Géographie physique et Quaternaire

# Interaction of Laurentide and Cordilleran ice in the Beaver Mines area, southwestern Alberta

# L'interaction entre les glaces laurentidiennes et de la Cordillère dans la région de Beaver Mines, dans le sud-ouest de Alberta

# Interaktion zwischen dem laurentidischen Eis und dem der Kordilleren im Gebiet von Beaver Mines, Süd- west-Alberta

Philip J. Holme, Stephen R. Hicock and Lionel E. Jackson, Jr.

Volume 54, Number 2, 2000

URI: https://id.erudit.org/iderudit/004834ar
DOI: https://doi.org/10.7202/004834ar

See table of contents

Publisher(s)

Les Presses de l'Université de Montréal

ISSN

0705-7199 (print)
1492-143X (digital)

Explore this journal

Cite this article

Holme, P. J., Hicock, S. R. & Jackson, L. E. (2000). Interaction of Laurentide and Cordilleran ice in the Beaver Mines area, southwestern Alberta. *Géographie physique et Quaternaire*, *54*(2), 209–218. https://doi.org/10.7202/004834ar

Article abstract

Surficial geology mapping of the Beaver Mines area, distribution of Canadian Shield erratics, stratigraphy of Quaternary sediments exposed along the Castle River valley and its tributaries and correlation with southwestern Alberta geochronology, indicate that Cordilleran and Laurentide ice were in contact in the lower Castle River valley during the Late Wisconsinan Substage. During this time two Cordilleran glacial advances are recognised in the lower reaches of the valley, its tributaries and the western Interior Plains: 1) an earlier advance (M1), during which ice thickness averaged between 320 - 350 m thick in the Beaver Mines area, and 2) a later readvance (M2). A single Laurentide advance (C2) into the Beaver Mines area was contemporaneous with retreat of Cordilleran ice from the M2 maximum position, resulting in coalescence of the two ice masses. This followed a C1 advance that is recognised outside the area. During montane advances, glaciers were topographically-controlled and efficiently eroded their substrates. Deglaciation was characterised by ice retreat, stagnation of detached ice masses, and damming of glacial lakes by retreating Laurentide ice.

*Géographie physique et Quaternaire*, 2000, vol. 54, n° 2, p. 209-218, 4 fig.

# INTERACTION OF LAURENTIDE AND CORDILLERAN ICE IN THE BEAVER MINES AREA, SOUTHWESTERN ALBERTA

Philip J. HOLME*, Stephen R. HICOCK**, and Lionel E. JACKSON, Jr., respectively: School of Earth Sciences, Victoria University of Wellington, P.O. Box 600, Wellington, New Zealand; Deparment of Earth Sciences, University of Western Ontario N6A 5B7; Terrain Sciences Division, Geological Survey of Canada, 101-605 Robson Street, Vancouver, British Columbia V6B 5J3.

ABSTRACT Surficial geology mapping of the Beaver Mines area, distribution of Canadian Shield erratics, stratigraphy of Quaternary sediments exposed along the Castle River valley and its tributaries and correlation with southwestern Alberta geochronology, indicate that Cordilleran and Laurentide ice were in contact in the lower Castle River valley during the Late Wisconsinan Substage. During this time two Cordilleran glacial advances are recognised in the lower reaches of the valley, its tributaries and the western Interior Plains: 1) an earlier advance (M1), during which ice thickness averaged between 320 – 350 m thick in the Beaver Mines area, and 2) a later readvance (M2). A single Laurentide advance (C2) into the Beaver Mines area was contemporaneous with retreat of Cordilleran ice from the M2 maximum position, resulting in coalescence of the two ice masses. This followed a C1 advance that is recognised outside the area. During montane advances, glaciers were topographically-controlled and efficiently eroded their substrates. Deglaciation was characterised by ice retreat, stagnation of detached ice masses, and damming of glacial lakes by retreating Laurentide ice.

RÉSUMÉ *L'interaction entre les glaces laurentidiennes et de la Cordillère dans la région de Beaver Mines, dans le sud-ouest de Alberta*. La cartographie des dépôts superficiels dans la région de Beaver Mines, la répartition des blocs erratiques du Bouclier canadien, la stratigraphie des sédiments du Quaternaire mis au jour le long de la vallée de Castle River et de ses tributaires, et leur corrélation avec la géochronologie du sud-ouest de l'Alberta montrent que les inlandsis laurentidien et de la Cordillère sont venus en contact dans la vallée inférieure de Castle River pendant le sous-stage du Wisconsinien supérieur. Au cours de cette période, deux avancées glaciaires de l'Inlandsis de la Cordillère ont été identifiés dans des coupes stratigraphiques sises le long de la vallée et de ses tributaires, ainsi que dans les plaines intérieures de l'Ouest : 1) une première avancée (M1) durant laquelle l'épaisseur de la glace était en moyenne de 320 à 350 m dans la région de Beaver Mines, et 2) une avancée ultérieure (M2). La seule avancée de l'Inlandsis laurentidien (C2) dans la région de Beaver Mines, contemporaine du retrait des glaces de la Cordillère de leur position maximale en M2, a entraîné la coalescence des deux masses glaciaires. Cet événement a suivi une avancée (C1) qui a été constatée à l'extérieur de la région. Les glaciers, au cours de ces avancées en montagne, étaient assujetis à la topographie et ont érodé le substratum de manière efficace. La déglaciation a été caractérisée par un retrait des glaces, la stagnation des masses scindées et par le barrage des lacs glaciaires par les glaces laurentidiennes en retrait.

ZUSAMMENFASSUNG *Interaktion zwischen dem laurentidischen Eis und dem der Kordilleren im Gebiet von Beaver Mines, Südwest-Alberta.* Die Kartographie der Oberflächenformationen des Gebiets von Beaver Mines, die Verteilung der erratischen Blöcke des kanadischen Schilds, die Stratigraphie der entlang des Castle River-Tals und seiner Zuflüsse ausgesetzten Quartär-Sedimente sowie die Korrelation mit der Geochronologie von Südwest-Alberta zeigen, dass das Eis der Kordilleren und der laurentidische Eischild während des Spät-Wisconsin-Unterstadiums im unteren Castle River-Tal in Verbindung standen. Während dieser Zeit kann man zwei glaziale Vorstöße des Inlandeises der Kordilleren im unteren Bereich des Tals, seinen Zuflüssen und den westlichen inneren Ebenen feststellen : 1) ein früherer Vorstoß (M1) mit einer durchschnittlichen Eisdicke von 320-350 m im Gebiet von Beaver Mines und 2) ein späterer Rückvorstoß (M2). Ein einziger Vorstoß des laurentidischen Inlandeises (C2) in das Gebiet von Beaver Mines fand gleichzeitig mit dem Rückzug des Eises der Kordilleren von der M2 Maximum-Position statt, was zu einem Zusammenschluss der zwei Eismassen führte. Dies erfolgte auf einen C1 Vorstoß, der außerhalb des Gebiets zu erkennen ist. Die Gletscher waren während dieser Vorstöße in den Bergen durch die Topographie kontrolliert und haben den Untergrund sehr erfolgreich ausgewaschen. Die Enteisung charakterisierte sich durch Eisrückzug, Stagnierung der losgelösten Eismassen und Eindämmung der glazialen Seen durch das zurückweichende laurentische Eis.

