QUATERNARY STRATIGRAPHY OF THE THREE RIVERS AREA, SOUTHWEST ALBERTA

by

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ABSTRACT

Over the last century, the southwest corner of Alberta has been the location of numerous investigations into the region's Quaternary glacial history. These studies have led to two diverging views on the number and timing of glaciations in the southwestern Foothills of Alberta: one school believes there have been many incursions of continental ice over much of the Pleistocene; the other claims that there has been only one continental advance. Surficial geology mapping at a scale of 1:50 000, paleomagnetic investigations, and detailed stratigraphic and sedimentologic logging of 24 natural sections around the Oldman Reservoir have resolved this issue.

The stratigraphy shows a consistent succession repeated throughout the area; one montane till or sequence of tills is always topped by either one continental till or a complex of continental tills, or a gravel unit containing Canadian Shield lithologies where a continental till has been eroded. There is no evidence for subaerial erosion representing a long hiatus between glacial advances responsible for continental till deposition. Evidence exists at the surface for the coalescence with montane glacial ice during the culmination of the continental ice advance.

Paleomagnetic sampling of Quaternary units in a complete stratigraphic section shows that all deposition occurred during the Brunhes chron (<0.78 Ma). ^{36}Cl dating of the Foothills erratics train further constrains the single continental glaciation to the late Wisconsinan.

DEDICATION

I dedicate this thesis to the members of the Alberta NATMAP crew, 1993-1995.

Thank you for help in the field, help in the office, and for three great summers.

QUOTATION

"Geology is a descriptive, interpretive science, and conflict is commonplace among its practitioners"

-John McPhee, "Rising from the Plains"

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I would like to extend a heartfelt thank you to Lionel Jackson for introducing me to the NATMAP project, trusting me with the responsibility of producing two of its maps, and encouraging me to proceed with a Master's degree. Without his constant supply of advice, software, hardware, red ink, and good humour, this thesis would not exist.

And last, thank you to the Queen, for lending me her lap-top.

TABLE OF CONTENTS

TABLES

FIGURES

MAPS
(IN POCKET)

CHAPTER 1

INTRODUCTION

The Foothills of southwest Alberta was one of the first Canadian locations where evidence of multiple glaciation was reported: interstratified glacial tills of continental and montane provenances were found. Since Dawson and McConnell published their early reconnaissance work in 1895, explorers and scientists have formulated theories about the history of Quaternary glaciation in this area based on stratigraphic evidence. Debate over the number of glaciations recorded in the region and synchroneity of montane and continental advances has occurred since formal research began.

Interpretation of the surficial geology in the southwest corner of Alberta has been shaped largely by the work of Horberg (1952, 1954), Stalker (1963), Wagner (1966), Alley (1973), Alley and Harris (1974), and Stalker and Harrison (1977). This work predates the explosion of research in contemporary glacial sedimentary environments that began in the early 1970s, as well as the development of paleomagnetic dating techniques. Also, this work was generally based on the interpretation of stratigraphic sections in the absence of detailed surficial geology mapping.

The primary objective of this study is to test past conclusions about the Quaternary glacial history of the Oldman Reservoir, through detailed investigation of the surrounding surficial geology and Quaternary stratigraphy. The Oldman Reservoir is situated at the confluence of the Castle, Crowsnest, and Oldman rivers, 200 km south of Calgary, and 100 km west of Lethbridge (Fig. 1). Four tasks are required to achieve this goal: the first is to

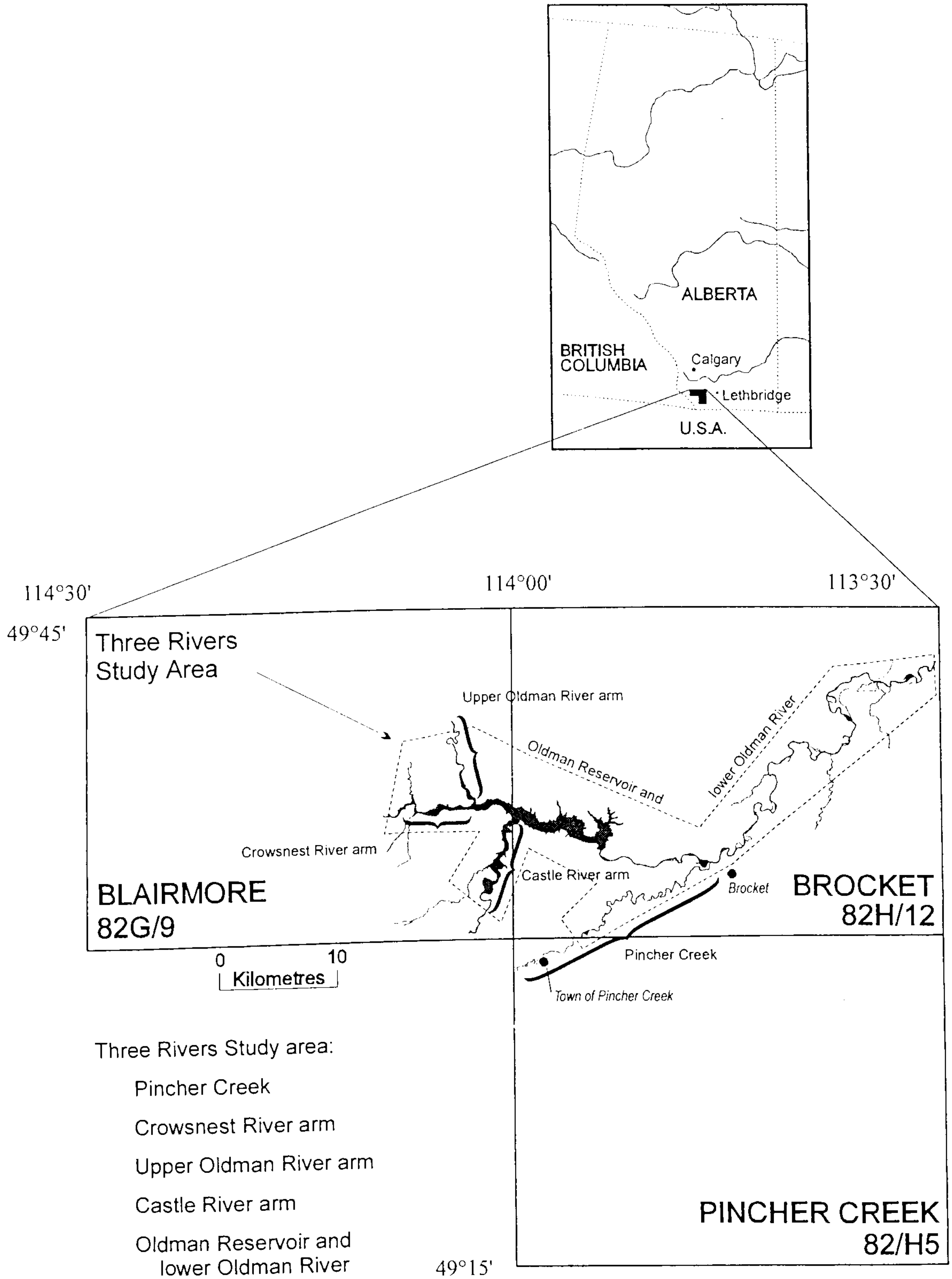


Figure 1: Location of the three NTS map sheets included in this thesis, the boundaries of the local area for stratigraphic work around the Oldman Reservoir, and five geographically separate areas along river valleys containing stratigraphic sections (described in Chapter 5).

