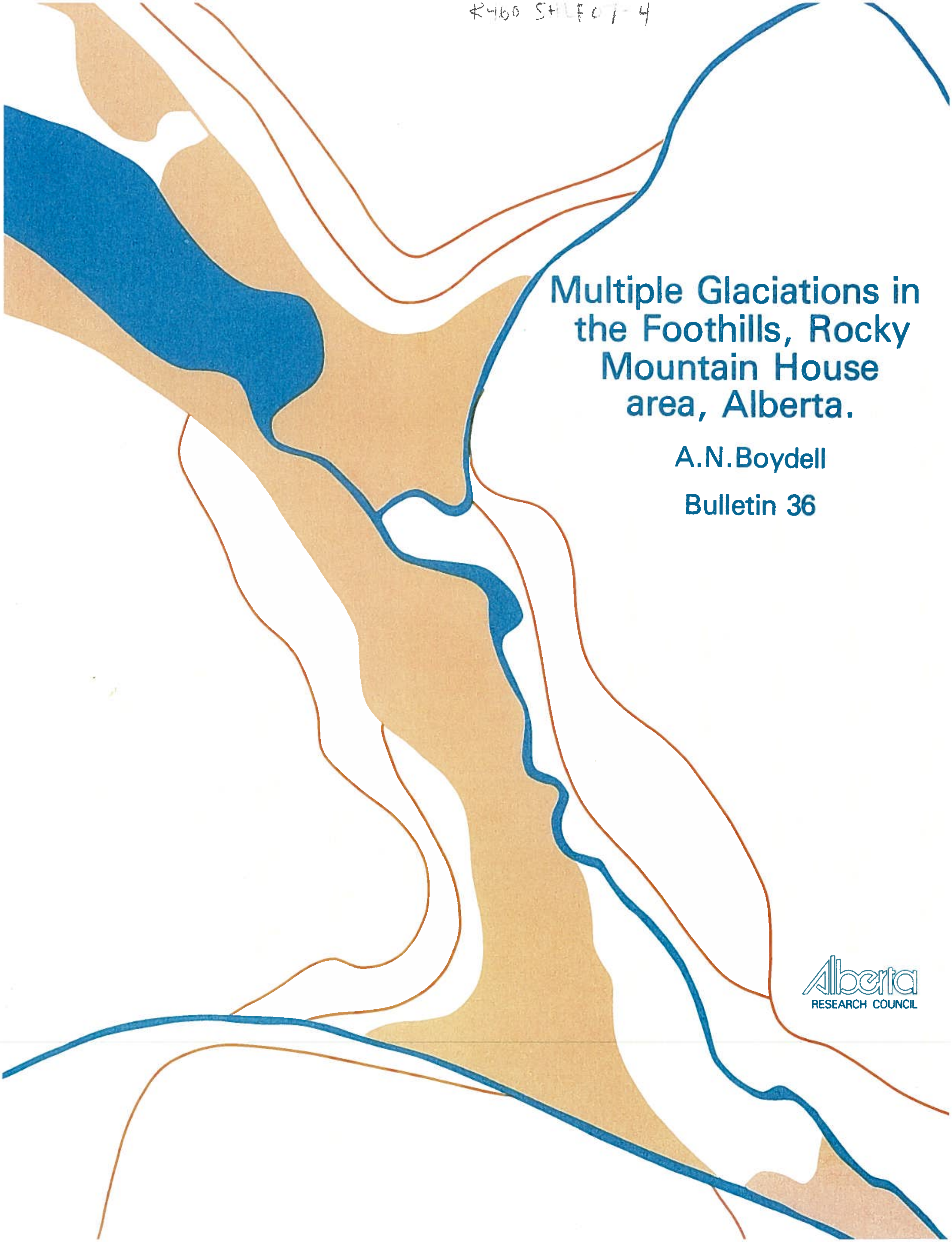

Multiple Glaciations in the Foothills, Rocky Mountain House area, Alberta.

A.N.Boydell

Bulletin 36

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MULTIPLE GLACIATIONS IN THE FOOTHILLS, ROCKY MOUNTAIN HOUSE AREA, ALBERTA

A.N. Boydell

Alberta Research Council
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Multiple Glaciations in the Foothills, Rocky Mountain House area, Alberta

ABSTRACT

The results of this study of the surficial deposits in the Rocky Mountain House area (Rocky Mountain Foothills region) indicate that in Wisconsin times the study area experienced multiple glaciations. Only one Laurentide advance (Athabasca-Sylvan Lake) was documented, but this ice probably remained in the area for the whole of the Late Wisconsin. One Early Wisconsin (Hummingbird-Baseline) and two Late Winsconsin (Lamoral and Jackfish Creek) Rocky Mountain advances were also documented. One "old glacial" area (Brazeau and Ram Ranges) situated above 5500 ft (1660 m) was glaciated during the Early Wisconsin but remained ice free in Late Wisconsin times. A number of proglacial lakes, impounded by Late Wisconsin ice masses, formed in the river valleys. A major lake (glacial Lake Caroline) occupied a substantial portion of the area during deglaciation. Rocky Mountain meltwaters were impounded by the Laurentide ice mass and cut successively lower spillways in the east and southeast. The entire study area was probably ice free soon after 9600 BP.

During the course of this study, the surficial deposits were mapped, and samples were taken from exposures and from material collected by dry auger drilling. Supplementary laboratory tests included till fabric analysis, and lithological, heavy mineral, and carbonate analyses. Only heavy mineral analysis and pebble counts were found to be useful for differentiating among the tills. The relative ages of the three Rocky Mountain advances were established from stratigraphic and morphological evidence, because of a lack of suitable radiometric data.

INTRODUCTION

The Rocky Mountain Foothills lie between the Rocky Mountain Front Ranges to the west and the Alberta Plains to the east. At times during the Pleistocene Epoch, ice masses in the Cordillera and on the Canadian Shield expanded, converged, and possibly coalesced in this zone. In order to understand better the relationships between continental and valley glaciers, an area in the southwest part of the Rocky Mountain House map area was studied, and its glacial history determined. This area was selected because it encompasses three major river valleys, which all probably served as outlets for an ice mass in the Front Ranges, so a comparative study of the characteristics of valley glaciation could be made.

This report summarizes the results of fieldwork and laboratory analyses, and describes the glacial history of the study area.

LOCATION OF THE STUDY AREA

The study area is contained largely within the southwest quarter of the Rocky Mountain House map area (NTS 83B), and is located about 100 mi (160 km) north of Calgary. The area lies between Caroline in the east and Nordegg in the west, and is bounded by the David Thompson Highway to the north and the Clearwater River to the south (Fig. 1).

Three river systems, the North Saskatchewan, the Ram, and the Clearwater, traverse the area from west to east, cutting through the northwest trending anticlinal ridges of the Ram and Brazeau Ranges.

PREVIOUS WORK

Study Area

No reports deal specifically with either the glacial deposits or the glacial record of the study area. Peters and Bowser (1957) mapped soils in the east half of the study area and described parent materials. They also stated that Rocky Mountain and Laurentide ice masses coalesced along a line near Rocky Mountain House.

Erdman (1950) mapped the geology of the Alexo and Saunders (North Saskatchewan River valley) areas, noting glacial erratics to elevations of 6900 ft (2090 m), and gravel ridges consisting of materials derived from the sedimentary rocks to the west. Stalker (1956) mapped the locations and elevations of a small number of the megaerratics of the Foothills Erratics Train.

More recently, Carlson (1971) and Tokarsky (1971) described respectively the bedrock topography and drift thicknesses, and the hydrogeology.

Adjacent Areas

Several studies have been conducted in areas either comparable with, or adjacent to, the present area of study.

In 1960 Stalker discussed the glacial geology of the Red Deer area (NTS 83A) and described three Laurentide tills in the area. He concluded that the upper till was deposited by a single, fairly long-lasting Wisconsin advance, and that the other two tills were deposited during earlier glacial episodes.

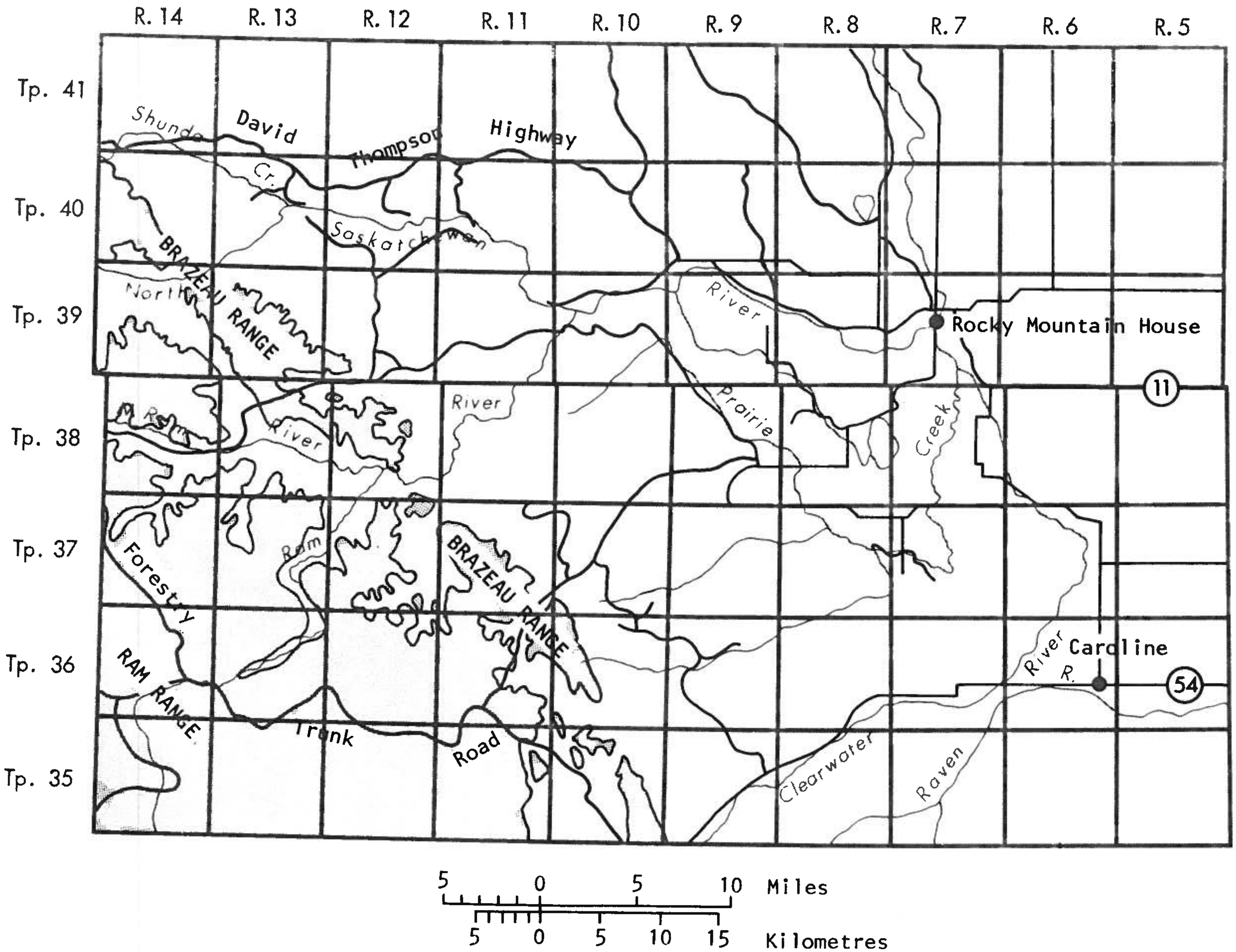

FIGURE 1. Map showing location of the study area and access

In 1968, Roed completed a study of the glacial geology of the Edson-Hinton region. He described five Cordilleran and two Laurentide advances, the three later Cordilleran advances being correlated with the three stades of the Pinedale advance as defined by Richmond (1965). Roed also described a mixed till which he attributed to the coalescence of his "Pinedale I" mountain advance with the second, and most recent, Laurentide advance. A similar mixed till, having the character of both Rocky Mountain and Laurentide deposits, is present in this study area. The Alberta Research Council published a map of the surficial geology of the Edson area (NTS 83F) in 1970 (Roed, 1970).

McPherson (1970) described two tills in the upper North Saskatchewan River valley, separated by gravels, and inferred two ice advances which he called "Big Horn" and "Main." He considered the Pleistocene ice-dispersal center to have been located east of the Continental Divide.

Boydell (1970) described the surficial deposits and glacial history of the Red Deer River valley near Sundre. He presented evidence for a single Late Wisconsin advance of both Rocky Mountain and Laurentide ice masses. Coalescence did not take place because the Rocky Mountain piedmont glacier had retreated prior to the Laurentide maximum. A C^{14} date of 10,700 ± 150 years BP on gastropods from a low level of proglacial Lake Sundre suggests a minimum age for deglaciation of that area. In the upper Red Deer River valley, a date of 11,220 ± 680 years BP on gastropods collected by Chambers (pers. comm. 1968) suggests that the Rocky Mountain ice had retreated well up-valley by that time (Harris and Boydell, 1972).

In the Dawson Creek (British Columbia) area, Reimchen and Rutter (1972) found evidence for three advances of Cordilleran ice and for at least one advance of Laurentide ice. The till of the earliest Cordilleran advance, deposited on a plateau surface, is extremely weathered, and in this respect bears a strong resemblance to the Baseline Till observed in this study area.

THE PRESENT STUDY

Fieldwork

The study area is part of a larger area mapped during 1970 and 1971 for the Alberta Research Council (Boydell, Bayrock, and Reimchen, 1974). Preliminary maps, based on airphoto interpretation, were used during the field program.

The preliminary identification of tills as either of Rocky Mountain or Laurentide origin depended upon the absence or presence of crystalline igneous and high-grade metamorphic pebbles. However, local ice-flow indicators, where present, were also considered to increase the probability of identifying correctly the provenance of the till and gravel deposits. Till units were then characterized according to color, texture, stoniness, depth of leaching of carbonates, and fabric. Depth to bedrock was recorded where known.

Although stratigraphic sections are abundant, they are largely restricted to river and stream valleys. To gather stratigraphic information in other locations, holes were drilled using a dry-auger drilling rig.

Much of the region in the west is heavily forested and poorly accessible, particularly areas of steep terrain. Government-built roads follow the river valleys (Fig. 1), and oil and gas exploration roads, while offering potential access, are often impassable in the summer months. All areas inaccessible by vehicle were examined and mapped by helicopter.

Laboratory Work

The main purposes of the laboratory analyses were to characterize the tills of the area to determine their provenance, and to obtain additional information which could be used to establish more firmly the stratigraphic relationships. Some samples of glaciolacustrine sediments and gravels were also examined during certain phases of the analysis.

Characteristics investigated were: grain-size distribution, pebble lithologies, carbonate content, heavy mineral composition, and the weathering of minerals in the weathered zones of specific till units.

ACKNOWLEDGMENTS

The writer thanks L. A. Bayrock for his invaluable advice in the field, and S. A. Harris, N. W. Rutter, J. E. Harrison, and J. P. Crowley for their guidance and advice during the preparation of the manuscript. Assistance in the field was ably provided by F. W. Kreuger in 1970 and K. Drabinsky in 1971.

THE PHYSICAL ENVIRONMENT

CLIMATE

Two standard rain gauges on Shunda and Prairie Creeks (Fig. 1) and a meteorological station maintained at Rocky Mountain House since 1915 are the only sources of climatic data for the study area. In general, the summers are moderately warm and the winters relatively cold. Mean annual precipitation, of which about 68 percent falls as rain, is a little over 20.5 in (52 cm) at Rocky Mountain House and increases westwards. Most of the area is snow covered from November to April, with mean depths ranging from 5 ft (1.5 m) in the east to greater than 7 ft (2 m) in the west.

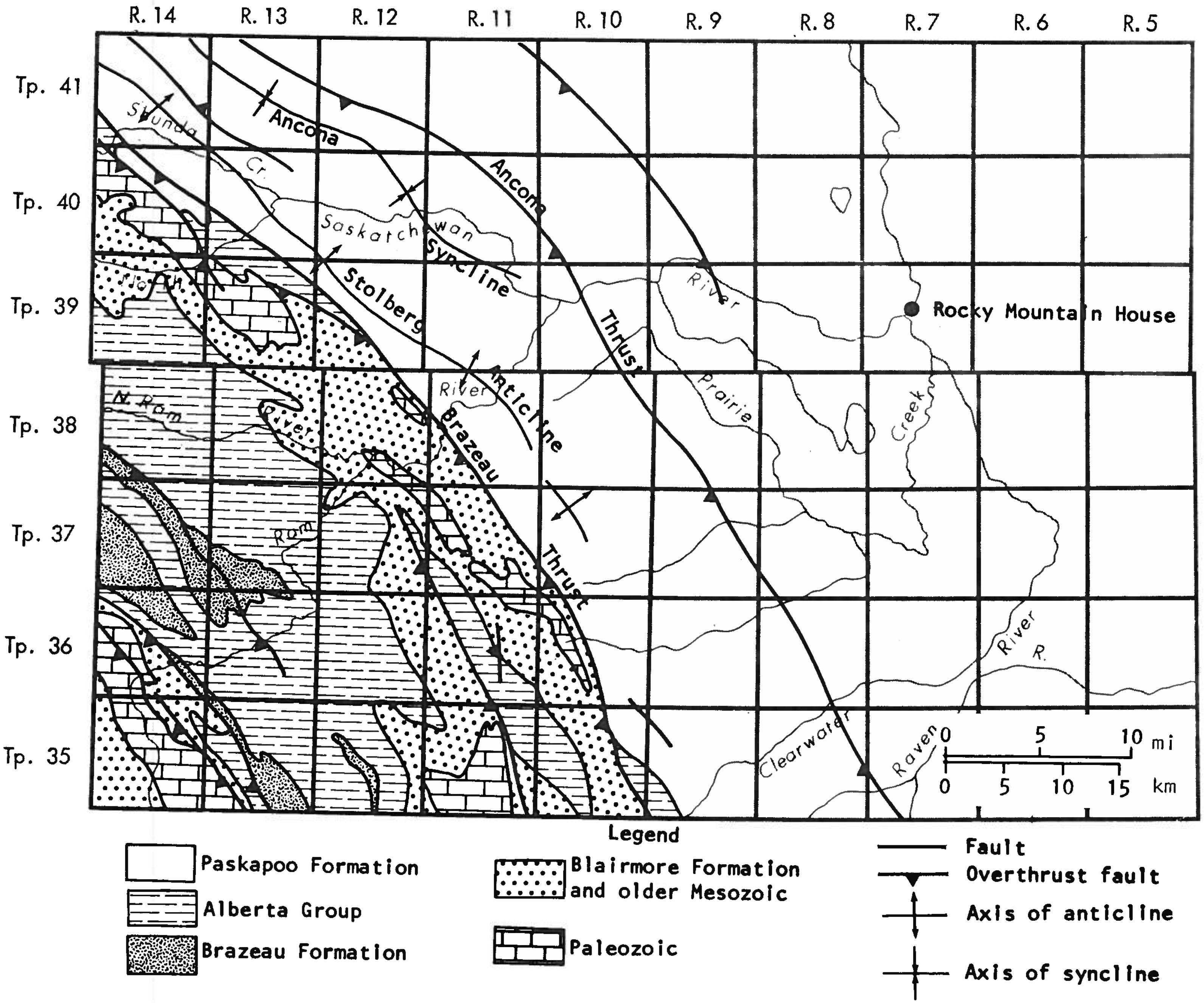

FIGURE 2. Bedrock geology

VEGETATION

The area lies within the Boreal-Cordilleran Transition phytogeographic zone (Moss, 1955). The dominant tree species are lodgepole pine *(Pinus contorta* var. *latifolia),* white spruce *(Picea glauca),* aspen *(Populus tremuloides),* and balsam poplar *(Populus balsamifera).* In the lower-lying marshy areas, black spruce *(Picea mariana),* dwarf birch *(Betula glandulosa),* and tamarack *(Larix laricina)* are common.

