacDonald, 1987a); 2) Yesterday Lake (MacDonald, 1987a); 3) Spring Lake (White et Mathewes, 1986); 4) Boone Lake (White et Mathewes, 1986); 5) Finlay River (Bobrowsky, 1989a); 6) Parsnip River (Rutter, 1976); 7) Fiddler's Pond (White et Mathewes, 1982); 8) Snowshoe Lake (MacDonald, 1987a); 9) Lac Ciel Blanc (MacDonald, 1984); 10) Tonquin Pass (Kearney et Luckman, 1983b); 11) Watchtower Basin/Excelsior Basin (Luckman et Kaerny, 1986); 12) Maligne Lake (Kearny et Luckman, 1987); 13) Wilcox Pass/Sunwapta Pass (Beaudoin, 1983; Beaudoin et King, 1990); 14) Lake O'Hara (Reasoner, 1988; Reasoner et Hickman, 1989); 15) Yamnuska Bog/Wedge Lake (MacDonald, 1989); 17) Elk Valley (Ferguson et Hills, 1985; Harrison, 1976a); 18) Crowsnest Lake (Driver, 1978); 19) Mitchell Lake (Mandryk, 1990); 20) Goldeye Lake (Schweger, 1989).

Postglacial pollen studies are quite common for the Foothills on the east side of the mountains (Fig. 37). One of the earliest studies covering most of the Foothills of northeastern B.C. is that of Hansen (1950). Notable studies based on modern methods include Fiddler's Pond (White, 1983; White and Mathewes, 1982), Boone Lake, Spring Lake (White and Mathewes, 1986), Lone Fox Lake, Yesterday Lake, and Snowshoe Lake (MacDonald, 1987a) in the north. In the central Rocky Mountains, several key sites are represented in Jasper National Park including Wilcox/Sunwapta Pass (Beaudoin, 1982, 1984, 1985, 1986; Beaudoin and King, 1984a, 1990; Bowyer, 1978; Bowyer-Beaudoin, 1982; Holland, 1980; Holland *et al.*, 1980a, 1980b), Watchtower Basin/Excelsior Basin (Kearney *et al.*, 1980; Luckman and Kearney, 1986), and Maligne Lake (Kearney and Luckman, 1981, 1983a, 1983b, 1987). Additional

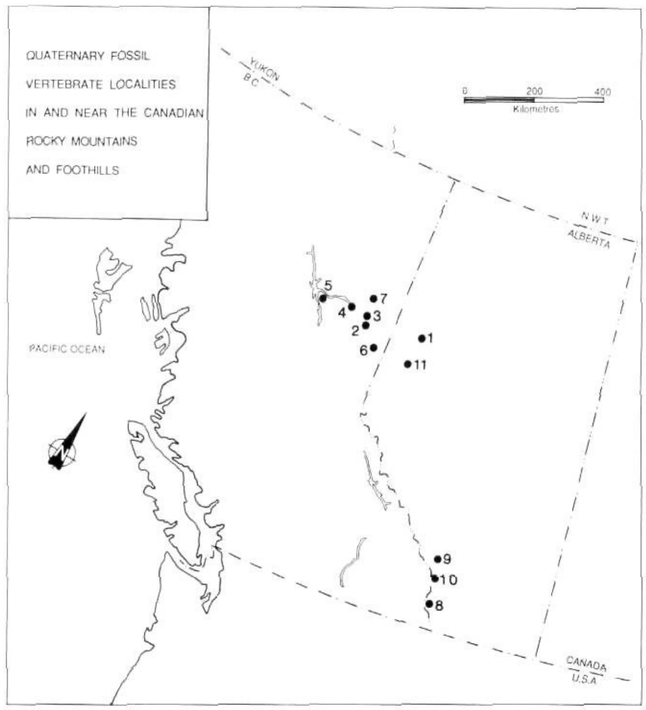

FIGURE 38. Location map of interglacial and postglacial vertebrate fossil sites near the Rocky Mountains and Foothills. Site numbers: 1) Peace River (Churcher and Wilson, 1979; Bobrowsky *et al.*, 1988); Taylor (Mathews, 1978; Bobrowsky *et al.*, 1991); 3) Fort St. John (Cowan, 1941); 4) Portage Mountain (Mathews, 1978); 5) Finlay Forks (Rutter *et al.*, 1972); 6) Dawson Creek (Reimchen and Rutter, 1972); 7) Charlie Lake Cave (Driver, 1988a and b); 8) Crowsnest Pass (Driver, 1985); 9) Cochrane (Stalker, 1968; Churcher, 1968, 1975); 10) January Cave (Burns, 1984, 1990); 11) Watino (Burns, 1986).

Carte de localisation des sites de fossiles de vertébrés interglaciaires et postglaciaires près des Rocheuses et du piémont. Numéros des sites: 1) Peace River (Churcher et Wilson, 1979; Bobrowsky et al., *1988); Taylor (Mathews, 1978; Bobrowsky* et al., *1991); 3) Fort St. John (Cowan, 1941); 4) Portage Mountain (Mathews, 1978); 5) Finlay Forks (Rutter* et al., *1972); 6) Dawson Creek (Reimchen et Rutter, 1972); 7) Charlie Lake Cave (Driver, 1988a et b); 8) Crowsnest Pass (Driver, 1985); 9) Cochrane (Stalker, 1968; Churcher, 1968, 1975); 10) January Cave (Burns, 1984, 1990); 11) Watino (Burns, 1986).*

sites are known in Yoho National Park including Lake O'Hara/ Opabin Lake (Reasoner, 1988; Reasoner and Hickman, 1989) and south of Banff National Park, including Yamnuska Bog/ Wedge Lake (MacDonald, 1980, 1982), Chalmers Bog (Mott and Jackson, 1982), and Elk Valley (Ferguson, 1978; Fergusson and Hills, 1985). Several important pollen sites with basal dates as far back as 18 ka years BP are now known east of the park limits, such as Goldeye Lake (Schweger, 1985, 1989; Schweger and Mandryk, 1986), and Mitchell Lake (Mandryk, 1989, 1990). The basal sample at Goldeye Lake, possibly older than 24 ka years BP, is dominated by *Artemisia* and Gramineae, thus indicating a sparse tundra vegetation. The nature of the dated material at these critical sites and the possibility of contamination warrants caution in their use and interpretation (*cf.* MacDonald *et al.*, 1987 for a cautionary critique of the early dates from Chalmer's Bog).