completely map the surficial geology of the Brocket and Pincher Creek map areas at a scale of 1:50 000. The second is the re-examination of previously described stratigraphic sections (from 1950 to the early 1970s), and to locate and describe new exposures. The interpretation of the results of these two tasks employs contemporary (post-1970) concepts in glacial sedimentary deposits and their sedimentary facies and facies associations. The third task is to relate glacial limits and drift sheets observed in the course of surficial geology mapping to the sediments seen in stratigraphic sections in order to test previous conclusions on Quaternary glacial history in the area. The fourth, and last, task is to date glacial deposits. Paleomagnetic sampling and analysis is used to place glacial sediments within the time frame of the geopolarity time scale. Early and middle Pleistocene ages have been assigned to some glacial deposits in the area. Paleomagnetism offers the possibility of testing the validity of these mid and early Pleistocene ages.

CHAPTER 2

PHYSICAL SETTING

This chapter first describes the physical characteristics of the study region and then briefly summarizes the physiography and geology of the Three Rivers study area.

GEOMORPHOLOGY AND BEDROCK GEOLOGY

The area east of the continental Divide may be divided into three main physiographic regions (Fig. 2): the Front Ranges of the Rocky Mountains, the Foothills, and the Interior Plains (Beaty, 1975). Each region has characteristic surface morphological features that are closely linked to the underlying bedrock structures. Their morphologies have been modified by glaciation. Furthermore, each region has characteristic bedrock lithologies that provide clues to the provenance of glacial tills deposited by ice that has traversed these areas (Fig. 3). The study area effectively lacks any plutonic or metamorphic bedrock exposures. The only minor exception is the Beaver Mines Formation, a lower Cretaceous conglomerate that contains minor amounts of granitic pebbles (Douglas, 1950).

Front Ranges

The Livingstone and Lewis and Clark Ranges form the Front Ranges of the Rocky Mountains. They consist of Proterozoic (late Precambrian) to Mesozoic sedimentary rocks that have been moved tens of kilometres to the east/northeast along numerous low-angle

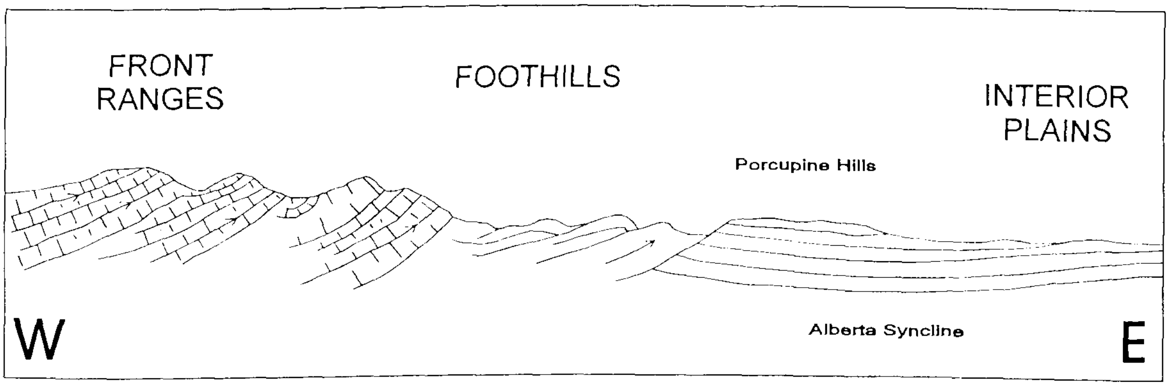
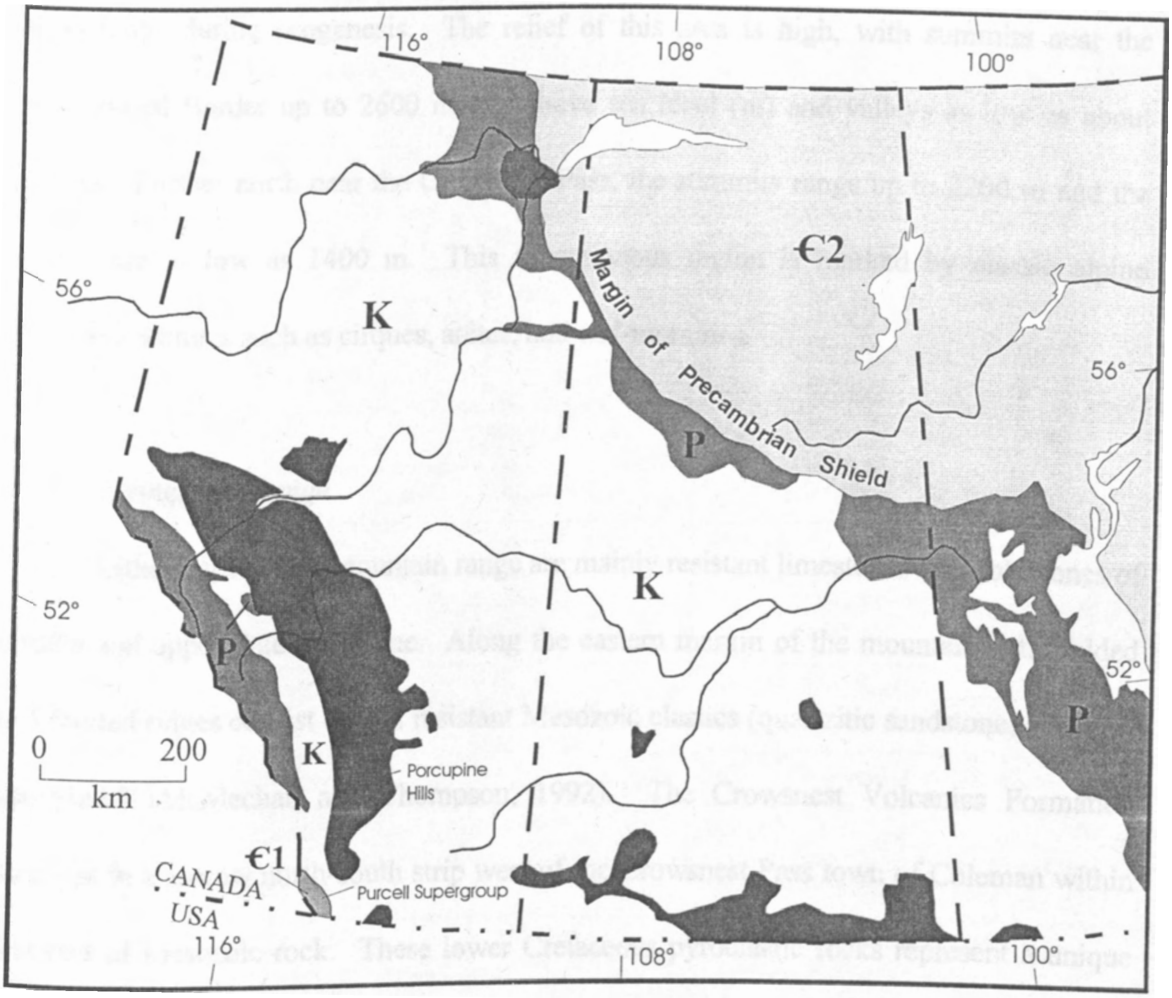


Figure 2: Cross-section of bedrock structural features from mountain front to plains (after Beaty, 1975).