Manuscrit reçu le 23 avril 1999 ; manuscrit révisé accepté le 8 mars 2000

* E-Mail address: Philip.Holme@vuw.ac.nz
** E-Mail address: shicock@julian.uwo.ca

## INTRODUCTION

In this paper we present new data on Laurentide-Cordilleran ice interaction from the southwestern part of Alberta, based on the distribution of glacial drift as determined from mapping surficial geology, ice limit elevations, and the study of Quaternary sediment exposed along the Castle River valley (hereafter called the Castle valley) and its tributaries (Fig. 1). Previous work in southwestern Alberta has concentrated on the record of the southwestern part of the (continental) Laurentide Ice Sheet that originated in the Keewatin accumulation sector (*e.g.* Dawson and McConnell, 1895; Alley, 1973; Stalker, 1977; Jackson *et al.*, 1989; Young *et al.*, 1994). Detailed studies that extended westward and considered Cordilleran (montane) ice in the Foothills and Rocky Mountains have included those of Horberg (1954), Stalker (1962, 1963, 1969), Wagner (1966), Alley (1973), Jackson (1980), Leboe (1996), Levson and Rutter (1996), and Barendregt and Irving (1998). From this work two incompatible hypotheses have emerged: 1) multiple drift units exposed along the Oldman, Belly and Waterton rivers represent multiple glaciations (Alley, 1973; Stalker, 1977; Stalker and Harrison, 1977; Jackson, 1980; Jackson *et al.*, 1989) and 2) all drift on the Interior Plains of Alberta was deposited during the Late Wisconsinan Substage (Horberg, 1954; Wagner, 1966; Bayrock, 1969; Liverman *et al.*, 1989; Young *et al.*, 1994; Little, 1995; Leboe, 1996; Jackson *et al.*, 1996, 1997, in press; Duk-Rodkin *et al.* 1998). The recent work strongly supports the latter hypothesis, as does this study. Furthermore, this study shows that Laurentide and Cordilleran ice coalesced near the mouth of the Castle valley and that an "ice-free corridor" could not have been open continuously through the Late Wisconsinan which corroborates earlier work by Young *et al.* (1994), Burns (1996), and Jackson *et al.* (1997).

The present study was conducted as part of the Geological Survey of Canada's eastern Cordillera National Geoscience Mapping Program (NATMAP project), and contributed a surficial geology map, two progress reports, and a thesis (Holme, 1997, 1998a, b; Holme *et al.*, 1998). Through the course of the study it was found that the absence or presence of granitoid clasts from the Canadian Shield (hereafter called shield clasts) could be used to differentiate between Cordilleran (montane) till that lacks them, and continental till (deposited by the Laurentide Ice Sheet) that has them. These shield plutonic and metamorphic lithologies are absent from the Rocky Mountains, Foothills, and Interior Plains of southwestern Alberta and adjacent areas of Montana and British Columbia (Wheeler and McFeely, 1991) with the exception of one localised source of rare small granitic clasts (Douglas, 1950). The latter are quite distinctive from granites that are characteristic of the Canadian Shield. Laurentide ice limits were determined by noting the distribution of continental till and the highest elevation at which shield clasts occur on hillsides. Because of the importance of finding shield clasts, great care was taken in searching for them, whether on the ground surface or in sedimentary exposures. Near-vertical cliffs along the Castle valley were accessed using rappel lines and trenched using pick and shovel. Following exposure, sediment units and contacts were photographed, documented, and sampled.

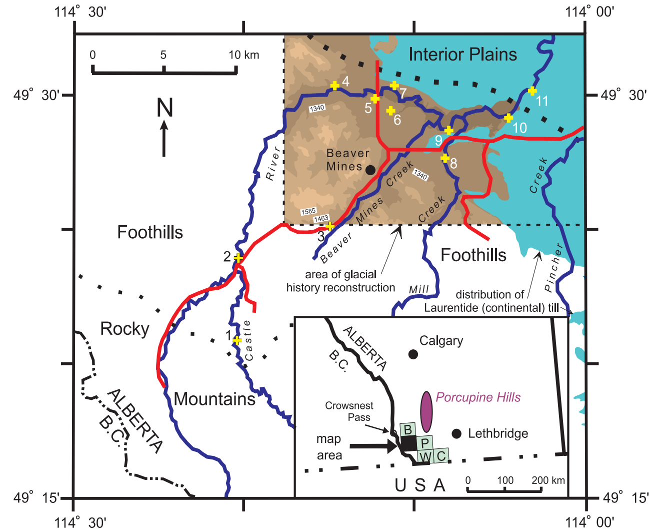


FIGURE 1. Location map of the Beaver Mines area showing major streams, roads, and physiographic boundaries (dotted lines), section locations (yellow crosses), distribution of Laurentide till (turquoise), and topography in the area of glacial history reconstruction. In the inset, light green squares adjacent to the Beaver Mines area (black square) represent the Blairmore (B), Pincher Creek (P), Waterton (W) and Cardston (C) map areas.

*Carte de localisation de la région de Beaver Mines avec les principaux cours d'eau, les routes et les limites physiographiques (pointillé), l'emplacement des coupes (croix jaunes), la distribtion du till laurentidien (turquoise), ainsi que la topographie dans la zone de reconstitution de l'évolution glaciaire. Les carrés vert pâle, adjacents à la région de Beaver Mines (carré noir) dans le carton, représentent les cartes des régions de Blairmore (B), de Pincher Creek (P), de Waterton (W) et de Cardston (C).*

## DRIFT DISTRIBUTION AND ICE LIMITS

Holme's (1998b) Beaver Mines surficial geology map, and the southern edge of the adjacent Blairmore sheet to the north (Jackson and Leboe, 1998), are simplified in Figure 1, which is referred to as the Beaver Mines area in this paper. It also shows the distribution of Laurentide drift in the northeastern part of the area (up to an elevation of 1355 m), based on the occurrence of shield clasts on hillsides and in continental till exposed in valleys. Montane drift occurs throughout the Beaver Mines area and discontinuously extends well into the Interior Plains to the east, reaching almost as far as Lethbridge (Fig. 1 inset; Stalker, 1963; Wagner, 1966; Leboe, 1998a, b). At its maximum, glacial ice in the area filled all valleys and was a discontinuous mass averaging 320 - 350 m in the study area.

Up to two montane tills are found in the Beaver Mines area, while a single continental till is recognised in the northeastern part of the area and along its eastern edge, based on the presence of shield clasts in till matrix. The tills are separated by various proportions and thicknesses of ice marginal, glaciofluvial, and glaciolacustrine sediments, and unit contacts are commonly erosional. Where two montane tills occur in stratigraphic sections (6 to 11 in Fig. 1), the lower till is designated M1 for an earlier advance of Cordilleran ice, and the upper is designated M2 for a later readvance. In sections 1 to 5 only one montane till is found and

M1 and M2 labels do not apply as Cordilleran ice appears to have occupied these sites continuously when M1 and M2 advances and retreats were occurring farther down the Castle valley and its tributaries.