In the southern Rocky Mountains, well documented pollen localities are not as common, but include Callum Bog (Alley, 1972) and Crowsnest Lake (Driver, 1978). Detailed descriptions are available for most of the above listed sites and basal radiocarbon dates are given here (Table I). Syntheses of the paleoecological data for all three regions are provided by Beaudoin and King (1990), Christensen and Hills (1985), Driver *et al.* (1985), Ferguson and Hills (1985), Huesser (1956), MacDonald (1987b), MacDonald and Ritchie (1985, 1986), Matthews *et al.*, (1989), Ritchie and MacDonald (1986) and Schweger (1989).

Macrobotanical finds of Holocene age are represented primarily at pollen sites, where wood remains are identified specifically for taxonomic information (*e.g.*, Wood Bog (Beaudoin, 1989), Lake O'Hara (Reasoner and Hickman, 1989) and Sunwapta Pass (Holland *et al.*, 1980a)). However, wood has been examined as a source of proxy climatic data (*e.g.*, Luckman, 1982, 1984, 1989b) and tree-ring chronology information (Luckman, 1989a). For example, quantification of tree-ring densitometry and $\delta^{18}O$ values, and application of various transfer functions permitted paleotemperature estimates to be made for the last few centuries in the central Rocky Mountains (Luckman *et al.*, 1985).

VERTEBRATE PALEONTOLOGY

Vertebrate remains found near the Rocky Mountains act as another useful proxy data indicator of paleoenvironments (Fig. 38). Unfortunately, the number of localities containing Quaternary vertebrate fossils are rare in this region (Harington, 1978). As with botanical remains, few interglacial or preglacial deposits and assemblages are known, but a number of late glacial and postglacial collections have been described. The Peace District of northeastern British Columbia and northwestern Alberta has provided a significant number of vertebrate finds including preglacial faunal remains. Near Dawson Creek, remains of *Pliohippus* sp., *Equus* sp. and *Mammuthus* sp., from preglacial and glacial sediments have been noted (Reimchen and Rutter, 1972). At Watino, remains of *Spermophilus* sp., *Equus niobrarensis, Bison* sp. and a proboscidean have been described from interglacial or older sediments (Churcher and Wilson, 1979). This fauna was interpreted to have existed in an aspen-poplar parkland or plains environment. Dated finds of pre-Late Wisconsinan mammoth have been retrieved from Taylor and the Portage Mountain moraine (Mathews, 1978a). East of the central Rockies, a dated specimen of *Mammuthus* cf. *M. columbi* was found at Babine Lake (Harington *et al.*, 1974). In the southern Rocky Mountains, Burns (1984, 1990, 1991) described a spectacular Middle Wisconsinan assemblage containing 34 species. This radiocarbon dated assemblage was interpreted to reflect alpine tundra conditions at higher elevations and steppe-tundra conditions in the lower valleys. Harington (1990) records *Oreamnos* sp. and *Megalonyx* sp. fossils from Sangamonian sediments near Quesnel and Quesnel Forks, west of the central mountain region.

Postglacial faunas are better documented for the Rocky Mountain region, although again these localities are restricted to the Foothills rather than true mountainous terrain (Fig. 38). In the northern part of the mountains, Driver (1988a, b) proposed a change from open to coniferous forest conditions near Fort St. John at about 10,000 years BP based on a faunal assemblage recovered from stratified sediments in the Charlie Lake Cave site. This presumed shift is supported by palynological data elsewhere in northeastern B.C. which also record the appearance of coniferous forest conditions by 10,000 years BP (MacDonald, 1987b). The Charlie Lake Cave fauna, spanning much of the Holocene and starting as early as 10,770±120 years BP (SFU-454), is extremely diverse and includes taxonomic representation for fish, amphibians, birds and mammals. Isolated *Bison* remains have been found near Fort St. John (Cowan, 1941) and Taylor (Bobrowsky *et al.*, 1991), the latter dated to 10,240±160 years BP (AECV-1206C). To the east, several extinct postglacial larger mammal taxa have been recorded including *Mammuthus primigenius* (woolly mammoth), *Equus* cf. *E. conversidens* (Mexican ass), *E. niobrarensis* (equid), *Bison priscus* (extinct large-horned bison), *B. occidentalis* (extinct western bison), *B. athabascae* (wood bison), *Ovibos* cf. *O. moschatus* (musk-ox), and *Camelops* sp. (camel) (Churcher and Wilson, 1979). Near Watino, Burns (1986) identified the skeleton of a 9000 year old wapiti (*Cervus canadensis*); remains of the same species were found in mid-Holocene sediments at Peace River (Bobrowsky *et al.*, 1988). In the northern Rocky Mountain Trench, a single skull specimen of a Bighorn sheep (*Ovis canadensis*) was dated to 9280±200 years BP (GSC-1497) (Rutter *et al.*, 1972).