K — Cretaceous shale, siltstone, and sandstone.

Tertiary siltstone and sandstone.

P — Paleozoic limestone, dolostone, sandstone and shale.

€1 — Precambrian igneous and metamorphic rocks and minor sedimentary rocks (units lack pink plagioclase feldspar crystals).

€2 — Precambrian igneous and metamorphic rocks containing pink plagioclase feldspars.

Figure 3: Source areas of distinctive rock types used in identifying till provenance (modified from Klassen, 1989).

thrust faults during orogenesis. The relief of this area is high, with summits near the International Border up to 2600 metres above sea level (m) and valleys as low as about 1700 m. Further north near the Crowsnest Pass, the summits range up to 2200 m and the valleys are as low as 1400 m. This mountainous region is marked by classic alpine glaciation features such as cirques, arêtes, and end-moraines.

Livingstone Range

Lithologies of this mountain range are mainly resistant limestones and dolostones of middle and upper Paleozoic time. Along the eastern margin of the mountains, the folded and faulted ridges consist of less resistant Mesozoic clastics (quartzitic sandstone, siltstone, and shale) (McMechan and Thompson, 1992). The Crowsnest Volcanics Formation outcrops in a narrow north-south strip west of the Crowsnest Pass town of Coleman within this belt of Mesozoic rock. These lower Cretaceous pyroclastic rocks represent a unique volcanic episode in the Canadian Rockies (Stelck *et al.*, 1972).

Lewis and Clark Ranges

The Lewis and Clark Ranges are composed of rocks of the Proterozoic Purcell Supergroup. They are found in the southernmost part of the Canadian Rockies in and around Waterton National Park (Table 1). Purcell rocks are the oldest in the Rocky Mountains in southwestern Alberta. Lithologies exposed at the surface in the Waterton Park area include red and green argillite, dolostone, limestone, maroon banded quartzite, metagabbro, and a dark green amygdaloidal basalt (Purcell Lava) (Höy, 1993).

Table 1: Geologic time scale and ages of selected rock formations relevant to study (after Palmer, 1983; Beaty, 1975).

ERA	Period	Epoch	Ma	Comments
CENOZOIC	Quaternary	Recent	0.01	
		Pleistocene	1.6	
	Tertiary	Pliocene	5.3	Saskatchewan sands and gravels
		Miocene	23.7	
		Oligocene	36.6	
		Eocene	57.8	
		Paleocene	66.4	Porcupine Hills sandstone and shale.
MESOZOIC	Cretaceous		144	Crowsnest Volcanics Coal seams in plains
	Jurassic		208	Coal seams in foothills
	Triassic		245	
PALEOZOIC	Permian		286	Livingstone Range
	Carboniferous		360	Rocks of Frank Slide
	Devonian		408	
	Silurian		438	
	Ordovician		505	
	Cambrian		570	
PRECAMBRIAN	Proterozoic		2500	Purcell Supergroup
	Archean		3800 ?	Basement of Canadian Shield

Foothills Belt

This is an elongate region of folded and thrust faulted Upper Paleozoic and Mesozoic sandstone, siltstone, and shale that stretches up to 40 km east from the base of the Front Ranges (McMechan and Thompson, 1992). The region is characterized by low, rolling hills and long, linear, sub-parallel ridges and valleys that follow the mountain front in a northwest-southeast direction. Relief is only about 150 m with summits nearing 1500 m. The general elevation and relief of the Foothills decrease gradually to the northeast; the eastern boundary of this physiographic region is marked by a gradual change from rolling to horizontal topography.

Interior Plains

The Interior Plains are underlain by near-horizontal Upper Cretaceous sandstone and shale thousands of metres thick. Its surface morphology is characterized by vast expanses of horizontal and very gently rolling surfaces cut by glacial coulees and major rivers entrenched 50-100 m in narrow valleys (Beaty, 1975). The elevation of the Plains at its western edge is about 1000 m, and the gentle regional slope is to the northeast.

Porcupine Hills

The Porcupine Hills are a remnant upland surface of near-horizontal Paleocene and Upper Cretaceous strata that lie in a broad and shallow syncline, structurally more like the Interior Plains than the Foothills Belt by which they are surrounded (Beaty, 1975). The highest portion of this plateau is at about 1800 m, and therefore rises about 600 to 750 m above the level of the Foothills and Plains regions. The fine-grained sandstone bedrock underlying the Porcupine Hills also forms benches and cuestas along the eastern and western edges of the Hills, respectively.

Canadian Shield

Although over 800 km to the northeast of the study area, the Precambrian Canadian Shield is an important source area for stones found in till and gravel units within the study area (Fig. 3). The stones have igneous and metamorphic lithologies. Granitic stones commonly contain distinctive pink plagioclase feldspar crystals. I will refer to these as "Shield stones" throughout this thesis.

CLIMATE

The Plains and Foothills Belt have a continental climate which is characterized by short, warm summers and bitterly cold winters with a maximum annual temperature range of 80°C, and an average annual rainfall of 380 mm. The region is also noted for its strong and persistent winds (Beaty, 1975). The harsh climatic conditions experienced in these regions place severe constraints on the variety of native vegetation, and on commercial crops.

Autumn is a short season; average temperatures drop below freezing and continuous snow cover may form at the beginning of November. Mid-winter temperatures average between -9°C and -12°C, and less than 25 mm of precipitation falls, on average, in any winter month. The warm and dry Chinook winds that descend the lee slopes of the Rockies several times each winter serve to moderate temperatures and can raise the mercury 20°C or more over a few hours. Mean temperatures rise above freezing again in April, and with spring comes the potential for heavy snowfalls, severe frosts, and flooding due to snowmelt in montane headwaters to the west. Temperatures average more than 16°C only from the beginning of July until mid-August, and most precipitation falls during the summer growing season in the form of convective thunderstorms (Hare and Thomas, 1974).