## SECTION DESCRIPTIONS AND SEDIMENT GENESIS

Exposures along the Castle River valley and its tributaries provided stratigraphic sections (Fig. 2) that are numbered 1 to 11 downstream toward the Plains in Figure 1. Grain size data from the matrix-supported, sandy silt diamictons reflect the textural composition of local substrate, and pebble lithology data from diamictons reflect local bedrock lithologies, except for the occurrence of shield clasts. Compaction (high density), fissility, subangular to subrounded, striated and faceted stones, and sheared lenses of sand into diamictons from underlying sediments at most sites indicate that diamictons were deposited as subglacial till under active ice. Exceptions occur at sites 5 and 8 where glaciogenic debris flow diamictons occur in ice contact complexes, as described below. Stone provenance confirms that montane ice flow was downvalley.

At section 1, montane till (lacking shield clasts) is sandwiched between gravel units. The lower gravel generally coarsens upward, is imbricated in places, and contains interbeds and lenses of laminated silt and clay with sharp contacts. We interpret this unit as proglacial outwash with ponded sediments that was deposited by a glacier advancing down the Castle valley prior to forming the overlying till that contains a large striated boulder. The upper gravel is horizontally and foreset bedded. We interpret it as retreat outwash following till deposition. The section is capped by thinly bedded sand with dewatering structures, interpreted as either distal outwash or postglacial fluvial sediment.

Section 2 also contains montane till that separates gravel units. At the base of the section is foreset-bedded medium sand with gravel interbeds near the top. It is abruptly overlain by poorly sorted gravel that is imbricated in places and contains sand lenses in its upper part. This sand-gravel sequence probably represents a proglacial delta that is overlain by channel outwash deposits of a glacier advancing down the Castle valley. Abruptly overlying this is the till with a boulder concentration and sheared sand lenses at its base. The upper gravel unit sharply overlies the till and is imbricated and interbedded with sand. We interpret it as retreat outwash topped by aeolian or lacustrine silt and fine sand.

Section 3 was an exposure in the wall of a trench for a natural gas pipeline. In the exposure montane till is crudely stratified in its upper part and is overlain by poorly sorted, slightly imbricated gravel that we interpret as proximal retreat outwash.

The creek gully at section 4 contains montane till with sheared sand lenses that rests on bedrock and is overlain by medium sand with stones that probably represents retreat outwash or proximal glaciolacustrine sediments.

At section 5, montane till with gravel lenses and joints rests on bedrock and is overlain by a complex package of contorted diamictons with clastic dykes, gravel, sand and silt with dropstones. A single shield clast was found at the base of the package. The package is interpreted as an ice-marginal complex with glaciogenic debris flows that formed during a brief retreat and/or stillstand of montane ice. It is covered by rhythmically laminated silty clay, likely deposited in a glacial lake that formed during final retreat of montane ice.

Section 6 contains two montane tills that are separated by sand and laminated silt. The lower till represents the earlier M1 advance. It rests on bedrock and contains sandy lenses with a cobble lodged into the top of one of them, deforming it. Fine sand and silt with occasional stones overlie the till and are interpreted as distal outwash with mud deposited in local areas of ponding, or as glaciolacustrine sediments. Sharply overlying this is the upper till that is texturally similar to the lower till but represents the M2 readvance. The upper till contains clasts of coal, sand stringers, and is sandier near its base, reflecting incorporation of underlying outwash as ice overrode it.

Section 7 also contains two montane tills, separated by gravel. The lower, M1 till rests on bedrock. It is sharply overlain by weakly bedded gravel that coarsens upward and is interpreted as advance outwash of the M2 readvance. This is overlain by M2 till that is texturally similar to the lower till and contains a sandy lens near its base. It is overlain by a thick sequence of rhythmically bedded fine sand and silt whose layering decreases in thickness upward and probably represents increasingly distal deposition in a glacial lake during M2 retreat. Poorly sorted postglacial gravel rests on the lake sediments and is overlain by fine dune or lacustrine sand.

At section 8, two montane tills overlie poorly sorted gravel that rests on bedrock. The gravel probably represents advance outwash of the M1 event. It was overridden by M1 ice, resulting in deposition of the lower till whose matrix has equal amounts of sand and silt. The lower till has a sand lens incorporated from underlying outwash and is separated from the upper till by a complex package of interbedded diamicton, sand, and gravel that is interpreted as an ice-marginal deposit with glaciogenic debris flows that formed when M1 ice experienced retreat and/or a stillstand near section 8. The upper till has more silt in its upper part than the lower till, but contains sand lenses, stringers, and more sand in its matrix near its base, reflecting overriding of the ice-marginal package during the M2 readvance.

Section 9 contains two montane tills with inclusions of sorted sediments. The lower till represents the M1 advance and is directly overlain by the upper till (M2 readvance) which is texturally similar to the lower one. The upper till contains blocks of gravel and sand stringers near its base that were probably incorporated from outwash that was deposited on the lower till but was eroded by M2 ice. The section is capped by interbedded sand and silt that are interpreted as either distal recessional outwash or lacustrine sediments.

Two montane tills are separated by gravel in the lower part of section 10, which was first described by Stalker (1969). At that time the lower till was not visible, whereas during the present study, the section was analysed just after a 100-year