Farther south, vertebrate fossil remains are not well known along the Rockies, although exceptional collections are recorded from deposits near Medicine Hat, Alberta (*e.g.*, Burns, 1989a, 1989b). Nonetheless, several assemblages have been collected and described from gravel pits near Cochrane, Alberta. The fauna includes *Cervus canadensis* (wapiti), *Rangifer tarandus* (caribou), *Equus conversidens* (extinct Mexican ass), *Bison occidentalis* (extinct western bison) and *Ovis canadensis* (mountain or bighorn sheep) (Churcher, 1968, 1975; Stalker, 1968). An important bone date of 22,700±1000 years BP (GAK-2335) from Eagle Cave in the southern Rockies indicates ice free conditions existed high in the mountains well into the Late Wisconsinan. Finally, Driver (1985) reviewed a number of faunal species excavated from Holocene age archaeological deposits near Crowsnest Pass. Most modern taxa found in the region today were represented in these prehistoric assemblages.

MISCELLANEOUS

A number of other miscellaneous Quaternary studies in the mountains include analyses of lichens (Bednarski, 1978), frost phenomena (Denny, 1952), micro-forest succession (Bray and Struik, 1964; Nanson and Beach, 1977), ^{230}Th-^{234}U of speleothems (Harmon et al., 1977; Ford et al., 1981) and diatoms (Reasoner and Hickman, 1989). Invertebrate studies from Quaternary deposits are very rare but include work by Westgate *et al.* (1971) for Middle Wisconsinan sediments at Watino. Many Holocene deposits containing molluscs are known, such as the postglacial terraces in Jasper National Park (Levson, 1986) in the north, sediments of Mitchell Lake (Mandryk, 1990) and lakes near Canmore (Rutter, 1972) in the central Foothills, and Yamnuska Bog/Wedge Lake (MacDonald, 1982) in the south. Harris and Pip (1973) itemized a number of Holocene localities and a extensive molluscan fauna from the southern Foothills region of Alberta.

POSTGLACIAL STUDIES

The preceding review concentrated on the Quaternary geology (glaciation and deglaciation) up to about the Pleistocene/Holocene boundary. Much of the Canadian Rocky Mountains were, however, ice free well before 10,000 years ago (Table I). Deglaciation dates of 13,430±450 years BP (GX-5599) in the southern Rocky Mountain Trench, 14,470±610 years BP (RL-362) in the Crowsnest Pass, 10,100±200 years BP (RIDDL-433) at Lake O'Hara, 11,900±120 years BP (GSC-3885) in the Athabasca valley and 10,100±90 years BP (GSC-2036) in the Omineca valley, as well as older dates in the adjacent Foothills, indicate the postglacial period started in the late Pleistocene and not the early Holocene. As research involved with the postglacial period proceeds, the timing of deglaciation and the geologic/paleoecologic history of the mountain area continues to become better understood. Postglacial radiocarbon dates from the Rocky Mountains have been summarized by Clague (1980) and Jackson and Pawson (1984).

The most common investigations for the postglacial period involve those associated with basic surficial mapping of terrain and landforms (e.g., Baranowski and Henoch, 1978; Lewis, 1969). Most of the Rocky Mountains and surrounding areas have been mapped at scales ranging from 1:1,000,000 to 1:20,000. A list of these maps according to NTS sheet and scale is provided in Figure 39 and Table III. The primary divisions of this compilation indicate the source of information as either federal or provincial government sponsorship.

Apart from surficial mapping, few geologic postglacial studies are known for the northern Rocky Mountain area. However, one early and comprehensive work is that of Denny (1952) between Dawson Creek and Liard River on frost phenomena and vegetational changes. Also in northeastern British Columbia, Rampton (1987) briefly commented on the formation of terraces in the Fort Nelson area. In the central Rocky Mountain region, a suite of Holocene glacial studies are known. Best known are the works of Batterson (1980), Bray (1964), Davis and Osborn (1987), Gardner (1972); Gardner and Jones (1985); Harris and Howell (1976, 1977a, 1977b, 1978), Leonard (1982b), Luckman (1985, 1986, 1988a, 1988b), Luckman and Osborn (1979), Luckman *et al.*, (1978), McCarthy (1989), Osborn (1975, 1976, 1978, 1980, 1982a, 1982b, 1984a, 1984b, 1985, 1986, 1987, 1989), Osborn and Davis (1985); Osborn and Duford (1976), Osborn and Karlstrom (1989), Osborn and Luckman (1988), Porter and Denton (1967) and Rogerson and Batterson (1982).

Recent glacier activity has been examined at such locations as the Emerald Glacier (Rogerson, 1985), President Glacier (Bray, 1964), Yoho Glacier (Kodybka, 1981, 1982); Wenchemna Glacier (Gardner, 1978), and Athabasca Glacier (Luckman, 1988b; Jones, 1989). In addition to these detailed studies, casual observation and monitoring of glaciers in the Rocky Mountains has been ongoing for several decades (*e.g.*,