SOILS

The study area is generally characterized by two great groups of the Chernozemic soil order. Black Chernozems are found in the westernmost portion of the Foothills. These are highly productive soils with A horizons between twelve and 25 centimetres thick, and a lime concentration layer at a depth between 75-125 centimetres. Dark Brown Chernozems are found further east in the slightly more arid eastern Foothills and adjacent Interior Plains. The A horizon of these soils averages eighteen centimetres in thickness, and the average depth of the lime concentration layer is 61 centimetres. Moisture is the main limiting factor to growth and productivity in this soil Great Group (Alberta, 1969).

VEGETATION

Most of the study area is classified as the highest Prairie Steppe, averaging about 1050 m. It is dominated by short and medium-grass prairie. The predominant vegetation is rough fescue, with willow and poplar trees in moist areas along watercourses (Moss, 1959). Vegetation in higher-elevation areas (above 1400 m) in the western portion of the Foothills belt and in the Porcupine Hills is montane forest, characterized by Douglas fir and white spruce, with limber pine, lodgepole pine, and poplars (Pawluk *et al.*, 1967). As in the Prairie Steppe, gullies and stream valleys are vegetated with willow and poplar scrub.

GEOLOGY AND GEOMORPHOLOGY OF THE THREE RIVERS AREA

The recently created Oldman Reservoir is centred at the confluence of the Castle, Crowsnest, and Oldman rivers (Fig. 1), 200 kilometres south of Calgary, and 100 kilometres west of Lethbridge. The reservoir is dammed by the Oldman Dam which is located five kilometres northeast of the town of Pincher Creek. The main body of the reservoir follows the Oldman River valley. It is approximately twenty kilometres long, and ranges from 0.5 to 1.5 kilometres in width. The Oldman River is joined by Pincher Creek ten kilometres east of the dam. The reservoir and surrounding area span National Topographic Service (NTS) map sheets 82 H/5 (Pincher Creek), 82 H/12 (Brocket), and 82 G/9 (Blairmore). The Three Rivers study area is loosely bounded by the Foothills and Front

Ranges to the west, the Porcupine Hills to the north, and the edge of the Interior Plains to the east.

Most of the study area is underlain by the near-horizontal sandstones and shales of the Plains, and in the northwestern corner of the Brocket map sheet, by the Porcupine Hills Formation. Elevations within the three map sheets of the study area range from 960 m in the northeast corner of the Brocket map sheet, to 1750 m in the Porcupine Hills, in the northwest corner of the Brocket map sheet. To the south, on the Pincher Creek map sheet, elevations rise from 1140 m at the town of Pincher Creek, to 1550 m in the southwest corner.

CHAPTER 3

PREVIOUS WORK

Over the last century, the southwest corner of Alberta has been the location of numerous investigations into the region's Quaternary geology (Table 2). This chapter briefly summarizes, in chronological order, the studies that have direct relevance to this thesis.

The early reconnaissance work of Dawson and McConnell (1895) in southwestern Alberta identified evidence of past interaction between glacial ice of montane and continental provenance. Interest has been focussed on determining the nature and timing of glaciation in this region ever since. With respect to glaciation by continental ice, extensive literature accumulated in the last 100 years articulates two diverging views (Table 2; last column):

1. The southwest Foothills of Alberta have been subjected to multiple glaciations by continental ice prior to and including the Wisconsinan glaciation.
2. Continental ice reached the area only once, during the Late Wisconsinan.

This dichotomy prompted the present investigation which strives to settle this issue.

EARLY INVESTIGATIONS

Dawson and McConnell (1895) observed the same general stratigraphy throughout southwestern Alberta. A basal gravel, termed the "Saskatchewan gravels", lies at the base of the stratigraphic column in the east, and grades westward into a montane "Western boulder clay", at the eastern edge of the Foothills. This unit is overlain by a Laurentide "Lower boulder clay", which is separated from the Laurentide "Upper boulder clay" by interglacial silt. Throughout their study area, the stratigraphic column is capped by waterlain and stratified sand, gravel, and silt:

Stratified sand, gravel, and silt
Laurentide "Upper boulder clay"
Interglacial silt
Laurentide "Lower boulder clay"
"Western boulder clay" (Albertan age), grades eastward into Saskatchewan gravels

Dawson and McConnell (1895) used Chamberlin's (1894) named series of stages in the glacial history of North America in their explanation of observed glacial stratigraphy. An initial Albertan (later termed Nebraskan) age montane glaciation deposited the "Western boulder clay". This unit graded eastward into sand and gravel. This event was followed by two glaciations of Kansan and Iowan age. Boulder clays (tills) deposited during these events overlie the western boulder clay and equivalent gravel, and are separated by fine sediments deposited during a Kansan/Iowan interglacial. Basing these interpretations on Lyell's (1833) theory of the iceberg-origin of drift, they ascribed their observations to a "Great Western Depression" which permitted icebergs to float in a giant inland sea, depositing drift on the plains and on the flanks of the Porcupine Hills.

