Géographie physique et Quaternaire

Pleistocene Stratigraphy of the Athabasca River Valley Region, Rocky Mountains, Alberta

La stratigraphie de la région de la vallée de l'Athabasca, dans les Rocheuses (Alberta) au Pléistocène

Stratigraphie der Athabaskafluß-Talregion im Pleistozän, Rocky Mountains, Alberta

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Article abstract

The Pleistocene stratigraphy of the central Canadian Rocky Mountains is described from a region where few studies of Late Quaternary deposits have been conducted. Six informal lithostratigraphic units are recognized from newly mapped exposures in Jasper National Park. The oldest deposits are interpreted as paleofan deposits (Unit 1) and they are overlain by glaciofluvial gravels and sands (Unit 2), glaciolacustrine sediments (Unit 3) and by a glacigenic diamicton sequence (Unit 4) that includes basal till, supraglacial deposits and ice-marginal debris flow sediments. Proximal glaciofluvial gravels, debris flow deposits and minor glaciolacustrine sediments (Unit 5) and paragiacial fan deposits and loess (Unit 6) cap the stratigraphic sequence. Limited chronologic control suggests that nonglacial fluvial and alluvial fan sedimentation began prior to 48 ka and continued throughout the Middle Wisconsinan. Braided stream deposits were accumulating in the Athabasca River valley near Jasper townsite about 29 ka. In the Late Wisconsinan, Rocky Mountain and Cordilleran glaciers advanced through the area, initially damming lakes in a number of Front Range tributary valleys. During déglaciation, ice-marginal glaciofluvial activity and paragiacial debris flows dominated sedimentation. Glacial lakes were limited in extent. A radiocarbon date on shells from one small ice-marginal lake indicates that glaciers were well in retreat by about 12 ka. Alpine glaciers in the region were at or near their present limits by 10 ka.

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PLEISTOCENE STRATIGRAPHY OF THE ATHABASCA RIVER VALLEY REGION, ROCKY MOUNTAINS, ALBERTA

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ABSTRACT The Pleistocene stratigraphy of the central Canadian Rocky Mountains is described from a region where few studies of Late Quaternary deposits have been conducted. Six informal lithostratigraphic units are recognized from newly mapped exposures in Jasper National Park. The oldest deposits are interpreted as paleofan deposits (Unit 1) and they are overlain by glaciofluvial gravels and sands (Unit 2), glaciolacustrine sediments (Unit 3) and by a glacigenic diamicton sequence (Unit 4) that includes basal till, supraglacial deposits and ice-marginal debris flow sediments. Proximal glaciofluvial gravels, debris flow deposits and minor glaciolacustrine sediments (Unit 5) and paraglacial fan deposits and loess (Unit 6) cap the stratigraphic sequence. Limited chronologic control suggests that nonglacial fluvial and alluvial fan sedimentation began prior to 48 ka and continued throughout the Middle Wisconsinan. Braided stream deposits were accumulating in the Athabasca River valley near Jasper townsite about 29 ka. In the Late Wisconsinan, Rocky Mountain and Cordilleran glaciers advanced through the area, initially damming lakes in a number of Front Range tributary valleys. During deglaciation, ice-marginal glaciofluvial activity and paraglacial debris flows dominated sedimentation. Glacial lakes were limited in extent. A radiocarbon date on shells from one small ice-marginal lake indicates that glaciers were well in retreat by about 12 ka. Alpine glaciers in the region were at or near their present limits by 10 ka.

RÉSUMÉ *La stratigraphie de la région de la vallée de l'Athabasca, dans les Rocheuses (Alberta) au Pléistocène.* On a reconnu six unités lithostratigraphiques informelles à partir d'affleurements récemment cartographiés dans le parc national de Jasper. Les dépôts les plus anciens ont été interprétés comme étant d'anciens cônes de déjection (unité n° 1), surmontés par des graviers et des sables fluvioglaciaires (unité n° 2), des sédiments glaciolacustres (unité n° 3) et par une séquence de diamictons (unité n° 4) qui comprend du till de fond, des dépôts supraglaciaires et des sédiments provenant de coulées boueuses de marge glaciaire. Des graviers fluvioglaciaires proximaux, des dépôts de coulée boueuse et des sédiments glaciolacustres (unité n° 5) ainsi que des dépôts de cône de déjection « paraglaciaires » et des lœss (unité n° 6) complètent la séquence. L'imprécision chronologique découle du fait que la sédimentation non glaciaire de type fluviatile et alluvionnaire en cône de déjection a commencé avant 48 ka et s'est poursuivie tout au long du Wisconsinien moyen. Les dépôts de cours d'eau anastomosés se sont accumulés dans la vallée de l'Athabasca, près de Jasper, vers 29 ka. Au cours du Wisconsinien supérieur, les glaciers des Rocheuses et de la Cordillère ont couvert la région, édifiant d'abord des barrages dans un bon nombre de vallées tributaires du Front Range. À la déglaciation, l'activité fluvioglaciaire de marge glaciaire et les coulées boueuses « paraglaciaires » étaient les principales formes de sédimentation. Les lacs glaciaires étaient peu étendus. Une date au radiocarbone de coquillages recueillis dans un petit lac de marge glaciaire montre que le retrait glaciaire était en bonne voie vers 12 ka. Les glaciers alpins avaient dès 10 ka atteint à peu près leur limite actuelle.

ZUSAMMENFASSUNG *Stratigraphie der Athabaskafluß-Talregion im Pleistozän, Rocky Mountains, Alberta.* Die Stratigraphie der zentralen kanadischen Rocky Mountains im Pleistozän wird für eine Region beschrieben, für die wenige Studien über Ablagerungen im späten Quaternär durchgeführt worden sind. Man hat inneu kartographierten Aufschlüssen im Jasper Nationalpark sechs informelle lithostratigraphische Einheiten identifiziert. Die ältesten Ablagerungen werden als Paläoschwemmfächer gedeutet (Einheit I),und bie sind von glazifluvialem Kies und Sand überlagert (Einheit 2), glaziallimnischen Sedimenten (Einheit 3) und einer glazigenen Diamiktit-Sequenz (Einheit 4), die Grundtill, supraglaziale Ablagerungen und Sedimente vom Schuttfluß am Eisrand enthält. Proximaler glazifluvialer Kies, Schuttflußablagerungen und geringere glaziallimnische Sedimente (Einheit 5) sowie paraglaziale Schwemmfächerablagerungen und Löß (Einheit 6) beschließen die stratigraphische Sequenz. Die begrenzte chronologische Kontrolle läßt annehmen, daß die nichtglaziale fluviatile und Schwemmfächer-Sedimentierung vor 48 ka begann und durch das ganze mittlere Wisconsinium fortdauerte. Verwilderte Stromablagerungen sammelten sich im Athabaskaflußtal in der Nähe der Stadt Jasper um etwa 29 ka an. Im späten Wisconsinium rückten die Gletscher der Rocky Mountains und der Kordilleren durch das Gebiet voran und dämmten Seen in einer Reihe von tributären Tälern des Front Range. Während der Enteisung haben glazifluviale Eisrandaktivität und paraglazialer Schuttfluß die Sedimentierung beherrscht. Glaziale Seen waren in ihrer Ausdehnung begrenzt. Eine Radiokarbondatierung von Muscheln von einem kleinen Eisrandsee zeigt, daß der Gletscherrückzug um etwa 12 ka schon eingetreten war. Alpine Gletscher des Gebiets befanden sich um 10 ka an oder nahe bei ihren heutigen Grenzen.

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INTRODUCTION

The preservation of Quaternary sediments in alpine regions of the Canadian Cordillera is generally poor because of repeated erosion by Pleistocene glaciers and Holocene mass wasting. Large valleys, however, acted as sediment accumulation areas during both glacial and nonglacial times. The resultant valley-fill sequences, although typically incomplete due to erosional unconformities, provide the best record of Pleistocene events in the Cordillera (Clague, 1991). The purpose of this paper is to present data from a part of the Rocky Mountains where the Pleistocene stratigraphy is relatively poorly known. The area centres on the part of Jasper National Park that is dissected by the Athabasca River valley (Fig. 1a).

In the Canadian Rocky Mountains, investigations of relatively thick valley-fill sequences have been restricted almost exclusively to the Rocky Mountain Trench (*e.g.* Clague, 1975; Rutter, 1976, 1977; Fulton and Archard, 1985) but there are few descriptions from sites within the Rocky Mountains east of the trench. Previous studies of the Quaternary stratigraphy of the Rockies were undertaken in the Peace River area approximately 450 km northwest of Jasper townsite (Mathews, 1978, 1980) and along the North Saskatchewan River valley (McPherson, 1970) and the Bow River valley (Rutter, 1972), 150 and 250 km southwest of Jasper, respectively.

Pleistocene sediments are exposed at a number of localities in the study area (Figs. 1a and 1b) and reveal a complex sequence of alluvial, glaciofluvial, glaciolacustrine and morainic deposits. The stratigraphic record is best preserved within the Athabasca River valley and major tributaries such as the Miette, Snake Indian and Rocky River valleys. Large stratigraphic sections also occur at the mouths of smaller tributary valleys such as the Portal Creek valley (Levson and Rutter, 1986). The preservation of Pleistocene sediments in the upper reaches of these valleys is restricted mainly to tills deposited during the last glaciation.

STUDY AREA

The Rocky Mountains consist of southwest-dipping thrust sheets of mainly Paleozoic and Precambrian carbonate and clastic strata, formed during Late Cretaceous-Early Tertiary orogenic events. The southeast striking Pyramid Thrust, located directly east of Jasper townsite, separates the Rockies into the Main Ranges, to the southwest, and the Front Ranges, to the northeast. The Front Ranges are composed of steep, southwesterly dipping, thrusted carbonate, shale and sandstone strata from upper Cambrian to Jurassic in age. The Main Ranges consist of thick, relatively flat lying or gently dipping, thrust blocks with broad folds and late, extensional, normal faults. The rocks are quartzose sandstones, shales, siltstones and carbonates of Cambrian and Precambrian age (Price and Mountjoy, 1970; Price *et al.*, 1977; Mountjoy and Price, 1985). Relief in the Front and Main Ranges is high, commonly in excess of 1500 m. Mount Robson, at an elevation of 3955 m in the western Main Ranges, is the highest peak in the Canadian Rockies and occurs just west of Jasper National Park (Fig. 1a).

The surficial geology of the study area is shown in Figure 1c. The Athabasca River valley and other large river valleys in the area are characterized by gravelly and sandy, floodplain alluvium as well as fluvial and glaciofluvial terrace deposits (units Ap and F^G on Fig. 1c). Gravelly alluvial fans (Af) encroach on the valley floors in many areas. Upland areas are characterized by thin (less than 2 m) colluvium (Cv) and exposed rock whereas lower valley sides are blanketed or veneered by morainal debris (Mb and Mv). Areas of thick colluvium (Cb) include mainly rock avalanche and large talus deposits. Units of organic deposits (O) and eolian sand (E), large enough to show on Figure 1c, are restricted mainly to the area west of Jasper and to the Jasper Lake region, respectively.

The size and orientation of major valleys in the area is commonly controlled by regional bedrock structures. The Athabasca River flows northwesterly along the strike of the Main Ranges from the Columbia Icefields (Figs. 1a and 1c), to the Jasper townsite area where it then flows northeastwards across the strike of the Front Ranges. In the Front Ranges, tributary valleys of the Athabasca River such as the Snake Indian and Rocky River valleys, occupy areas underlain by relatively weak shales and sandstones between mountain ranges dominated by resistant Paleozoic carbonates. These valleys tend to follow the southeasterly structural trend and they are relatively large compared to most tributary valleys of the Athabasca River in the Main Ranges. The Miette River valley, crossing the strike of the Main Ranges west of Jasper townsite, is one exception (Figs. 1a and 1c).

Seasonal climatic variability in the study area is high. Mean January and July temperatures at Jasper townsite are approximately −13°C and +15°C, respectively (Atmospheric Environment Service, 1982). Temperature ranges throughout the year are broad with snow falling at any time of year, especially at high altitudes. Approximately 400 mm of precipitation falls annually, including about 150 cm of snow. Climatic variations are also large over short distances due to the effects of high relief. Precipitation along the Continental Divide, for example, is much higher than in the valley bottoms and temperatures are lower, resulting in the development of extensive icefields, alpine glaciers and rock glaciers (Fig. 1c). The climate of the study area and related discussions of the region's vegetative and soils characteristics were provided by Holland and Coen (1983) and Levson *et al.* (1989).