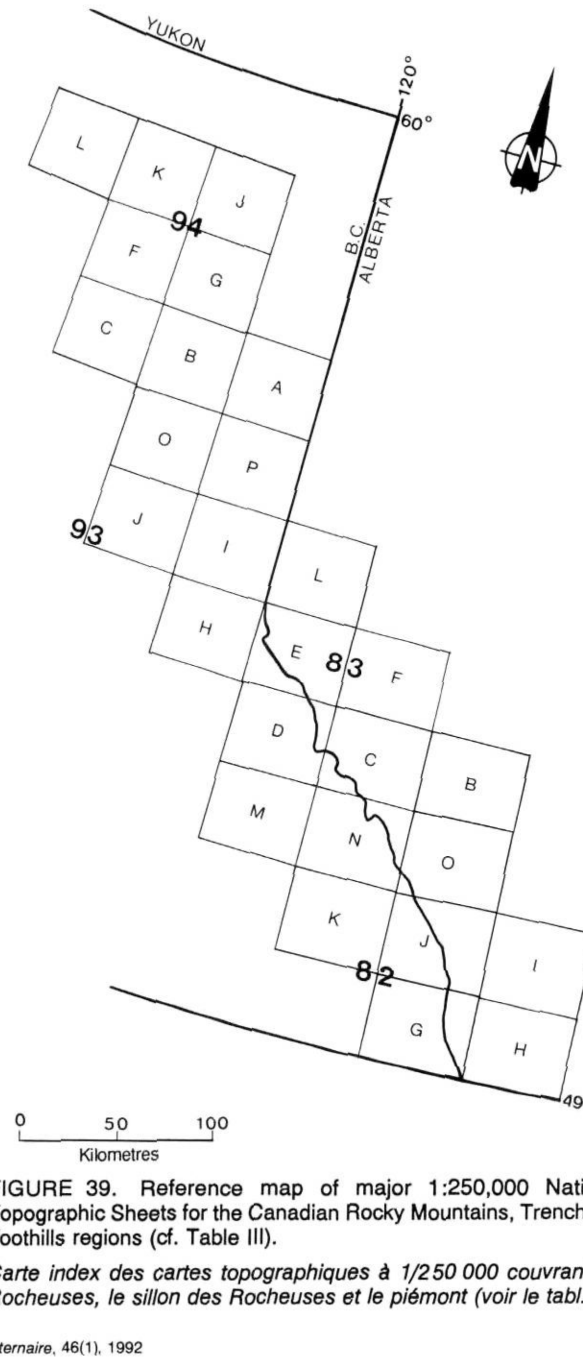

FIGURE 39. Reference map of major 1:250,000 National Topographic Sheets for the Canadian Rocky Mountains, Trench and Foothills regions (cf. Table III).

Carte index des cartes topographiques à 1/250 000 couvrant les Rocheuses, le sillon des Rocheuses et le piémont (voir le tabl. III).

TABLE III

Surficial terrain maps of the Canadian Rocky Mountains and adjacent areas. Maps listed according to NTS designation and scale. Authors and dates not always available. Primary NTS sheets illustrated in Figure 39.

NTS Sheet	Sheet Name	Authors
(Geological Survey of Canada and Alberta Council maps)		
1:1,000,000		
82	Kootenay Lake	Fulton, Rutter and Shetsen 1984
94	Beatton River	Mathews 1980
1:500,000		
82H	Southern Alberta	Shetsen 1987
82J	Southern Alberta	Shetsen 1987
82O	Southern Alberta	Shetsen 1987
1:250,000		
82G	Fernie	Stalker 1962a; Bayrock and Reimchen 1980
82H	Fort McLeod	Stalker 1959, 1962b, 1963d; Bayrock and Reimchen 1980
82J	Kananaskis Lakes	Bayrock and Reimchen 1980
82M	Seymour Arm	Fulton, Alley and Achard 1986
82N	Golden	Rutter 1972; Bayrock and Reimchen 1980
82O	Banff	Rutter 1972; Bayrock and Reimchen 1980
83B	Rocky Mt House	Boydell, Bayrock and Reimchen 1974
83C	Brazeau	Bayrock and Reimchen 1980
83E	Mt. Robson	Bayrock and Reimchen 1980
83F	Edson	Bayrock and Reimchen 1980; Roed 1970
83L	Wapiti	Bayrock and Reimchen 1980; Andriashek 1983
93J	McLeod Lake	Armstrong and Tipper 1949; Tipper 1971a
93P	Dawson Creek	Reimchen 1980
94A	Charlie Lake	Mathews 1978a
1:100,000-1:125,000		
82J	Kananaskis Lakes	Jackson 1987a
82M	Seymour Arm area	Fulton, Alley and Achard 1984
82N	Banff area	Rutter 1972
82O	Banff area	Rutter 1972
94B	Williston Lake area	Rutter 1974
94C	Williston Lake area	Rutter 1974
1:50,000		
82G	Several	Harrison 1976b
82H	Several	Harrison 1976b
82J	Several	Stalker 1973a, 1974; Rutter 1972; Bayrock and Reimchen 1976b
82K	Several	Fulton and Achard 1970
82M	Several	Achard 1973a; Fulton and Achard 1970
82N	Several	Achard 1973a; Rutter 1972; Bayrock and Reimchen 1976b
82O	Several	Stalker 1973a, 1974; Rutter 1972; Bayrock and Reimchen 1976b
83C	Several	Bayrock and Reimchen 1976a
83D	Several	Achard 1973a, 1973b; Bayrock and Reimchen 1976a
83E	Several	Bayrock and Reimchen 1976a

NTS Sheets

(B.C. Ministry of Environment
and Ministry of Energy, Mines and Petroleum Resources Maps)

1:100,00
82 M/NE, M/NW, M/SW, M/SE
93 P/SE, P/SW

1:50,000
82 G/1[a], G/2[a], G/3, G/4, G/5, G/6[a], G/7[a], G/8, G/10[a], G/11[a], G/12, G/13[a], G/14, G/15[a]
82 J/2[a], J/3[a], J/4, J/5, J/6, H/7, J/10, J/11, J/12, J/13
82 K/1[c], K/2[b], K/7[c], K/8[c]
82 M/1, M/2, M/3, M/4, M/5, M/6, M/7, M/8, M/9, M/10, M/11, M/12, M/13, M/14, M/15, M/16
82 O/4
83 D/1[a], D/9, D/10, D/14, D/15, D/16
83 E/2, E/3, E/6
93 H/3, H/4, H/5, H/6, H/7[b], H/9, H/11, H/12, H/14, H/15[a]
93 I/1, I/2, I/3, I/4, I/5, I/6, I/7, I/8, I/9, I/10, I/11, I/12, I/13, I/14, I/15, I/16
93 J/1, J/2, J/3, J/4, J/5, J/6, J/7, J/8, J/9[a], J/10, J/14, J/15, J/16
93 O/3, O/4[b], O/5, O/6, O/11, O/12, O/13, O/14
93 P/2, P/3[b], P/4, P/10, P/11, P/15, P/16
94 A/1[b], A/2[b], A/3[a], A/4[a], A/5[a], A/6[a], A/7[b], A/8[b]
94 B/3, B/4, B/5, B/9, B/10, B/15, B/16
94 C/1, C/2, C/7, C/8, C/9, C/10, C/11, C/14, C/15