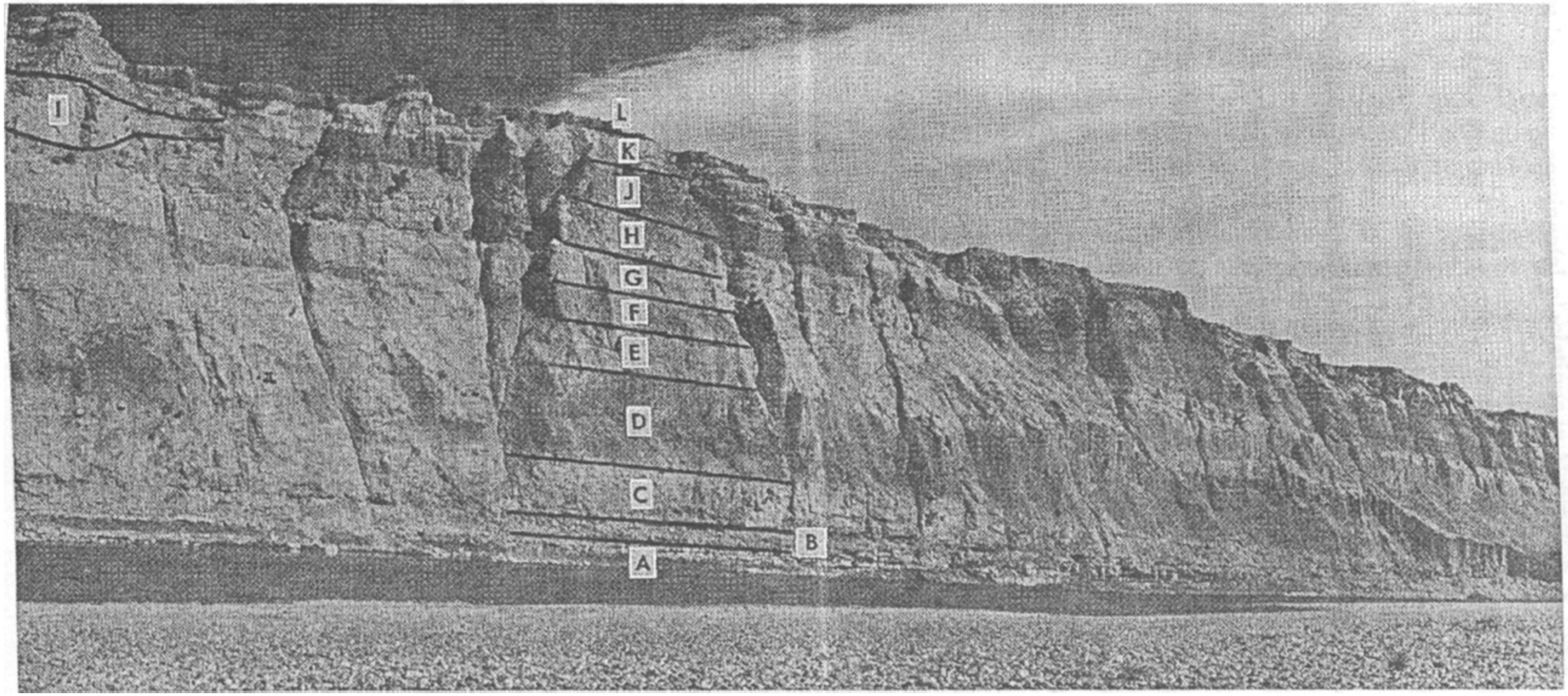
In the early 1900s, although largely agreeing with Dawson and McConnell's stratigraphy, workers in southwest and south-central Alberta began making significant modifications to the depositional model. Both Calhoun (1906) and Alden and Stebinger (1913) re-interpreted the "Saskatchewan sands and gravels" as a non-glacial deposit and discontinued the name "Albertan" for the lowest montane till. Dowling (1917) rejected the "Great Western Depression" concept based on his analysis of the pattern of drainage channels in southeast Alberta, which he attributed to ice-marginal fluvial action during glacier retreat. Alden (1924) may have been the first to suggest that the Dawson and McConnell's (1895) Upper till is Wisconsinan, based on well preserved surface features of moraine relative to "older" drift sheets. Johnston and Wickenden (1931) cited the interglacial nature of beds and weathering of the underlying continental till as evidence for an interglacial in post-Kansan time, and claimed that the upper drift sheet was early Wisconsinan, or the now obsolete Iowan glaciation. Bretz (1943), in one short but intense field season, re-examined moraines mapped by Alden (1932) and Johnston and Wickenden (1931) in Saskatchewan, Alberta, North Dakota, and Montana. Bretz drew heavily upon previously unpublished maps by W.A. Johnston and R.T.D. Wickenden (Stalker quoted in Jackson, 1993, p. 64), in his mapping of glacial moraines, proglacial lakes, and meltwater drainages over more than 100 000 square kilometres in the Alberta plains. Although Bretz did not examine any stratigraphy for his study, he did suggest that moraines are progressively younger toward the east, and that today's drainage pattern contains "aberrant routes" that must be due to ice-front deflections during the Wisconsinan glaciation, and perhaps older ones.

Horberg (1952, 1954) suggested that the interglacial sediments identified by all previous workers were, in fact, glaciolacustrine sediments deposited in front of the retreating continental ice sheet which deposited Dawson and McConnell's (1895) Lower till. He also subdivided this Lower till at Lethbridge into two new units, which he termed the Basal till and Lower till. He was the first to propose an entirely different hypothesis for glacial deposits in the vicinity of the Foothills of Alberta: that the deposition of all unconsolidated sediments stratigraphically above the Saskatchewan sands and gravels occurred during the Late Wisconsinan glaciation.

NEW TECHNIQUES AND INVESTIGATIONS BY A. MacS. STALKER

During the 1950s, the use of radiocarbon (^{14}C) as a dating tool began to make an appearance in studies conducted in the midwestern United States (Flint and Rubin, 1955) and southwestern Alberta (Stalker, 1958). Lithological analyses also became an important tool for differentiation of glacial diamicton units.

It was during this period that Dr. A. MacS. Stalker (1953), a Quaternary geologist with the Geological Survey of Canada, began his investigations of surficial deposits, glacial limits, and stratigraphic sections of southwestern Alberta. In 1963, Stalker described a dozen sections along the Oldman and Castle Rivers. From these, and particularly his Brocket Section on the Oldman River (Fig. 4), he concluded that after one major Nebraskan advance of montane ice onto the eastern margin of the Foothills, there was a succession of



L. Sandy loam; modern soil.
K. Sand; lake and outwash.
J. Varved clay, silt and fine sand; glacial lake.
I. Till (Buffalo Lake); Laurentide.
H. Sand, silt, clay; lacustrine or alluvial; possibly mid-Wisconsin.
G. Till (unnnamed), medium light brown; Laurentide?
F. Till (Brocket), dark brown; Laurentide.
E. Till (Maunsell), light bluish grey; Laurentide.
D. Till (Labuma), dark brown to black; Laurentide.
C. Till (Albertan), light grey; Cordilleran.
B. Gravel (no Canadian Shield stones); mostly outwash.
A. Bedrock (Willow Creek Formation); Paleocene.

Figure 4: Stalker's "Brocket Section" (1963): the section upon which many workers' interpretations of Quaternary history in southwestern Alberta have been based. After Prest (1970), Plate XII-4.

at least four continental glaciations in Nebraskan, Kansan, Illinoian and Wisconsinan time. (He later revised the record, extending it only back as far as the Illinoian (Stalker and Harrison, 1977). Stalker's work has proven to be very influential, and until very recently, was the work to which other scientists (Rutulis, 1962; Day, 1971; Alley, 1972, 1973; Alley and Harris, 1974; Stene, 1976; Stalker and Harrison, 1977; Jackson, 1980; Jackson, 1994) correlated their findings.

A SINGLE, LATE WISCONSINAN ADVANCE RE-PROPOSED

Wagner (1966), in an unpublished Ph.D. thesis, re-examined the stratigraphic and surficial geology evidence for both the montane and continental ice advances into southwestern Alberta. With respect to continental ice advances, he agreed with previous workers' observed limits of Shield erratics in the Porcupine Hills. However, excepting Horberg (1952, 1954), he refuted all previous authors' conclusions of multiple, pre-Wisconsinan continental glaciations based on the fact that all observed deposits may be explained by one Wisconsinan continental advance with a fluctuating ice margin during its retreat.

Bayrock (1969) also proposed a single continental advance in southern Alberta, but based on the occurrence of late Pleistocene fauna in preglacial gravel. Liverman *et al.* (1989) and Young *et al.* (1994) corroborated Horberg (1952), Wagner (1966), and Bayrock (1969) with sequences of finite radiocarbon ages from mammal bones and wood found beneath a single continental till in west central and central Alberta, respectively. These ages indicated that continental ice could not have entered southwestern Alberta until late Wisconsinan time (after 30-20ka BP).