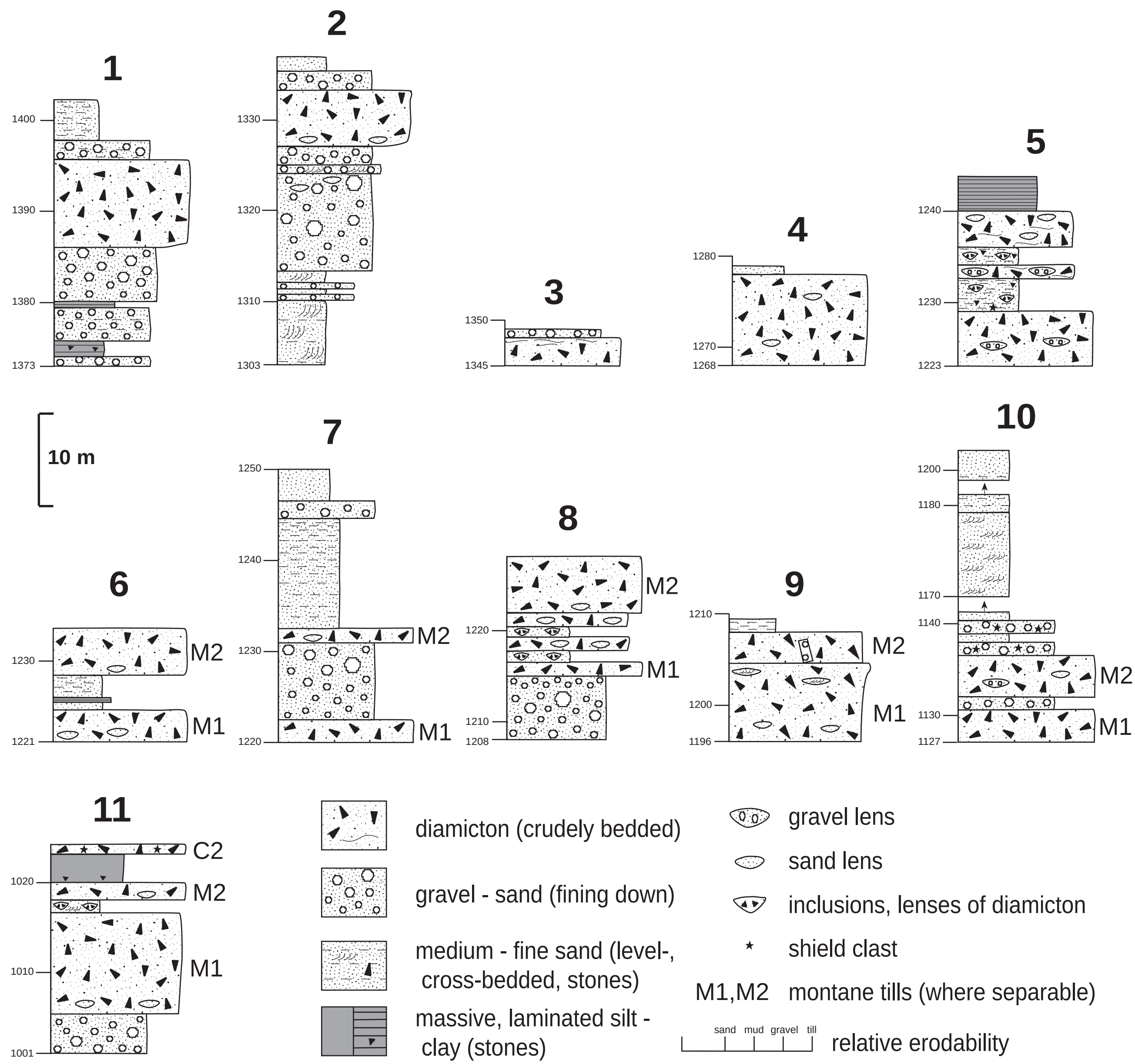


FIGURE 2. Stratigraphic sections (1 to 11) with elevations (metres above sea level) arranged downstream toward the Interior Plains. Gaps with arrows in section 10 represent continuation of the same sediment as below, to the top of the gap.

*Coupes stratigraphiques (1 à 11) avec les altitudes (mètres au-dessus du niveau de la mer) réparties d'amont en aval vers les plaines de l'intérieur. La lacune où apparaît une flèche dans la coupe 10 représente le prolongement du même sédiment qu'en dessous jusqu'au haut de la lacune.*

flood that scoured the base of the section clean. The lower till represents the M1 advance and is truncated by gravel and sand that coarsen upward and are most likely advance outwash deposits. The outwash is overlain by another till with dykes and wedges of gravel and sand near its base that reflect incorporation of outwash during the M2 readvance. The M2 till is overlain by more than 30 m of gravel that is interbedded with sand and contains a mixture of montane and shield lithologies (Fig. 2). This is overlain by a sequence of cross-bedded medium to coarse sand that grades up into 19 m of interbedded sand and silt with scattered stones and paleosols in its upper part that is capped by aeolian or lacustrine sand. The lowest coarser part of the interbedded gravel-sand sequence is probably outwash reflecting a retreating M2 ice margin. The interbedded sand-silt part probably represents Holocene sediments that were deposited in a small stream channel that was carved into Pleistocene glaciofluvial sediments. This is indicated by radiocarbon ages of bones, charcoal, and shells that range from 6.3 to 1.8 ka (Stalker, 1969).

Stalker (1969) interpreted section 10 (his Mountain Mill Bluff) as comprising a single montane till that was obscured by slump at its base and overlain by thick outwash, fluvial, and aeolian sediments. He thought the morphology of the till represented a terminal moraine that was deposited by an ice advance between 6.2 and 7.2 ka. These conclusions were disputed by Wagner and Eschman (1970) and we also disagree. First, the till cannot represent a terminal moraine because both M2 and M1 tills were found farther downvalley during this study at section 11. Second, the morphology of the till unit was likely caused by differential glaciofluvial erosion, resulting in the till thickening and thinning in places to give the impression of a buried moraine. Furthermore, Stalker's (1969) radiocarbon ages were on organic remains (including bones) in sand and gravel beds that overlie the upper (M2) till. He thought the sand and gravel package was recessional outwash and the dates represented minimum ages for the underlying till. Wagner and Eschman (1970) reported that the exposure was heavily slump-covered so that stratigraphic relations were obscured and the organics could have been deposited by postglacial streams about 6.2 ka. We propose that the organics and host sediment are a Holocene fluvial deposit nested within M2 retreat outwash that was incised by the postglacial Castle River. In addition, there has been no evidence from the Canadian or American Cordillera (*e.g.* Osborn and Luckman 1988) to support a Holocene glacial event of sufficient magnitude to extend down the Castle valley as far as 30 km beyond the mountain front.

Finally, section 11 contains two montane tills overlain by a continental till, all of which are separated by sorted sediments. The lowest unit is poorly sorted gravel that rests on bedrock and is probably an outwash deposit of the M1 advance. The lower till represents the M1 advance and contains sheared sand stringers and pockets in its lower part, probably reflecting ice overriding of outwash. The till is truncated by deformed coarse sand containing lenses of diamicton that together probably represent outwash and/or ice marginal deposits. These are overlain by the middle, M2 till that is texturally similar to the lower one and contains sand stringers near its base, probably from ice overriding and deforming outwash. The M2 till is overlain by medium silt with stones, probably distal outwash or glaciolacustrine sediments. The section is capped by C2 till, the only continental till encountered in our stratigraphic sections. It is compacted and contains shield clasts, indicating that ice originated from the northeast.

## GLACIAL HISTORY

In general, till was deposited under glacial ice that efficiently eroded and comminuted substrate and commonly sheared up and incorporated underlying sediment into the till, as reflected in its textural and lithologic composition. Stone provenance indicates that montane ice flow was topographically-controlled down mountain valleys in most of the area and coalesced to form piedmont glaciers at the mountain front before flowing to the east and southeast. Ice marginal, glaciofluvial, and glaciolacustrine sediments were associated with glacial advances and retreats. Based on the distribution and stratigraphic relations of the three drift units identified in the study area, as well as regional correlation, the following sequence of events is reconstructed. These events apply mainly to the lower Castle valley area (coloured in Fig. 1) where Cordilleran and Laurentide ice interacted. Resulting Quaternary sediments and landforms are shown on the Beaver Mines, Blairmore and Pincher Creek map sheets by Holme (1998), Jackson and Leboe (1998) and Leboe (1998b).