PREVIOUS QUATERNARY STUDIES

Terrain mapping was conducted in the region by Reimchen (1976) and, as part of a biophysical mapping program, by Holland and Coen (1982). A lithofacies classification of glacial deposits in Jasper National Park was provided by Levson (1986) and revised by Levson and Rutter (1988). The Quaternary stratigraphy of the Portal Creek area (Fig. 1a) was described by Levson and Rutter (1986) as was the Quaternary history of the Jasper townsite area (Levson and Rutter, 1989). The stratigraphy and sedimentology of coarse clastic deposits in the region are discussed by Levson (1995). Roed (1975) investigated the Quaternary geology of the Athabasca River valley region immediately east of Jasper Park in the Hinton-Edson area and Roed *et al.* (1967) discussed the origin of the Athabasca Valley erratics train. Holocene glaciations in the Jasper region have been investigated by numerous authors including Luckman and Osborn (1979), Kearney and Luckman (1981, 1983a, b, 1987), Beaudoin (1984, 1986), Luckman (1986, 1988), Luckman and Kearney (1986) and Osborn and Luckman (1988). Levson *et al.* (1989) provided a review of the Quaternary geology and paleoecology of the region as well as a number of detailed descriptions of sites where Late Wisconsinan and Holocene paleoenvironmental and geological data have been collected.

LITHOSTRATIGRAPHY OF THE ATHABASCA VALLEY

The locations of measured sections in the study area are shown on Figures 1a and 1b and composite stratigraphic columns from several main areas are given in Figure 2. Five main lithostratigraphic units are recognized in the region. From oldest to youngest these units consist of massive, clast-supported diamicton and poorly sorted gravels

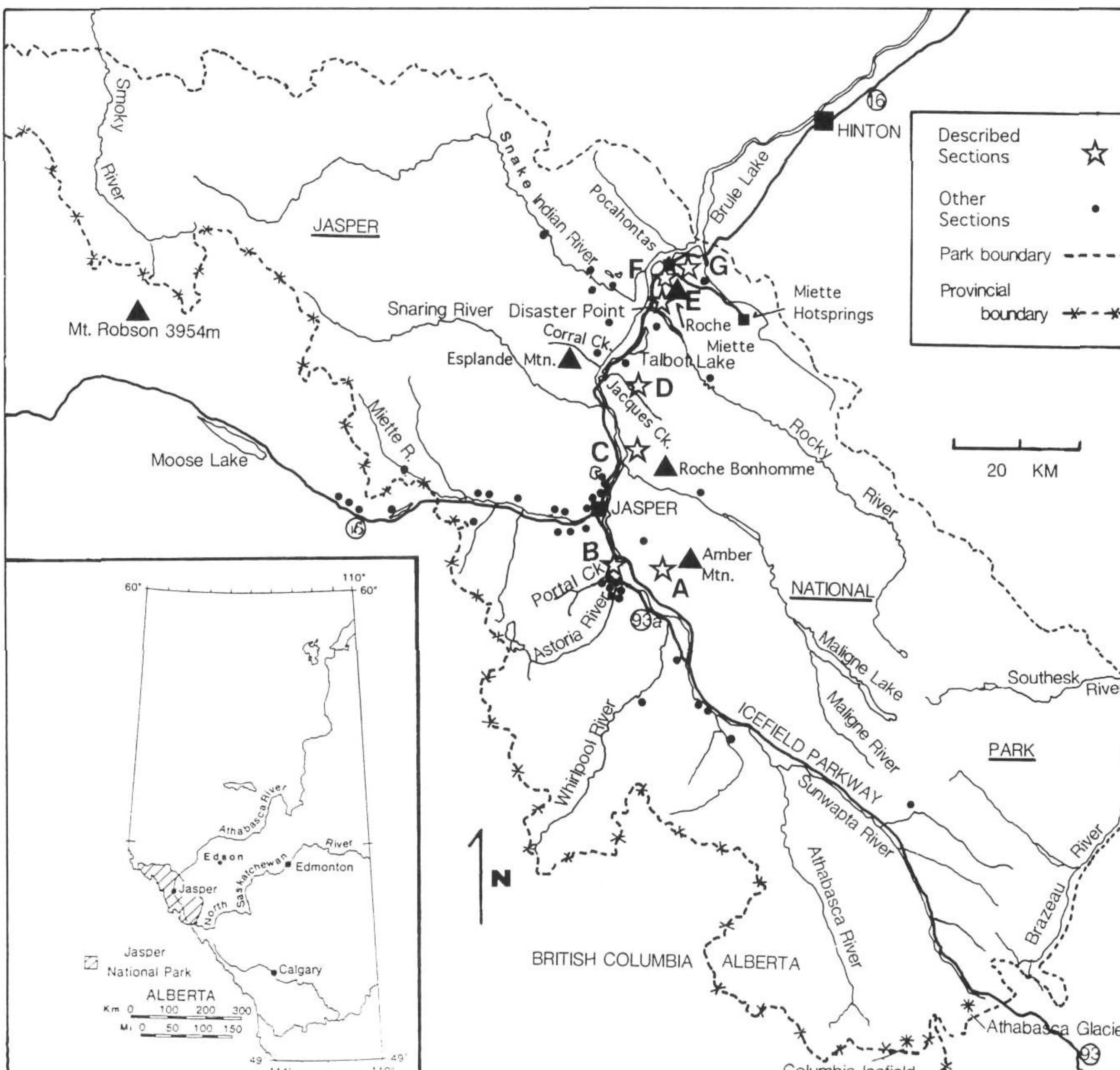


FIGURE 1a. Location map of measured lithostratigraphic sections and place names in the Jasper National Park region. Sites labeled A to G correspond to sections shown in Figure 2.

Localisation des coupes lithostratigraphiques mesurées et toponymie de la région du parc national de Jasper. Les sites identifiés de A à G correspondent aux coupes de la figure 2.

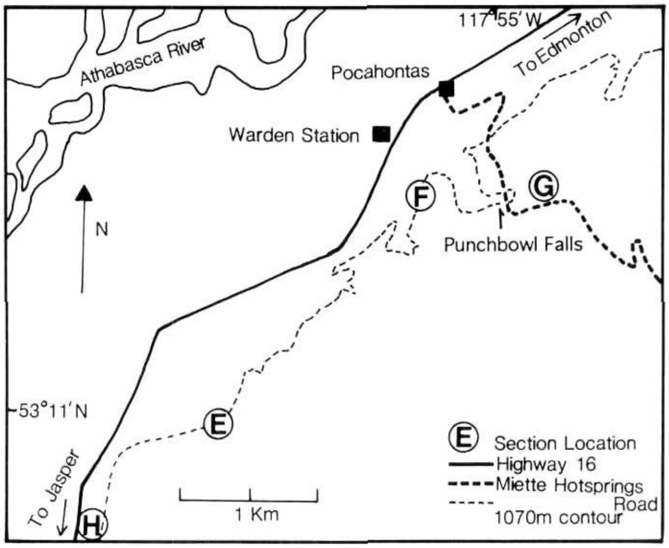


FIGURE 1b. Detailed location map of sections discussed in the text in the Pocahontas area. Sites labeled E to G correspond to sections shown in Figure 2. Site H is the location of the section provided in Figure 11a.

Localisation des coupes de la région de Pocahontas dont il est question dans le texte. Les sites identifiés de E à G correspondent aux coupes de la figure 2. Le site H montre l'emplacement de la coupe de la figure 11a.

(Unit 1), stratified gravels and sands (Unit 2), parallel laminated silts, clays and fine sands (Unit 3), matrix-supported diamicton (Unit 4) and an upper clay, silt, sand, gravel and diamicton sequence (Unit 5). Descriptions and interpretations of each unit follow. Correlations of units between sites are based mainly on stratigraphic position, deposit type, and lithologic composition.

UNIT 1: CLAST-SUPPORTED DIAMICTON AND POORLY SORTED GRAVEL (PALEOALLUVIAL FAN DEPOSITS)

The lowermost succession of deposits at the described localities consists of up to 50 m of mainly clast-supported, gravelly diamicton (Unit 1, Fig. 2 and Fig. 3a). (Diamicton, as used here, refers to unsorted or very poorly sorted deposits containing mud, sand and gravel in varying proportions.) Interbedded massive and cross-stratified gravels and minor sands also occur. Diamicton beds containing cobble to boulder-sized clasts dominate and are usually more poorly sorted than pebbly diamicton beds. They are generally very poorly sorted, massive or crudely bedded and up to several metres thick. Clasts are subrounded to angular (Fig. 3b). Large pebble to cobble gravel interbeds are locally common, especially in the Front Ranges. Well to moderately well sorted gravel beds exhibiting horizontal, planar and trough cross-stratification are less common as are sandy strata and discontinuous interbeds and lenses of open work gravel. Beds dip generally about 5° to 8° but up to 11°, towards the valley centre (Fig. 3a). Clasts of local, tributary basin origin dominate (Fig. 4). This unit contains mostly cobble to boulder-sized clasts in the Main Ranges and pebbles to cobbles in Front Range sections. A systematic variation in the relative proportion of diamicton in comparison with sand and gravel beds was observed only in the Roche Miette area (Fig. 2E). At this site, a slight increase in the abundance of diamicton beds and a corresponding decrease in sorted sand and gravel beds can be seen both vertically up-section and laterally up-flow (towards the valley side).

An alluvial fan origin for these deposits is indicated by the consistent dip of strata towards the valley centre and by the dominance of clasts derived from tributary drainage basins on the adjacent valley sides. Also consistent with an alluvial fan origin is the crude stratification, coarse grainsize, high clast angularity and overall poor sorting. The dominance of massive to crudely bedded diamicton beds suggests that deposition occurred mainly from episodic debris and flood flows associated with fan development and to a lesser extent from intermittent fluvial activity.

Erratic lithologies are rare or absent in the bulk of the fan sediments but erratics and glacially abraded clasts are abundant in matrix-supported diamicton successions (see Unit 4 below) that stratigraphically overlie the fan sequences (Fig. 3a). This is believed to reflect the transition from nonglacial to glacial depositional environments. This transition is also locally shown by paleoflow indicators and provenance studies of clasts that indicate that a significant component of clasts in the uppermost part of some of the fan sequences are derived from upstream regions in the main valleys (Fig. 4, Unit 1-2 transition) rather than from tributary valleys. The local influx of clasts of main valley provenance probably reflects the influence of glaciofluvial activity during the advance of ice into the area.

UNIT 2: STRATIFIED GRAVELS AND SANDS (FLUVIAL / GLACIOFLUVIAL DEPOSITS)

The paleoalluvial fan deposits of Unit 1 are stratigraphically overlain by a complex, bedded gravel and sand sequence (Unit 2, Fig. 2) that is divided into two subunits. The lower subunit, interpreted as fluvial or distal glaciofluvial sediments, grades upwards into the upper subunit, interpreted as proximal braided stream deposits. The thickest exposures of the unit occur in the Pocahontas (Figs. 1b, 2F and 5a), Jasper townsite (Fig. 6a) and Punchbowl Falls (Figs. 1b, 2G, 5b) areas. These deposits are generally found about 100 to 200 m higher than the modern rivers.