This conclusion was corroborated by Little (1995) and Jackson *et al.* (1996) south of the Oldman River through 1:50 000 scale surficial geology mapping, re-examination of previously described key stratigraphic sections, description of new stratigraphic sections, and paleoglaciology of the continental ice sheet. Much of Jackson's (1996) report was based upon work in progress in 1995, which is now fully reported in this thesis.

Table 2: Summary of significant work, in chronological order, relating directly to this study. NB: "Pre-Wisc?" means "Did the authors recognize any continental glaciations within this study's area prior to Wisconsinan time?".

STUDY	STUDY AREA	CONCLUSIONS	COMMENTS	TILLS RECOGNIZED (Oldest to most recent)	Pre Wisc?
Dawson and McConnell (1895)	49°00' to 51°00' N 114°30' to 111°00' W U.S. border to Bow River. Eastern edge of Rocky mountains to eastern edge of Foothills.	Deposition of Saskatchewan gravels synchronous with Albertan-age montane till in west. Followed by "Great Western Depression" during which thousands of feet of subsidence allowed an incursion of Arctic waters from the NW, during which drift from a first continental advance was deposited to 1615 m in the Porcupine Hills (Kansan). Followed by an interglacial ("post-Kansan interval") and one more continental advance to the Foothills (Iowan). No continental tills of Wisconsinan time.	Recognized region as a zone of interaction between montane and continental ice. Believed boulder clays (tills) were deposited along the margins of an extensive glacial sea; re-emergence of the land resulted in expulsion of the sea from the region. Placed observed stratigraphic units into timescale proposed by Chamberlin (1894). Based interpretations on stratigraphic sections and scattered surface observations.	Montane: 1: Western Boulder Clay (Albertan till). Continental: 1: Lower Boulder Clay (Kansan, west to mountain front); 2: Upper Boulder Clay (Wisconsinan).	Yes
Horberg (1952)	49°30' to 50°00' N 111°15' to 114°15' W From Foothills, 140 km east along the Oldman River to Lethbridge.	Saskatchewan gravels are preglacial. Following an extensive montane advance, continental ice fluctuated, resulting in several till units separated by glacial lake sediments. All continental ice incursions occurred in Wisconsinan time: no evidence for any large time hiatus.	Re-interpreted Dawson and McConnell's work and rejected their chronology. Interpreted interglacial (Lenzie) silts as proglacial lake sediments, not interglacial sediments. Based interpretations on stratigraphic sections and 1:800,000 mapping.	Montane: 1: Western Boulder Clay Continental: 1: Basal till (Pre-Classical Wisconsinan); 2: Lower till (Classical Wisconsinan, to 1590 m); 3: Upper till (small readvance to Lethbridge moraine).	No
Horberg (1954)	49°00' to 49°30' N 113°15' to 114°07' W Rocky Mountain front just north of the U.S. border.	Three ages of montane drift: Kansan, early and late Wisconsinan. The latter two tills are overlapped by Outer Continental Drift (Horberg's (1952) Lower till) from a late Wisconsinan continental ice lobe. As ice retreated (with some readvances) to the Lethbridge moraine, it deposited two lower and more eastern moraine belts: Kimball moraine and Glenwoodville moraine. In every section, continental drift is stratigraphically above Montane drift. Maxima of montane and continental glaciers were synchronous.	Attempted to correlate Pleistocene events at mountain front to standard North American chronology of the Mississippi Valley. Based interpretations on stratigraphic sections and 1:200,000 mapping.	Montane: 1: Kennedy drift (Kansan, on Mokowan Butte); 2: Early Wisconsin drift (up to 10 km from mountain front); 3: Late Wisconsin drift (within moraines of Early drift). Continental: 1: Late Wisconsinan ice lobe with several retreat/ readvance moraine belts: Outer Continental Drift; Kimball moraine; Glenwoodville moraine; Lethbridge moraine.	No

STUDY	STUDY AREA	CONCLUSIONS	COMMENTS	TILLS RECOGNIZED (Oldest to most recent)	Pre Wisc?
Stalker (1963)	49°20' to 49°55' N 114°10' to 111°50' W Along Castle, Oldman, St. Mary rivers.	Preglacial Saskatchewan gravels overlapped by maximum advance Nebraskan montane till. Followed and buried by no less than four continental tills representing Nebraskan, Kansan, Illinoian and Wisconsinan advances.	Based interpretations on twelve stratigraphic sections.	Montane: 1: Albertan Continental: 1: Labuma; 2: Maunsell; 3: Brocket; 4: "Light brown"; 5: Buffalo Lake; 6: "Younger tills"	Yes
Wagner (1966)	49°15' to 49°50' N 112°00' to 114°30' W Mountains, Foothills and Plains southwest of Calgary and west of Lethbridge.	One montane ice advance in Illinoian time, followed by a hiatus during which Cloudy Ridge soil formed. In Wisconsinan time, montane ice advanced and climaxed just before the glacial maximum of continental ice, which reached to almost 1675 m in Porcupine Hills. All continental tills in stratigraphic sections may be explained by a single continental glaciation with a fluctuating ice margin.	Based interpretations on stratigraphic sections and 1: 150,000 mapping. Proposed one single, late Wisconsinan continental glaciation event marked by several sub-events of retreat and readvance. Disagreed sharply with Horberg's (1954) Montane chronology and Stalker's (1963) continental stratigraphy and chronology.	Montane: 1: MI (Cloudy Ridge); 2: MII, Cirque moraines (restricted to mountains) Continental: 1: Basal till; 2: Lower till (advanced to Porcupine Hills, Kimball moraine); 3: Upper till (Lethbridge moraine)	No
Bayrock (1969)	Southern Alberta, and adjacent areas in Saskatchewan and Montana.	An ice-free corridor existed along the Foothills during Nebraskan, Kansan, and Illinoian time. continental ice only advanced into southern Alberta, closing the corridor, during the Late Pleistocene (Wisconsinan glacial stage).	Disagreed with Stalker's (1963) interpretation of the Brocket section. Based conclusions on physiographic and stratigraphic positions of Saskatchewan sands and gravels in Alberta, and horse and mammoth fossils (determined to be late Pleistocene) found within this unit.	Continental: One till, unnamed.	No
Day (1971)	49°50' to 50°05' N 113°35' to 114°08' W Trout Creek drainage basin, west of Claresholm.	Porcupine Hills were glaciated two times by continental ice; pre-Wisconsinan (ice reached to 1750 m), and Wisconsinan (ice reached to 1460 m). No montane ice ever reached the study area.	Disagreed with Wagner (1966) and Horberg (1952). Based interpretations on 1:160,000 mapping and description and sampling of 69 exposures and soil pits, 7 of which exhibited both till units discussed. No interglacial sediments or soil horizons identified in or on older till	Continental: 1: Porcupine till (more extensive); 2: Furman till.	Yes