On some of the upper, south-facing hill slopes, and in parts of the Ram River gorge, small alpine meadows are found. These seem to provide winter sheep range and appear to consist largely of *Elymus innovatus* communities (Ogilvie, 1968).

SOILS

The soils have been mapped by Peters and Bowser (1957) as far west as the Forest Reserve boundary; these soils consist mainly of Gray Luvisols (Agriculture Canada, 1970) developed on till and glaciolacustrine and eolian sediments. The most common subgroup is the Lobley Loam which is developed on till covering undulating to hilly topography at elevations usually above 5900 ft (1800 m).

In many of the low-lying areas flanking the North Saskatchewan River valley organic soils predominate. These poorly drained soils, largely undifferentiated Fenno- and Sphagno-Fibrisols, are common in similar depressions throughout the area.

The larger river valleys contain Regosolic soils developed either on coarse gravel or sandy alluvium. In the valleys of the North Saskatchewan River, Ram River, and Prairie Creek the soils are largely Orthic Regosols, but in the Clearwater River valley Lithic Regosols predominate with occasional patches of the Rego Dark Gray subgroup.

The unmapped area to the west of the Forest Reserve boundary lies within the Undifferentiated Mountain Soil Complex (Alberta Government and University, 1970). For the purposes of this study, the major soil groups in this zone were noted with respect to their parent materials and were mapped accordingly. Three zonal subdivisions are suggested for this area:

(1) bare rock, mostly steeply sloping with minimal soil development;
(2) relatively shallow soils on lower slopes, mainly developed on till and generally of the Luvisolic Order;
(3) soils of the lower areas and valley floors, mostly Fibrisols and Lithic Regosols.

BEDROCK GEOLOGY

Rocks ranging in age from Devonian to Paleocene are present (Fig. 2), with an exposed aggregate thickness of more than 14,400 ft (4400 m). An erosional disconformity between Paleozoic and Mesozoic strata marks the absence of Pennsylvanian, Permian, Triassic, and lowest Jurassic sediments (Erdman, 1950).

Structure

The Brazeau and Ram Ranges are the outermost outliers of Paleozoic rocks in the Rocky Mountains, and were created by the movement of large masses northeastward along southwest dipping thrust faults (Erdman, 1950). The ranges are breached anticlinal structures, with elevations ranging up to 9850 ft (3000 m) in the higher parts of the Ram Range. Rocks as old as Late Devonian are exposed in the cores of the ranges where river gaps have been cut.

Immediately east of the Brazeau Range are the northwest trending, colinear, largely asymmetrical folds of the Stolberg Anticline and the Ancona Syncline (Fig. 2). Also present are the parallel and subparallel faults of the Ancona and Brazeau Thrusts. Generally, the southwest limbs of the anticlines are gentle, and the northeast limbs are steep to overturned. Most of the faults dip towards the southwest.

Farther east and northeast the youngest rocks, of Paleocene age, are present in synclines characterized by broad, open folds and relatively little faulting.

Lithology and Stratigraphy

The part of the study area east of the Brazeau Range is underlain by Upper Cretaceous to Paleocene rocks, largely of the Paskapoo Formation. These consist of friable, brown and gray, medium-grained arkosic sandstones, interbedded with gray-green mudstones and shales. These make up the bulk of the pebble lithologies of the younger mountain tills. Carbonaceous rocks, tuff, and bentonitic beds are also common in the area.

Upper Devonian rocks are exposed in the core of the Brazeau Range. These are composed mainly of argillaceous limestones, siltstones, calcareous shales, and saccharoidal dolomites. The Mississippian comprises the Banff and Rundle Formations which are shaly limestones and calcareous dolomites interbedded with cherty bands, and the Exshaw Formation, which is composed of fissile, paper-thin, black shales. The Rundle outcrops as a peripheral strip around the Brazeau Range, and forms an almost continuous dip slope on the range's southern flank.

The Lower Cretaceous Blairmore Group outcrops in much of the area of the Brazeau and Ram Ranges, and is also present in Ram Gorge. These strata consist of thin-bedded sandstones and carbonaceous shales, and include the prominent Cadomin Conglomerate which has contributed to the pebble lithologies of the Baseline Till.

Table 1. Local Formations Contributing to the Pebble Lithologies of Rocky Mountain Tills

Era	Period	Epoch	Group	Formation	Lithology
	Tertiary-Cretaceous	Paleocene-Upper Cretaceous		Paskapoo/Brazeau	Paskapoo: brown and gray, arkosic sandstone, interbedded with green mudstone and shale; tuff, bentonite and carbonaceous rocks are common (found in plains region)
					Brazeau: gray and green sandstone and sandy shale; gritty carbonaceous sandstone, and maroon weathering sandstone; lower part exposed in area (found in Foothills)
MESOZOIC	Cretaceous	Upper Cretaceous	Alberta	Wapiabi	black shale and sandy shale; scattered concretions and bands of rusty weathering limestone
				Bighorn	resistant, siliceous sandstone member at top and bottom; a thicker, soft shale and shaly sandstone member in middle
				Blackstone	soft, thin-bedded, black, fissile shale; ironstone concretions and limy bands
		Lower Cretaceous	Blairmore	Mountain Park	gray and green weathering, gritty sandstone, and interbedded shales; conglomerates
				Luscar	interbedded, thin-bedded sandstones, shales and carbonaceous rocks; commercial coal seams
				Cadomin	resistant, chert and quartz pebble-conglomerate and interbedded sandstone
	Jurassic			Nikanassin	upper part: alternating shale and sandstone, more shaly in Saunders area; lower part: persistent, hard, bedded, black, cherty, phosphatic limestone
PALEOZOIC	Mississippian	Upper Devonian	Rundle		upper part: thick, massive, light weathering limestone, and limy dolomite; middle part: soft, thin-bedded, shaly limestone; lower part: massive coarse-grained limestone
				Banff	thin-bedded limestone and shaly limestone, platy at base; cherty bands in lower part
	Devonian			Exshaw	fissile, paper-thin, black shale part
				Palliser	gray, fine-grained limestone
				Alexo	siltstone, dolomite and argillaceous limestone; also sandstone and mudstone
			Fairholme	Mount Hawk	shales, dolomitic limestone, and siltstone
				Perdrix	gray-black shales
				Flume	argillaceous limestone

*from Erdman (1950) and de Wit and McLaren (1950)

The Upper Cretaceous Alberta Group, consisting of black shales with ironstone concretions, siliceous sandstones, and sandy shales, outcrops at the South Ram River Falls and is found throughout most of the central area between the Brazeau and Ram Ranges.

At the western margin of this central area, and in the Ancona Syncline, beds of the Upper Cretaceous to Tertiary Brazeau Formation overlie the Alberta Group. The Brazeau Formation is composed mainly of sandstone and sandy shales, including a maroon-weathering sandstone which is occasionally found in the younger mountain tills.

A detailed description of local formations which have contributed to the mineralogical composition of the Rocky Mountain tills is given in table 1.

PHYSIOGRAPHIC SUBDIVISIONS

Four distinct physiographic zones describe areas of high, medium, and low relief (Fig. 3):

(1) Brazeau and Ram Ranges area
(2) Elk Creek Basin
(3) Brazeau Piedmont
(4) Northern and Eastern Lowlands.

Brazeau and Ram Ranges Area

The high mountain area to the west of the Brazeau Thrust Fault is dominated by anticlinal ridges with summit elevations reaching 9850 ft (3000 m). The physical characteristics of both ranges are similar and may be summarized as follows:

(1) Many slopes are covered by colluvial mantles, including both active and fossil talus.
(2) The numerous bedrock outcrops show signs of intensive weathering.
(3) Glacial forms, such as cirques, are either very subdued or absent.

Both ranges have been breached by the North Saskatchewan River, the North and South tributaries of the Ram River, and the Clearwater River. On the summit ridge of the Brazeau Range north of the Ram River, weathered quartzite and conglomeratic glacial erratics resting on Carboniferous limestone surfaces provide the only direct evidence of former glaciation.

Elk Creek Basin

The Elk Creek Basin area includes the margins of both the South Ram and Clearwater River valleys. The basin contains gravels, generally up to 56 ft (17 m) thick, which consist partly of outwash from the South Ram glacier, and partly of ice-contact deposits from both the South Ram and Clearwater glaciers. Glacial drift mantles the lower valley slopes, and a number of small glacial drainageways have dissected the underlying Mesozoic bedrock in the north.

Brazeau Piedmont

The Brazeau Piedmont lies between the Brazeau and Ancona Thrust Faults (Fig. 2) and between the North Saskatchewan and Clearwater Rivers. This piedmont is a highland plateau region with elevations up to 5450 ft (1660 m), possessing flat summits and relatively steep-sided slopes. Terrain of this nature has been previously described as "Tableland" by Bayrock (*in* Lindsay *et al.,* 1960) and by Roed (1968). Dissection by northeast-flowing streams has created an average relief of about 1650 ft (500 m) between valley floor and plateau summit.

Glaciers probably occupied the whole area at one time or another; tills are found either on the flat summits or in the valley bottoms, but are absent on the intervening slopes. Many of the southwest-northeast interfluves have been breached by glacial spillways aligned perpendicular to the ridges. Glaciolacustrine sediments are present in the areas up-valley from the tills, and generally separate the valley tills from the till on the plateau surface.

Northern and Eastern Lowlands

This region comprises the remaining part of the study area and is dominated by the valleys of the North Saskatchewan and Clearwater Rivers. Although the area is underlain by the relatively soft Paskapoo Formation, the surface expression, while generally subdued, is characterized by several low, southeast-trending bedrock ridges.

The surficial deposits are largely of glacial origin, and tills and glaciolacustrine sediments predominate. The two river valleys have been infilled with postglacial gravels, and in these a number of terraces have been cut. Two substantial areas of postglacial eolian sands are located to the northwest and southeast of Rocky Mountain House. Organic sediments occupy the courses of many of the former drainageways.

STUDY METHODS

Field methods employed were: field sampling, field mapping, drilling, and till fabric analysis. Laboratory analyses were performed to determine: lithology of pebbles, grain sizes, carbonate content, and amount and kind of heavy minerals. Most of the laboratory methods permit description, not differentiation, of glacial deposits. Differentiation appears to be achieved reliably only by pebble counts, heavy mineral analysis, and stratigraphic mapping.

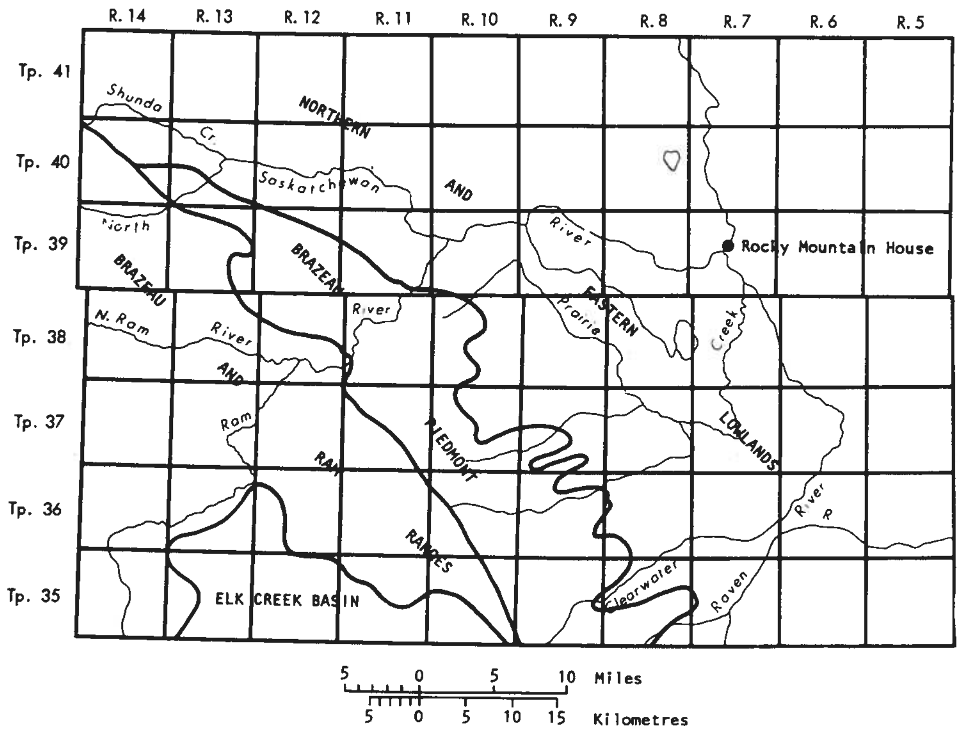

FIGURE 3. Physiographic subdivisions

FIELD SAMPLING

Stratigraphic samples were collected both from exposed sections and from material collected by dry-auger drilling in areas lacking complete exposed sections. In sections samples were obtained from below the upper levels of disturbance, and generally above and below the limit of leaching as determined by testing with hydrochloric acid. In the case of the Baseline and Hummingbird Tills, samples were gathered systematically through the weathered to the unweathered zone so that the changes in percentages of heavy minerals could be studied. During drilling, changes in both the degree of resistance to and the cutting motion of the auger indicated stratigraphic boundaries. Uncontaminated samples were removed from the auger flights, after scraping away the outer layer. The depth below surface of the material sampled could be estimated to within 1½ ft (½ m). For all tills augered, enough material was collected to enable pebble counts.

The areal sampling design was very flexible in order to accommodate unfavorable terrain, patchy distribution of deposits, and a preponderance of river-cut sections. Sampling ranged from systematic at 12-mi (20-km) intervals along the length of the North Saskatchewan River valley to scattered in areas where locations of sampling points were determined by the availability of suitable helicopter landing sites.

FIELD MAPPING

Precise areal definition of many of the surficial deposits was not always possible, mainly because of the difficult terrain and heavy forest cover. Therefore, the positions of geological boundaries were largely determined from detailed airphoto analysis, both before and after field mapping.

STRATIGRAPHIC DRILLING

Twenty-seven boreholes were drilled in the study area with maximum depths not exceeding 100 ft. (30 m). The stratigraphy was recorded (Fig. 4), and where possible, samples of the bedrock were taken and the approximate depth of the water table noted. In 16 of the boreholes, tills were discovered at some depth below the surface, and were subsequently identified by laboratory analysis. The locations of the drilling sites are shown on the map of the surficial deposits of the study area (Fig. 5).

Drilling to bedrock at every site was not always possible, either because the depth was greater than the available auger length, or because the drill would not penetrate the very coarse gravel deposits.

TILL FABRIC ANALYSIS

Because of the patchy distribution of the older glacial deposits, till fabric analysis was the only means available for establishing ice-movement directions at the time these were deposited. Thus fabrics were measured only in the lower tills of multiple-till sections and in the older tills. For the youngest (Jackfish Creek) till, regional ice movements were inferred from the distribution of surficial deposits, and by the presence of flutings, lineations, and drumlins.

The conventional two-dimensional method (Andrews, 1971) was used to measure till fabrics, and the chi-square test was applied to the results to determine significant orientation. The detailed results are presented in Boydell (1972).

LABORATORY METHODS

The laboratory analysis program was designed to both describe and differentiate the glacial deposits of the study area. The results were then used to extend the observations and conclusions of the field program. Tests were run principally on till samples, but some gravels and glaciolacustrine sediments were also included.

Pebble Lithologies

Ninety till and gravel samples were analyzed. Twenty of these, collected from sites to the east of the study area, were of Laurentide till. Most of the pebbles in the samples ranged in size from 0.8 to 2.3 in (2 to 6 cm).

After local (Mesozoic) bedrock lithologies were omitted, the percentages were calculated for three groups:

(1) total quartzites
(2) granites, gneisses, and other high-grade metamorphic rocks from the Canadian Shield
(3) carbonate rocks (limestones, dolomites, and cherts).

These results are plotted on a ternary diagram (Fig. 6).

The results support the initial assumption that both continental and mountain glaciers invaded the area because two groups are distinguishable on the diagram:

(1) the tills interpreted to be Laurentide, which contain Shield rocks, and in which the quartzites are restricted to a 30 percent spread;
(2) the tills interpreted to be Rocky Mountain, in which no Shield rocks are present, and in which the quartzite and carbonate contents display a much greater variability.