Notes:
a Two separate versions of the map sheet available
b Three separate versions of the map sheet available
c Four separate versions of the map sheet available

Cooper, 1952; Denton, 1975; Falconer *et al.*, 1965, 1966; Hattersley-Smith, 1964; Henoch and Stanley, 1967; Konecny 1964; Kucera and Henoch, 1978; Lang, 1943; Luckman *et al.*, 1987; McFarlane, 1946; Meek, 1948a, 1948b; Sherzer, 1905, 1906, 1907, 1908; Vaux and Vaux, 1906, 1907a, 1907b, 1908; Vaux, 1911, 1913; Wheeler, 1907, 1908, 1910, 1911, 1913, 1915a, 1915b, 1920a, 1920b, 1923, 1931, 1934). McLaren and Hills (1973) provided a quantitative method of modelling *Pleistocene ice advances in the high mountains* based on a study of 53 cirques in Banff National Park.

Other postglacial research topics include those associated with pedogenesis/paleosols, glacial lakes and geologic hazards. The majority of paleosol/pedogenic contributions come from the southern part of the Rocky Mountains. In a series of publications dealing with the Waterton National Park and Glacier National Park areas of southwestern Alberta and northern Montana, Karlstrom (1981, 1982a, 1982b, 1984, 1985, 1986, 1988a, 1988b) has refined the Quaternary stratigraphy, and defined limits of glaciation as well as probable time limits for soil development. At Mokowan Butte, a series of pre-Wisconsinan soils which developed on glacial diamictons and span the last 4.9 Ma have been identified (Karlstrom, 1987a). Farther north, Dormaar and colleagues have added important insights to our understanding Holocene soils (*cf.* Dormaar, 1976 and Valentine *et al.*, 1987 for reviews). For instance, Dormaar and Lutwick (1975) provide evidence of Holocene fire activity affecting soils along the North Saskatchewan River, whereas King (1982) and Beke and Pawluk (1971) relied on tephrochronology to document pedogenetic development in the south central Rockies. Just west of the Canadian Rockies, Osborn and Karlstrom (1989; Karlstrom and Osborn, 1988) explored several paleosols related to Neoglacial activity of the Bugaboo Glacier. Quite often, the paleosol studies are integrated with archaeological work. For example, Bobrowsky *et al.* (1988) dated a series of paleosols in the Peace district and correlated these surfaces with intermittent periods of prehistoric human occupation. A similar application farther west along the Peace valley was provided by Valentine *et al.* (1980). Finally, Reeves and Dormaar (1972) detailed the variation in soil types found in prehistoric sites in the southern Foothills region of *Alberta, and Howell and Harris (1978) and King (1984a, 1984b)* examined Holocene soil formation as affected by volcanic ash. Additional paleosol investigations are presented in Rutter (1980b), Waters (1979) and Waters and Rutter (1984).

Postglacial lake studies have taken on two forms: detailed sedimentology of specific lakes or generalized accounts of large ice marginal lakes. In the area of Banff National Park, Leonard (1980, 1986b, 1987) has managed to document the timing of deglaciation, changes in Holocene glacial history, and the influence of climatic shifts on glaciolacustrine sedimentation. Other site specific lake studies include those of Reasoner and Hickman (1989), Reasoner and Rutter (1988) and Reasoner *et al.* (1987) on Lake O'Hara, where the timing of deglaciation, sedimentology and paleoecology is well documented. On a broader scale, St-Onge (1972) defined the history of postglacial lakes following retreat of the Laurentide ice mass, east of Jasper in the Foothills and plains regions.

Apart from the research interest in the paleoecology of glaciated terrain reviewed earlier, Holocene tephra studies have also attracted wide research efforts. Much of the southern and central Canadian Rocky Mountains were affected by volcanic eruptions during the Holocene (Fig. 40). Their age and distribution have long concerned Quaternarists active in stratigraphic research problems. Descriptive studies are available for individual tephras such as Bridge River (Mathewes and Westgate, 1980) and St. Helens Y (Luckman *et al.*, 1986). More common, however, are papers that deal with the characteristics and distribution of several tephras (*e.g.*, Bacon, 1983; Beaudoin and King, 1984b, 1986; Henoch *et al.*, 1979; Horberg and Robie, 1955; Nasmith *et al.*, 1967; Mullineaux *et al.*, 1975; Powers and Wilcox, 1964; Reasoner and Healy, 1986; Westgate, 1977; Westgate and Dreimanis, 1967; Westgate and Evans, 1978; Westgate *et al.*, 1970). Clague (1981, 1989) provides comprehensive reviews of the tephra data for the Rocky Mountains.