The gravels are mainly crudely to well stratified, well imbricated and moderately to well sorted. They are typically horizontally bedded (Fig. 6a) but planar and trough cross-bedding are also locally common (Fig. 5b). Clasts are mainly subrounded to well-rounded pebbles to small cobbles. In comparison to the underlying fan deposits these gravels have more clasts derived from main valley basins (Fig. 4). In the Front Ranges, for example, where quartzitic rocks indicate transport of clasts down major valleys from the Main Ranges, gravels in Unit 2 typically contain 20-30% quartzites compared to less than 5% in Unit 1. At some sites such as Roche Miette the lithologic contrast is abrupt (Fig. 3b) whereas at other sites, such as Jacques

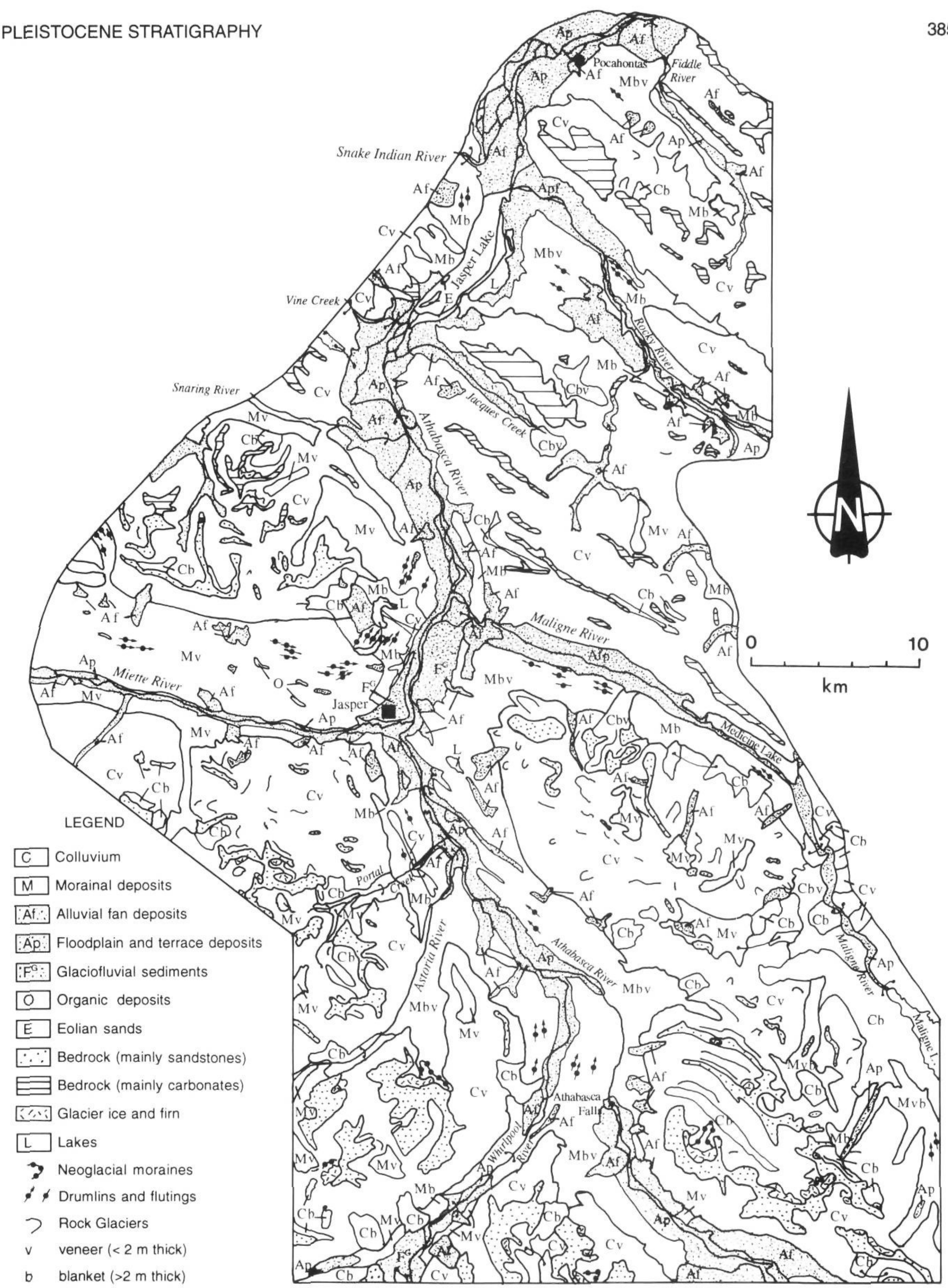
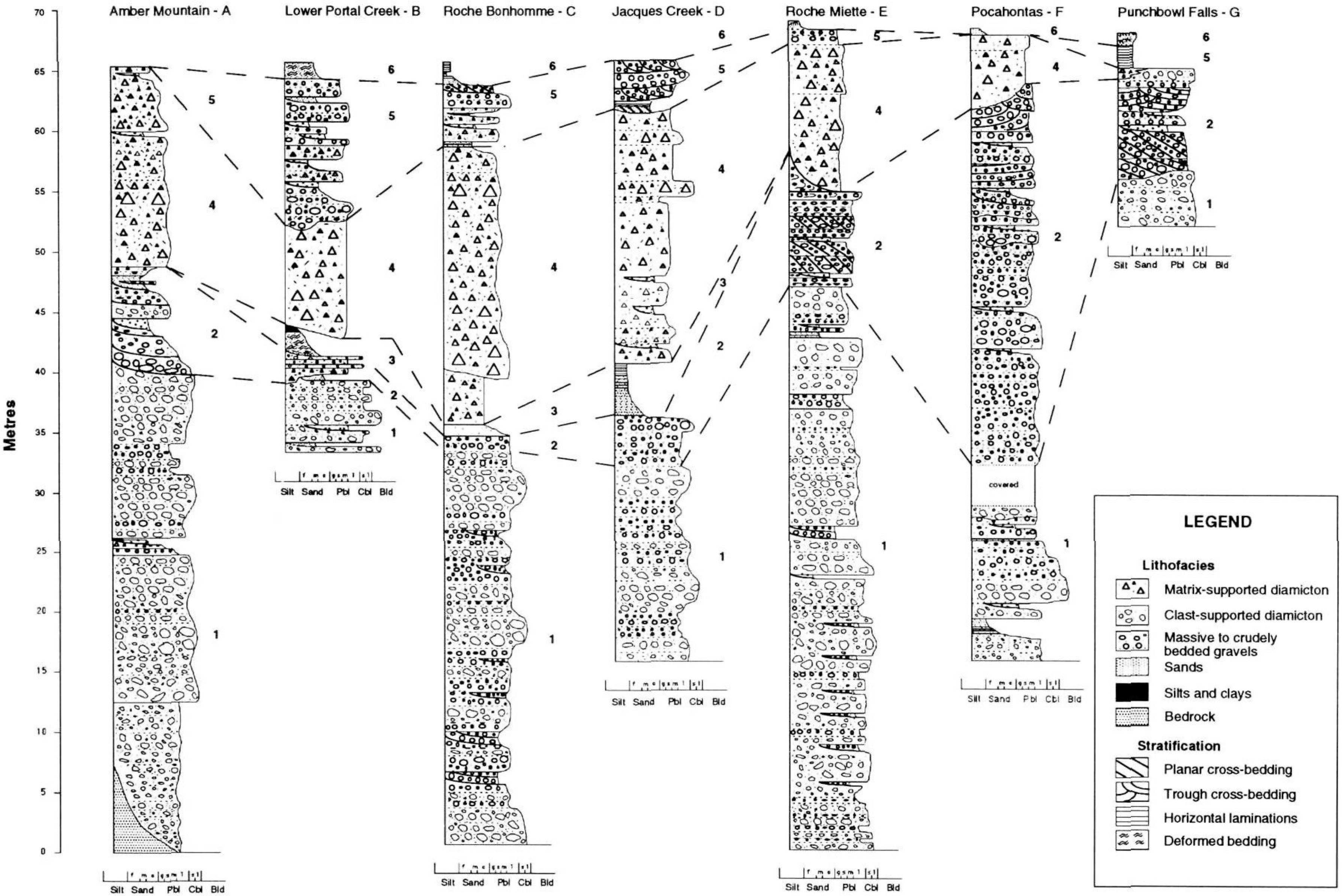


FIGURE 1c. Surficial geology map of the study area showing the present distribution of Late Wisconsinan morainal deposits (M), Neoglacial moraines and other surficial sediments (compiled and modified from unpublished data by Reimchen [1976] and Levson [1995]).

Carte des formations superficielles de la région montrant la répartition actuelle des dépôts morainiques du Wisconsinien supérieur (M), les moraines néoglaciaires et autres sédiments de surface (compilé et modifié à partir de données non publiées de Reimchen [1976} et Levson [1995]).



Colonnes stratigraphiques composites de chacun des principaux sites et des unités dont il est question dans le texte. Localisation aux figures 1a et 1b.

FIGURE 2. Composite stratigraphic columns from each of the main study sites and units discussed in the text. Section locations are shown on Figures 1a and 1b.

Creek and Pocahontas, transitional gravels, occurring between Units 1 and 2, contain intermediate quantities of quartzite (5-20%). Paleoflow directions also indicate deposition in main valley fluvial systems that generally flowed parallel to the present day Athabasca River. A conformable contact between gravels in Unit 2 and the underlying paleofan sequences is locally indicated by interbedding of debris flow diamicton, of probable alluvial fan origin, in the lower part of the unit and by the typically gradual, increase in abundance of distally derived rocks between Units 1 and 2.

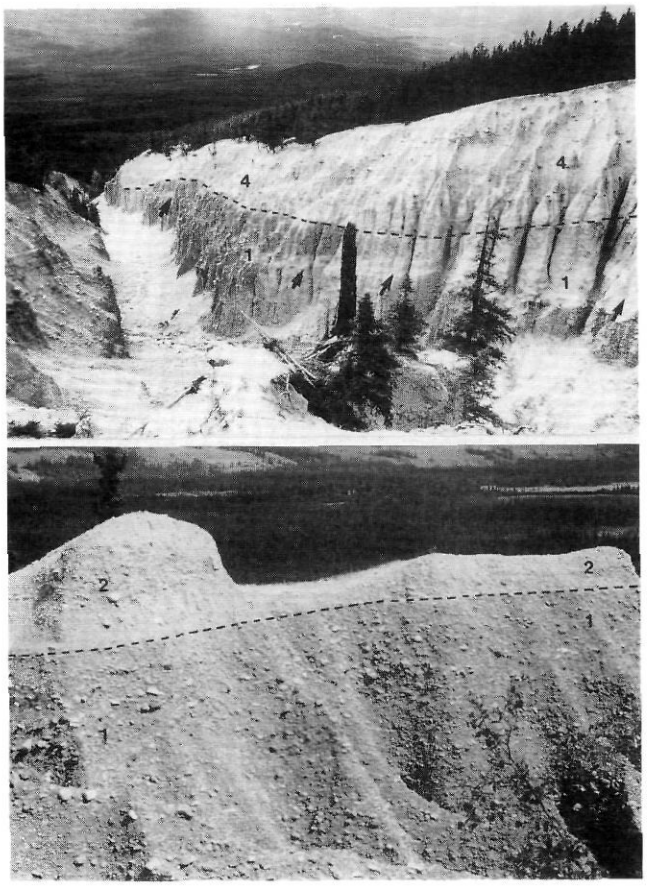


FIGURE 3. a) Paleoalluvial fan, debris-flow deposits (Unit 1) unconformably overlain by matrix-supported, glacial deposits (Unit 4) at Amber Mountain (location A on Fig. 1a; see also Fig. 2A). Note the crude bedding dipping down valley, coarse grain-size and overall poor sorting of the alluvial fan deposits. Wood fragments yielding infinite radiocarbon dates were recovered from the prominent, light coloured, sand and gravel horizon (arrowed) in the upper part of the fan deposits (view looking down fan to the northwest; Athabasca River valley in distance); b) angular, poorly sorted alluvial fan debris flow deposits (Unit 1) at the Roche Miette section (location E on Figs. 1a and 1b) overlain by glaciofluvial gravels of Unit 2 (light coloured unit at top).

a) Paléocône alluvial, dépôts de coulée boueuse (unité n° 1) surmontés en discordance par des dépôts glaciaires à support matriciel (unité n° 4) à Amber Mountain (site A de la fig. 1a) ; fig. 2A). Noter la stratification grossière à inclinaison vers l'aval, la granulométrie grossière et le faible triage des dépôts de cône alluvial. Les fragments de bois, qui ont livré des datations au radiocarbone non significatives, ont été prélevés dans l'horizon en saillie de sables et graviers de couleur pâle (flèches) dans la partie supérieure (vue vers le nord-ouest en aval du cône alluvial ; vallée de l'Athabasca au loin) ; b) dépôts de cône alluvial anguleux et faiblement triés (unité n° 1) à la coupe de Roche Miette (site E des fig. 1a et 1 b) surmontés par les graviers fluvioglaciaires de l'unité n° 2 (partie supérieure en pâle).

1. Lower Subunit

Sediments in the lower part of this unit are dominated by horizontally bedded gravels, sands and minor silts (Fig. 6a). Trough and planar cross-bedding are restricted mainly to sandy strata or small pebble gravel beds. Gravels are imbricated, poorly to well sorted, clast-supported and have a medium to coarse sand matrix. Beds average 40 to 80 cm in thickness. Clasts are mainly pebble to cobble-sized and subrounded to well rounded. Planar cross-stratified sand beds up to 4 cm thick occur sporadically within the gravels. The grain-size distribution and sorting of most individual beds are laterally uniform over tens of metres.