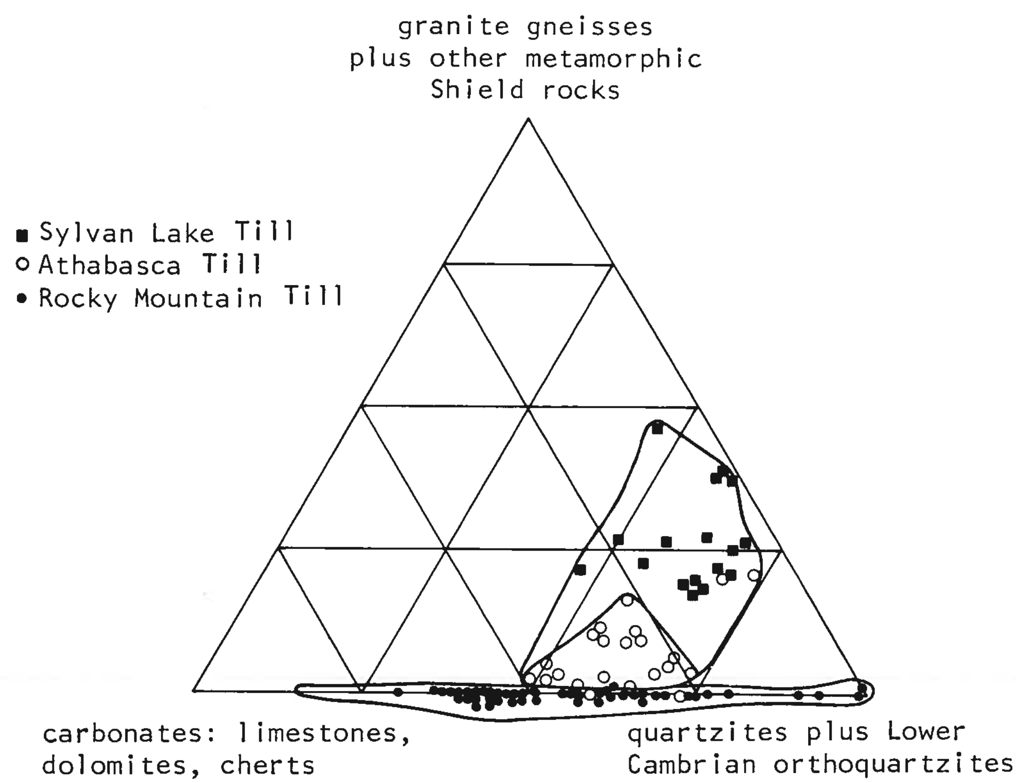

FIGURE 6. Relationships of principal pebble lithologies in tills

Within the Laurentide group a subgroup is discernible in which carbonate rocks increase and Shield rocks decrease. A second distinction of this subgroup, too small to be shown on the ternary diagram, is the presence of Lower Cambrian (Gog Group) orthoquartzites, which are also present in all the Rocky Mountain tills.

Of the samples lying within the Rocky Mountain group, only two (less than 4 percent) are anomalous. These belong to the zone of mixed characteristics and have been so defined by their heavy mineral composition. The conclusion is that a gross but generally reliable differentiation between deposits of Rocky Mountain and Laurentide provenance can be obtained by the pebble count method.

Grain-size Analysis

Grain-size analysis was performed to test whether the various tills could be differentiated using this method. Dreimanis *et al.* (1966) used textural analysis with some success in eastern Canada, although in Alberta Westgate (1968) obtained poor results. Boydell (1970) found the method useful in the Red Deer River valley where single units of Rocky Mountain and Laurentide provenance were present.

The pipette method (Krumbein and Pettijohn, 1938) was the technique employed as it offered simplicity of apparatus, and speed and accuracy in handling a large number of samples. The resultant percentages of sand, silt, and clay in the glacial sediments in size fractions finer than 0.05 mm (USDA), 0.02 mm (INT), and 0.002 mm (USDA) respectively, are plotted on ternary diagrams (Fig. 7).

Although on a general level a relatively higher average silt and clay content seems to be a characteristic of the younger Rocky Mountain tills, no differences are apparent in the spread of values for the Rocky Mountain House area. This method is thus not suitable for differentiating tills in the study area.

Carbonate Content

The total carbonate contents of the tills were determined principally to test the hypothesis that the carbonate-rich environment of the Rocky Mountains produced tills with highly variable carbonate contents. If this hypothesis were true, a gross division between Rocky Mountain and Laurentide tills might be observable.

The percentages of calcite and dolomite in the till matrix finer than 0.003 in (0.074 cm) were measured using a modified Chittick gasometric apparatus (Dreimanis, 1962). The results are graphed, plotting percentage calcite against percentage dolomite for both Rocky Mountain and Laurentide tills (Fig. 8). The expected high degree of variability is demonstrated in the plot of the Rocky Mountain tills. However, comparison of the two graphs shows a total overlap of the lower values, even though in the case of the Laurentide tills only one observation exceeds a total carbonate content of 25 percent while in the Rocky Mountain tills 46 percent of the observations exceed the same value.

This method, then, is not reliable for differentiating tills in the Foothills Zone, but could be used to identify rapidly the more calcareous mountain tills.

Heavy Minerals

Analysis of the heavy mineral content of Alberta tills received little attention in the past. The few studies that were carried out (Bayrock, 1962; Roed, 1968; Day, 1971; Rutter, 1972) were devoted only to description and differentiation of tills. In fact, Roed (1968) used differences in mineralogical composition to distinguish between Cordilleran and Laurentide glacial deposits. Elsewhere, heavy mineral studies have also examined rates of depletion or weathering (Ruhe and Scholtes, 1956; Brophy, 1959; Bhattacharya, 1963; Willman *et al.,* 1966). The collected data were then used to attempt to differentiate the deposits on a time-stratigraphic rather than a rock-stratigraphic basis.

In this study, both composition and relative quantities of different heavy minerals were examined in order to:

(1) improve the reliability of the gross differentiation of the tills by the pebble count method;
(2) attempt to assist in establishing relative ages for the apparently older tills (Baseline and Hummingbird).

The standard bromoform technique (Krumbein and Pettijohn, 1938) was used to separate out the light and heavy minerals. Samples were prepared from all tills in the study area, and, in addition, samples were collected throughout the weathering profiles of the Baseline and Hummingbird Tills. The results are shown in graph form in figure 9. Details are given in Boydell (1972, Appendix B).

Rutter (1972) used heavy mineral counts to describe the tills of the Bow Valley, and reported appreciable quantities of hypersthene and very small amounts of garnet and hornblende. Roed (1968) used the presence of hornblende in Laurentide till to distinguish it from the Cordilleran tills. Also, relatively high percentages of garnet, tourmaline, and zircon in both mountain and continental tills led him to look for other possible diagnostic minerals. He was able to add kyanite and hypersthene to the list of minerals diagnostic of Laurentide till, and chloritoid, chlorite, and epidote to those diagnostic of Cordilleran tills.

The results of this study correspond more closely to Roed's findings than to Rutter's, with differences attributable to regional differences in bedrock formations. However, in this

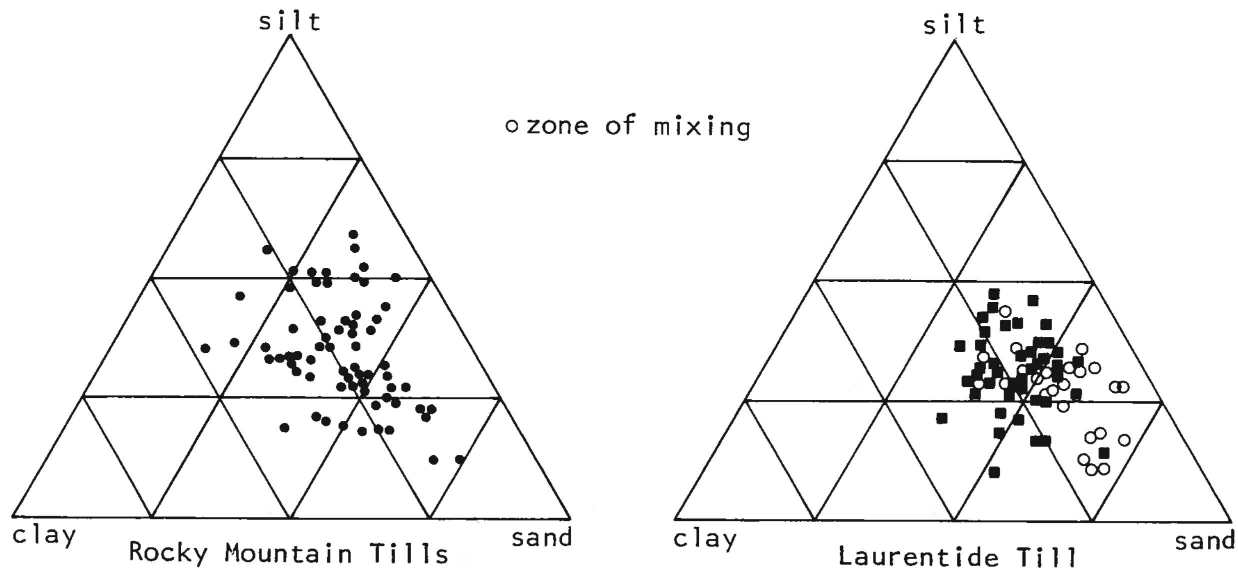

FIGURE 7. Percentages of sand, silt and clay in tills

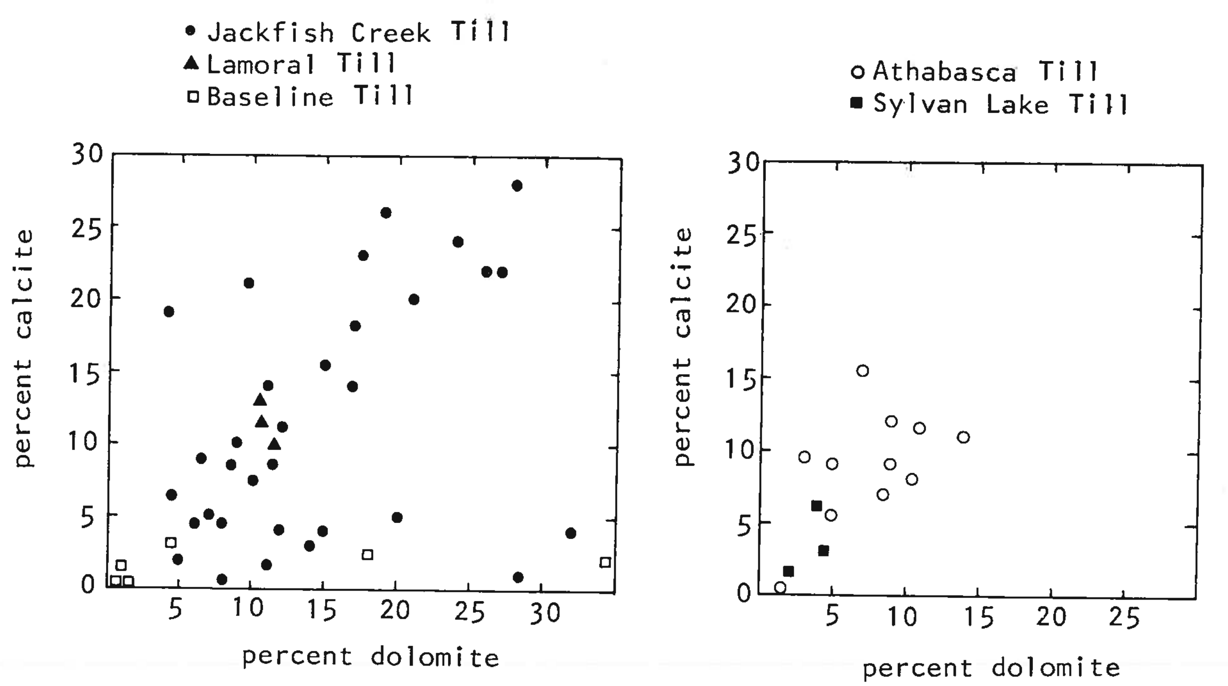

FIGURE 8. Percentages of calcite and dolomite in the total carbonate content of tills

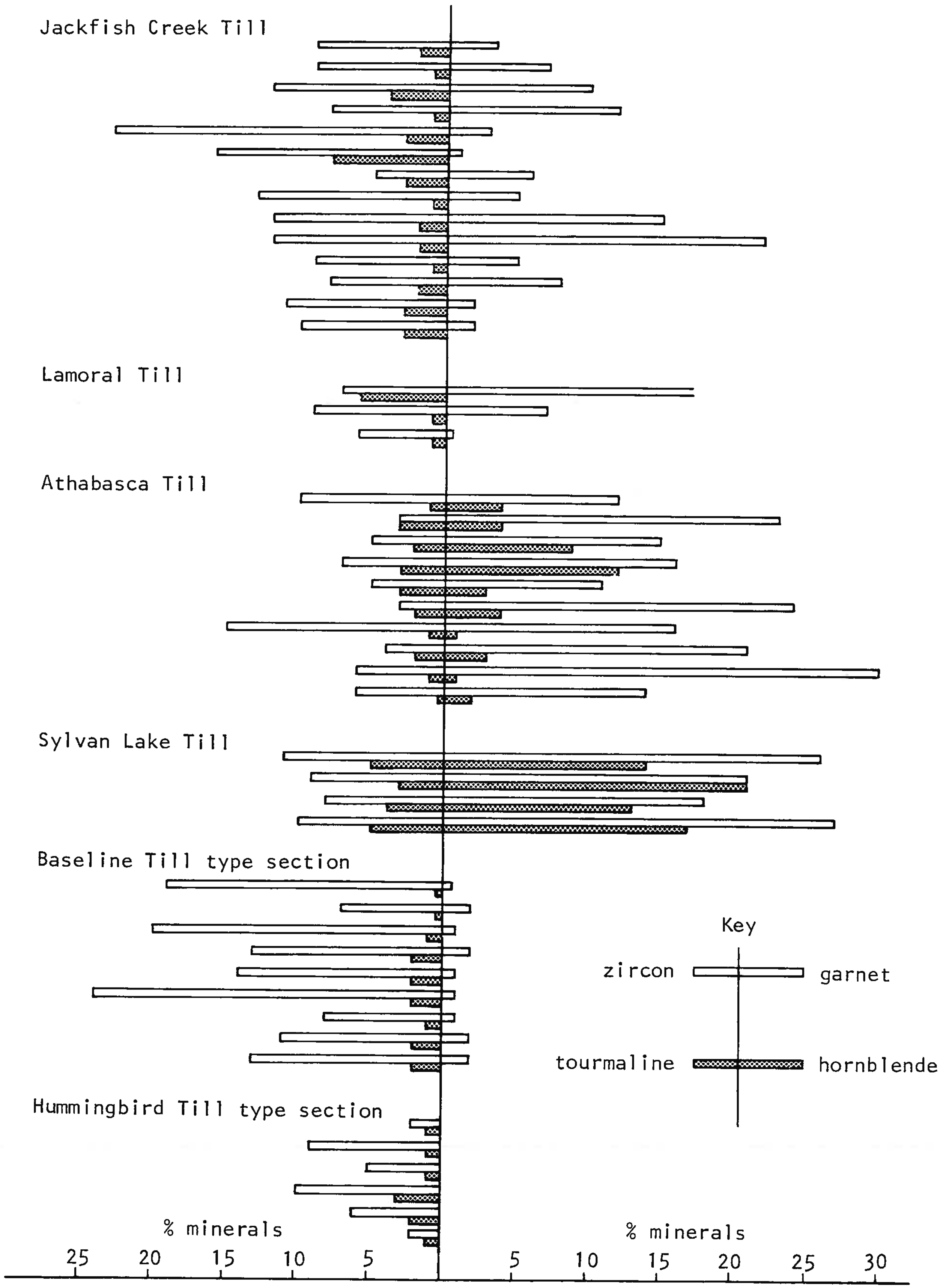

FIGURE 9. Percentages of principal heavy minerals in tills

area, no kyanite was found in Laurentide till and no chloritoid in the Rocky Mountain tills. Also, it was difficult to separate the brown variety of hornblende from aegirine-augite, so these two minerals were counted as one. No hornblende-aegirine-augite was found in tills of Rocky Mountain provenance, but in the Laurentide till the average contents were 7 percent in the zone of mixing and 12 percent outside the zone of mixing.

The second objective, to establish the relative ages of the older tills by measuring the depletion of their heavy minerals, was not achieved. Since neither pyroxenes nor amphiboles were found in the Rocky Mountain tills, the only possible indicator of weathering was garnet. Although garnet is absent from Hummingbird Till, and present in low percentages relative to other tills in Baseline Till, the results may only reflect differences in the local provenance of the various units.

In general, the analysis of heavy minerals provided information which supported the gross differentiation achieved by the pebble counts, but did not help establish relative ages of tills, nor, in this regard, add significantly to the evidence provided by the morphological and stratigraphic studies.

MULTIPLE GLACIATION

The lithologic, stratigraphic, and geomorphic evidence indicates that the study area experienced four glacial events and that an "old-glacial" area, the Brazeau and Ram Ranges area, exists. Informal stratigraphic names for these four events are: Hummingbird-Baseline advance, Lamoral advance, Jackfish Creek advance, and Laurentide advance. Each of these advances was marked by the deposition of a till. The tills of the first three advances were named after their type localities. The till of the Laurentide advance is subdivided into the Athabasca and Sylvan Lake Tills for ease of description.

The source areas for till material were three:

(1) areas east of the Continental Divide, and here designated *Rocky Mountain;*
(2) areas west of the Continental Divide, and here designated *Cordilleran* (Roed, 1968);
(3) the Canadian Shield, here called *Laurentide.*

Using this terminology, the Hummingbird, Baseline, Lamoral, and Jackfish Creek Tills are all Rocky Mountain, while Athabasca Till is mixed Rocky Mountain, Cordilleran, and Laurentide, and Sylvan Lake Till is purely Laurentide.

The "old-glacial" Brazeau and Ram Ranges area is a region thought to have been unglaciated since Hummingbird-Baseline time, the main evidence being the lack of glacial forms and the degree of colluviation of surficial deposits in the area.

Figure 10 is a diagrammatic cross section showing the relationships of the principal surficial deposits in the study area.

HUMMINGBIRD-BASELINE ADVANCE

Although the Hummingbird and Baseline Tills are dissimilar and are discussed separately, there is no evidence for a discrete Hummingbird advance. The two advances have, therefore, been equated.

Hummingbird Till

Stratigraphic and Geomorphic Data

Hummingbird Till is named after a tributary of the South Ram River. The principal deposit of the till is located west of the study area (Sec 25, Tp 36, R 16), but the type section is located immediately below the upper falls on the South Ram River (Sec 8, Tp 36, R 14).

The stratigraphy of Hummingbird Till is illustrated in figure 11 by means of three columns taken from two sections at the type locality (Plate 1) to which is added a fourth column, a sequence of varves (Plate 2), from about 1.1 mi (1.8 km) downstream. In all, seven rock-stratigraphic units and four discernible erosional hiatuses are present.

The morphology of the Hummingbird Till at the type section is partly obscured by the overlying Jackfish Creek Till. However, in the Hummingbird Creek area surface expression is a low plateau (Plate 3), dissected by numerous stream valleys which have been infilled with outwash gravels and later organic deposits. Hoodoos have developed on some of the lower slopes (Plate 4), and the unconformable Jackfish Creek Till is the surface unit over much of the area.