### M1 ADVANCE

The M1 was the most extensive glacial advance from the Rocky Mountains during the last (Late Wisconsinan) glaciation in southwestern Alberta. At the Late Wisconsinan maximum, the paleo-firn line was in the range of 1680 to 1820 m and glacier extended into the Interior Plains at least 100 km beyond the Rocky Mountains - well beyond the Beaver Mines area (Stalker, 1963; Jackson *et al.*, 1996; Wagner, 1966; Leboe, 1998a, b). The limits of this advance are primarily based upon the distribution of the stratigraphically lowest (oldest) montane till found in the buried valley systems of the Foothills and adjacent Interior Plains in southwestern Alberta. This is likely the Albertan Till of Stalker (1963) and it lacks any evidence of shield clasts or minerals. Thus it was concluded that continental ice did not reach the Foothills prior to the deposition of the Albertan Till (Dawson and McConnell, 1895; Horberg, 1954; Stalker, 1963; Wagner, 1966; Stalker and Harrison, 1977). The largest single source of glacial ice in the southwestern Foothills was the Crowsnest Pass area (Fig. 1 inset) where ice crossed the continental divide from extensively glaciated areas of the Rocky Mountains to the west and joined glaciers draining the eastern side of the continental divide (Jackson *et al.*, 1996). This combined glacier flow was roughly west to east across the Foothills immediately north of the area depicted in Figure 1.

Within the Beaver Mines area (Fig. 1) valley glaciers emerged from the Rocky Mountains and flowed northeast through pre-Late Wisconsinan river valleys in the Foothills (Fig. 3a). The largest source of ice in the study area was the Castle valley and its tributaries. As the glaciers filled their valleys they spilled over interfluves and coalesced. Lowest cirque and nunatak elevation data (from air photos) reveal that the resultant ice mass (Fig. 3b) reached elevations between 1660 and 1720 m near the mountain front, and up to 1525 m along the western edge of the Interior Plains. Although ice thickness varied according to local topographic configurations and size of ice-sheds, it averaged 320 - 350 m in the study area. At its maximum, the M1 ice mass was almost continuous with only mountain peaks and the highest parts of the Foothills protruding as nunataks.

### M1 RETREAT AND C1 ADVANCE

After reaching its maximum position near the present site of Lethbridge, Alberta (Jackson *et al.* 1996), the retreat of M1 was followed by the incursion of the Laurentide Ice Sheet into the Foothills. This initial continental (C1) advance is represented by the stratigraphically lowest continental till found in the Foothills. This was originally called the "lower till" by Horberg (1954) and Labuma Till by Stalker (1963) which is used here. The Labuma Till either directly overlies the Albertan Till or is separated from it by lacustrine or distal outwash deposits with conformable contacts. No evidence of fluvial erosion deposits such as lag gravels or weathered profiles have been

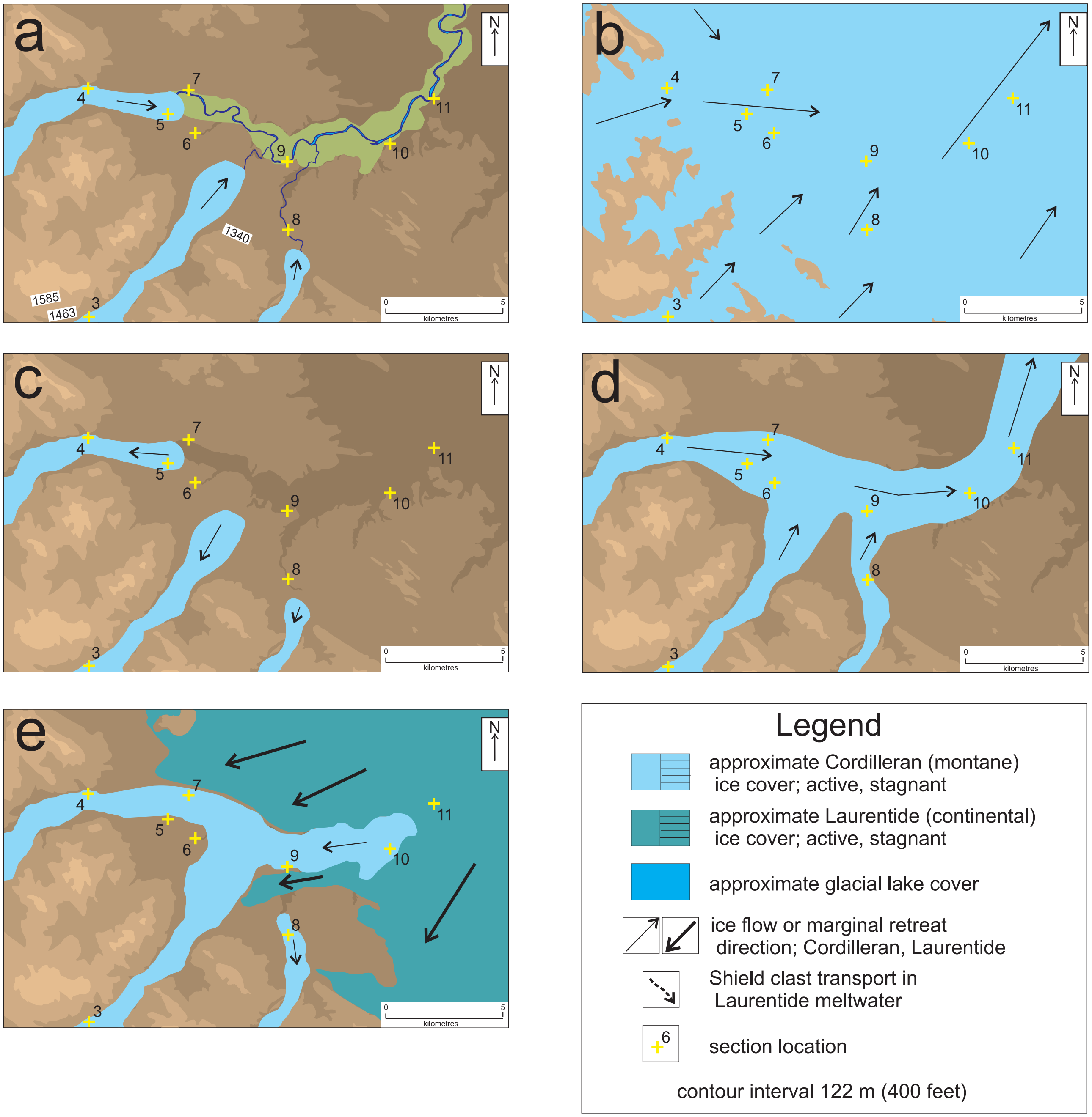


FIGURE 3. Paleogeographic maps of glaciation in the study area: a) onset of Cordilleran valley glaciation; b) M1 maximum (probably coalesces with Laurentide ice outside the area depicted); c) limit of M1 retreat into mountain valleys (position of C1 probably outside area depicted); d) M2 readvance; e) Laurentide maximum C2 position and first stillstand or slowdown of M2 retreat in Castle valley. Contour interval is 122 m (400 feet). Lack of contours on ice does not imply a flat glacier surface.