Fining-up sequences 3 to 15 m thick dominate this subunit (Fig. 6a). Clast-supported gravels at the base of the sequences exhibit large scale, crude, horizontal bedding. They grade upwards into matrix-supported, pebbly sand beds. Sandy strata, dominating the upper part of each cycle, show horizontal laminae, planar and trough cross-bedding and climbing-ripple cross-laminae. Massive sand beds, up to one metre thick, locally with dish structures are also common. Most fining-upwards cycles are capped by beds of sandy silt, a few centimetres thick, that may extend laterally for tens of metres before pinching out. They exhibit wavy laminae, load and injection structures, and may contain up to 50% granules and small pebbles. Some overall fining-up

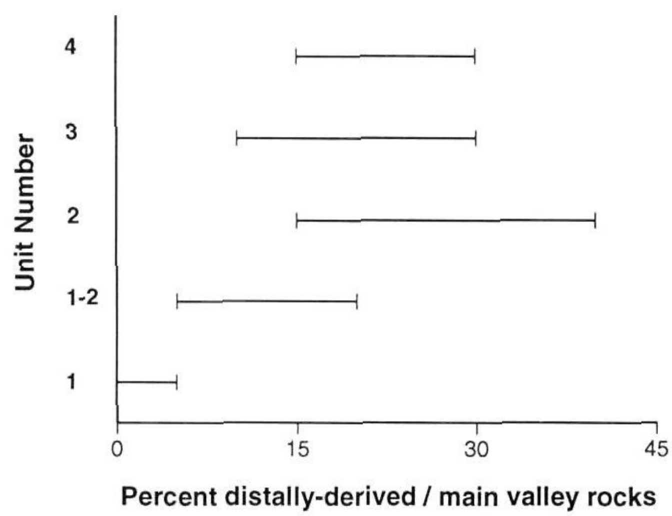


FIGURE 4. Ranges in percentage of distally-derived clasts in main stratigraphic units in the study area. 'Distal' clasts include those derived from within the main valley drainages as well as far-traveled erratics (*e.g.* metamorphics) but excludes local tributary basin rocks.

Étendue (%) des fragments de provenance lointaine dans les principales unités stratigraphiques de la région à l'étude. Les fragments «distaux» comprennent les fragments provenant du drainage de la vallée principale aussi bien que les erratiques lointains (par ex. métamorphiques), mais excluent les roches des bassins tributaires locaux.

units are underlain by a coarsening-up sequence, up to 0.5 m thick.

Organic materials, including wood and gastropod and pelecypod shell fragments, occur throughout this subunit but they decrease in abundance towards the top. A radiocarbon date of 29,100+560 years BP (GSC-3792) was obtained from wood in these deposits near Jasper townsite at a depth of 17.9 m below the surface (1115 m asl).

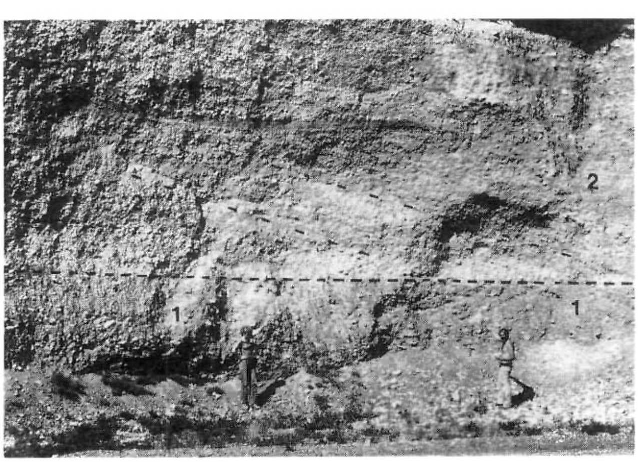
2. Upper Subunit

Sediments in the upper subunit exhibit a much higher degree of sedimentologic variability than in the lower subunit. In addition to horizontal bedding, planar cross-bedded gravels and large trough cross-bedded sand and gravel lenses, up to several metres thick and tens of metres wide, are locally common (Figs. 5b and 6b). Coarse gravel commonly occurs at the base of these lenses and the overlying sediments generally fine upwards. Some coarsening-upward sequences occur in the upper part of this subunit. Scour-and-fill structures also increase in abundance towards the top of the subunit as does the coarseness of the lag gravels at the bottom of the scours. Diamicton intrabeds containing striated clasts and poorly sorted coarse gravels also occur in some areas in the upper part of this subunit (Figs. 2A, 2B and 2D). Strata locally dip steeply in various directions and show lateral and vertical variability in grain size and sorting both within and between beds (*cf.* Levson and Rutter, 1989, Figs. 3 and 6). Faults and load and injection structures are common. In addition, bedding in the upper few metres of the gravels at some sites shows overturned folds and thrust faults (Fig. 2E). Deformation is most intense in the vicinity of large 'embedded' boulders (Fig. 5c) that commonly have faceted and striated upper surfaces.

Gravels of this subunit at Amber Mountain (Fig. 2A) are restricted to the valley side above a sequence of fan deposits of Unit 1 (Fig. 6b). The sands and gravels at this site are laterally interbedded with more poorly sorted gravels and diamicton beds.

3. Interpretation

Well developed pebble roundness, imbrication, cross-bedding and sorting in gravels of this unit indicate a fluvial depositional environment. The dominance of horizontally bedded gravel suggests deposition mainly in longitudinal bars. Crude horizontal stratification is typical of longitudinal bars in shallow, gravel-bed, braided streams (Smith, 1974; Hein and Walker, 1977). Similar deposits characterized by horizontally stratified gravels with thin interbedded sand



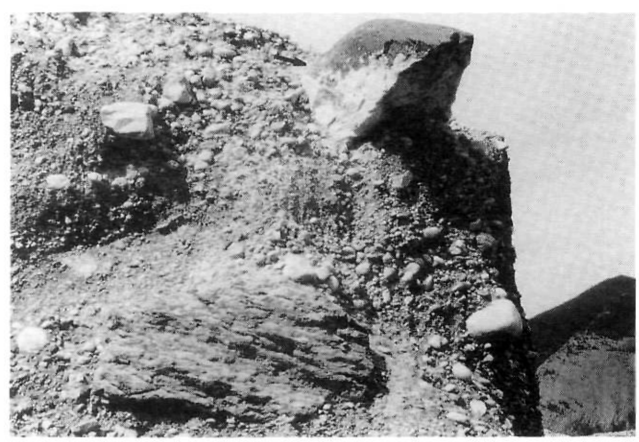


FIGURE 5. a) Till of Unit 4 unconformably overlying glaciofluvial gravels (Unit 2) at the Pocahontas section (location F on Figs. 1a and 1b; see also Fig. 2F); b) glaciofluvial gravels (Unit 2) overlying debris flow deposits (base) of Unit 1 at the Punchbowl Falls section (location G on Figs. 1a and 1b; Fig. 2G). Note cross-bedding in lower part of Unit 2; c) deformed gravels and lodged boulder (arrowed at top) in the upper part of the glaciofluvial gravels shown in 3b); the upper surface of the lodged boulder is faceted and striated, with striae trending parallel to the main valley. Note differences in clast size, sorting and deformation in comparison to undeformed gravels in Figures 3b and 5b.

a) Till de l'unité 4 reposant en discordance sur des graviers fluvioglaciaires (unité n° 2) à la coupe de Pocahontas (site F des fig. 1a et 1b; voir aussi la fig. 2F) ; b) graviers fluvioglaciaires (unité n° 2) surmontant des dépôts de coulée boueuse à la base de l'unité 1 à la coupe de Punchbowl Falls (site G des fig. 1a et 1b ; fig. 2G). Noter la stratification entrecroisée à la partie inférieure de l'unité n° 2 ; c) graviers déformés et bloc inséré près du sommet des graviers fluvioglaciaires de la figure 3b ; la partie supérieure du bloc est tronquée et striée, les stries étant parallèles à la vallée principale. Noter les différences de dimension, de triage et de déformations entre les fragments en comparaison avec les graviers non déformés des figures 3b et 5b.

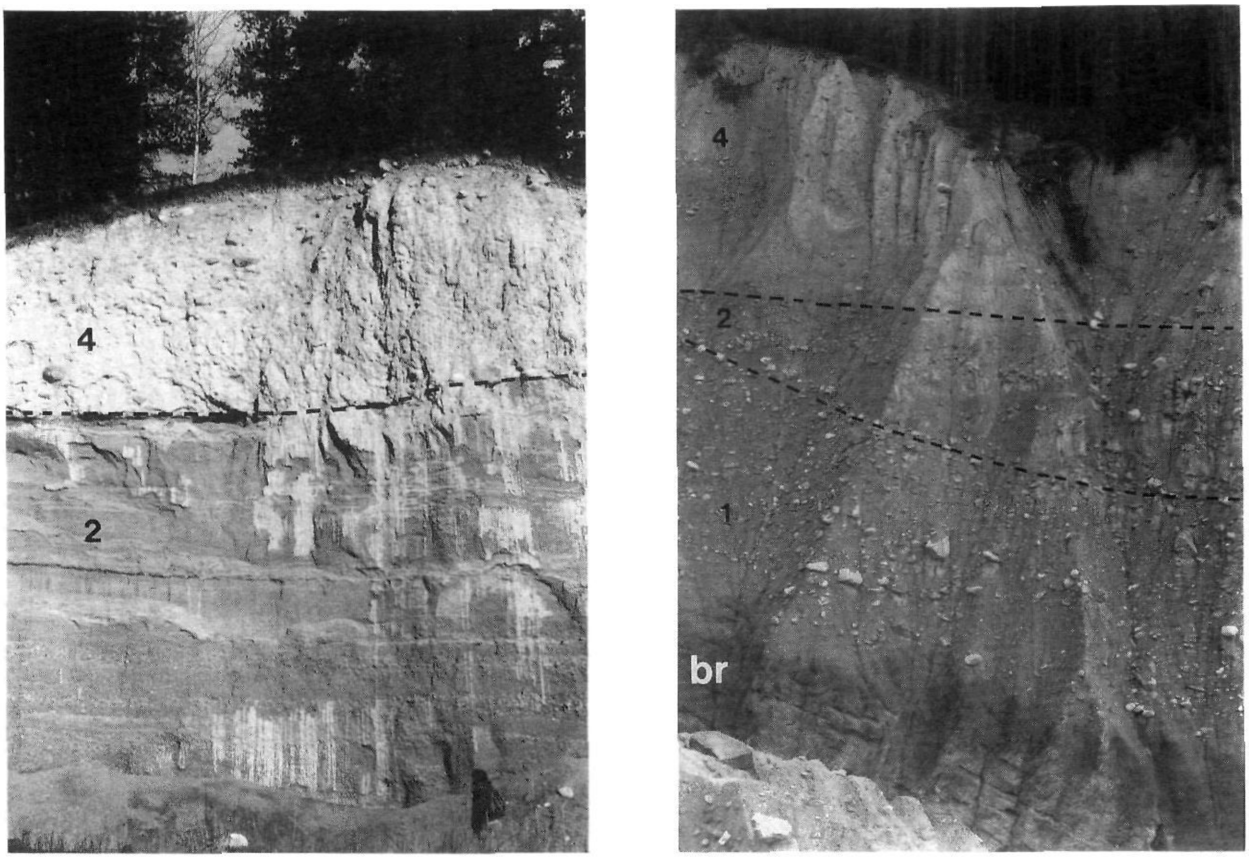


FIGURE 6. a) Late Wisconsinan till (Unit 4) erosionally overlying Middle Wisconsinan, braided stream gravels near Jasper townsite (Unit 2). Radiocarbon dating of wood recovered from the upper most sand and gravel horizon shown indicates that deposition of this unit occurred about 29,100 + 560 years BP (GSC-3792); b) matrix-supported till of Unit 4 (top) unconformably overlying channelized glaciofluvial gravels and sands of Unit 2 (centre) and clast-supported, bouldery, alluvial fan deposits in Unit 1 (bottom) at Amber Mountain (location A on Fig. 1a). Dark unit at base of section (br) is bedrock.

a) Till du Wisconsinien supérieur (unité n° 4) surmontant des graviers de cours d'eau anastomosé, près de Jasper (unité n° 2). La datation au radiocarbone du bois prélevé dans l'horizon visible le plus élevé de sables et graviers montre que la mise en place de cette unité s'est faite vers 29 100 ± 560 BP (GSC-3792) ; b) till à support matriciel de l'unité n° 4 (en haut) reposant en discordance sur les graviers et sables fluvioglaciaires de chenaux de l'unité n° 2 (au centre) et les dépôts de cône alluvial à blocs et à support matriciel de l'unité n° 1 (en bas) au site (A sur la fig. 1a) de Amber Mountain. L'unité sombre à la base de la coupe (br) est le substratum.

lenses and showing ripple-drift cross-laminae and mud veneers, have been described in modern braided stream systems (Boothroyd and Ashley, 1975; Church and Gilbert, 1975).