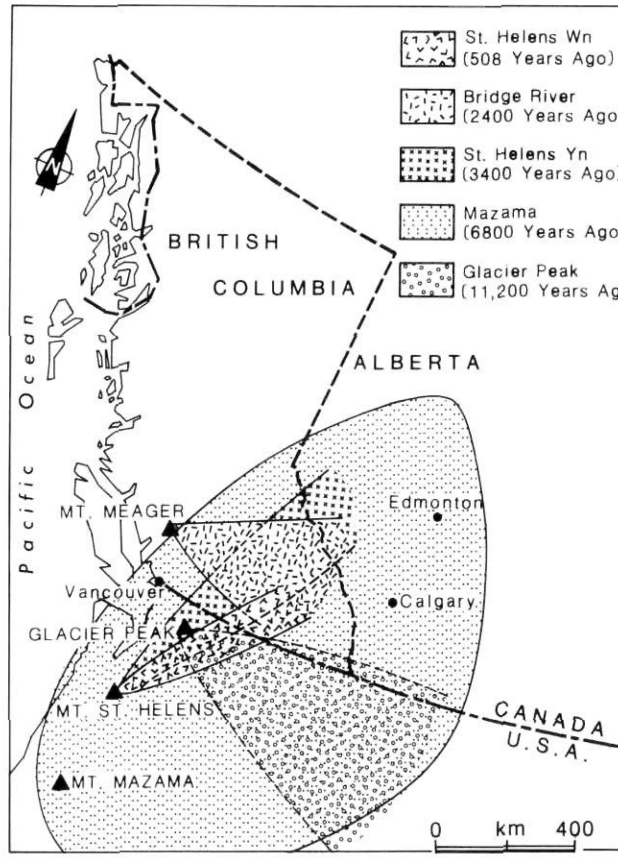

FIGURE 40. Late Quaternary volcanic ash distribution for western Canada illustrating only those tephras found in the Canadian Rocky Mountain region. Sources include Bacon (1983), Beaudoin and King (1984b, 1986), Clague (1981, 1989), Henoch *et al.* (1978), Horberg and Robie (1955), Nasmith *et al.* (1967), Powers and Wilcox (1964), Reasoner and Healy (1986), Westgate (1977), Westgate and Dreimanis (1967), Westgate and Evans (1978), and Westgate *et al.* (1970).

Répartition des cendres volcaniques du Quaternaire supérieur dans l'ouest du Canada; n'apparaissent que les tephras trouvés dans les Rocheuses. Sources: Bacon (1983), Beaudoin et King (1984b, 1986), Clague (1981, 1989), Henoch et al. *(1978), Horberg et Robie (1955), Nasmith* et al. *(1967), Powers et Wilcox (1964), Reasoner et Healy (1986), Westgate (1977), Westgate et Dreimanis (1967), Westgate et Evans (1978), and Westgate* et al. *(1970).*

ARCHAEOLOGY

In the regions under discussion, archaeological attention has generally centred on the Foothills rather than the Rocky Mountains area. The complex interaction of Laurentide and Rocky Mountain ice during the Wisconsinan provided unique possibilities for vast ice-free areas to exist between the ice sheets. The absence of ice coalescence between the two ice masses would have resulted in the existence of an ice-free corridor. Long recognized as a potential route for migration of early man (Reeves, 1971, 1973, 1983, 1985), renewed archaeological interest in the area called the ice-free corridor seems to be growing (*cf.* Ives *et al.*, 1989, 1990).

Recent archaeological research has shifted from statistically oriented sampling studies for site discovery to more focussed examination of landforms ideally suited for long term preservation of past cultural activity. The depositional environments most often examined for human occupation include caves, terraces and postglacial strandlines (*e.g.*, Bobrowsky *et al.*, 1988; Fladmark, 1983; Fladmark *et al.*, 1988; Wright, 1988, 1989).

In general, archaeological studies are strongly dependent on the quality of geologic data available, and rarely are archaeological data of use to geologists (*cf.* Bobrowsky *et al.*, 1990 for a review of geoarchaeology in western Canada). For instance, a number of geological studies have dealt specifically with the notion of an ice-free corridor (Catto and Mandryk, 1990; Jackson, 1979b, 1980b; Mathews, 1978b; Parris, 1975; Rutter, 1978, 1980a, 1981b, 1982; Stalker, 1970b, 1978, 1980), and it is these studies which archaeologists have come to rely upon in their own work. Nonetheless, material well suited for dating is often preserved in prehistoric cultural deposits and can provide geologists with much needed chronologic data (*e.g.*, Valentine *et al.*, 1980). Several of the late Pleistocene dates listed in Table I, for instance, are derived from early archaeological sites in the Rockies and Foothills regions of Canada. Similarly, detailed analysis of faunal remains in stratified contexts from these sites can provide proxy data on changing paleoenvironmental conditions (see section on Paleoecology).

Several important and well studied archaeological sites occur in the Canadian Rocky Mountain and Foothills region. In the northeast, the Charlie Lake Cave site provided a diverse assemblage of artifacts including a fluted projectile point, and has been dated to 10,770±120 years BP (SFU-454) (Driver, 1987, 1988a, 1988b; Fladmark *et al.*, 1988). Another old site farther south, near Banff, is the Vermillion Lakes site which has been dated to 11,700±290 years BP (Fedje, 1985; Hobson and Nelson, 1984). Vermillion Lakes contained a number of postglacial large mammal remains such as *Bison*, caribou and bighorn sheep. The Sibbald Creek site, southeast of Banff, dated to 9570±320 years BP (GX-8808), contained two fluted points and other Paleoindian artifacts, as well as material identified with Agate Basin, Midland and Scottsbluff (Gryba, 1983).

SUMMARY AND DISCUSSION

In the past, the Quaternary geologic history of western Canada could be easily summarized in a single publication (Barton *et al.*, 1964; Chapman and Turner, 1956; Holland, 1930; Prest, 1957, 1970; Read, 1921), whereas today either numerous or lengthy publications are required (*cf.* Fulton 1984c, 1989). This paper addresses the Quaternary geologic database for the Canadian Rocky Mountains, Trench and Foothills regions. Although the geographic area discussed in this paper represents a minor part of western Canada, and a comparably small part of the Canadian Cordillera, a lengthy discussion of various individual Quaternary studies could not be provided. The brief discussions of pertinent investigations presented above attempted to highlight selected areas and important data, evidence and conclusions.