STUDY	STUDY AREA	CONCLUSIONS	COMMENTS	TILLS RECOGNIZED (Oldest to most recent)	Pre Wisc?
Alley (1973)	49°30' to 50°20' N 113°30' to 114°45' W Continental divide to Livingstone Range, Foothills, Porcupine Hills, and plains east to to Fort Macleod.	Three major episodes of decreasing magnitude in which montane ice advanced and retreated significantly before continental ice advanced. Early events were pre-Wisconsinan. Latest was early Wisconsinan. Ice never coalesced at maxima.	Grouped Stalker's Maunsell, Brocket and unnamed tills into one Maunsell till. Based interpretations on stratigraphic sections and 1:50,000 mapping (not included in publication).	<u>Montane</u>: 1: Albertan; 2: Maycroft; 3: Ernst; 4: Hidden Creek (valleys only); 5: Cirque moraines. <u>Continental</u>: 1: Labuma; 2: Maunsell; 3: Buffalo Lake.	Yes
Stene (1976)	49°40' to 50°10' N 114°10' to 113°35' W Porcupine Hills.	Fossils found in alluvium and lake sediments in Porcupine Hills river valleys only date back to 14 ka BP; therefore ice must have been present in these valleys in the late Wisconsinan. Porcupine Hills were glaciated three times in late Wisconsinan time, the first time being the most extensive.	Based interpretations on re-examination of some key sections of other workers (mainly Stalker) and ^{14}C dates from fossils. Disagreed with theory that SW Alberta was not glaciated in late Wisconsinan supported by Stalker (1970), Reeves (1970, 1973) and Alley (1972).	<u>Continental</u>: 1: Labuma (deposited Shield erratics to 1675 m); 2: Maunsell (hummocky till deposits in valleys to 1370 m); 3: Buffalo Lake (deposited Foothills Erratics train, to 1250 m).	Yes
Stalker and Harrison (1977)	48°45' to 50°00' N 113°00' to 114°45' W From mountain front to SW corner of plains, and U.S. border to Oldman River.	At least 4 major events since Illinoian time, each consisting of first one montane advance then a continental advance, decreasing in intensity and strength with time. In addition, a continental glaciation in classical Wisconsinan time reached only as far as Lethbridge and Medicine Hat. Continental ice did not reach study area during classical Wisconsinan time.	Based interpretations on data obtained from previous work by both authors and other workers. No new data was presented.	<u>Montane</u>: 1: Waterton I (Great glaciation); 2: II (synchronous with 4 below); 3: III (synchronous with 5 below); 4: IV (synchronous with 6 below). <u>Continental</u>: 1: Labuma (Great glaciation); 2: Maunsell; 3: Brocket; 4: Buffalo Lake; 5: Erratics Train advance; 6: Lethbridge and Medicine Hat advances (one event).	Yes
Liverman et al. (1989)	55°00' to 55°45' N 117°45' to 118°15' W Two river-cut sections in west central Alberta.	The study region and areas to the south and west were glaciated by continental ice only in the Late Wisconsinan, the Quaternary glacial maximum.	Based interpretations on ^{14}C dates of wood samples derived from sand and gravel stratigraphically below continental till, and lacking in Shield material.	<u>Continental</u>: One till, unnamed.	No

STUDY	STUDY AREA	CONCLUSIONS	COMMENTS	TILLS RECOGNIZED (Oldest to most recent)	Pre Wisc?
Young et al. (1994)	53°00' to 35°40' N 113°20' to 113°50' W Subtill valley fills in west central Alberta.	Dates of fossils found below continental till are between 21 and 43 ka BP. Only one late Wisconsinan event at Edmonton, and therefore areas that are at higher elevation and further to the south and west will share the same glacial history.	Based interpretations on stratigraphic sections and 29 organic samples from preglacial Saskatchewan sands and gravels.	Continental: One till, unnamed.	
Little (1995)	49°00' to 49°15' N 113°00' to 114°00' W	Only one Continental glaciation reached Waterton Park region, and it reached its maximum (1585 m) in late Wisconsinan time, coalesced with existing Montane ice, then retreated to a recessional position (1430 m) before retreating out of study area.	Based interpretations on stratigraphic sections, glacial sedimentology, and 1:50,000 mapping.	Continental: One till, unnamed.	No

CHAPTER 4

METHODOLOGY

NATMAP PROJECT

This work was completed as a part of Canada's National Geoscience Mapping Program (NATMAP) in the Foothills of southwestern Alberta and contiguous areas of the Interior Plains and Rocky Mountain Front Ranges. The surficial geology component of the project covered twelve adjoining 1:50 000 National Topographic Service (NTS) map sheets between Turner Valley and the Montana border. Field research for this study was carried out during the summers of 1993-1995. This thesis is based primarily on the results of surficial geology mapping and stratigraphic interpretations of three NTS sheets surrounding the Three Rivers Reservoir: 82 H/12 (Brocket), 82 G/9 (Blairmore), and Pincher Creek (82 H/5) (Fig. 5). The author mapped the surficial geology and carried out Quaternary stratigraphic investigations for the Pincher Creek and Brocket map areas and investigated the Quaternary stratigraphy of the Blairmore map area around the Oldman Reservoir. The surficial geology of the Blairmore map area was mapped by L.E. Jackson, Jr.

SURFICIAL GEOLOGY MAPPING

The surficial geology of the study area was mapped by subdividing the areal distribution of unconsolidated deposits (uppermost 1-1.5 m) according to their genesis and