*Cartes paléogéographiques de la glaciation dans la région à l'étude : a) début de la glaciation de vallée de la Cordillère ; b) maximum de M1 (coalescence probable avec les glaces laurentidiennes en dehors de la région décrite) ; c) limites du retrait de M1 à l'intérieur des vallées (l'emplacement de C1 est probablement à l'extérieur de la région décrite) ; d) l'avancée de M2 ; e) la position C2 du maximum laurentidien et première pause ou premier ralentissement au cours du recul de M2 dans la vallée de la Castle River. L'intervalle entre les courbes est de 122 m. L'absence de courbe sur la glace n'implique pas qu'elle soit plate.*

found between the two tills. This led Stalker and Harrison (1977; and all subsequent investigators) to conclude that what we call the M1 retreat and C1 advance were roughly time equivalent, although their absolute age was contended. Douglas (1950) and Jackson *et al.* (1996, in press) found that, during what we call C1, continental ice overtopped the northern end of the Porcupine Hills where it deposited erratics on summits presently as high as 1750 m (up to 1585 m on Cloudy Ridge) along the Rocky Mountain front between the Beaver Mines area and the Waterton area to the south (Fig. 1 inset). However, within major valleys like the Castle, which head along the Continental Divide, the western limit of Canadian Shield erratics is found farther east and at lower elevations compared to the upper limits of Shield erratics on interfluves. Wagner (1966) suggested that these were areas where montane and continental ice were in contact and where continental ice was prevented from penetrating deeper into the Foothills. Jackson *et al.* (1996) recorded the same pattern and noted the highest elevations of shield erratics to occur in areas between major valleys along the Rocky Mountain front and along the summit of the Porcupine Hills. The absence of shield clasts from M2 till within the Beaver Mines area supports Wagner's (1966) suggestion that at its maximum position, the C1 Ice Sheet was excluded from the Beaver Mines area by M1 ice. Following the C1 maximum, montane ice from the Castle valley retreated to the Rocky Mountain front (Fig. 3c). In the Castle valley it retreated to a point between sections 7 and 4 at a minimum elevation of 1220 m, according to the occurrence of glaciofluvial and glaciolacustrine sediments between M1 and M2 tills at section 7 and only a single montane till at section 4. Similarly, ice marginal deposits separating two tills at section 8 suggest that ice retreated up the Mill Creek valley to at least that position.

## M2 ADVANCE

A subsequent lesser advance of montane ice reached beyond the mountain front (Fig. 3d), based on the occurrence of M2 till at all sections downvalley of section 7. It is possible that the M2 advance eroded earlier continental tills in the valley but, if so, some evidence of this should be preserved (*e.g.* reworked shield clasts in M2 drift). None was found by us. However, Leboe (1996, 1998b), working along the Rocky Mountain front immediately to the east in Pincher Creek map area (82 H/5; Fig. 1, area P), found hummocky montane drift bearing shield stones which were clearly derived from reworking C1 drift (area of UTM zone 12 U, UTM 283000, 5463000). Continental ice was able to reach the wall-like mountain front in this area during C1 because only small drainage basins breach it. As a consequence, the barrier presented by local montane glaciers was minimal. The M2 drift in this area is in turn overlain in part by the C2 moraine (see below).

## M2 RETREAT AND C2 ADVANCE

Glacial retreat from the M2 maximum was complex, involving at least three stillstands within the Castle valley, as well as the coalescence of montane ice with readvancing Laurentide ice (C2; Fig. 3e). From its M2 maximum, Cordilleran ice retreated westward as Laurentide ice advanced into the lower Castle valley area from the east and northeast. The Castle valley glacier either slowed its retreat or experienced a stillstand at about 1060 m elevation between sections 10 and 11 as Laurentide ice advanced and overran section 11, depositing C2 continental till there. In fact, the Castle valley glacier may have acted as a barrier to Laurentide ice and prevented it from entering the valley upstream of section 11.

Shield erratics on uplands to the north and south of the Castle valley indicate that Laurentide ice invaded farther west than section 10. To the north, Laurentide ice overtopped at least one bedrock ridge and reached an elevation of 1310 m (Jackson and Leboe, 1998). South of Castle valley Laurentide ice pushed westward into the Foothills between Mill and Pincher valleys where it reached as high as 1356 m (Figs. 1, 3e). Finally, the presence of a small patch of Laurentide till to the northwest of site 8, at 1280 m, infers that a small tongue of Laurentide ice flowed southwestward along the southern edge of the Castle valley (Fig. 3e) because small hills immediately east of this patch do not contain Laurentide till.

## DEGLACIATION

Following its C2 maximum, Laurentide ice generally retreated eastward in a series of stillstands resulting in a fluctuating ice margin that produced numerous glacial lake phases (Leboe, 1996). From the great thickness of outwash with mixed provenance at section 10 it is suggested that the Castle valley glacier either slowed its retreat or experienced another stillstand while outwash from both ice masses accumulated there. As a source of continental material, it is proposed that a block of stagnant Laurentide ice survived on the lee side of the ridge that was overridden north of Castle valley (Fig. 4a). Its meltwater could have flowed along the north flank of the Castle valley glacier and mixed with montane outwash at section 10. No imbricated gravel deposits or meltwater channels were found but evidence for this transport of shield clasts may be buried under glaciolacustrine sediments. It is possible that the shield clasts are reworked from a previous incursion of continental ice (C1?), but this is unlikely because there are no shield clasts in either of the underlying tills.

During Laurentide retreat the Castle valley glacier receded up its valley to section 5 at an elevation of about 1255 m where ice retreat slowed or a third stillstand occurred, resulting in the deposition of a complex sequence of ice-marginal sediments (Fig. 4b). The Shield erratic found at the base of this sequence could have been transported to the site in outwash that originated from the stagnant remnant of Laurentide ice to the north of section 7. Alternatively, it could have been reworked from earlier (C1?) Laurentide drift not yet recognised in the lower Castle valley. With subsequent retreat, ice no longer spilled across interfluves, leaving ice remnants to downwaste in some valleys (Fig. 4c). Evidence for ice stagnation includes eskers preserved at the mountain front near Mill Creek valley, and eskers, crevasse-fills, and kettled terrain present in a depression that is surrounded by higher glaciolacustrine sediments near the mouth of the Beaver Mines valley. The latter were deposited in Glacial lakes Caldwell (1310 m;