General observations can be made regarding the nature of the database for the Canadian Rocky Mountain region including: 1) a paucity of absolute dates exist for the region, although the number of available dates has increased significantly in the last decade; and, 2) there is little evidence for event continuity between contiguous regions, but this is improving with time as geographic gaps are eventually investigated (Rutter, 1976). These two observations provide limitations in any attempt at broad stratigraphic correlation. Changing research paradigms and opinions in Quaternary geology over the last few decades have further restricted realistic use of the data. In the past, sections containing multiple diamictons were interpreted to represent multiple tills and quite often multiple glaciations. More recently, a stronger reliance on sedimentologic interpretation and better chronologic control have resulted in the recognition of fewer tills and hence, fewer glaciations. Multiple till sections are now considered rare and often represent glacial limit areas where fluctuating ice positions of a single glacial event are recorded. Most works pre-dating the last decade will require a re-examination of the field evidence in light of recent advances in glacial sedimentology. In the absence of re-examining field evidence, it is difficult to assess the integrity of published data, so continued attempts at inter-montane correlation are inadvisable.

Several observations concerning the timing and extent of Quaternary glaciations for the Canadian Rocky Mountain region and surrounding areas can be summarized. In southwestern Alberta, deposits from three glaciations are present including an early event of Cordilleran provenance and two later events of local Montane provenance. These western derived glaciations apparently preceded three equivalent eastern derived Laurentide glaciations; hence there is no evidence for coalescence during the Quaternary in this area. The age of these events is unconfirmed, and the assumption of Early Wisconsinan glaciations is speculative. Deglaciation occurred sometime around 14.5 ka years ago (Location 9; Fig. 32). Across the Continental Divide in the southern Rocky Mountain Trench area, three Cordilleran glaciations are recorded and interpreted as Late Wisconsinan in age. A date of 19.1 ka years for this area signals the start of the Late Wisconsinan (Location 5; Fig. 32). Apparently there is no evidence for a pre-Late Wisconsinan glaciation in this area. Deglaciation may have occurred as early as 13-14 ka years ago (Locations 4 and 12; Fig. 32). Farther north, in the Kananaskis/Elbow River area at least three, and possibly four glacial episodes are recorded. The age of these events is unknown, as subtill dates are not available for this area. The early glacial episodes may have involved coalescence of Laurentide and Rocky Mountain ice, whereas the final episode did not involve coalescence. A minimum age for deglaciation is provided by a date of about 10.6 ka years BP (Location 16; Fig. 21), although much older, but possibly contaminated samples are available (Table I). In the Bow River valley four glacial events, some including both Rocky Mountain and Laurentide ice, are recorded. Evidence for coalescence is lacking, as are absolute dates for the timing of the events, but Montane glacial events apparently preceded Laurentide events. The upper Bow valley was ice-free by about 11 ka years BP (Locations 22, 59, 61; Fig. 21).

In the Red Deer River area, evidence for a single Montane glaciation which preceded a Laurentide glaciation is presently recognized. The upper Red Deer valley was apparently ice free by 11.2 ka years BP, whereas farther east ice free conditions may have prevailed for about 18 ka years (Locations 21 and 25; Fig. 21). Directly to the north, in the North Saskatchewan River valley, there is evidence for three Rocky Mountain events and one Laurentide event. Absolute dates are not available to chronologically control these events, but interpretations suggest ice coalescence during the early part of the Late Wisconsinan and no coalescence during the latter part of the Late Wisconsinan. Radiocarbon dates indicate ice-free conditions persisted since about 14.5 ka years ago (Location 29; Fig. 21). On the west side of the mountains sub-till dates of 21.5 ka years ago in the Rocky Mountain Trench signal a late start for the Late Wisconsinan glaciation (Location 24 and 30; Fig. 21). In the Brazeau River area, there is convincing evidence for ice coalescence from three directions, but the timing of this event cannot be established. Radiocarbon dates indicate that minimally, ice free conditions existed since about 12.3 ka years ago to the northwest and 14.5 ka years ago to the south (Locations 62 and 29; Fig. 21). In the Athabasca River valley area at least three and possibly four episodes of Rocky Mountain and two Laurentide glaciations are recognized, with ice coalescence restricted to the final Laurentide advance. The events lack chronologic control other than a single date of 29.1 ka years BP obtained under one of the Rocky Mountain tills. Deglaciation occurred as early as 13.6 years BP for the Laurentide ice and 12.3 ka years BP for Rocky Mountain ice (Locations 36 and 62; Fig. 21).

Northeast of Jasper National Park, there is evidence for at least two and possibly three Cordilleran or Montane glaciations and one or two Laurentide glaciations. Near McGregor Plateau equivocal evidence for pre-Late Wisconsinan ice coalescence has been offered. Additionally, the Late Wisconsinan probably consisted of a Laurentide event preceding a Montane event. Directly north in both the Peace River valley and along the remaining Foothills region up to the Liard Plateau, a similar series of events has been proposed. In this region, an early Cordilleran event of pre-Late Wisconsinan age is recognized based on a series of subtill dates in the area (Locations 43, 44, 47, 50 to 56; Fig. 11). During the Late Wisconsinan, the Laurentide ice advanced and retreated before local Montane ice (~15.2 ka) advanced into the area. This region remained ice free since before 13.5 ka years ago (Location 36; Fig. 21).