Lithology

Hummingbird Till is buff to light brown except where oxidation has discolored exposed surfaces. The deposit is extremely compact and strongly cemented, calcite cement being present throughout even the deepest section (82 ft or 25 m) and as a translucent coating on many of the pebbles.

The till is stony, and the high percentage of carbonate pebbles (36 to 42 percent) suggests a source area somewhere in the Rocky Mountain Front Ranges. Heavy mineral analysis revealed an apparent lack of change in percentage composition with depth (Fig. 9), which implies the absence of a weathering profile. The calcite cement may, therefore, be a product of highly mineralized groundwater conditions rather than the result of a period of long and intensive weathering. A till fabric measured in the Hummingbird Creek area indicates that ice was moving from the upper North Saskatchewan River valley (Kootenay Plains), southeast into the South Ram River valley. However, the localized nature of the deposit prevents definition of the limits of this advance.

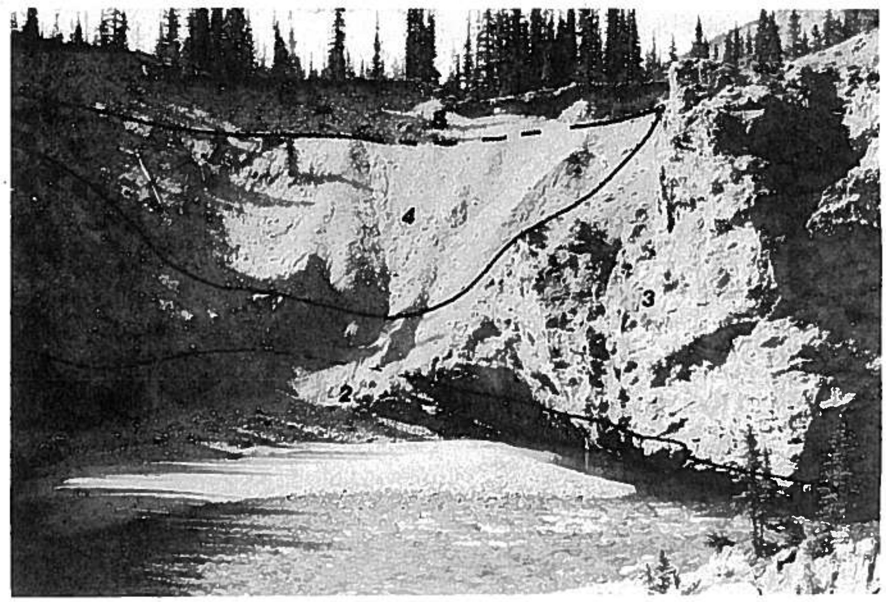

PLATE 1. Western end, Hummingbird Till type section, South Ram valley

PLATE 2. Lamoral varve-rhythmite sequence, South Ram valley

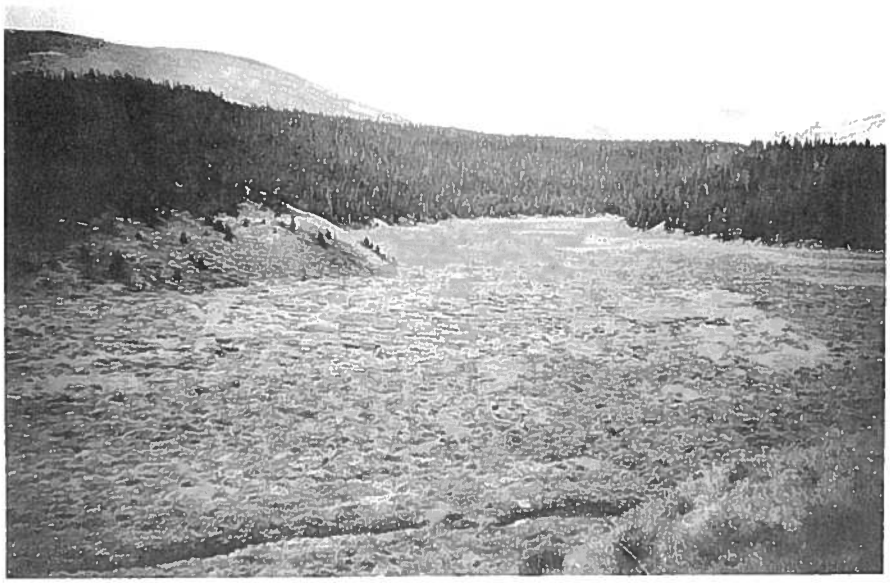

PLATE 3. Dissected plateau of Hummingbird Till, Hummingbird Creek

PLATE 4. Tors and cracks developed in exhumed surface of Hummingbird Till

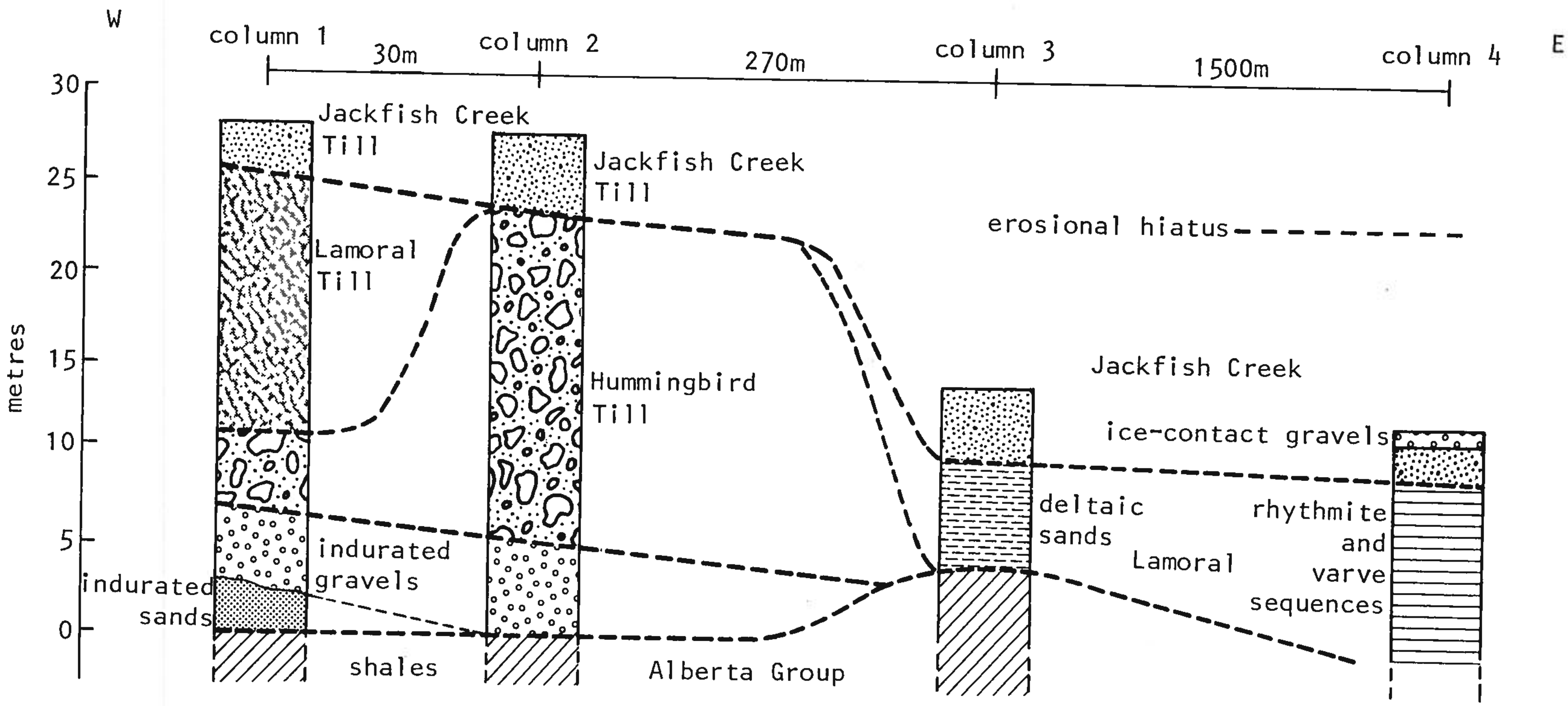

FIGURE 11. Stratigraphy of Hummingbird Till, South Ram valley

Baseline Till

Till of the Baseline advance is found only on the plateau of the Brazeau Piedmont (Fig. 12), and is named after the Baseline Ski area in which the type section is located (Sec 19, Tp 37, R 10). The till is absent, even in colluviated form, from the valley slopes below the rim of the plateau, and no traces of it have been discovered either above or beneath the deposits presently in the valley bottoms. Because of this unique position on the Brazeau Piedmont, the till has no demonstrable stratigraphic contacts with any other glacial deposit of the study area. Evidence for the characteristics of advance is thus drawn from the morphology and pebble lithologies of the till, and from the inferred direction of ice movement.

Stratigraphic and Geomorphic Data

The character of the till is remarkably uniform across the piedmont area due to its thinness and the topography of the underlying Mesozoic sediments. Field tests show leaching of carbonates to a depth of 8 ft (2.4 m) at the type section, and to bedrock elsewhere.

Tills of the Lamoral and Jackfish Creek advances are not found above 5500 ft (1660 m) and are mainly present below 4900 ft (1500 m). To cross the Brazeau Range, ice of the Baseline advance would have to have been at an elevation of over 6600 ft (2000 m), a difference of at least 1600 ft (500 m). If the gradients of the respective ice masses were roughly equivalent, then a considerable eastward extension of the Baseline ice front beyond the present limits of distribution of the Jackfish Creek Till is implied.

Maximum thicknesses of less than 10 ft (3 m), a uniform surface, and isolated position are thus not consistent with the presumed size and character of the ice mass that deposited the till.

Lithology

Baseline till is stony, and its principal pebble constituents are chert, quartzite, and sandstone. Limestone and dolomite are present (about 5 percent) in the weathering zone but commonly exhibit rinds up to 0.1 in (3 mm) thick. The cherts and quartzites are extremely well rounded and possess diameters of not more than 1½ in (4 cm). The till has not been observed in a totally unweathered state, so its color, unmodified by oxidation, is not known. Texture is variable but often sandy. The average carbonate content of the matrix is 2 percent calcite and 12 percent dolomite probably derived from the weathering of limestone and dolomite pebbles.

The limited size fraction and the roundness of the principal pebble types (chert and quartzite) together with a predominantly sandy matrix indicate that the till is at least partly derived from the Cadomin Conglomerate. Mellon (1967) described the conglomerate at the type area at Cadomin as consisting of sandy pebble conglomerate in the lower part, grading in the upper 10 ft (3 m) into pale gray, medium-grained, cherty sandstone. The pebbles, up to 6 in (15 cm) in diameter, are composed of well-rounded white and pink quartzite, and gray to black chert or argillite. The Cadomin Conglomerate forms a continuous outcrop of both the western and eastern flanks of the Brazeau Range to the west of the limits of distribution of the Baseline Till (Fig. 12).

The maximum exposed thickness of Baseline Till is found at the type section where 10 ft (3 m) are exposed. This section is weathered to within 12 in (30 cm) of the base. From the surface to the base, nine samples were collected and analyzed for their heavy mineral content. Figure 9 shows the results. The stable-mineral (zircon and tourmaline) content is variable but increases slightly towards the base. The garnet content is low but variable throughout the section.

Ice Movement

Lithologic evidence, till fabric analysis, and a limited number of flutings visible on the airphotos indicate that the ice mass which deposited the Baseline Till moved across the Brazeau Range from northwest to southeast, a direction opposite to that indicated by the flutings and lineations associated with the Jackfish Creek Till in the valley below. Thus the weathered erratics on the Brazeau summit ridge correspond to the Baseline Till and reflect an ice mass substantially larger than those which occupied the major valleys in more recent times.

The source area of the Baseline ice mass is not known although the character of its till suggests a Rocky Mountain origin. The inferred size of the ice mass implies that the present area covered by the till (Figs. 3 and 12) is only a small remnant of the area formerly covered, so the limits of the Baseline advance are unknown.

LAMORAL ADVANCE

The Lamoral advance is evidenced by widely distributed tills and glaciolacustrine deposits. Lamoral deposits are observable in sections in the North Saskatchewan and South Ram River valleys, and in Lick and South Prairie Creek valleys on the Brazeau Piedmont.

Stratigraphy and Geomorphology

The Lamoral advance is named after the type section (Sec 20, Tp 40, R 11) located near the ghost town of Lamoral. Illustrated in figure 13 are two sections showing the stratigraphy of Lamoral deposits: one is the type section and one is a section located along Lick Creek (Sec 8, Tp 38, R 10).

At the type section, 65 ft (20 m) of Lamoral Till rest on Paskapoo sandstone and underlie 23 ft (7 m) of glaciolacustrine silty clay. Overlying the clay are 7 ft (2 m) of Jackfish Creek Till which are overlain in turn by 43 ft (13 m) of silts. The lower part of this silt sequence is separated from the upper part by a

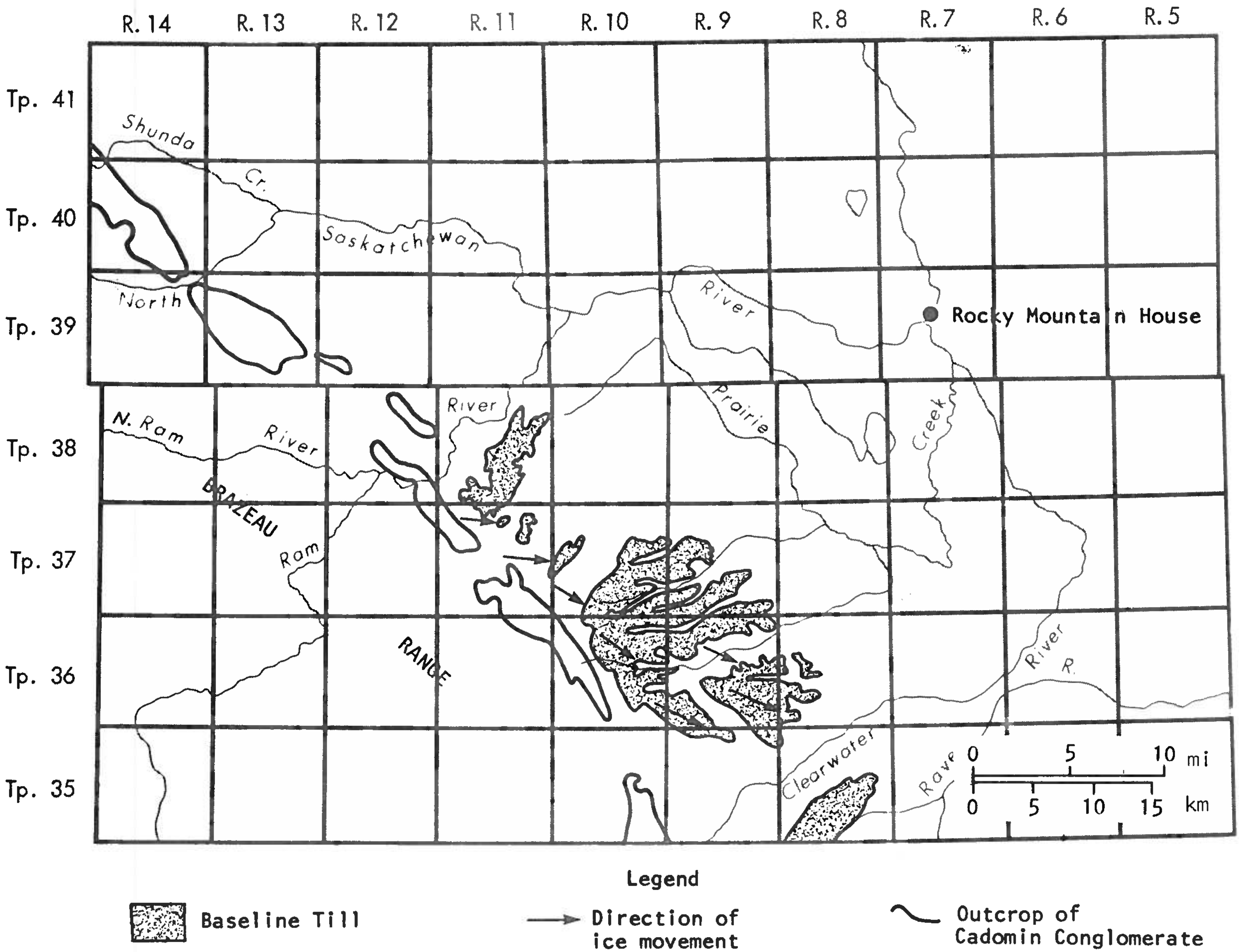

FIGURE 12. Distribution of Baseline Till on Brazeau Piedmont direction of ice movement, and relationship to the outcropping Cadomin Conglomerate

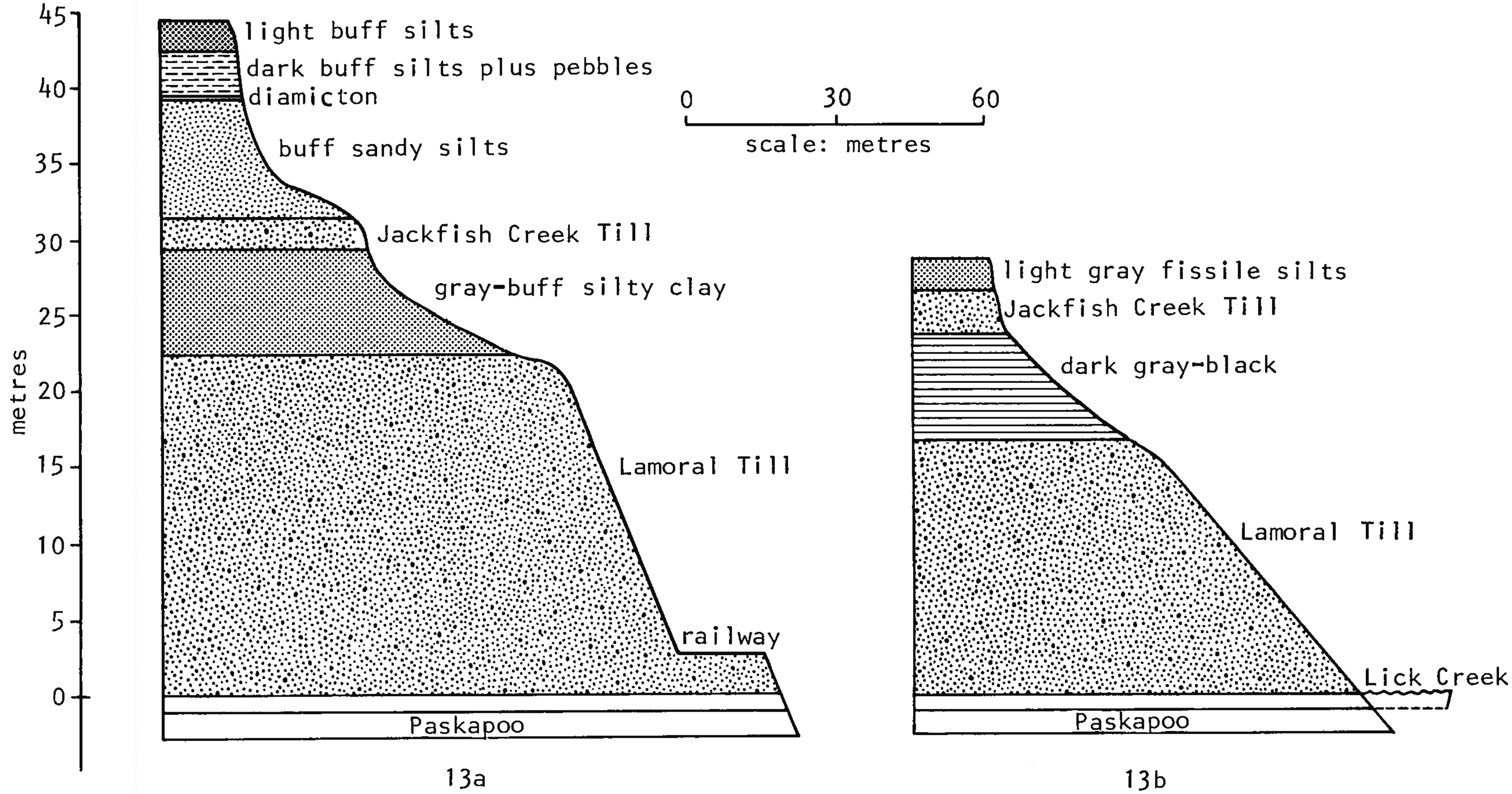

FIGURE 13. Stratigraphy of Lamoral Till

diamicton which varies in thickness from 6 to 11 in (15 to 27 cm) and has characteristics similar to Jackfish Creek Till. No flow structures are present in the diamicton and its origin is unknown.