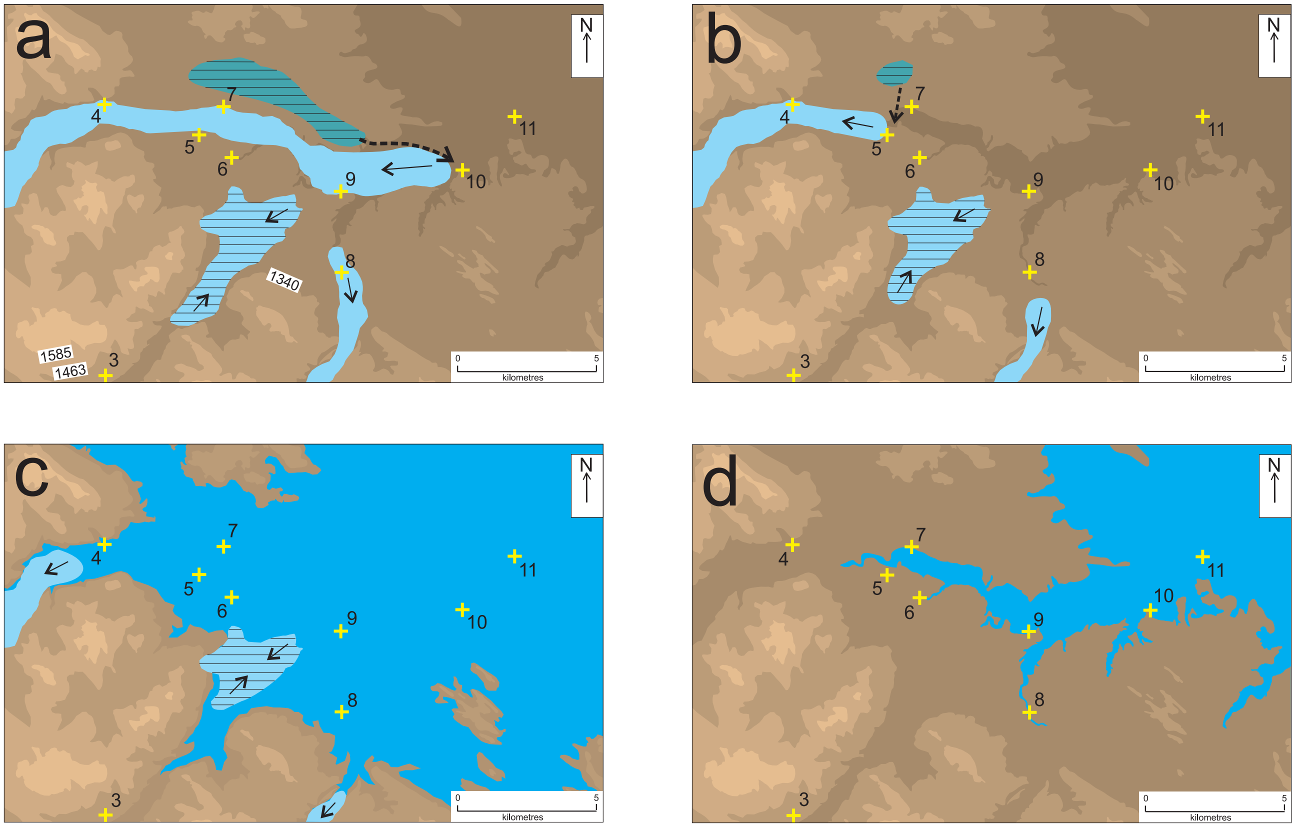


FIGURE 4. Paleogeographic maps of deglaciation in the study area (see legend on Fig. 3): a) second stillstand or slowdown of M2 ice retreat showing stagnant mass of Laurentide ice and possible meltwater transport of shield clasts to section 10; b) third stillstand or slowdown of Castle valley glacier retreat at section 5 showing possible meltwater transport of shield clasts from a Laurentide ice remnant; c) glacial Lake Caldwell (1310 m) surrounding a stagnant Cordilleran ice mass at the mouth of Beaver Mines valley; d) glacial Lake Cardston (1213 m) dammed by retreating Laurentide ice.

*Cartes paléogéographiques de la déglaciation dans la région à l'étude (voir la légende à la fig. 3) : a) deuxième pause ou deuxième ralentissement au cours du recul de M2 montrant la masse glaciaire laurentidienne stagnante et peut-être le transport par l'eau de fonte de fragments du Bouclier vers la coupe 10 ; b) troisième pause ou troisième ralentissement au cours du recul du glacier de la vallée de la Castle River à l'emplacement de la coupe 5 montrant peut-être le transport par l'eau de fonte de fragments du Bouclier à partir de la glace laurentidienne résiduelle ; le Lac glaciaire Caldwell (1310 m) entourant une masse glaciaire stagnante de la Cordillère à l'embouchure de la vallée du Beaver Mines Creek ; d) le Lac glaciaire Cardston (1213 m) barré par la glace laurentidienne en retrait.*

Fig. 4c; Bretz, 1943; Horberg, 1954) and Cardston (1219 m; Fig. 4d) that were dammed by minor readvances of the Laurentide Ice Sheet (Leboe, 1996), flooding most of the lower Castle valley area while montane ice stagnated near Beaver Mines valley. As deglaciation progressed, large volumes of meltwater coursed through valleys and lowlands recently vacated by glacial ice.

## CHRONOLOGY

M1 and M2 tills predate C2 till at section 11 but there is no evidence of weathering or soil formation in any of the sediments studied that is indicative of a significant hiatus in glacial sedimentation. Perhaps the evidence has been removed by glaciation but we think it probable that some evidence would have survived (*e.g.* inclusions of weathered sediment or paleosol within glacial drift) and that we should have found it. Therefore, it is likely that all sedimentary units of this study were formed during the same glaciation. Although no datable materials were found in our Pleistocene sediments, correlation can be made with ages recently determined outside the study area in southern Alberta.

Leboe (1996) analysed Pleistocene sediments for paleomagnetism in a high river bank 3.5 km north of section 11. All 59 samples were normally polarised, indicating that all sediments there are younger than 780 ka, as was later confirmed by the regional study of Barendregt and Irving (1998). Further refinement comes from the work of Liverman *et al.* (1989) and Young *et al.* (1994) who obtained Middle Wisconsinan radiocarbon ages from wood and bone in gravel beneath continental till in central Alberta, thereby limiting the maximum age for the till to the Late Wisconsinan. The absence of pre-Late Wisconsinan till in the Edmonton area indicates that Laurentide ice did not reach Edmonton until the Late Wisconsinan. These results are supported by cosmogenic chlorine-36 exposure dating of boulders in the Foothills erratics train (Jackson *et al.*, 1997) and erratics associated with the C1 and C2 advances in the Waterton, Cardston, and Porcupine Hills areas (Fig. 1; areas W, C, B; Jackson *et al.* in press). The Late Wisconsinan ages (*ca.* 11-17 ka) of these erratics indicate the minimum time elapsed since boulder transport and deposition of the erratics. Thus, Laurentide and M2 tills in southwestern Alberta are of the same (Late Wisconsinan) age. Furthermore, the lack of evidence for significant subaerial exposure and weathering in our sediments suggests that M1 and M2 tills were also deposited during the Late Wisconsinan Substage.

## CONCLUSIONS

At its maximum the Laurentide Ice Sheet was in contact with Cordilleran ice near the mouth of the Castle valley. Based on stratigraphic relations at site 11, lack of evidence for weathering, and correlation with southern Alberta Quaternary geochronology, all glacial sediments investigated in this study are most likely of Late Wisconsinan age. In the study area valley glaciers eroded local substrate while they advanced and coalesced beyond the mountain front on at least two occasions, separated by a glacial retreat that was not long enough for weathering to occur. At its maximum extent, montane ice attained an average thickness in the study area generally between 320 – 350 m and only the highest parts of the Foothills protruded as nunataks. Deglaciation of the area was characterised by retreat and stagnation of montane ice near valley mouths while retreating continental ice dammed meltwater to form glacial lakes.