Other general observations that can be made for the Rocky Mountain region concern the contribution of Cordilleran ice from

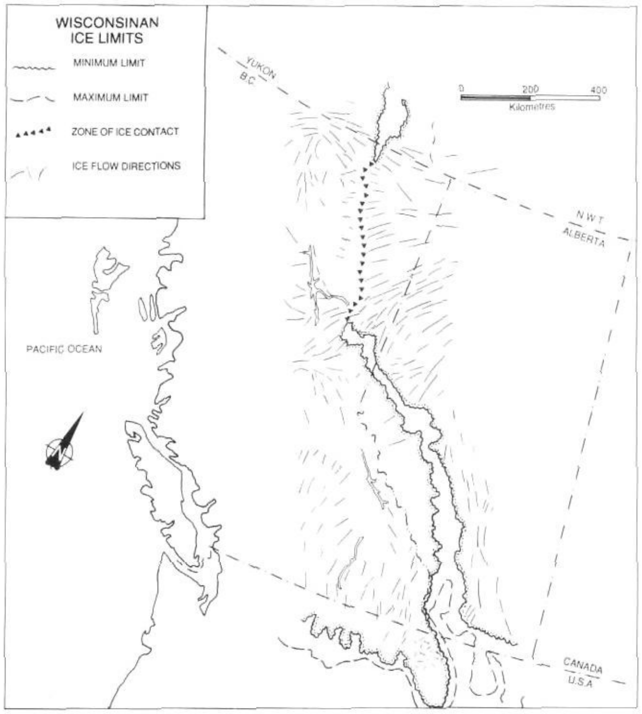

FIGURE 41. Wisconsinan ice limits (minimum and maximum) for the Canadian Rocky Mountain region only, modified after Prest (1984b).

Limites glaciaires maximales et minimales wisconsiennes dans la région des Rocheuses (modifiées à partir de Prest, 1984b).

west of the trench. Although field evidence supports the contention that western Cordilleran ice did in fact cross the Rocky Mountain Trench and the Continental Divide at a number of locations, it is equally clear that in all areas but Jasper, such an event probably pre-dates the latest Wisconsinan glaciation. The current concept of the Cordilleran Ice Sheet Complex must be revised and restricted in usage only to the earlier stages of glaciation in western Canada. During the Late Wisconsinan, glaciation in the Rocky Mountains and Foothills was of local origin (Montane ice), although Cordilleran ice probably affected much of the coastal and intermontane regions in the province of British Columbia.

Finally the timing of Late Wisconsinan glaciation must be critically assessed. As new radiocarbon dates are continually added to the list of absolute dates, it becomes apparent that the Late Wisconsinan glacial event did not fully occupy the often cited period of 25 ka to 10 ka years ago. Indeed, it now appears that in the Rocky Mountains of Canada, Late Wisconsinan glaciation may have started as late as 19 ka years ago in the south and 15 ka years ago in the north, and deglaciation may have started as early as 14 ka years ago in the south and slightly later in the north.

Collectively, the information provided in this paper further complicates the prevailing interpretations of maximum and minimum ice limits in the Canadian Rocky Mountains and Foothills regions of western Canada (Fig. 41). The suggestion of an ice-free corridor extending from the international border north to the area of McGregor Plateau, and potential ice coalescence from this point northward to the territorial border must be revised. A revised interpretation must first illustrate that the maximum limits of ice advance for the Laurentide and Rocky Mountain glaciers occurred at different times. This fact is consistently evident in the numerous composite stratigraphies presented in this paper. Additionally, any new compilation must show an absence of ice coalescence in northeastern British Columbia. Finally, revision may have to be provided for the central region, between the Athabasca and Red Deer River valleys, where coalescence did in fact occur at certain times, but that the timing of this coalescence is as yet unconfirmed. Given some of the radiocarbon dates now available for the central area, coalescence may be earlier than traditionally proposed. Although ice-free conditions were present in the extreme southern and northern parts of the "corridor" during the Late Wisconsinan, it may be possible that the corridor was closed in the central region.

IMPLICATIONS

Several items warrant consideration in research concerning the Canadian Rocky Mountains. Respecting the Quaternary, paleo-glaciological explanations must be provided for a number of questions:

— why was ice extent pan-provincial or truly Cordilleran only during pre-Late Wisconsinan times, whereas during later glacial episodes ice extent was much less? Profile estimates of the ice cap, which at one time covered the province, are not applicable for the Late Wisconsinan when local ice centres prevailed; new profiles must be developed which take into account Montane ice centres.

We have yet to reconcile the apparent anomalies of the Laurentide Ice Sheet margin:

— why would Laurentide ice originating in the Canadian Shield not expand into the adjacent areas of northwestern Alberta and northeastern British Columbia (elevations near 600 m a.s.l.) and yet expand repeatedly into southwestern Alberta (elevations near 1600 m a.s.l.) during pre-Late Wisconsinan times?

— if the pre-Late Wisconsinan Cordilleran event was so extensive why did the Laurentide Ice Sheet not expand farther along its western margin during the same period of glaciation?

— conversely, if the Late Wisconsinan Laurentide ice advance extended to the Foothills of northeastern British Columbia, why was the glaciation limit restricted in southwestern Alberta and moreover, why did the Cordilleran Ice Sheet not expand pan-provincially?

During earlier glacial episodes Cordilleran ice appears to have preceded Laurentide expansion into the Foothills regions. However, during later glacial episodes this pattern is either reversed or not evident as both ice sources expanded at about the same time. Very little is known of the Middle Wisconsinan interval in the Rocky Mountains, even though it now appears that this nonglacial interval may have lasted much longer than previously supposed. Sufficient data now exist to address many of the issues raised above. Quantitative models and qualitative speculation will both prove invaluable additions to glacial studies in the Canadian Rocky Mountains.

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