Fining-upward sequences, dominant in the lower subunit, probably formed as a result of waning flow conditions subsequent to major flood events. Braided stream deposits characterized by fining-up gravel and sand cycles, formed under progressively decreasing energy levels in successive flood events have been described by several authors (Rust, 1972, 1978; Boothroyd and Ashley, 1975; Miall, 1977; Rust and Koster, 1984). Since no disconformities are present within each cycle, deposition may have occurred during single large flood events (*cf.* Maizels, 1989). Cyclicity in the sedimentation pattern probably resulted from re-occupation of the channel during subsequent high flow events. Preservation of fine-grained sediments at the end of each cycle suggests that subsequent flows were initially depositional and increased in strength gradually. This is supported by a coarsening upwards of grains at the base of some otherwise fining-upwards sequences. Silt and clay beds capping the cycles probably were deposited by suspension from muddy waters in recently active channels cut-off by falling water levels.

Sediments in the lower subunit are believed to have been deposited in a distal braided stream environment. The lateral uniformity and continuity of these sediments supports this interpretation. The relatively high abundance of wood fragments, gastropods and pelecypod shells in the lower subunit suggests a more viable environment for flora and fauna, possibly also reflecting a greater distance from glaciers. In addition, parallel laminated mud facies, such as occur throughout the lower subunit, are more common in distal or inactive reaches of modern glaciofluvial streams, where preservation potential of muds is higher, than in proximal reaches (Rust, 1972). The lack of organic matter in the top of the lower subunit and throughout the upper subunit is consistent with this interpretation, and suggests that a progressive transition, from fluvial, or distal glaciofluvial, to more proximal glaciofluvial environments, occurred between the deposition of the lower and upper subunits.

The sedimentologic complexity of the upper subunit reflects a more varied depositional environment. In addition to longitudinal bar deposits, planar cross-bedded gravels, interpreted as transverse bar deposits, occur in the upper subunit. Large trough-shaped units of fining-up channel-fill gravels and sands at some sites, indicate that well developed channels also occurred locally. The restriction of these gravels at Amber Mountain to sites high along the valley side (Fig. 6b), suggests that they may have been deposited in channels along the margin of a glacier occupying the centre of the Athabasca valley. This confined flow probably resulted in the more pronounced channelization of the gravels in this area compared to most other sites. Coarse gravel concentrations at the base of some of these channels are interpreted as lag gravels resulting from winnowing and channel erosion.

Deposits in the upper subunit are inferred to have a more proximal glaciofluvial origin than gravels in the lower subunit. In the Jasper townsite and Roche Miette areas (Figs. 1a and 1b), an upward increase in the number of cut and fill structures, erratic clasts, overall grain size of the unit and coarseness of lag gravels, as well as a vertical decrease in abundance of wood and shell fragments, are believed to reflect the increasing proximity of glaciers. Large variations in sediment sorting, grain-size distribution, clast size and shape, and paleocurrent direction in this subunit, also indicate proximity to a sediment source and highly variable flow conditions, typical of proximal ice-marginal environments (Banerjee and McDonald, 1975; Church and Gilbert, 1975; Boulton and Eyles, 1979). This interpretation is further supported by the local presence in the upper part of this subunit of diamicton intrabeds containing striated clasts of non-local lithology. These diamicton beds have characteristics similar to glacially-derived debris flows described in modern glacial environments (*e.g.* Lawson, 1979a) and they were probably deposited in ice-marginal streams of the advancing glaciers. Massive diamicton beds overlying the gravels at most sites (Fig. 2) are interpreted as tills deposited by these glaciers (see Unit 4 below). The presence of faceted, embedded and striated clasts as well as inferred glaciotectonic deformation structures such as overturned folds and thrust faults in the upper part of these gravels at some sections also indicates that they were eventually overridden by glacial ice (*e.g.* Figs. 2E, 5c).

UNIT 3: PARALLEL LAMINATED SILTS, CLAYS AND FINE SANDS (ADVANCE-PHASE GLACIOLACUSTRINE DEPOSITS)

In the lower reaches of several valleys tributary to the Athabasca valley such as the Jacques, Snake Indian and Rocky River valleys (Fig. 1a), glaciofluvial gravels in Unit 2 are overlain by horizontally laminated silts, clays and fine sands (Figs. 2 and 7). These sediments are very well sorted, rhythmically bedded and contain rare isolated clasts, some of which are striated. The unit commonly coarsens upwards from dominantly, parallel laminated, silts and clays at the base (Fig. 7a) to trough cross-bedded and ripple-bedded silts and sands near the top (Fig. 7b). Diamicton intrabeds, locally exhibiting flow folds as well as load and injection structures, and some sand and gravel lenses also occur in the upper part of the unit (Fig. 7c). The lower contact of the unit is generally sharp and planar (Fig. 7a).

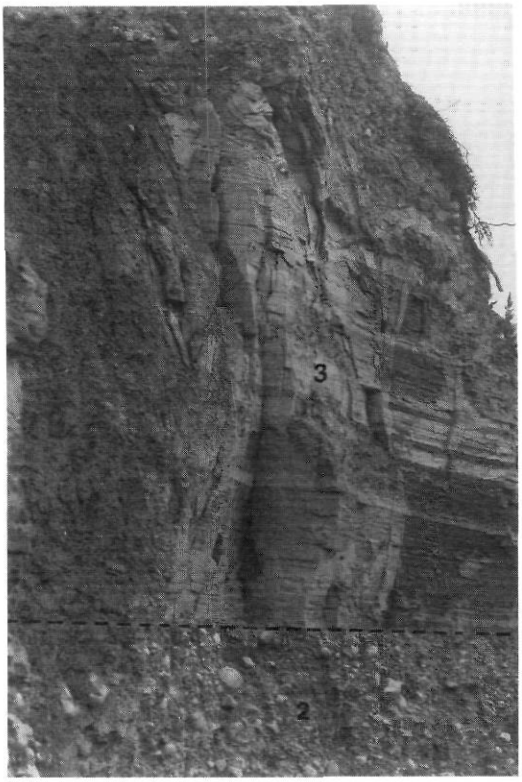
The sediments are interpreted as glaciolacustrine deposits. Parallel laminated, silts and clays at the base of the unit represent relatively deep water deposits whereas cross-bedded sands are inferred to be more proximal glaciolacustrine sediments. Diamicton intrabeds common in the upper part of the unit are interpreted as subaqueous debris flow deposits. Vertical facies changes in the unit are equivalent to the distal to proximal, glaciolacustrine facies sequence described by Ashley (1988) and probably reflect the increased proximity and eventual advance of glaciers into the lakes as glaciation in the region progressed. Similar facies associations also have been described from several modern glacial lakes in mountain regions (Gilbert and Shaw, 1981; Ashley *et al.*, 1982).

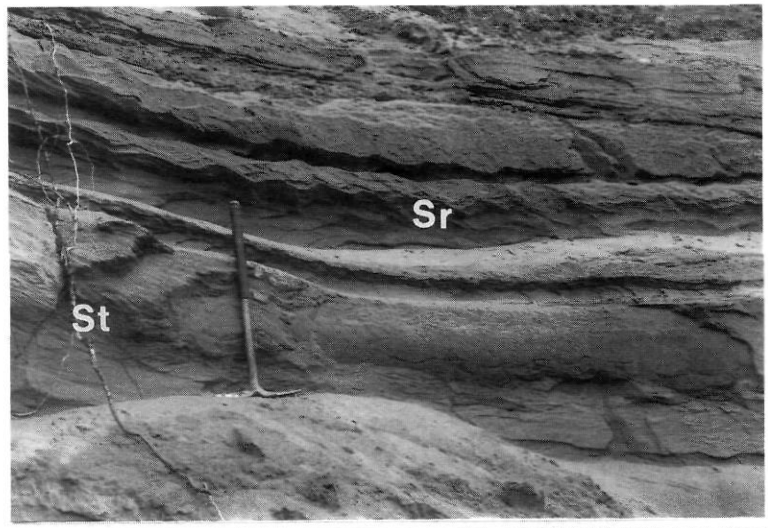
Ice-dammed lakes were a characteristic feature of tributary valleys in the study area at the onset of the last glacial period, particularly in Front Range valleys that remained ice free during the early phases of glaciation (Levson, 1990). The regional distribution and stratigraphic position of this unit suggests that deposition occurred when the drainage in tributary valleys was suddenly dammed, presumably by glaciers in adjacent trunk valleys. This interpretation is supported by the sharp lower contact of parallel laminated silts and clays conformably overlying coarse gravels, indicating a rapid transition from glaciofluvial to glaciolacustrine sedimentation.

UNIT 4: MATRIX-SUPPORTED DIAMICTON SEQUENCES (TILL AND GLACIGENIC DEBRIS FLOW DEPOSITS)

Diamicton facies of glacial origin in the area have been described in detail by Levson and Rutter (1988). Three of the main facies associations recognized are: 1) fine-grained, massive, compact diamicton with rare sand lenses (upper unit in Figs. 6a and 6b), 2) silty to sandy, very poorly or poorly sorted diamicton, usually with interstratified gravels and sands or fine sediments, and 3) loose, sandy or gravelly diamicton containing numerous angular clasts. The first facies association dominates Unit 4, whereas the latter two are restricted mainly to the upper part of the unit.

Units 1 to 3 at all of the study sites are stratigraphically overlain by up to 20 metres of dominantly massive, matrix-supported diamicton (Unit 4, Fig. 2; Figs. 3a, 5a, 6a, b). The diamicton is typically unsorted, dense and has a fine-grained matrix. Striated and faceted clasts are common and up to 85% of the clasts are the same lithology as the underlying or local bedrock. Pebble fabric analyses of the long axes of clasts indicate a strong unimodal preferred orientation parallel to the valley (*e.g.* S_1=0.74 at the Pocahontas section, Figs. 2F and 8A). The basal contact of the diamicton is generally sharp and erosional, truncating bedding in underlying sand and gravel units (Figs. 2F, 3a,





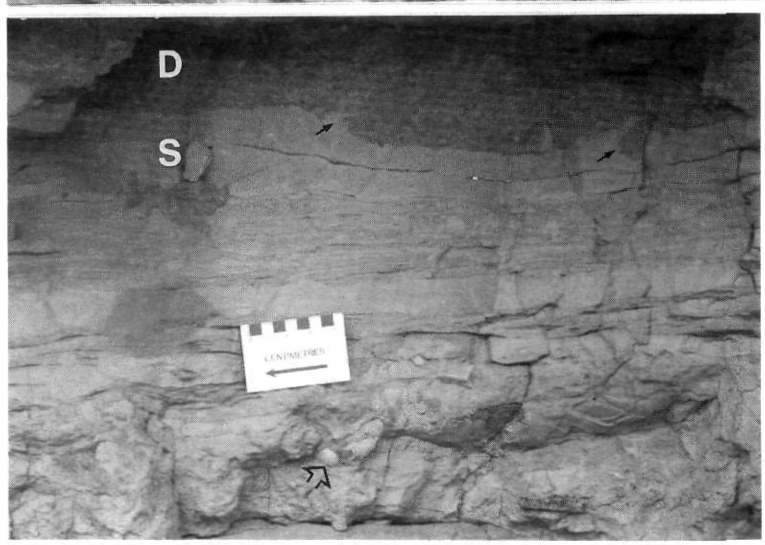


FIGURE 7. Glaciolacustrine deposits of Unit 3 exposed along the lower reaches of the Snake Indian River valley near its confluence with the Athabasca River: a) horizontally stratified, glaciolacustrine silts and clays (distal, lake basin deposits) at the base of Unit 3, sharply but conformably overlying glaciofluvial sands and gravels of Unit 2 (silt and clay exposure is 4.25 m thick); b) climbing ripples (Sr) and trough cross-bedded sands (St) in the upper part of Unit 3, interpreted as proximal glaciolacustrine deposits and c) deformed sandy strata (S) overlain by diamicton bed (D), inferred to be of a subaqueous debris flow origin. Note the load and injection structures (arrowed) at the base of the diamicton and dropstone below scale (open arrow).