The Lick Creek section (Fig. 13b) contains 56 ft. (17 m) of Lamoral Till overlying Paskapoo Formation bedrock. The till is overlain by 23 ft (7 m) of glaciolacustrine clay, 10 ft (3 m) of Jackfish Creek Till, and 7 ft (2 m) of glaciolacustrine silts.

The lower glaciolacustrine unit records the retreat of the Lamoral advance and forms a stratigraphic unit between Lamoral and Jackfish Creek Tills. There is no erosional hiatus between the Lamoral Till and the overlying glaciolacustrine sediments. Although these sediments mainly form inter-till units in the multiple-till sections, they are also present as a varve-rhythmite sequence in the South Ram River valley, where they were laid down in a lake extending from the gorge area to the location of the Hummingbird Till type section.

Spillway gravels were encountered during drilling (Fig. 4, borehole 15) in a gravel pit near Strachan (Sec 7, Tp 38, R 8). They lie beneath about 3 ft (1 m) of Jackfish Creek Till, which is overlain by about 30 ft (9 m) of more recent spillway gravels. On the basis of this stratigraphic evidence, the lower gravel unit is thought to record the retreat of the Lamoral ice mass.

Lithology

Till

In the North Saskatchewan River valley, the unweathered Lamoral Till is very dark gray to black, clayey, compact, and stony. The principal pebble lithologies are carbonates and quartzites, including a number of Lower Cambrian (Gog Group) orthoquartzites. Heavy mineral analyses (Fig. 9) confirmed a Rocky Mountain origin for the till and revealed, in particular, a garnet percentage more than twice that of the Jackfish Creek Till, which is also present in the type section (Fig. 13). The total carbonate content of the fines is 21 percent.

In the Lick Creek section, unweathered Lamoral Till is dark gray, clayey (48 percent), compact, and has a total carbonate content in the matrix of 22 percent.

Glaciolacustrine Silts

At the Lamoral type section, the inter-till unit consists of 23 ft (7 m) of buff glaciolacustrine silts. In the Lick Creek section, this unit is represented by a dark gray glaciolacustrine clay containing ice-rafted pebbles and numerous small, woody fragments.

Varve-Rhythmite Sequence

In the South Ram River valley a sequence of varves consisting of alternating bands of dark gray-black clay and either silt or fine sand grades upward into coarse sand and silt rhythmites.* The bedrock contact was not observed. At random throughout the varve sequence, rhythmites of medium to fine, buff sand up to 11 in (28 cm) thick are present. These display cross-bedding and also contain numerous specks of lignite. Also in the sequence are six, randomly spaced, compact, clay bands which weather grayish white. The origin of these bands is not known, although they may be drainage varves (Antevs, 1925) formed during periodic discharges of a glacier-dammed lake.

The varves are titled to the west, with an average dip of about 10 degrees, although in places the dip is as much as 35 degrees. The variability of the dips and some evidence of slumping suggests that melting of ice, rather than tectonic activity, was the agency responsible for the tilting of the deposit.

Outwash Gravels

The pebble lithologies of the outwash gravel unit in South Prairie Creek consist largely of quartzites and carbonates and appear to be typical of the Rocky Mountain glacial deposits.

Spillway Gravels

The spillway gravels of the Strachan gravel pit (sec 7, Tp 38, R 8) are generally well-rounded and oxidized, and consist largely of quartzites, with small quantities of chert, sandstone, and gneiss. The mixed pebble lithologies may indicate channel erosion of both the Rocky Mountain and Laurentide tills during the retreat of the Lamoral advance.

Ice Movement

The results of the lithologic and mineralogic analyses (especially the observation of Gog orthoquartzites) indicate that the source of the Lamoral Till was near the location of the head-waters of the present North Saskatchewan River. The preferred orientation in the till fabric at the type section together with the distribution of the till in the North Saskatchewan River valley suggest that the principal direction of ice movement was eastwards along the valley. Because the till has been observed in only four sections, the precise limits of the Lamoral advance are not known. However, since the till does not appear either in sections or boreholes near the eastern margin of the Jackfish Creek Till, it is thought that the Lamoral advance was less extensive than the later Jackfish Creek advance.

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*This sequence is the only deposit of its kind found in the study area. It is located in the South Ram River valley, on the Onion Lake road, about 1.7 mi (2.7 km) west of the Forestry Trunk Road, and about 2000 ft (600 m) upstream from a bedrock gorge.

JACKFISH CREEK ADVANCE

The most complete record of a Rocky Mountain glacial advance is presented by Jackfish Creek deposits which are found in the major river valleys, in the Elk Creek Basin, and in the larger valleys of the Brazeau Piedmont (Fig. 5). This widespread distribution has contributed to local differences in the characteristics of the deposits, particularly in Jackfish Creek Till. The till is found either at the surface or beneath an associated glaciofluvial or glaciolacustrine unit, and is confined to elevations below 5500 ft (1660 m) above sea level. The conclusion that the Jackfish Creek Till represents a single advance is based primarily on the continuity of the unit throughout the study area.

Glaciofluvial and glaciolacustrine deposits form gradational units overlying Jackfish Creek Till, and are a record of the retreat of the Jackfish Creek ice mass. Glaciofluvial deposits consisting of gravels form an area of outwash in the Elk Creek Basin and infill the spillway channels at the eastern margin of the Brazeau Piedmont.

An abundance of proglacial lakes and related spillways is a characteristic of the Foothills Zone (Johnson and Wickenden, 1931). The regional axis of drainage to the northeast was followed by meltwaters from the Rocky Mountain glaciers. However, the Laurentide ice mass covered much of the area to the northeast, impounding proglacial lakes against the mountain front. The glaciolacustrine Jackfish Creek deposits are largely the product of this ponding. The Laurentide ice created, in particular, a large proglacial lake (Lake Caroline) near the site of Rocky Mountain House.

Stratigraphic and Geomorphic Data

Jackfish Creek Till is the principal glacial deposit in the study area. The name was chosen because good exposures are found along Jackfish Creek, particularly where the creek is crossed by the David Thompson Highway (Sec 32, Tp 40, R 11). Stratigraphic sequences are variable, depending on regional location. In the deeper sections in the North Saskatchewan River valley, and in Lick and South Prairie Creeks, the till's lower contact is the glaciolacustrine unit of the Lamoral retreat, but elsewhere it rests on the underlying bedrock. The till is generally overlain by its own glaciolacustrine unit (Fig. 13).

In the Ram and South Ram River valleys, the till forms the upper unit at the Hummingbird Till type section, but is overlain by ice-contact gravels in the northern part of Elk Creek Basin (Fig. 4) and in the eastern part of the South Ram River gorge. In both areas, the lower contact is the bedrock (Alberta Group). To the east of the Brazeau Range and west of the Ram-North Saskatchewan confluence, glaciolacustrine silts form the upper contact and increase in thickness eastwards to a maximum of about 50 ft (15 m).

In the southern part of Elk Creek Basin, Jackfish Creek Till grades both laterally and vertically into ice-contact gravels (Fig. 4). Elsewhere, in the western part of the Clearwater Valley, the till is exposed and rests on the bedrock. To the east of the Clearwater Gap through the Brazeau Range, the till is not exposed, being overlain by glaciolacustrine sediments and postglacial valley train gravels.

Ice-contact gravels form the surface unit over much of the Elk Creek Basin. In the south-central part of the basin, eroded gravel mounds up to 26 ft (8 m) thick and often partly infilled with sandy silts overlie Jackfish Creek Till (Fig. 4) and represent an area of extensive ice stagnation. In the northern part of the basin, a prominent esker (Lsd 10, Sec 5, Tp 36, R 13) overlies Jackfish Creek Till from the South Ram River valley. Imbrication in the gravels suggests that flow of water was to the south.

In the upper South Ram River valley, vertical and lateral gradation of Jackfish Creek Till to gravels is also common. Towards the west, these gravels tend to replace Jackfish Creek Till as the principal deposit.

South of the North Saskatchewan River, in the Trout Creek area (Tp 40, Rs 12 and 13), a series of linear gravel ridges form an esker complex overlying, and grading laterally into, Jackfish Creek Till. The general trend of the ridges is to the east and southeast.

Outwash gravels overlying Alberta Group bedrock form the surface unit in the east-west valley in the central part of Elk Creek Basin (Tp 36, Rs 12 and 13). Outwash gravels in small, localized deposits also occur near Saunders in the North Saskatchewan River valley, where the deposits form a unit 13 ft (4 m) thick between Jackfish Creek Till and its glaciolacustrine equivalent. On the west bank of the Ram River (Sec 18, Tp 39, R 10), upstream from its confluence with the North Saskatchewan, outwash gravels form a high terrace overlain by a silty, glaciolacustrine unit about 13 ft (4 m) thick.

Two major spillways to the west of Cow Lake (Fig. 5) contain extensive deposits of gravel; these spillways originally drained the meltwaters of glaciers in the North Saskatchewan River valley and South Prairie Creek and are presently occupied by North Prairie and Vetch Creeks, respectively. In much of North Prairie Creek valley the gravels are partly overlain by Recent sandy alluvium and organic sediments; however, the gravels are exposed in Vetch Creek.

The gravels were examined in a pit near Strachan (Sec 7, Tp 38, R 8) where they are about 30 ft (9 m) thick and are moderately well sorted. The gravels also occupy the central and eastern parts of Vetch Creek. In the central area they overlie Jackfish Creek Till, while to the east the lower contact is Paskapoo Formation. Thicknesses of up to 33 ft (10 m) are common and the unit grades laterally into the upper gravels of North Prairie Creek.

Glaciolacustrine sediments, deposited in proglacial lakes ponded between the ice masses and the mountain front, form the surface unit of most of the Northern and Eastern Lowlands area, the middle reaches of the North Saskatchewan River, and the upper valleys of the Brazeau Piedmont (Fig. 5). In the Northern and Eastern Lowlands the sediments lie areally between exposures of Laurentide Till. They form a continuous, mostly exposed stratigraphic unit, varying in thickness between 20 in (50 cm) and 95 ft (29 m) (Fig. 4). Near Crimson Lake and southeast of Cow Lake, the unit is overlain by eolian sands up to 59 ft (18 m) thick. The lower contact of the unit is glaciofluvial sands or gravels, tills, or Paskapoo Formation bedrock.

In the middle reaches of the North Saskatchewan River valley glaciolacustrine sediments form the upper unit (as for example, in the Lamoral type section shown in Fig. 13) overlying Jackfish Creek Till. On the Brazeau Piedmont, glaciolacustrine sediments overlie Jackfish Creek Till on the valley floors, but overlie colluvium and bedrock on the valley sides and lie between Jackfish Creek and Baseline Tills on the plateau surface. The sediments also extend westward up the valleys beyond the limits of the Jackfish Creek advance, and overlie colluvial deposits and bedrock.

In the North Saskatchewan River valley and Eastern Lowlands, Jackfish Creek Till is moderately thin, not exceeding 33 ft (10 m) in thickness, but it forms a variety of features, including drumlins and linear till ridges, that indicate direction of ice movement. In the Ram and South Ram River valleys, the till is not more than 23 ft (7 m) thick, patchy in distribution, and largely an erosional remnant, forming a high terrace along both sides of the valley. Lateral graduation into ice-contact gravels is common. In Elk Creek Basin and the Clearwater Valley, Jackfish Creek Till is found largely as a thin veneer, plastered on the lower valley slopes.

The major spillways in North Prairie and Vetch channels were part of a spillway system that drained the proglacial lakes of the North Saskatchewan River valley and the larger valleys of the piedmont. The valleys of this plateau area were also drained by a series of channels which link one valley to the next across their interfluves. The meltwaters drained to the southeast and eventually to the Red Deer River valley.

The glaciolacustrine unit above Jackfish Creek Till was mapped into the upper channels which served as primary spillways, and although they were not examined in detail, the remaining series of channels to the east are thought to be ice marginal. The continuity of the channels across the interfluves suggests ice-frontal positions rather than equivalent lake elevations, since the heights of the interfluves are variable. However, the heights of the spillways across successive interfluves are consistent at about 4480 ft (1365 m), whereas the elevations of the ice marginal channels all decrease at the same rate towards the east, from 4380 ft (1335 m) to 4150 ft (1265 m).

The area of glaciolacustrine sediments in the Northern and Eastern Lowlands has been dissected by the postglacial North Saskatchewan and Clearwater Rivers, and by numerous small drainageways, now infilled with organic deposits. Surface morphology usually reflects the broadly undulating bedrock topography except in the Crimson Lake area, where the sediments are very thick (Fig. 4), and in an area to the south and west of Caroline (Tps 35 and 36, R 6) where they form numerous hummocks. Sections and drilling revealed that the hummocks did not reflect the topography of the underlying deposits, but were formed as collapse features after the melting out of large blocks of rafted ice.

The continuous area of glaciolacustrine deposits is given the name glacial Lake Caroline. Its margins (Fig. 14) were formed as the ice masses receded after coalescence, and consisted of the Sylvan Lake (Laurentide) ice to the east and stagnating Athabasca (Laurentide) and Jackfish Creek ice to the west. The absence of beaches and shorelines is probably due to fluctuating glacier-ice margins and lake levels, and to a probably limited lake duration.

The lake was drained by five main channels: Lasthill, Stauffer, Crammond I, Crammond II, and Kevisville (Fig. 14), all of which were walled on both sides by ice during their early stages. The last three have higher elevations, representing an older part of the lake, and are located in the southeast. The remaining two are lower and are located in the north. In all five channels water flowed southeast because the Laurentide ice mass was retreating to the northeast.

Lithology

Till

The regional differences in the Jackfish Creek deposits are best seen in the till. In the North Saskatchewan River valley and Eastern Lowlands the till is relatively silty, dark buff at the surface, and grayish brown in the unweathered zone. Carbonates are leached to a depth of approximately 3 ft (1 m). In the unweathered till the total carbonate content of the matrix, based on 20 samples, varies between about 20 and 50 percent, increasing with increasing proximity to the Brazeau Range. The pebble lithologies of the till are also variable, but pebbles are largely carbonates and quartzites, including Gog orthoquartzites. The percentage of local (Mesozoic) rocks tends to increase eastwards from the Brazeau Range. The heavy minerals (Fig. 9) are mainly garnet, zircon, and tourmaline, with minor amounts of diospide, tremolite, and rutile.