## ACKNOWLEDGEMENTS

Research was supported by a Natural Sciences and Engineering Research Council of Canada operating grant to Hicock and by the Geological Survey of Canada's Nattional Geoscience Mapping Program (NATMAP). V. Levson and J.-S. Vincent provided thorough and helpful reviews of the manuscript.

## REFERENCES

Alley, N.F., 1973. Glacial stratigraphy and the limits of the Rocky Mountain and Laurentide ice sheets in southwestern Alberta, Canada. Canadian Petroleum Geology Bulletin, 21:153-177.

Barendregt, R.W. and Irving, E., 1998. Changes in the extent of North American ice sheets during the late Cenozoic. Canadian Journal of Earth Sciences, 35:504-509.

Bayrock, L.A., 1969. Incomplete continental glacial record of Alberta, Canada: Quaternary geology and climate. National Academy of Sciences Publication 1701: 99-103.

Bretz, J.H., 1943. Keewatin end moraines in Alberta, Canada. Geological Society of America Bulletin, 54: 31-52.

Burns, J.A., 1996. Vertebrate paleontology and the alleged ice-free corridor; the meat of the matter. Quaternary International, 32: 107-112.

Dawson, G.M. and McConnell, R.G. 1895. Glacial deposits of southwestern Alberta in the vicinity of the Rocky Mountains. Geological Society of America Bulletin, 7: 31-66.

Douglas, R.J.W., 1950. Callum Creek, Langford Creek, and Gap map-areas, Alberta. Geological Survey of Canada Memoir 255, Ottawa.

Duk-Rodkin, A., Lemmen, D.S. and Klassen, R.W., 1998. Interactions of Laurentide and Cordilleran ice during the Late Wisconsinan. Geological Society of America, Annual Meeting, Abstracts with Programs 30: A51-52.

Holme, P.J., 1997. Quaternary geology and terrain inventory, eastern Cordillera NATMAP project report 4: Investigation of continental and montane advances in the Beaver Mines map area, southwestern Alberta. Geological Survey of Canada, Current Research 1997-A: 177-182.

Holme, P.J., 1998a. Surficial geology, Beaver Mines, Alberta. Geological Survey of Canada, Map 1932A, 1:50 000.

Holme, P.J., 1998b. Quaternary geology and stratigraphy of the Beaver Mines map area, southwest Alberta. M.Sc. thesis, The University of Western Ontario, London, 124p.

Holme, P.J., Hicock, S.R. and Jackson, L.E., Jr., 1998. Quaternary geology and terrain inventory, eastern Cordillera NATMAP project report 5: Stratigraphic correlation of glacial deposits in the Beaver Mines map area, southwestern Alberta. Geological Survey of Canada Current Research 1998-E: 11-17.

Horberg, L., 1954. Rocky Mountain and continental Pleistocene deposits in the Waterton region, Alberta, Canada. Geological Society of America Bulletin, 65:1093-1150.

Jackson, L.E., Jr., 1980. Glacial history and stratigraphy of the Alberta portion of the Kananaskis Lakes map area. Canadian Journal of Earth Sciences, 17: 459-477.

Jackson, L.E., Jr. and Leboe, E.R., 1998. Surficial geology, Blairmore, Alberta. Geological Survey of Canada, Map 1930A, 1:50 000.

Jackson, L.E., Jr., Little, E.C., Leboe, E.R. and Holme, P.J., 1996. A re-evaluation of the paleoglaciology of the maximum continental and montane advances, southwestern Alberta. Geological Survey of Canada Current Research 1996-1a: 165-173.

Jackson, L.E., Jr., Phillips, F.M., and Little, E.C., in press. Cosmogenic $^{36}Cl$ dating of the maximum limit of the Laurentide Ice Sheet in southwestern Alberta, Canada. Canadian Journal of Earth Sciences.

Jackson, L.E., Jr., Phillips, F.M., Shimamura, K. and Little, E.C., 1997. Cosmogenic $^{36}Cl$ dating of the Foothills erratics train, Alberta, Canada. Geology, 25: 195-198.

Jackson, L.E., Jr., Rutter, N.W., Hughes, O.L. and Clague, J.J., 1989. Glaciated fringe *in* R.J. Fulton, ed., Quaternary Geology of Canada and Greenland. Geological Society of America, Geology of North America, K-1: 63-68.

Leboe, E.R., 1996. Quaternary stratigraphy of the three rivers area, southwest Alberta. M.Sc. thesis, Simon Fraser University, Burnaby, 166 p.

____ 1998a. Surficial geology, Brocket, Alberta. Geological Survey of Canada, Map 1931A, 1:50 000.

____ 1998b. Surficial geology, Pincher Creek, Alberta. Geological Survey of Canada, Map 1933A, 1:50 000.

Levson, V.M. and Rutter, N.W., 1996. Evidence of Cordilleran late Wisconsinan glaciers in the “ice-free corridor”. Quaternary International, 32: 33-51.

Little, E.C., 1995. A single maximum-advance hypothesis of continental glaciation restricted to the late Wisconsinan, southwestern Alberta. M.Sc. thesis, University of Western Ontario, London, 229 p.

Liverman, D.G.E., Catto, N.R., and Rutter, N.W., 1989. Laurentide glaciation in west-central Alberta: A single (Late Wisconsinan) event. Canadian Journal of Earth Sciences, 26: 266-274.

Osborn, G. and Luckman, B.H., 1988. Holocene glacier fluctuations in the Canadian Cordillera (Alberta and British Columbia). Quaternary Science Reviews, 7: 115-128.

Stalker, A.M., 1962. Surficial geology, Fernie (east half), Alberta and British Columbia. Geological Survey of Canada Map 31-1961.

____ 1963. Quaternary stratigraphy in southern Alberta. Geological Survey of Canada, Paper 62, 52 p.

____ 1969. A probable late Pinedale terminal moraine in Castle River valley, Alberta. Geological Society of America Bulletin, 80: 2115-2122.

____ 1977. The probable extent of classical Wisconsin ice in southern and central Alberta. Canadian Journal of Earth Sciences,14: 2614-2619.

Stalker, A.M. and Harrison, J.E., 1977. Quaternary glaciation of the Waterton-Castle River region of Alberta. Canadian Petroleum Geology Bulletin, 25: 882-906.

Wagner, W.P., 1966. Correlation of Rocky Mountain and Laurentide glacial chronologies in southwestern Alberta, Canada. Ph.D. thesis, University of Michigan, Ann Arbor, 141 p.

Wagner, W.P. and Eschman, D.F., 1970. A probable Late Pinedale terminal moraine in Castle River valley, Alberta: Discussion. Geological Society of America Bulletin, 81: 3773-3774.

Wheeler, J.O. and McFeely, P., 1991. Tectonic assemblage map of the Canadian Cordillera and adjacent parts of the United States of America. Geological Survey of Canada Map 1712 (1:2,000,000).

Young, R.R., Burns, J.A., Smith, D.G., Arnold, L.D. and Rains, R.B., 1994. A single, late Wisconsin, Laurentide glaciation, Edmonton area and southwestern Alberta. Geology, 22: 683-686.