Dépôts glaciolacustres de l'unité n° 3 affleurant le long des biefs aval de la vallée de la Snake Indian River, près de sa confluence avec l'Athabasca : a) silts et argiles glaciolacustres (4,25 m d'épaisseur) à stratifications horizontales (dépôts lacustres, distaux) situés à la base de l'unité n° 3, surmontant de façon nette et en concordance les sables et graviers fluvioglaciaires de l'unité n° 2 ; b) ondulations (Sr) et sables à stratifications entrecroisées (St) dans la partie supérieure de l'unité n° 3, interprétés comme étant des dépôts glaciolacustres proximaux et c) lits de sables défomés (S) surmontés par un lit de diamicton (D), provenant d'une coulée boueuse. Noter les figures de charge et en flamme (flèches) à la base du diamicton et le caillou de délestage sous l'échelle.

5a, 6a and 6b). Clasts at the base of this unit locally are embedded in underlying deposits and commonly have faceted and striated upper surfaces with both striae and clast long-axes showing preferred orientations parallel to the valley (Fig. 8A). Shear structures and compressively deformed bedding in underlying sediments are locally apparent. Lenses of sorted sand and gravel, typically plano-convex or circular in cross-section, are rare. Stratification within the diamicton is also rare and occurs as diffuse beds with slight textural differences that commonly drape underlying boulders (see Fig. 8 *in* Levson and Rutter, 1988). The diamicton surface at some sites is fluted.

Diamicton beds with weak stratification, relatively high clast contents, silty to sandy matrix textures and poorly developed fabrics commonly cap, and in a few cases underlie, denser, massive diamicton sequences (Fig. 2). Pebble fabric data from these diamicton beds display weak trends (*e.g.* S_1=0.55 in the upper most diamicton unit at the Pocahontas section, Figs. 2F and 8B), commonly oblique or transverse to ice-flow direction. Diamicton beds dominate but locally present are, less than 1 m thick, sand and gravel lenses that are typically trough-shaped, moderately to well sorted and stratified. Interstratified lenses and beds of gravels, sands and silts commonly are faulted, folded or show other evidence of post-depositional deformation. Shear structures and thrust faults locally occur in these strata near the base of the unit.

Sandy, poorly consolidated, diamicton, containing angular clasts up to boulder size, locally occurs on the surface in the study area and typically overlies massive, compact

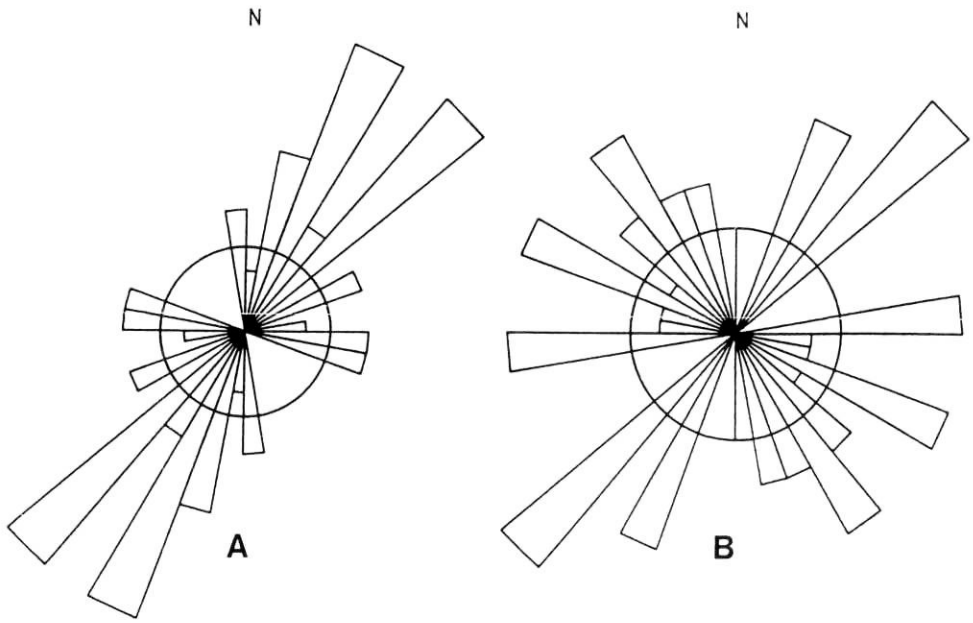


FIGURE 8. Representative rose diagrams of a-axis orientations in matrix-supported diamicton units interpreted as (A) till (S1= 0.74, N= 25) and (B) debris flow deposits (S1=0.55, N=25). Fabrics were measured in Unit 4 at the Pocahontas section (Fig. 2F, location E on Fig. 1b). The main valley orientation at this site is northeasterly.

Diagrammes circulaires représentatifs des orientations de l'axe en a dans les unités de diamicton à support matriciel interprété comme étant (A) du till (S1= 0,74, N= 25) et (B) des dépôts de coulée boueuse (S1=0,55, N=25). Les fabriques de l'unité 4, à la coupe de Pocahantas ont été mesurées (fig. 2, site E de la fig. 1b). À ce site, l'orientation principale de la vallée est vers le nord-est.

diamicton or bedrock. Diamicton beds are often interbedded with sands and gravels and are usually poorly exposed due to their poor compaction, sandy texture and thinness (generally less than 1 m thick). The diamictons occur sporadically and locally are recognized only by the presence of scattered, angular, low to medium grade, metamorphic erratics. These erratics are commonly mica-garnet schists and biotite-muscovite schists that occur mainly on the surface of diamicton units and on surrounding bedrock exposures, most commonly in the Front Ranges up to an elevation of about 1400 m. Source areas for these metamorphic erratics occur only west of the Continental Divide (Roed *et al.*, 1967).

Interpretation

Dense, fine-grained, massive diamicton beds in Unit 4 are interpreted as basal tills deposited by both lodgment and meltout processes. The main characteristics of the diamictons, including fine matrix textures, over consolidation and abundant glacially abraded clasts, are typical of basal tills (Boulton, 1976; Kruger, 1979; Haldorsen, 1982; Dreimanis, 1988). This interpretation is supported by the preferred orientations of clast long-axes which parallel former ice-flow directions (as determined primarily by valley trend). Sedimentary structures indicating lodgment processes include numerous faceted and embedded clasts, shear structures and strong valley-parallel pebble fabric trends (Boulton, 1976, 1978; Kruger, 1984). The local presence of 'relict' englacial features, such as rare, plano-convex or circular sand and gravel lenses, and diamicton strata that drape large clasts, suggests that deposition by meltout processes also occurred (Haldorsen and Shaw, 1982; Shaw, 1982; Levson and Rutter, 1988). Erosional basal contacts probably formed at the sliding base of overriding ice, and fluted topography also reflects glacial cover over these deposits. Tills at all of the sites were deposited mainly by Athabasca Valley ice but the influence of tributary-valley glaciers at valley junctions is indicated by stratigraphically complex diamicton sequences of variable provenance (*e.g.* Levson and Rutter, 1986).

Poorly sorted, diamicton deposits in this unit with weak stratification, chaotic fabrics, relatively high clast contents, and interbedded sand and gravel lenses are typical of debris flow deposits in glacial environments (Marcussen, 1975; Lawson, 1979a, b, 1981a, b, 1982, 1988; Jong and Rappol, 1983; Dreimanis, 1988). Stratification, relatively high clast contents and sandy matrix textures in these diamictons are interpreted to reflect the influence of gravity and water reworking of the debris flow deposits. Diamicton beds rich in gravel and sand may have undergone several cycles of resedimentation resulting in the removal of silts and clays by winnowing (*cf.* Lawson, 1979a, 1981a, b). Lenses and beds of sorted material are interpreted as ice-proximal glaciofluvial sediments deposited between debris flow events. Lawson (1979a, 1988) found that diamictons deposited by individual flows in modern ice-marginal environments were often separated by layers of glaciofluvial sand and silt. Shear structures and thrust faults in these strata near the base of the unit are interpreted as glaciotectonic features.

Diamicton beds in the area containing distally derived (>50 km from source) metamorphic erratics, probably originated as supraglacially transported debris. The metamorphic erratics are lithologically similar to, and interpreted to be part of, the supraglacially transported Athabasca Valley erratics train, first described by Roed *et al.* (1967) from the area east of Jasper National Park. The sandy matrices, poor consolidation, high clast angularity and large modal clast-size of the diamictons and their common superposition over deposits interpreted as basal or englacial meltout tills (Levson and Rutter, 1988), suggests that they were supraglacially derived. Similar characteristics have been described for supraglacial tills from both ancient and modern glacial deposits (Sharp, 1949; Drake, 1971; Stewart and MacClintock, 1971; Boulton and Eyles, 1979; Lawson, 1979a, 1981a, b; Levson and Rutter, 1988, 1989). Their relative thinness, local interbedding with sands and gravels, and common occurrence on the surface is also compatible with a supraglacial origin. Deposition probably occurred in the form of debris flows off the glacier surface or by gradual let-down by melting during deglaciation.

UNIT 5: UPPER GRAVEL, SAND AND DIAMICTON SEQUENCES AND FINE-GRAINED SEDIMENTS (DEGLACIAL DEPOSITS)

This unit consists of complex sequences of interbedded gravel, sand and / or diamicton deposits and local fine-grained sediments that invariably occur at or near the surface. Sequences containing diamicton are distinguished from Unit 4 by the relatively high proportion of sand and gravel strata in Unit 5 and by an erosional lower contact. Deposits of Unit 5 unconformably overlie unit 4 at all sites. Two subunits are recognized on the basis of the dominant sediment type.

1. Stratified Gravel, Sand and Diamicton Sequences (Proglacial Deposits)

Interbedded gravel, sand, diamicton and minor silt unconformably overlie Unit 4 at a number of locations including the Lower Portal Creek, Roche Bonhomme and Jacques Creek sites (Figs. 2B, 2C and 2D). Gravel and sand beds show horizontal stratification as well as planar and trough cross-stratification. Gravel beds are poorly to well sorted whereas sandy and silty strata are mainly well sorted. Clast lithologies are similar to the underlying glacial deposits (Fig. 4). Clasts are mainly moderately to well rounded and some are striated. Diamicton interbeds are commonly associated with these deposits but they are typically less abundant than sand and gravel and their relative proportion generally decreases towards the top of the subunit. Paleocurrent directions indicate valley-parallel flow. The lower contact of this subunit typically is erosional (Fig. 2).

Gravel, sand and diamicton strata of this subunit show highly variable dips and dip directions at some sites. Strata commonly dip steeply (up to 35°) towards the valley sides or rarely up valley. Normal faults and deformation structures indicating collapse towards the valley centre also occur in these deposits as do load and injection structures. Deformation structures generally are most abundant in the upper part of the subunit. Exposures of these deformed deposits are particularly common in terrace-like benches that flank the Athabasca River valley at various levels up to about 200 m above the modern river (Figs. 9A and 9B). Sediments exposed in these terraces in the Jasper townsite area are described in detail by Levson and Rutter (1989). The terraces occur at different levels along the valley walls and they commonly are incised by large gullies with disproportionately small drainage areas.

2. Interpretation

Gravels and sands of this subunit are interpreted as ice-proximal glaciofluvial deposits. Their stratigraphic position indicates deposition during or shortly after deglaciation. At most locations, such as at the Lower Portal Creek and Jacques Creek sites (Figs. 2B and 2D), these interbedded gravels and sands show mainly down valley paleoflow directions and scoured lower contacts, suggesting that they were deposited as channel-fill sequences in proglacial streams issuing off the retreating glaciers (Levson and Rutter, 1986). Diamicton interbeds are similar to the glacially derived debris flow deposits in Unit 4 and their decrease in abundance towards the top of this unit probably reflects the decreased proximity of the glacial debris sources as deglaciation progressed.