In the Ram and South Ram River valleys the till is light buff at the surface and dark buff in the unweathered zone, and generally has a high silt content. Depth of leaching is about 3 ft (1 m); the total carbonate content of the matrix of the unweathered till, based on 12 samples, is also between 20 and 50 percent. The pebbles are composed chiefly of carbonates and quartzites but in this area there is a consistently greater

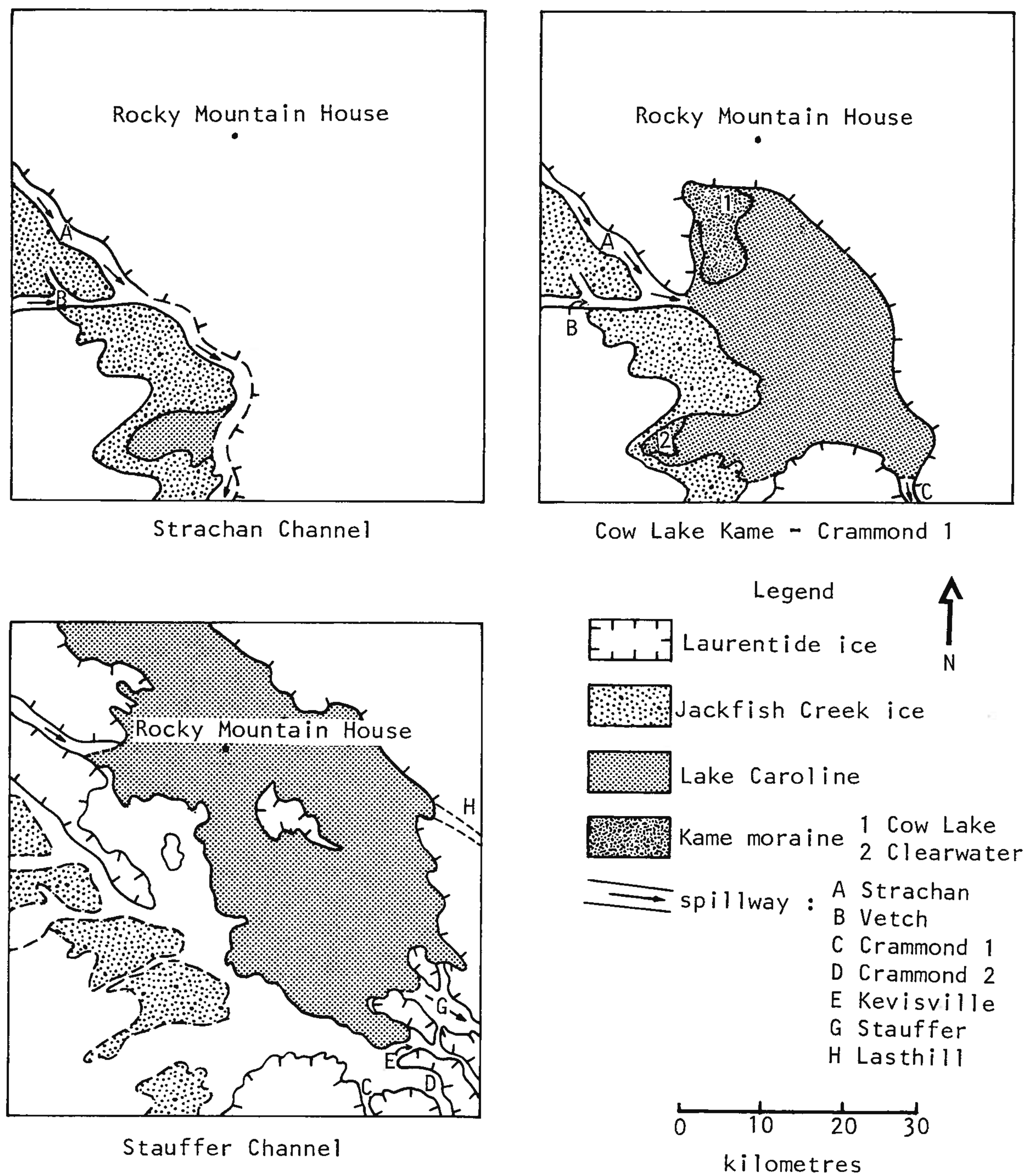

FIGURE 14. Stages in development of glacial Lake Caroline

proportion of Mesozoic sandstones derived from the rock units lying to the west of the Brazeau and Ram Ranges. The heavy minerals are similar to those in Jackfish Creek Till in the North Saskatchewan River valley area.

In the Clearwater River valley and in the Elk Creek Basin Jackfish Creek Till is sandy, light buff, and patchy in its distribution. Leaching depth is commonly about 3 ft (1 m), and the total carbonate content of the fines of 9 samples ranges from 25 to 50 percent. Pebble lithologies indicate a Rocky Mountain source, being dominated by carbonates and quartzites, with a relatively low sandstone content. The heavy minerals reflect the regional characteristics of Jackfish Creek Till.

Glaciofluvial Gravels

The smallest regional variability is in the ice-contact and outwash gravels. From Elk Creek Basin to the North Saskatchewan River valley the gravels consist predominately of rounded quartzites, quartzitic sandstones, limestones, and cherts. Changes in composition are found only in gravels derived at least partly from the local bedrock: for example, sandstones and carbonaceous shales (Alberta Group) and present in gravels in the upper Elk Creek Basin and coarse sandstones (Paskapoo) are found in deposits in the North Saskatchewan River valley.

Spillway Gravels

The lithologies of the spillway gravels in North Prairie and Vetch Creeks demonstrate that the spillways were marginal to both the Rocky Mountain and Laurentide ice masses. In Vetch Creek the gravels are quartzites, with local sandstones, shales, and cherts, suggesting a Rocky Mountain source. In North Prairie Creek, orthoquartzites, quartzites, and carbonates are mixed with granites and gneisses derived from the Shield.

Glaciolacustrine Deposits

The glaciolacustrine deposits vary in texture, depending on locality, and range from the sandy silt of many of the surface exposures to a heavy clay in the deeper boreholes of Lake Caroline (Fig. 4). Scattered throughout the deposits are numerous rocks of all size fractions from ice-dropped pea gravels to rafted megaerratics larger than 35 ft^3 (1 m^3).

Ice Movements

The continuity of the deposits, their restriction to elevations below 5500 ft (1660 m), and their similar morphologies suggests that the Jackfish Creek advance was contemporaneous throughout the study area. However, the presence of deposits in all three major river valleys also suggests that more than one local source area existed for the Jackfish Creek advance, even though it is clear from the lithologic evidence that, regionally, the advance originated in the Rocky Mountain Front Ranges. In the North Saskatchewan River valley area (Fig. 4), the flutings and drumlins indicate that ice moved initially west to east, but changed to southeast as it travelled down-valley. The shift in direction appears to have been caused by the mass of the Laurentide ice to the east.

The North Saskatchewan glacier, moving to the southeast, also entered many of the valleys of the Brazeau Piedmont. Tongues of ice pushed in a west to southwest direction towards the Brazeau Range, and stagnated in the upper reaches of the valleys at elevations of about 3940 to 4230 ft (1200 to 1290 m).

In the rest of the study area, the Jackfish Creek advance was largely contained within the mountain and valley region west of the Brazeau Range. Small tongues of ice in the South Ram and Clearwater River valleys advanced into the northern and southern ends of Elk Creek Basin, depositing ice-contact gravels and the outwash plain. In the Ram and Clearwater River valleys, the main advance barely penetrated east of the Brazeau Range. The limits of the Jackfish Creek advance thus closely resemble the mapped limits of its till (Fig. 5).

Events in the Brazeau and Ram Ranges Area

The region described as the Brazeau and Ram Ranges area (Fig. 3) is distinctive because of its almost total lack of evidence of glaciation. The area is defined as a zone of colluviation on the map of surficial deposits (Fig. 5).

Weathered erratics resting on bedrock on the summit ridge of parts of the Brazeau Range and the presence of what are thought to be remnant glacial cirques are the only surviving record of a formerly extensive glaciation (Hummingbird-Baseline advance). Throughout most of the area widespread, well-developed colluvial mantles constitute the greater part of the surficial deposits.

The maximum elevations reached by deposits of the Jackfish Creek advance is 5500 ft (1660 m), which suggests that the portion of the Brazeau and Ram Ranges area above this height was ice-free during the Jackfish Creek advance.

LAURENTIDE ADVANCE

Although only one advance of the Laurentide ice is demonstrable for the Rocky Mountain House area, its deposits are divided into two groups in order to describe and explain the mixed characteristics encountered at its western margins. The Athabasca Till, of mixed characteristics, is the principal glacial deposit in the eastern part of the study area, and is named after the Athabasca River valley region where it was first described (Roed, 1968). The Sylvan Lake Till is present only at the eastern margin of the study area, and is so named because of its widespread distribution in the Sylvan Lake area farther east.

Stratigraphic and Geomorphic Evidence

Athabasca Deposits

Till — Throughout much of its area, the Athabasca Till is generally less than 50 ft (15 m) thick, although southeast of the Clearwater River valley Carlson (1971) reports thicknesses greater than 115 ft (35 m). However, good stratigraphic sections of the till are lacking, largely because the North Saskatchewan is the only nearby river. The designated type section (Fig. 15a) is on the south side of the North Saskatchewan River in Sec 8, Tp 39, R 7, where Athabasca Till is the lowest of three units. Its lower contact is Paskapoo Formation bedrock. Overlying the till is a 13-ft (4 m) unit of thick glaciolacustrine silts, which is in turn overlain by 20 ft (6 m) of postglacial eolian sand.

The stratigraphy of the Athabasca Till was also observed in a borehole on Highway 54 west of Caroline (Sec 17, Tp 36, R 6) (Fig. 15b). The upper contact of the till lies about 62 ft (19 m) below the surface. Although 7 ft (2 m) of coarse sand are interposed at 69 ft (21 m), the two tills are considered to be the same unit because of very similar characteristics. Overlying the till are 23 ft (7 m) of coarse sand, above which lie 39 ft (12 m) of glaciolacustrine sediments.

The morphology of the Athabasca Till is varied: flutings in the northwest give way to dead-ice moraine in the southeast. The Athabasca Till is also noteworthy in that it is the till associated with the Foothills Erratics Train (Stalker, 1956; Roed, 1968). The distribution of these megaerratics is shown on the map of surficial deposits (Fig. 5). It should be noted that they do not necessarily define the eastern boundary of Athabasca Till, and that most of the erratics rest on glaciolacustrine sediments.

Glaciolacustrine and Glaciofluvial Deposits — Glaciolacustrine and glaciofluvial deposits which overlie and grade laterally into Athabasca Till occupy areas of the Northern and Eastern Lowlands. The glaciolacustrine sediments are principally those of the previously described glacial Lake Caroline, and are also associated with the Jackfish Creek ice.

The glaciofluvial sediments are in the form of a kame moraine (gradational to a delta-kame) and outwash gravels and sands. An extensive area of sandy kames (named the Cow Lake kame moraine) surrounds Cow Lake (Sec 13, Tp 38, R 8) on the north, east, and south. The average thickness of the moraine is not known but in some places is thicker than 98 ft (30 m). At an average depth of about 89 ft (27 m), a very coarse gray sand was encountered, and the water table was noted at about 56 ft (17 m) below the surface on the east side of Cow Lake (Fig. 4). On the west side of Cow Lake, the kame moraine is replaced by 26 ft (8 m) of silty, glaciolacustrine clays, which overlie about 10 ft (3 m) of weathered Paskapoo sandstone. At the northern and northeastern margins of the kame, the sands grade laterally into sandy Athabasca Till, or in places are overlain by a thin veneer of the till.

Local relief in the moraine is about 33 to 39 ft (10 to 12 m) where it has not been obscured by postglacial eolian sands. Cross-bedding is evident in the few exposures north of Cow Lake, but does not appear in the south. The thickness of the kame is due to a bedrock topographic low in which the sands accumulated, deposited there by meltwater from the disintegrating Laurentide ice mass.

Outwash gravels were encountered below the kame, as a unit 10 ft (3 m) thick, at depths of 79 ft (24 m) in the north and 69 ft (21 m) in the south. On the north side, its upper contact is a coarse gray sand and the lower, a coarse reddish-brown sand. On the south side, the lower contact was not observed, but the upper contact is a light gray, glaciolacustrine silt.

The coarse gray sand below the kame moraine forms part of a deposit of outwash sand that is confined to the area between the exposures of Athabasca and Sylvan Lake Till, and between Crimson Lake in the northwest and the Caroline area in the southeast. The sands are seldom exposed, and lie beneath either postglacial dunes or glaciolacustrine sediments. In the Crimson Lake area, the sands are present in a section on Prentice Creek (Sec 2, Tp 40, R 8), where they are overlain by eolian sands. The lower contact was not observed.

In the Cow Creek area (Sec 33, Tp 38, R 8), coarse gray sand at 36 ft (11 m) depth forms the lower contact of a sandy, glaciolacustrine unit (Fig. 4). The total thickness of the sand unit is 56 ft (17 m), and its lower contact is another glaciolacustrine unit, containing scattered pebbles. The bedrock was not encountered.

Sylvan Lake Deposits

Sylvan Lake deposits are represented by till and glaciolacustrine sediment, and although these deposits cover only a very small portion of the study area, they are significant for the understanding of the regional ice movements and the glacial record.

The only variation in the stratigraphy of the Sylvan Lake Till is the changing thicknesses of its two units: the upper glaciolacustrine silt which is generally less than 7 ft. (2 m) thick, and the lower till unit with a variable thickness up to 116 ft (35 m). The lower contact of the till is bedrock Paskapoo Formation.

The morphology is often subdued, being interrupted only by higher bedrock topography at the eastern margins of the study area (Fig. 5). Extensive areas of dead-ice moraine exist on and

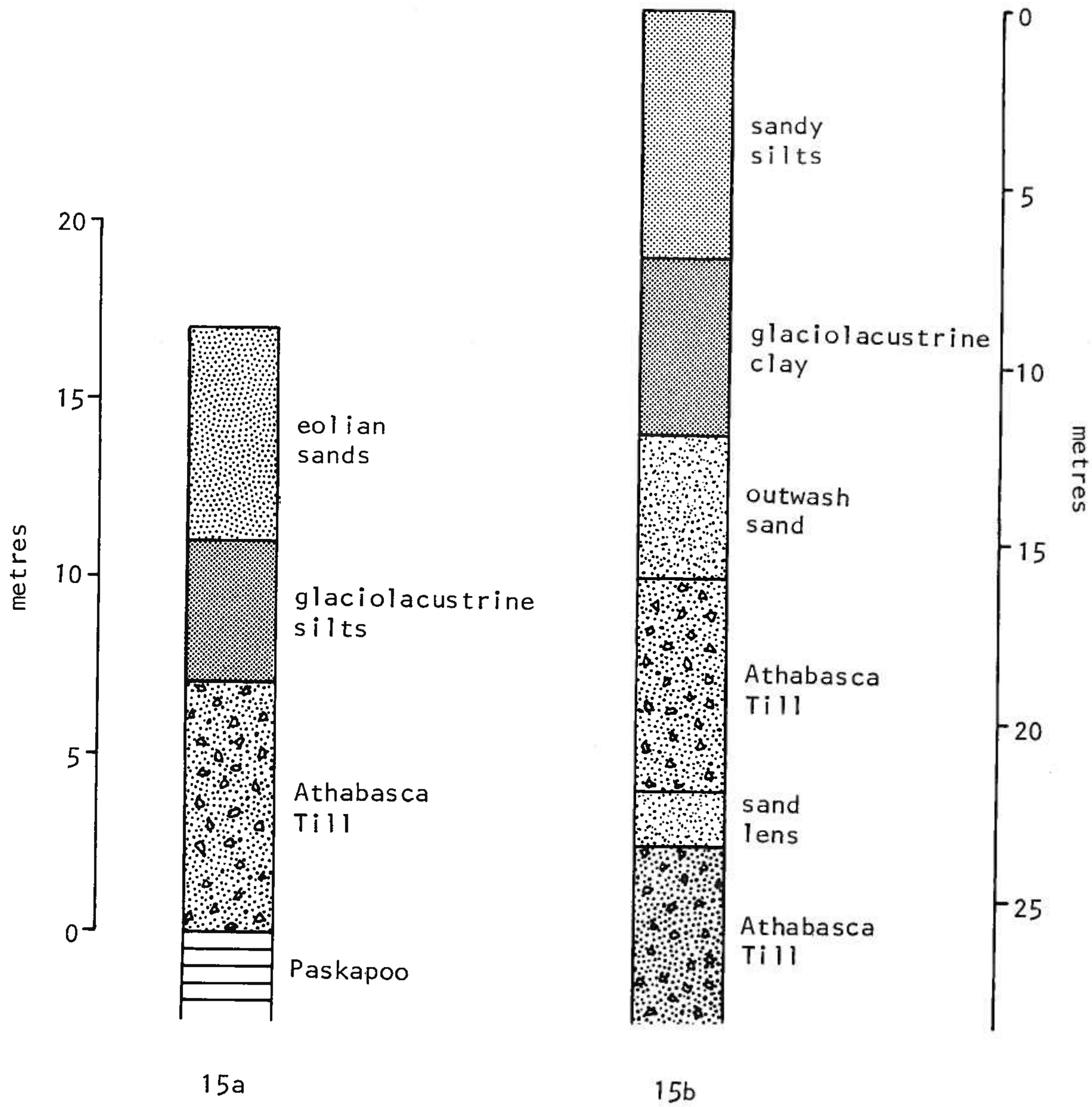

FIGURE 15. Stratigraphy of Athabasca Till

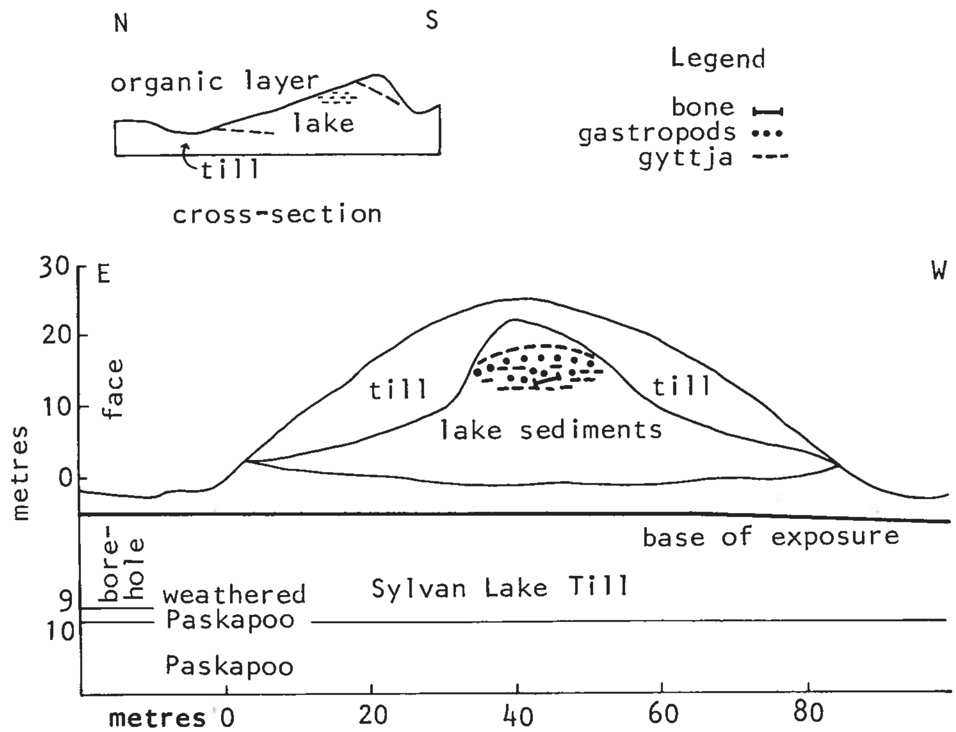

FIGURE 16. Leslieville bison site

around these topographic highs and display a variety of features and a stratigraphic complexity that includes gravels, sands, silts, Sylvan Lake Till, and pond sediments. From one of these areas (Lsd 3, Sec 29, Tp 40, R 4), a post-cranial bison bone and freshwater gastropod shells were recovered (Fig. 16 and Plate 5) subsequently radiocarbon dated.