Highly deformed deposits of this subunit showing paleoflow directions towards the valley sides are interpreted as proximal glaciofluvial and debris flow sediments depos-

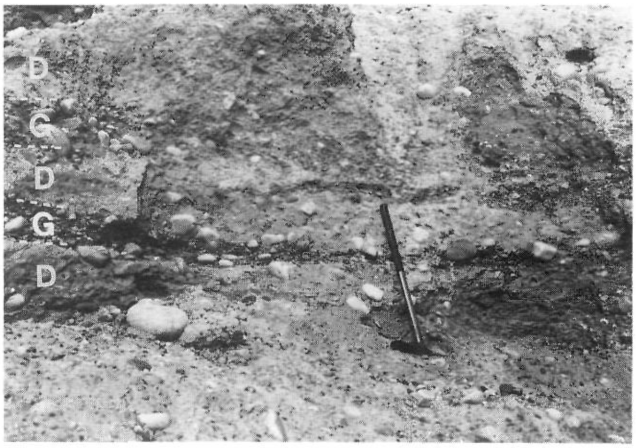


FIGURE 9. a) Glacial and glaciofluvial terrace-like benches (arrowed) flanking the west side of the Athabasca River valley below Esplanade Mountain, opposite the mouth of the Jacques Creek (Fig. 1a). Note the variable slopes and levels of the benches and Corral Creek alluvial fan (Af) at centre-left. b) Typical exposure of interbedded debris flow deposits (D) and fluvial gravels (G) in Unit 5.

a) Replats d'origine glaciaire et fluvioglaciaire disposés en terrasses (flèches) sur le versant ouest de l'Athabasca, sous l'Esplanade Mountain, face à l'embouchure du Jacques Creek (fig. 1a). Noter les pentes variables et les différents niveaux des banquettes et le cône alluvial du Coral Creek (Af), au centre-gauche. b) Coupe caractéristique de dépôts de coulée boueuse (D) et de graviers fluviatiles (G) de l'unité n° 5.

ited along the lateral margins of debris covered ice remaining in the valley centre. The terrace-like benches that these deposits are associated with, in the Jasper townsite area and elsewhere along the sides of the Athabasca valley, are interpreted as kame terraces. The presence of normal faults with large displacements and associated deformation structures indicate that substantial collapse occurred after deposition, probably as a result of melting of supporting ice in the valley centre. Boulton and Eyles (1979) and Bordonau (1993) described similar ice-marginal deposits along the flanks of former valley glaciers. The debris source for these features is believed to be ablating medial moraines and medial debris septa that extended into the Athabasca valley from tributary valleys (Levson and Rutter, 1989). This interpretation is supported by the occurrence of the terraces below major stream confluences such as the Miette, Maligne, Snaring, Rocky and Snake Indian rivers where medial moraines and debris septa would have been best developed. The ice-marginal kame terraces probably formed as debris washed and slumped down the margins of the ablating ice during the late stages of retreat onto the adjacent valley sides. Small lateral benches at different elevations along the valley walls may have formed as ice ablated down to progressively lower levels. Large isolated gullies within the terraces, that are not connected to any significant modern stream drainage, may have formed by melting of localized ice cores within the terraces or by glacial meltwater incision shortly after their formation. These geomorphic characteristics support an ice-marginal or ice-contact origin for the deposits that comprise the terraces.

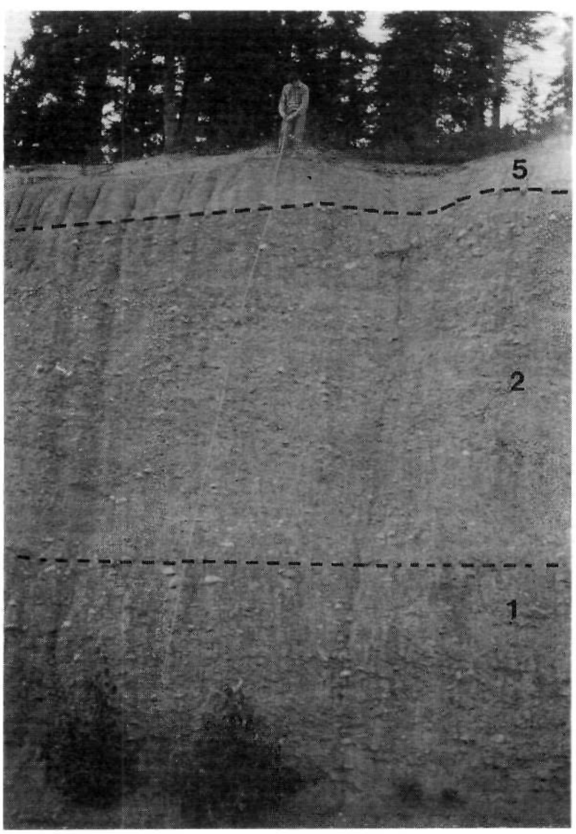


FIGURE 10. Ice-marginal, glaciolacustrine silts and clays of Unit 5 unconformably overlying gravels of Units 1 and 2 in the Pocahontas area (location G on Fig. 1b). A radiocarbon date of 11,900 ± 120 years BP (GSC-3885) on gastropod shells within the silts and clays provides a minimum date for retreat of Late Wisconsinan glaciers in the Athabasca River valley. Measuring tape is extended 15 metres.

Les silts et argiles glaciolacustres de marge glaciaire de l'unité n° 5 reposant en discordance sur les graviers des unités n^{os}1 et 2, dans la région de Pocahantas (site G de la fig. 1b). Une datation au radiocarbone de 11 900 ± 120 BP (GSC-3885) sur des coquilles de gastropodes dans les silts et graviers fournit une date minimale pour le retrait glaciaire au Wisconsinien supérieur dans la vallée de l'Athabasca. Le ruban à mesurer donne 15 m.

3. Silt and Clay Dominated Sequences (Glaciolacustrine Deposits)

At a few sites in the Athabasca River valley (*e.g.* Fig. 2G), diamicton beds of Unit 4 are overlain by massive to horizontally laminated silts and clays. These sediments are similar to those in Unit 2 and they are also interpreted as glaciolacustrine deposits. Their stratigraphic position indicates that they were deposited in ice-marginal lakes during retreat of glaciers occupying the Athabasca Valley. They are relatively rare compared to deposits in Unit 3, suggesting that during deglaciation, glaciers in the Athabasca valley did not dam drainage in tributary valleys as they did during the advance phase. It is therefore inferred that the Athabasca Valley became ice-free before or at about the same time as its tributary valleys. In the Punchbowl Falls area (Figs. 2G and 10), silts and clays of this subunit occur at the top of an incised bench on the southeast side of the valley and it is more likely that they were deposited in a lake confined there by ice than in an unconfined postglacial lake. These sediments contain various species of gastropods that yielded a radiocarbon date of 11,900±120 years BP (GSC-3885), giving a minimum date for retreat of ice from the region (Levson *et al.*, 1989).

UNIT 6: FINE SAND, SILT AND DIAMICTON SEQUENCES (POSTGLACIAL DEPOSITS)

1. Fine Sand and Silt Deposits (Loess sequences)

Most sections in the region are capped by about 0.2 to 2 m of massive fine sands and silts interpreted as loess (Figs. 2 and 11). These sediments are most common in the Pocahontas and Punchbowl Falls areas (Fig. 1b) where they overlie silt and clay dominated sequences in Unit 5. Fine sands and silts of Unit 6 locally contain buried Bm and Ah soil horizons and volcanic ash beds. Paleosols have a loose to friable consistence when moist and are not indurated. In comparison to the underlying sediments, Ah horizons have lower color values and are enriched in organic matter including charcoal fragments; alteration in Bm horizons is indicated by higher chromas and redder hues. A prominent volcanic ash layer in silts overlying poorly sorted gravels at Pocahontas (Figs. 1b and 11b) has bracketing radiocarbon dates on charcoal of 4180±210 years BP (AECV-602C) and 3070±90 years BP (AECV-603C). The ash is interpreted as St. Helens Yn tephra which was erupted about 3400 years BP (Mullineaux *et al.*, 1975; Westgate,

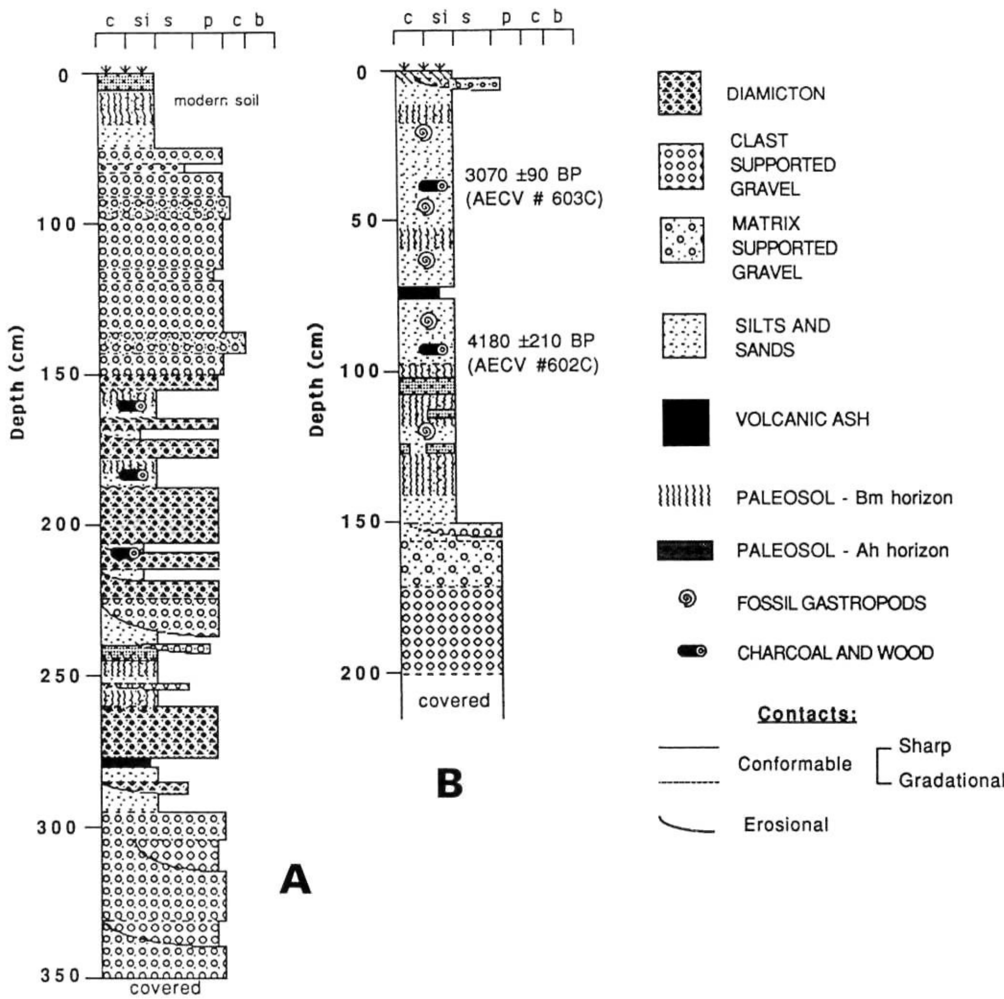


FIGURE 11. A. Stratigraphic section of the upper few metres of a small alluvial fan near Disaster Point (location H on Fig. 1b). Paleosol horizons indicate periods of temporary stability on the fan surface between deposition of debris flow deposits (diamicton) and alluvial gravels. B. Radiocarbon dates, volcanic ash and paleosol horizons in loess deposits unconformably overlying glaciofluvial gravels in the Pocahontas area (location F on Fig. 1b).

A. Coupe stratigraphique de la partie supérieure d'un petit cône alluvial près de Disaster Point (site H de la fig. 1b). Les horizons du paléosol indiquent les périodes de stabilité provisoire à la surface du cône entre la mise en place des dépôts de coulée boueuse (diamicton) et celle des graviers alluviaux. B. Datations au radiocarbone, cendre volcanique et horizons de paléosols dans des dépôts de lœss reposant en discordance sur des graviers fluvioglaciaires (site F de la fig. 1b).

1980). Although not positively identified in the Pocahontas area, tephra chemically similar to Mount Mazama ash (Table I), has been identified in reworked glaciolacustrine sediments elsewhere in the Athabasca River valley (Levson *et al.*, 1989). Intermittent deposition, and possible reworking, of volcanic ash occurred during deposition of the loess. Periods of non-deposition allowed for soil development. Glaciolacustrine silts of Unit 5, in combination with floodplain silts and sands in the Athabasca Valley, probably were the main sources of the eolian deposits.

2. Diamicton Dominated Sequences (Paraglacial Fan Deposits)

Interbedded diamicton and poorly sorted gravels occur at the surface in a number of shallow exposures along the lower slopes of the Athabasca valley (Figs. 11A and B). These deposits are thickest at the base of steep valley slopes. They occur mainly at lower elevations in small fan-shaped landforms. Diamicton beds are mostly matrix supported, muddy and massive or crudely bedded. They contain mixtures of both angular, local clasts and glacially abraded, distally-derived clasts. Gravels are poorly sorted and may be matrix or clast supported. Interbedded sands and gravels occur mainly as thin trough-shaped lenses. Wood and charcoal fragments are common only in the uppermost parts of these deposits as are massive silt and fine sand beds containing multiple buried Bm and Ah soil horizons. Near Disaster Point (Fig. 1a), silt and fine sand deposits with several buried paleosols and numerous charcoal fragments are interbedded with diamicton and poorly sorted gravels of this subunit (Fig. 11A).

3. Interpretation

Diamicton beds in these deposits are believed to have originated as valley-side debris flows that incorporated previously deposited glacial sediments as well as local bedrock materials. Resedimentation of debris along the valley walls probably was most active during and shortly after deglaciation when environmental conditions were most conducive to slope instabilities (Ryder, 1971; Jackson *et al.*, 1982). The occurrence of wood mainly in the upper parts of these deposits suggests a restricted forest cover at least during their initial depositional phase. The occurrence of the resedimented materials in low elevation fans suggests that they were deposited in early postglacial times after some stream incision had taken place. Sand and gravel lenses interbedded with diamicton beds in this subunit probably were deposited in small rills and fan channels by surface runoff. Massive silt and fine sand beds that occur in the upper one or two metres of the diamicton and gravel sequences are interpreted as loess deposits.

TABLE I

Chemical composition of glass shards from tephra interpreted as Mount Mazama ash in alluvial fan deposits near the confluence of the Whirlpool and Athabasca rivers

Sample #	841	842	843	844	Average	Regional Average*
Si	32.72	33.93	33.57	32.26	33.12±0.66	33.11±0.29
Ti	0.27	0.30	0.26	0.33	0.29±0.03	0.29±0.01
Al	7.43	7.41	7.47	7.23	7.39±0.09	7.70±0.08
Fe	1.54	1.56	1.60	1.60	1.57±0.03	1.54±0.04
Ca	1.05	0.94	0.98	0.95	0.98±0.04	1.13±0.03
Na	3.59	3.53	3.72	3.49	3.58±0.09	3.80±0.11
K	2.33	2.44	2.37	2.44	2.39±0.05	2.17±0.03
Cl	0.27	0.03	0.26	0.28	0.21±0.10	0.18±0.02

* average of 14 samples from northwest USA and southwest Canada (Smith and Westgate, 1969)

CHRONOSTRATIGRAPHY

The informal lithostratigraphic units described above are placed here into a general chronostratigraphic framework for the region, mainly on the basis of radiocarbon dates and some tephrochronologic control. Materials suitable for radiocarbon dating from the paleofan sediments of Unit 1 are rare but wood fragments (*Picea* sp.), obtained from an exposure at Amber Mountain (Fig. 3a), were dated at >39,750 (AECV 450c) and >48,000 (GSC-4646HP). Since the wood occurs at a relatively high level in the section, a large part of the fan sequence at that site must have accumulated prior to 48 ka. Deposits in the upper part of the paleofan sequences are locally interbedded with overlying glaciofluvial gravels indicating that alluvial fan sedimentation must have continued until the onset of the last glaciation. In addition, as ice did not reach the area until sometime after 29 ka (see below), fan sedimentation must have continued for at least an additional 20,000 years after deposition of the wood bearing horizon. Thus, sedimentation in the Amber Mountain fan probably spanned most of the Middle Wisconsinan and probably part of the Early Wisconsinan. The age of the oldest fan deposits in Unit 1 is unknown but the presence of rare glacial erratics throughout the sequences indicates that they began to accumulate sometime after the first Pleistocene glaciers reached the area. Evidence of earlier Pleistocene glaciations in the Jasper region is restricted mainly to these erratic clasts and to some high level erratics that occur at elevations above the locally inferred level of the last glaciation (Levson and Rutter, in press). The poor lithification and cementation of the paleofan deposits is also consistent with a Pleistocene age.

Although the morainal and associated glaciofluvial sediments in Units 2 to 5 comprise a group of sedimentologically complex deposits, they are interpreted to be the product of only one glacial event. The age of this event is constrained by a radiocarbon date of 29,100±560 years BP (GSC 3792) obtained on wood in gravels of Unit 2 underlying till near Jasper townsite. This date provides a maximum age for the onset of the last glaciation and indicates that ice moved into the area during the Late Wisconsinan stadial. A minimum date for deglaciation is provided by gastropods from ice-marginal lake sediments in the Pocahontas area, dated at 11,900±120 years BP (GSC 3885). Numerous other limiting radiocarbon dates from at least four different high elevation areas in Jasper Park, ranging from 9445±375 years BP (Beta 1480) to 9660±280 years BP (BGS 465), indicate that glaciers throughout the region had receded to near their present limits by shortly after 10 ka (Luckman and Osborn, 1979; Kearney and Luckman, 1983a, b; Beaudoin, 1984; Luckman and Kearney, 1986; Osborn and Luckman, 1988). Only minor advances, extending about one to two kilometres beyond present glacier margins, have since occurred (Kearney and Luckman, 1981; Osborn and Luckman, 1988).

Paraglacial conditions at the end of the last glaciation resulted in widespread resedimentation of glacigenic debris in the region and the development of numerous paraglacial fans (see Unit 6) in the Athabasca valley. Radiocarbon dates on charcoal in the loess deposits blanketing fan surfaces near Pocahontas indicate that most fan sedimentation had ceased by about 7500 years ago (Levson *et al.*, 1989). A number of dates ranging from approximately 4000 yrs BP to 7250 yrs BP have been obtained from stratigraphically equivalent loess deposits in the region (Dumanski *et al.*, 1980; Levson *et al.*, 1989). St. Helens Yn tephra occurs within the loess sequence in the Pocahontas area and volcanic ash chemically similar to Mount Mazama tephra (Table I), dated at about 6800 years BP (Bacon, 1983), occurs near the surface in alluvial fan deposits reworked from glaciolacustrine silts near Athabasca Falls. Similar stratigraphic relationships between Mount Mazama ash and paraglacial alluvial fan deposits were described in central British Columbia by Ryder (1971) who concluded that the bulk of fan sedimentation occurred shortly after deglaciation when paraglacial conditions resulted in unstable slopes and high depositional rates. This environment probably existed for a relatively short period of time following deglaciation. Jackson *et al.* (1982) also concluded that postglacial alluvial fan sequences in the Kananaskis area in the southern Canadian Rocky Mountains were deposited mainly in paraglacial conditions in the Late Pleistocene. Most of the low elevation alluvial fan sequences of Unit 6 in the Athabasca River valley, therefore were probably deposited during the Late Pleistocene and/or early Holocene.

SUMMARY

The Athabasca River in Jasper National Park occupies a broad, low-relief valley within an overall high-relief region in the Rocky Mountains. The valley acted as a depositional sink during the Late Pleistocene and allowed for the accumulation of a locally thick sequence of Quaternary deposits. Exposures of these sediments are dominated by thick accumulations of paleoalluvial fan deposits as well as a complex glacial sequence associated with the last glaciation. The paleoalluvial fan deposits (Unit 1) are characterized by coarse-grained, gravelly diamicton beds, interpreted as debris flow and flood flow deposits, with interstratified gravels and minor sands deposited by intermittent streams. Radiocarbon dates on wood in the fan deposits indicates that the fans began to accumulate well before 48 ka and probably continued to develop until Late Wisconsinan glaciers advanced into the area. Deposits resulting from fluvial sedimentation in the valley bottoms during this non-glacial period either were eroded or buried in most areas but braided stream gravels preserved near Jasper townsite were deposited about 29 ka. These gravels (Unit 2, lower subunit) are clast-supported, well imbricated and horizontally bedded, and are interpreted as longitudinal bar deposits. Wood and shell fragments occur throughout this subunit but decrease in abundance towards the top.

The transition from alluvial fan sedimentation in Unit 1 to braided stream deposition in Unit 2, reflects the increasing influence of outwash systems that developed in front of glaciers advancing down the main valleys. Local interbedding of diamicton beds, of probable alluvial fan origin, and a gradual rather than sudden increase in abundance of distally derived rocks (between Units 1 and 2), suggests that glaciofluvial sedimentation was locally coeval with the latter stages of alluvial fan development. The high elevation of the glaciofluvial gravels at most sites compared to present day rivers indicates a higher local base level, probably reflecting aggradation in the main valleys prior to glaciation. An increase in the number of cut and fill structures, erratic clasts and coarse lag gravels as well as a decrease in abundance of organics in the upper part of Unit 2, are inferred to reflect a more proximal glaciofluvial origin for these gravels than for those in the lower subunit. Large variations in sediment sorting, grain-size distribution, clast size and shape, and paleocurrent direction in the upper subunit, as well as the presence of glacially-derived debris flow deposits, also indicate a proximal ice-marginal environment.

Parallel laminated silts and clays (Unit 3) overlying glaciofluvial gravels in Unit 2 in some tributary valleys of the Athabasca River valley, particularly in the Front Ranges, are interpreted as glaciolacustrine sediments deposited in ice-dammed lakes. These sediments locally coarsen upwards and contain interbedded subaqueous debris flow deposits in their upper part. This is believed to reflect the progressive deposition of more proximal glaciolacustrine deposits as glaciers advanced down these valleys.

Massive, matrix-supported, compact, diamicton sequences (Unit 4), unconformably overlying deposits of Units 1 to 3, are interpreted as basal tills deposited by the advancing glaciers. These deposits exhibit strong valley-parallel fabrics and they contain numerous glacially abraded and erratic clasts. Lodged clasts and glacially-induced folds and thrust faults occur in sediments directly underlying this unit at some sections. Massive diamictons in Unit 4 may be underlain or overlain by stratified, sandy diamicton, commonly with poorly developed fabrics and interbedded sand and gravel lenses. These deposits are interpreted as glacially derived, debris flow and glaciofluvial sediments. They were deposited during both the advance and retreat stages of glaciation. Angular metamorphic erratics derived from west of the Continental Divide, locally occur in the Athabasca River valley, mainly on the surface in association with a sandy, poorly consolidated, diamicton. They are inferred to be part of the Athabasca Valley Erratics Train and the associated diamicton is interpreted as a supraglacial till.

During deglaciation, a complex sequence of deposits (Unit 5) consisting of interbedded gravel, sand and diamicton as well as local clay and silt sediments was deposited on the surface at many sites. Gravel and sand dominated strata exhibit characteristics of proximal glaciofluvial deposits and interbedded diamictons are interpreted as glacigenic debris flow deposits. These sediments are preserved mainly as channel-fill sequences and in kame terraces along the flanks of the Athabasca River valley. Kame terrace deposits show large variations in paleoflow directions and abundant post-depositional deformation structures including numerous normal faults indicating collapse towards the valley centre. Silt and clay dominated sequences in Unit 5 are relatively rare, occurring at only a few sites where small ice-marginal lakes formed during deglaciation. The absence of glaciolacustrine sediments at the surface, in most valleys where advance-phase glacial lakes formed, suggests that the Athabasca River valley probably became ice-free before or at approximately the same time as its tributary valleys. Radiocarbon dating of shells in glaciolacustrine silts at Pocahontas suggest that deglaciation occurred there sometime after 12 ka. Shortly after degla-ciation, much of the unconsolidated glacial debris flanking the valley sides was resedimented under paraglacial conditions resulting in deposition of numerous fan sequences at the base of the valley slopes. Deposition occurred mainly in early postglacial times, as indicated by radiocarbon dates on wood and by the presence of Mazama ash (6800 years BP) near the top of the fan deposits. Reworking of older deposits, especially sandy glaciolacustrine and glaciofluvial sediments, by wind, also occurred in late-glacial and postglacial times and resulted in widespread deposition of a loess mantle over the region.

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