Lithology

Athabasca Deposits

Till — Athabasca Till is medium brown at the surface, changing to a gray-brown in the unweathered zone. It has a relatively high sand content (Fig. 7) and is stony. Depth of leaching ranges up to 3 ft (1 m), and the average total carbonate content of the unweathered matrix is 18 percent. The unusual character of the till is reflected principally in its pebble lithologies, and also in the heavy minerals, both of which show evidence of Rocky Mountain and Laurentide provenance. Pebbles (Fig. 6) consist of limestones, dolomites, Lower Cambrian orthoquartzites, and feldspathic quartzites derived from the Rocky Mountain Front Ranges, and granites and high grade metamorphic rocks derived from the Canadian Shield. Also present, though in small numbers, are garnet talcose schist pebbles described by Roed (1968) as being one of the components of the Athabasca Valley Erratics Train. Since he stated that the source of the erratics train lay to the west of the Continental Divide, this till is described as Cordilleran.

The principal heavy minerals of the till (Fig. 9) similarly reflect its mixed origins. Garnet content is 18 percent as compared to 8 percent in the Jackfish Creek Till; tourmaline and zircon are approximately equivalent while hornblende-aegirine-augite, which is absent from the Rocky Mountain tills, is present, although not in the quantities present in the Sylvan Lake Till.

At the type section the Athabasca Till is gray-brown, stony, and possesses a predominantly sandy matrix. Total carbonate content of the fines is 18 percent. Of the diagnostic indicators, granites and high grade metamorphic rocks constitute 10 percent of the pebble lithologies, and hornblende-aegirine-augite constitute 3 percent of the heavy minerals. In the borehole (Sec 17, Tp 36, R 6), the till is dark gray, sandy, and stony. Total carbonate content of the matrix is 17 percent; granites and high grade metamorphic rocks from 15 percent, biotite schist 2 percent, and feldspathic quartzites 2 percent of the pebble lithologies; hornblende-aegirine-augite makes up 7 percent of the heavy minerals.

Kame Moraine — Most of the Cow Lake kame moraine consists of a medium to coarse, buff sand in which are scattered gravels and small gravel lenses containing pebble lithologies of mixed Rocky Mountain and Shield provenance. Coarse outwash sands exposed in the Prentice Creek section are variable in texture, and grade into a lower, coarser unit containing clay balls and gravels. The dip of the planar bedding in the upper unit indicates a flow direction generally to the south. The lithologies of the gravels are typically those of Athabasca Till.

Sylvan Lake Deposits

Sylvan Lake Till is variable in color, ranging from medium brown in oxidized samples through gray in unweathered samples, to a yellow-green near its contact with the Paskapoo sandstone. The till is moderately sandy and the average total carbonate content of the matrix of these samples is 7 percent.

The principal pebble lithologies of this stony till are quartzites and Shield-derived rocks. Heavy minerals are similar to those of Athabasca Till (Fig. 9) except that the average hornblende-aegirine-augite count is appreciably higher (16 percent, as compared to 7 percent in Athabasca Till). Hypersthene and sphene are also present in small amounts, but are not found in any other till of the study area.

Relationships of Athabasca-Sylvan Lake and Jackfish Creek Tills

As a regional unit, Athabasca Till grades laterally into Sylvan Lake Till. Evidence for this gradation is based on field mapping of the stratigraphic and morphologic continuity of the tills, and on the irregular but gradual change in the composition of the pebble lithologies (Fig. 6). Neither unit overlies the other, nor is there any break apparent in their respective characteristics. The change from one unit to the other is thus not marked by any distinctive feature so it is thought that Athabasca Till is a lithofacies of Sylvan Lake Till, being deposited by the same advance of Laurentide ice.

To the west the contact with Jackfish Creek Till is poorly defined. No evidence has been found for superposition of the tills, nor do the distributions of the deposits suggest that an overlap might have taken place. Defined largely on the basis of diagnostic pebble lithologies and heavy mineral suites, the tills possess sufficiently distinctive characteristics that the zone of lateral contact may be defined, even though it is not visible. Throughout the study area, this zone of lateral contact has been replaced by a series of ice-walled channels, and subsequently infilled either with coarse gravels or with organic deposits. The only evidence of an underlying till is that of the Jackfish Creek unit, encountered in the borehole at Strachan (Sec 7, Tp 38, R 8).

AGES, CORRELATIONS, AND GLACIAL HISTORY

In the previous discussion of the evidence for the different glacial advances, the relationships among the glacial deposits were assumed and the relative order of the advances was implied. These assumptions together with evidence assem-

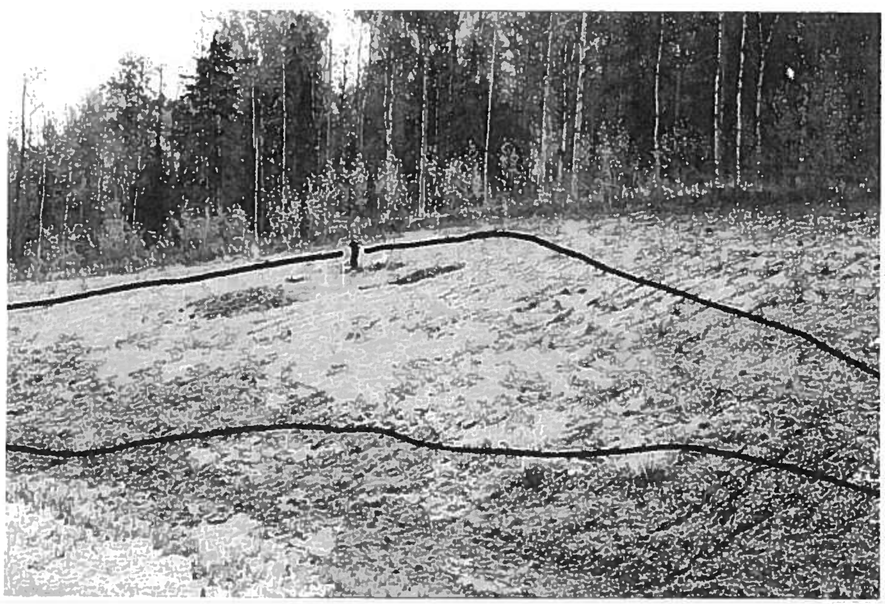

PLATE 5. Leslieville bison site

Table 2. Correlation Chart, Rocky Mountain House Area

Age	Advance: Rocky Mountain	Advance: Laurentide	Recession: Rocky Mountain	Recession: Laurentide	Morphologic and Stratigraphic units
LATE WISCONSIN				Athabasca-Sylvan Lake	dead-ice moraine (dated) glacial Lake Caroline Cow Lake Kame Moraine Strachan and Vetch spillways
			Jackfish Creek		
	Jackfish Creek				
			Lamoral		Lamoral lake deposits Delta and varves, South Ram River
	Lamoral	Athabasca-Sylvan Lake			Athabasca-Sylvan Lake Till and Lamoral Till
EARLY WISCONSIN			Hummingbird Baseline		Not observed
	Hummingbird Baseline				Hummingbird Till and Baseline Till; no evidence of a contemporaneous Laurentide advance

bled from each locality allow the description of the regional sequence of events. The terminology of the mid-continent of the United States is used for descriptive convenience even though correlation is not possible. It is assumed that the younger advances are Late Wisconsin, and that the older are Early Wisconsin or perhaps earlier.

AGES AND INTRA-CORRELATION OF EVENTS

Jackfish Creek-Laurentide Advance

The stratigraphy of the glacial deposits of the Jackfish Creek and Laurentide advances indicates that they represent the most recent glacial event in the study area. Evidence of the deflection of the Jackfish Creek glacier by the Laurentide ice mass (Fig. 17) and the presence of a Jackfish Creek glaciolacustrine unit formed in a proglacial lake over a bedrock surface rising to the west demonstrates the synchronous presence of the two ice masses in the Rocky Mountain House area. Further support for this is the absence of Jackfish Creek deposits either above or below Athabasca Till, and the presence of the North Prairie Creek ice-walled channel that likely lay between the Rocky Mountain and Laurentide ice masses (Fig. 14).

Radiocarbon dates of 1970 ± 140 BP and 10,250 ± 165 years BP were obtained respectively on bison bone and gastropods buried in lake sediments within a till hummock from an area of dead-ice moraine in Sylvan Lake Till (Fig. 17). Despite the problems associated with radiocarbon dates from dead-ice moraine (Porter and Carson, 1971), these dates demonstrate the persistence of the Laurentide ice at the end of the Wisconsin.

Clayton (1967), basing his argument on a series of radiocarbon dates, stated that in the Missouri Coteau stagnant ice masses required at least 3000 years to melt. However, to account for the long duration of this melting period he also stated that the ice masses must have been buried below supraglacial drift. At the Leslieville bison site this was true.

The dates of 9670 ± 140 years BP on bone and 10,250 ± 165 years BP on shell are clearly minimum age for dating the Laurentide advance and when Clayton's argument is considered these dates have two implications:

(1) that Laurentide ice, even as dead ice, was probably not present in the Rocky Mountain House area much after 9600 years BP;

(2) that cessation of the Laurentide advance may have occurred as early as 13,500 - 12,500 years BP.

On the basis of this evidence the Laurentide advance, and therefore the Jackfish Creek advance, is assigned to the Late Wisconsin (Table 2).

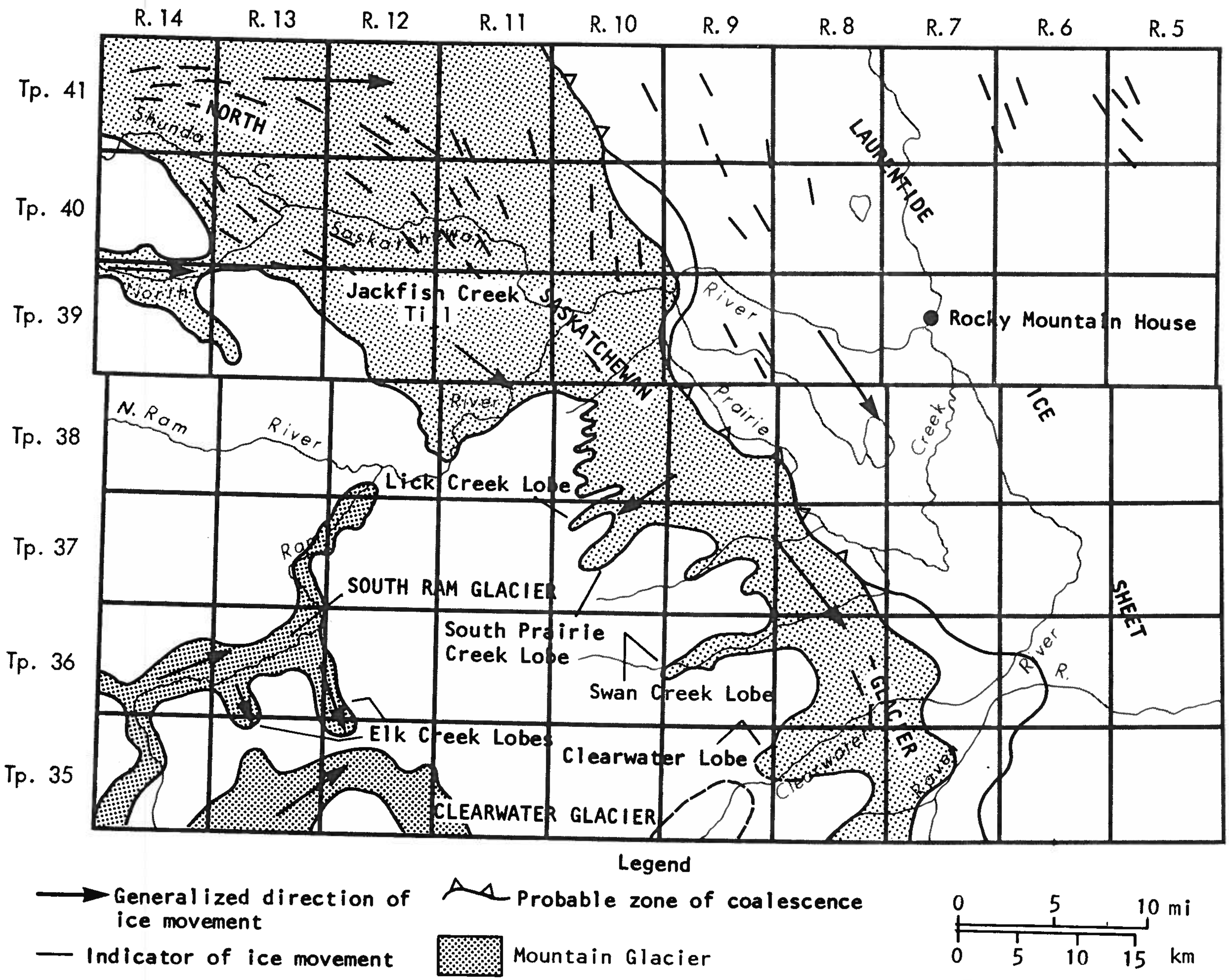

FIGURE 17. Distribution and movement of Rocky Mountain and Laurentide ice masses at the Jackfish Creek maximum

Lamoral-Laurentide Advance

The stratigraphic position of Lamoral glacial deposits with respect to those of Jackfish Creek indicates that they belong to an earlier advance of the Rocky Mountain glaciers. In the North Saskatchewan River valley, and in the tributary valleys of the Brazeau Piedmont, they are separated by a glaciolacustrine unit. In the South Ram River valley the separation is indicated by an erosional hiatus. Also, the presence of the South Ram varves imply a relatively long period of stability between the two advances.

Three lines of evidence demonstrate that the Lamoral was also equivalent to the Laurentide advance:

(1) The distribution of Lamoral Till in the valleys of the Brazeau Piedmont and the absence of the till east of the limits of Jackfish Creek Till suggest a pattern similar to that of the Jackfish Creek advance.
(2) The glaciolacustrine unit in the North Saskatchewan River sections was probably formed under similar conditions (in a proglacial lake) to the Jackfish Creek unit.
(3) The stratigraphy of the North Prairie Creek channel shows that it served as a spillway for the proglacial Lamoral lakes, and the lithologies of its lower gravels are of mixed provenance.

The Laurentide advance would therefore seem to have been equivalent to both the Lamoral and Jackfish Creek advances. On the basis of this equivalency, the Lamoral advance is assigned to the Late Wisconsin. Also, because the Lamoral and Jackfish Creek advances are separated by a recession and a period of stability, it is probable that the Laurentide ice was present in the area for much of the Late Wisconsin.

Hummingbird-Baseline Advance

Hummingbird Till

The stratigraphy of the Hummingbird Till (Fig. 11) demonstrates that it represents the oldest of three glacial advances, each separated by time periods of indeterminate length. As neither the induration of Hummingbird Till nor the development of hoodoos in its exhumed surface positively indicate antiquity, the stratigraphic evidence is tentatively accepted. As the till underlies Lamoral and Jackfish Creek deposits, it should be the equivalent of Baseline Till, and therefore a part of the same advance. However, the erosional hiatus above the till introduces an unknown factor, thus not excluding the possibility of a discrete Hummingbird advance. The stratigraphy of Hummingbird deposits suggests that the advance may be Early Wisconsin or older.

Baseline Till

Baseline Till has been distinguished from the other tills (Lamoral and Jackfish Creek) in the area to the east of the Brazeau Range by its character and by the magnitude of the ice mass that crossed the Brazeau Range, now an area of intense colluviation in which there is almost no evidence of former glaciation.

The till's uniformity of morphologic expression, its fragmentary distribution, its deposition by an ice advance of which evidence has all but disappeared, and its relatively deep weathering, all suggest that Baseline Till is of some antiquity. This evidence also implies that a period of erosion and weathering separated the advance from the Lamoral and Jackfish Creek advances whose deposits are found in the valleys below the piedmont plateau surface.

Correlations in the Brazeau and Ram Ranges Area

The evidence indicates that the last ice advance which crossed the Brazeau and Ram Ranges was probably Early Wisconsin in age. Because these ranges were ice-free during the Late Wisconsin this period of non-glaciation lasted from the time of recession of the Hummingbird-Baseline advance to the present.

INTERCORRELATION OF GLACIAL ADVANCES IN THE ALBERTA FOOTHILLS

The deposits in the study area can be correlated with deposits in three adjacent Foothills areas: Edson-Hinton (Roed, 1968); Sundre area, Red Deer Valley (Boydell, 1970); and upper North Saskatchewan River valley (McPherson, 1970). These correlations are not entirely satisfactory because only the Sundre area is contiguous, but the regional similarities in character and stratigraphy of the tills indicate that some glacial events are approximately synchronous and occurred in all areas.

The only Rocky Mountain event common to all areas is that represented by the Obed (Roed, 1968), Elkton Creek (Boydell, 1970), Main (McPherson, 1970), and Jackfish Creek (this report). With the exception of the Sundre area, this is the second, and most recent, advance of Late Wisconsin Rocky Mountain ice (Table 3). Correlation is based on:

(1) contiguity of Jackfish Creek-Elkton Creek Tills, traced by the author through the adjacent map areas;
(2) stratigraphic position of the Obed above the Marlboro-Edson Tills, which are equivalent to the Lamoral-Athabasca Tills of the Rocky Mountain House area;
(3) the stratigraphic position of the Main which, although separated from the present study area, is present at the surface through the intervening distance, traced from deposits of Jackfish Creek Till.

If this second Late Wisconsin advance was approximately synchronous in the correlated areas, then tentative correlation may be made with the other reported events.

Table 3. Intercorrelation Chart, Rocky Mountain House Area

		Edson-Hinton area Roed (1968)		Sundre-Red Deer valley area Boydell (1970)		Upper North Saskatchewan River valley McPherson (1970)	Rocky Mountain House area Boydell (1972)	
Age		Rocky Mountain	Laurentide	Rocky Mountain	Laurentide	Rocky Mountain	Rocky Mountain	Laurentide
LATE WISCONSIN		Drystone Creek	not present	not present	not present	not present	not present	not present
		Obed	not present	Elkton Creek	Sundre	Main	Jackfish Creek	Athabasca-Sylvan Lake
		Marlboro	Edson	not present	?	Big Horn	Lamoral	
EARLY WISCONSIN		Valley or piedmont (?)	Marsh Creek	?	?	?	Baseline	?
		Early Cordilleran (?)	?	?	?	?	Hummingbird	?

The first advance of Rocky Mountain ice in the Late Wisconsin is reported for all areas except the Red Deer Valley. The deposits are correlated on the basis of:

(1) stratigraphic position as the lowest unit in many Rocky Mountain till sections;
(2) stratigraphic equivalency, in the Edson-Hinton and Rocky Mountain House areas, to the Laurentide advance;
(3) fragmentary character and implied time separation from deposits of the most recent Late Wisconsin advance.

The absence of a stratigraphic equivalent in the Sundre area is difficult to explain as Boydell (1970) reported a relatively brief duration for the Elkton Creek advance. Lack of borehole data in an area generally poor in deep stratigraphic sections may explain why this equivalent was not observed; alternatively, these deposits may have been removed by subsequent events. However, a lower till was not found farther up the valley, either by the author or by Pheasant (1968). This absence is an anomaly in the pattern of regional events.

No equivalent to Roed's Drystone Creek advance is found in the other areas and there is, in fact, some doubt concerning its distinction from the Obed advance (Roed, 1968). However, if Drystone Creek was indeed a true advance, it was restricted to small mountain valleys, and so lack of equivalents would likely be due to differences in regional position with respect to the Front Ranges.

Evidence for earlier Rocky Mountain advances is either absent or so fragmentary that correlation is hardly feasible. If Roed's inferred early glaciations are correct, then it is possible that they may be the equivalents of the Hummingbird-Baseline advance of the Rocky Mountain House area.

The Late Wisconsin Laurentide ice apparently advanced into all areas at about the same time, although it does not seem to have been present in the Athabasca Valley in Obed time. However, Roed (1968) refers to glacial lakes equivalent to the Obed, implying the Laurentide ice was in the vicinity at that time. Similarly, in the Sundre area, the lack of evidence for its early presence is probably due to local distribution, rather than early deglaciation.

INTERCORRELATIONS WITH OTHER PARTS OF THE ROCKIES

The question remains as to the possibility, or even advisability, of correlating the events of the study area with those accepted for the Rocky Mountains of the United States (Richmond, 1965). It is clear that during the Late Wisconsin expansion of ice masses in the Cordillera took place both in the United States and Canada, and that the first recorded advance has been variously named Pinedale I (Richmond, 1965), Vashon (Fulton, 1971), Bow Valley (Rutter, 1972), Marlboro (Roed, 1968), and Lamoral (this report). However, the climatic complexity of the Canadian Cordillera as compared to its southern counterparts and the lack of radiometric controls prevent the demonstration of the synchrony of these Rocky Mountain advances in their respective areas (Porter, 1971).

GLACIAL HISTORY

An ice mass advanced eastwards from the Rocky Mountains during the Early Wisconsin, crossing the outlying Ram and Brazeau Ranges and terminating somewhere to the east of the Foothills Zone. Neither the duration of this advance nor the character of its recession are known. No indication of an equivalent advance of the Laurentide ice was found in the study area although Roed (1968) has cited evidence for an early Laurentide (Marsh Creek) advance in the Edson-Hinton area.

The period of time following deglaciation of the Rocky Mountain Foothills was evidently of sufficient duration to allow removal of much of the evidence of the Hummingbird-Baseline advance, through processes of weathering and erosion. Despite the probable absence of related sediments, this period is defined in the Rocky Mountain House area as an interstade, possibly equivalent to that suggested by radiocarbon dates for the Peace River-Finlay River region to the northwest (Westgate *et al.,* 1971; Lowdon *et al.,* 1971).

The Late Wisconsin is marked by the advance of both Rocky Mountain and Laurentide ice masses into the Foothills Zone. Lamoral ice advanced eastwards along the North Saskatchewan River valley, and was then deflected to the southeast by the Laurentide ice mass. The Lamoral ice then entered the valleys of the Brazeau Piedmont and impounded meltwaters in their upper reaches. In the South Ram River valley the extent of this advance is not recorded.

The effect of the advance was to create a series of temporary lakes, hemmed in by opposing Lamoral and Laurentide ice fronts, and it was during this time that the piedmont valley spillways and the North Prairie Creek channel were first cut.

The recession of the Lamoral advance is not well recorded in the study area. If the Lamoral is equivalent to McPherson's Big Horn advance (1970), then a relatively slow recession of ice from the lower parts of the North Saskatchewan River valley is indicated because outwash gravels of the retreat are found only to the west of the present study area.

In the South Ram River valley, the deltaic sand-varve sequences suggest the proximity of a relatively stable ice mass to the west. As the valley is linked in the northwest to the North Saskatchewan, it is likely that the Lamoral ice had at that time withdrawn to a position above the western end of the Kooteney Plains in the North Saskatchewan River valley, and to the west of the Ram Range in the South Ram River valley.

The contemporaneous Laurentide advance moved through the study area from northwest to southeast (Fig. 17), but was deflected in the Athabasca River valley by the Marlboro advance (Roed, 1968). The western limits of the Laurentide advance are represented by the mapped western limits of Athabasca Till (Fig. 5). Although the Lamoral ice retreated, there is no evidence of a similar recession of Laurentide ice, so it is likely that, at this time, the Laurentide ice was either approaching or was at its maximum in the Rocky Mountain House area.

The second and final Late Wisconsin advance of Rocky Mountain ice was the Jackfish Creek advance, which moved eastwards to a position approximately equivalent to the mapped limits of its till (Fig. 5), blocking the North Prairie Creek channel in the process. This ice coalesced with the already-present Laurentide ice, although the extent of coalescence is not known, as the probable zone of contact was subsequently obliterated by a series of channels developed between the two ice masses (Fig. 14).

The spillways of the piedmont valleys were reoccupied by meltwaters draining the lakes impounded between the Brazeau Range and the advancing Jackfish Creek ice. These spillways thus predate the reopening of the North Prairie Creek-Strachan channel which did not take place until the recession of the Jackfish Creek ice was under way. At that time, meltwaters impounded by the Laurentide ice removed the greater part of the Jackfish Creek deposits from the channel. The Jackfish Creek recession thus predates the disintegration of the Laurentide ice.

The Laurentide ice mass appears to have remained substantially the same during the Jackfish Creek advance, although the distribution of lake sediments and rafting of megaerratics suggests a more unstable, and probably thinner, western margin. Recession was characterized by in situ stagnation of large ice masses, usually on areas of higher ground, surrounded at lower elevations by glacial lakes. Following the reopening of the North Prairie Creek channel, the Cow Lake kame moraine was formed during a period of ice retreat and rising lake levels. In this same period, the first spillway (Crammond I) draining glacial Lake Caroline was opened, and the Laurentide ice front lay to the west of Rocky Mountain House (Fig. 15).

Further recession, and the cutting of Crammond II and other spillways, resulted in a general lowering of lake levels and the standing of numerous Erratics Train erratics, particularly in the Chedderville area (Sec 18, Tp 37, R 6). This represents the last stages of retreat of the Laurentide ice in the study area, although its disintegration may be traced progressively farther to the east and northeast. Deglaciation probably began between 13,500 and 12,500 years BP, and the Rocky Mountain House area was probably ice-free soon after 9600 years BP.

CONCLUSIONS

In the Rocky Mountain House area of the Foothills a record of at least three Rocky Mountain advances in Early and Late Wisconsin times has been established by relative dating methods, in the absence of radiometric controls. Evidence was found for only one equivalent advance of Laurentide ice, which existed in the area the whole of the Late Wisconsin. This Laurentide ice mass exerted a marked influence upon the distribution and movements of the Rocky Mountain advances. The last Rocky Mountain glacier retreated prior to the disintegration of the Laurentide ice mass, and the Rocky Mountain House area was virtually ice-free soon after 9600 years BP.

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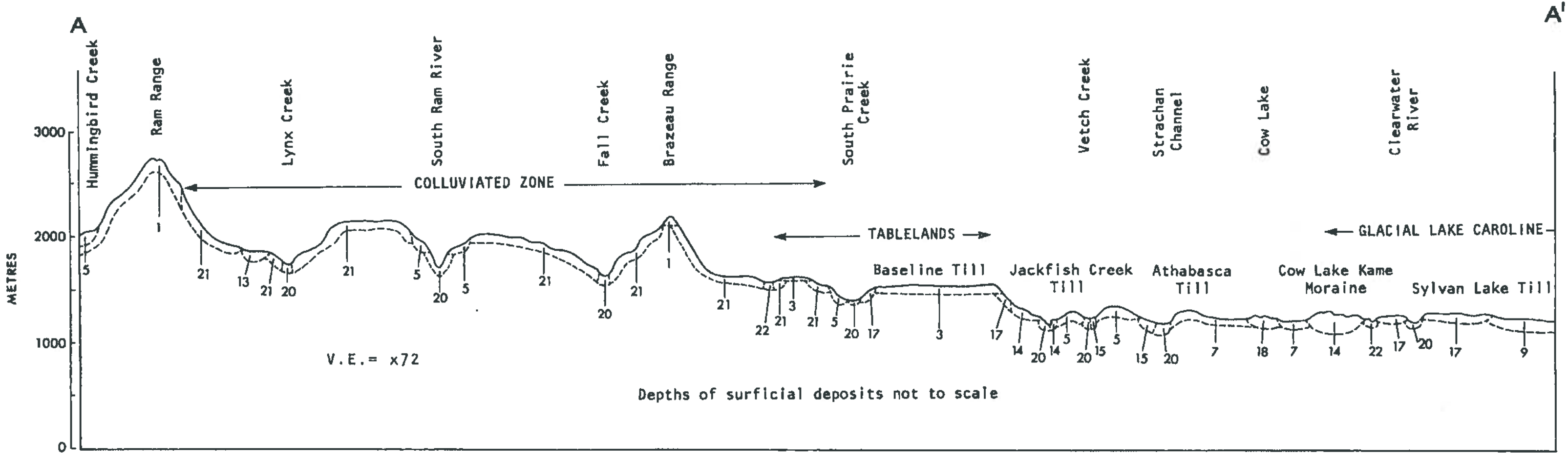

FIGURE 10. Diagrammatic cross section showing relationships of principal surficial deposits

LEGEND

RECENT

Depositional Features

- 22 *Organic*
- 21 *Colluvium*
- 20 *Alluvium*
- 19 *Alluvial fan*

PLEISTOCENE TO RECENT

Eolian Deposits

- 18 *Eolian sand*

PLEISTOCENE

Glaciolacustrine Deposits

- 17 *Silt, clay, and sand*

Glaciofluvial Deposits

- 16 *Ice-contact gravel -- undifferentiated*
- 15 *Meltwater channel deposit*
- 14 *Kame, kame moraine*
- 13 *Esker complex*
- 12 *Outwash gravel*
- 11 *Outwash sand*
- 10 *Alluvial train*

Glacial Deposits

- 9 *Sylvan Lake till ground moraine*
- 8 *Sylvan Lake till dead-ice moraine*
- 7 *Athabasca till ground moraine*
- 6 *Athabasca till dead-ice moraine*
- 5 *Jackfish Creek till ground moraine*
- 4 *Jackfish Creek till dead-ice moraine*
- 3 *Baseline till*
- 2 *Hummingbird till*

DEVONIAN TO PALEOCENE

Bedrock Outcrop

- 1 *Undifferentiated bedrock*

Geological boundary: defined, approximate ......

Dominant mode of till fabric ......

Drumlin (direction of ice movement indicated) ......

Meltwater channel ......

Location of megaerratic ......

Borehole site ...... bh

Site of material C^{14} dated ......

Line of cross-section ...... A A'

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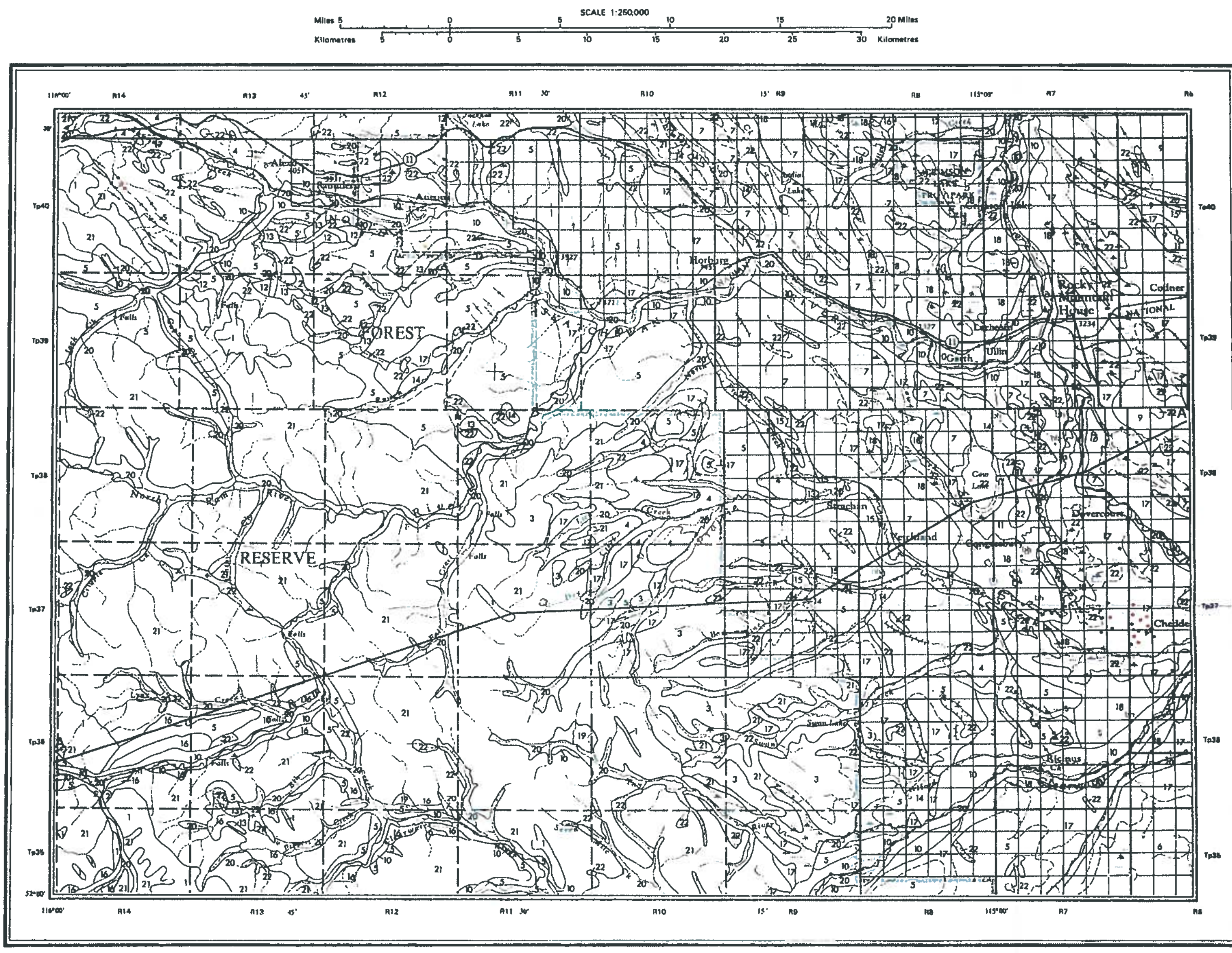
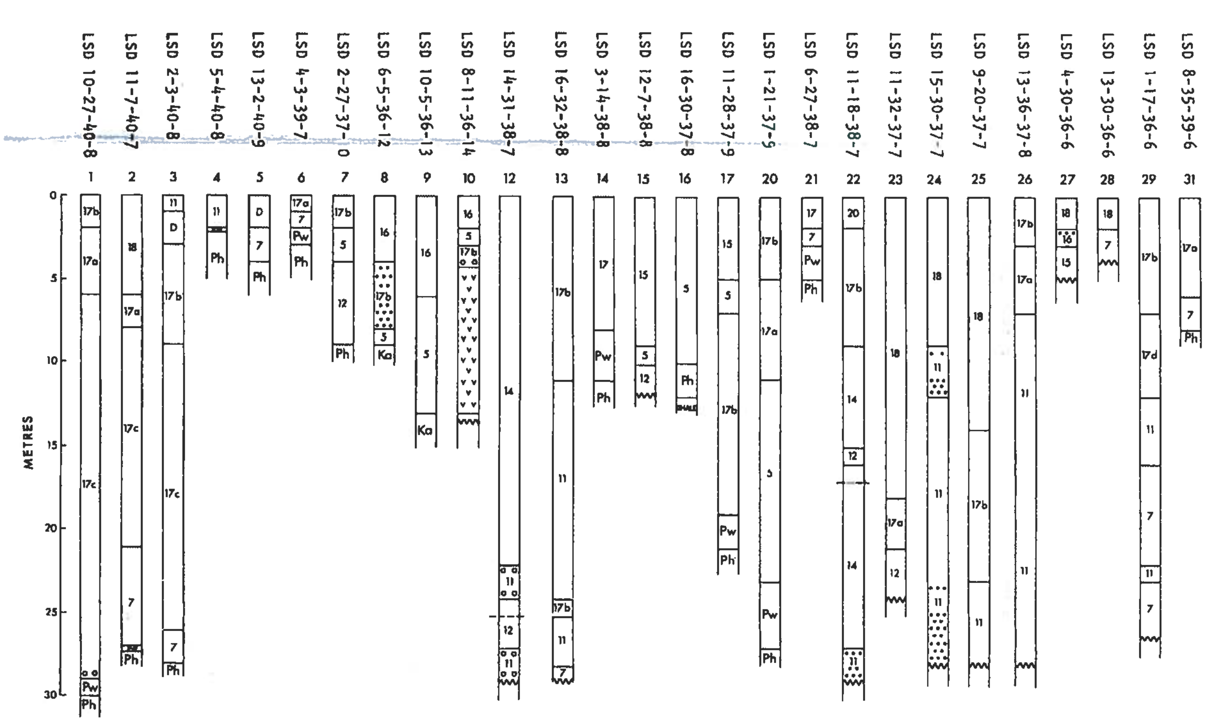


FIGURE 5. Surficial geology, Rocky Mountain House area



LEGEND

RECENT

- 20 *Alluvial fill*
- 18 *Eolian sand*

PLEISTOCENE

Glaciolacustrine

- 17a *Silt*
- 17b *Sandy silt*
- 17c *Silt (dark grey)*
- 17d *Clay*
- v v *Varves*

Glaciofluvial

- 16 *Ice-contact gravel*
- 15 *Spillway gravel*
- 14 *Kame sand*
- 12 *Outwash gravel*
- 11 *Outwash sand*

Tills

- 7 *Athabasca*
- 5 *Jackfish Creek*

Diamicton

- D

BEDROCK

- Pw *Weathered Paskapoo*
- Ph *Hard Paskapoo*
- Ka *Alberta Group*

MISCELLANEOUS

- o o Pebbles
- Fine gravel
- ----- Water table
- Maximum penetration

FIGURE 4. Borehole stratigraphy