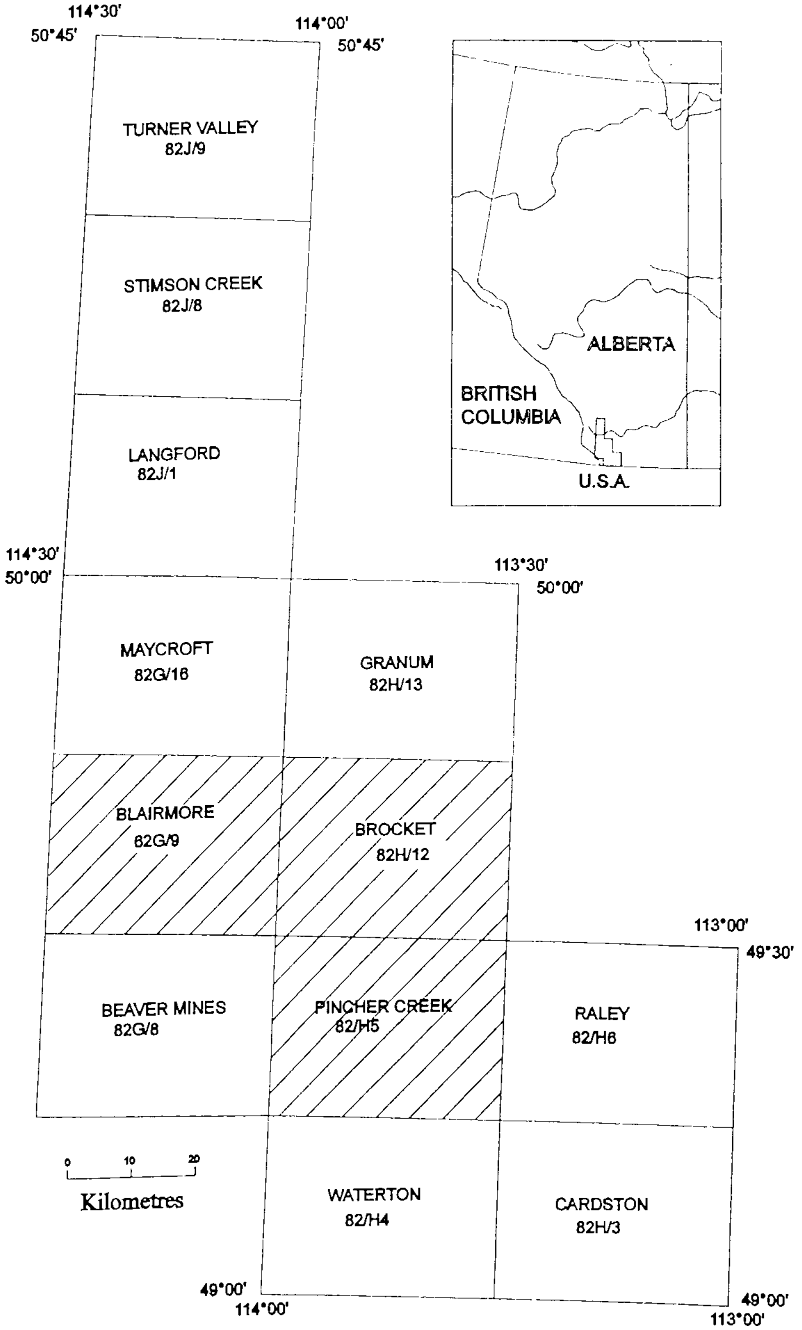


Figure 5: Location of study area relative to Canada's National Geoscience Mapping Program (NATMAP).

provenance. Deposit morphology aided in determining genesis and defining unit boundaries. The first step in the mapping process was to define preliminary map unit boundaries based on airphoto analysis. Field checking followed this initial step, and involved two methods: road traverses and foot traverses.

Road traverses

A one-mile-square grid of roads and trails following the Township and Range survey system covers most of the study area. Field checking involved east-west and north-south traverses along roads and road allowances. Auger holes were driven to one metre below the surface at approximately 2-3 km intervals where natural exposures or roadcuts were lacking. Sediments encountered with hand auger or exposed at roadcuts were described. Descriptions included basic observations of texture, colour, pebble lithology, and other relevant information, bearing in mind that the sediments obtained from an auger can be distorted. In hilly areas where roadcuts are more common, more direct observations of the uppermost sediments could be made; other exposures such as river-cut banks, gravel pits and slump scarps were described where encountered.

Foot traverses

Foot traverses were carried out in the high relief areas of the Porcupine Hills, where there is little or no road access. The prime objective in ground checking these areas was to establish the limits of glaciation. The highest deposits of glacial diamicton (till) on hillslopes were mapped along with the uppermost occurrences of clasts of Canadian Shield and montane provenances beyond the limits of continuous or discontinuous drift cover. Meltwater erosional features (notches, ice-walled channels) were also noted.

Approximately 400 spot checks were done on the Pincher Creek and Brocket map areas, which results in an overall control point density of approximately one every five square kilometres. However, the site density was not uniform; density increased with complexity of the landscape as determined from the initial airphoto interpretation. Access was denied to the Peigan Indian Reserve, consequently no field checking was done within it; map units therein are based on airphoto interpretation alone. Once sediment types, unit boundaries, and morphological features were determined, information was transferred from airphotos onto topographic base maps. The final digital and paper maps were produced at the Geological Survey of Canada office in Vancouver, B.C. under the direction of Kazuharu Shimamura.

STRATIGRAPHIC SECTIONS

Twenty-two sections were described from eighteen different locations along the shores of the Oldman Reservoir, the Oldman and Castle rivers and Pincher Creek. Due to access restrictions to the Peigan Indian Reserve, two of Stalker's (1963) key sections (the Brocket and Peigan sections) could not be re-examined along the Oldman River. His descriptions are included in Appendix A, and in the correlation chart (Map 4, in pocket) included with this thesis.

Flooding in the early part of the 1995 summer field season swept cliff bank bases clear of slumped material. New vertical sections were formed where slopes calved off after being undercut by torrential high waters and wave action along Oldman Reservoir. Sections were studied on foot where natural gullies cut through them. However, many sections were nearly vertical and these were sampled using a two-rope, belayed safety system.

Measurement

Two methods were used to measure the vertical height of each section and the thickness of each unit within. The first method was to level up a slope with a Brunton compass or a clinometer, using a ranging pole or the leveller's known eye height to measure vertical distance; this method was employed only on short, easily climbed sections. The second method involved calculating vertical distance from measurements of slope angle and distance.

Unit description

Stratigraphic units were measured from the base up, and were defined on the basis of textural, and sedimentological (and sometimes colour) differences. For each unit, several different non-genetic properties were described: texture, colour, clast angularity and lithology, percentage of clasts (stoniness), and sedimentary structures. The nature of the contacts of a unit were described as either sheared, depositional or erosional, and abrupt or gradational. Photomosaics were taken along exposures from a boat when on the reservoir, or from the opposite shore when on a river, as an aid to correlation.

Three-dimensional pebble fabrics

Three-dimensional pebble fabrics (azimuth and plunge of long axes) were measured in some diamicton units in order to provide evidence for genesis and ice flow direction. The orientations of between thirty and fifty rod-shaped pebbles were determined within a one-metre square area on the face of a diamicton outcrop. This data was entered into "Stereo", a 3-dimensional orientation analysis and plotting program from RockWare Scientific Software. Clast orientations (azimuth and plunge) and the program-generated mean lineation vector were plotted on an equal area Schmidt net. Point density for each fabric was calculated using a step function in combination with the Kamb (1959) method of contouring points. These density values were reported in a second, contoured stereonet as standard deviations from an expected point density if clast orientations were from a completely uniform (random) population.

The program generated the following statistics:

Mean lineation azimuth: vector resultant sum of all the two-dimensional vectors in the data set.

Mean lineation plunge: average plunge of all the data in the set.

E1, E2, and E3 (first, second, and third eigenvalue): these values provide information about the distribution and uniformity of the samples in the data set. The eigenvector associated with the greatest (first) eigenvalue gives the mean lineation direction. There are three types of point distributions that can be determined from looking at the relationships of the eigenvalues: 1) the first eigenvalue is much greater that the other two; this indicates a single area of point concentration on the hemisphere. 2) The first and second eigenvalues are roughly equal, but much greater than the third value; this indicates a girdle distribution, where the points lie along a great circle trace. 3) All of the eigenvalues are of the same magnitude. This typically indicates a uniform distribution.

Other statistical values generated include:

r1 (ln (E1/E2)), r2 (ln (E2/E3)), and K (r1/r2): these values also describe the distribution of points.

Rbar: value allows testing of data set for uniformity when compared to a table of values for cutoffs at certain levels of significance (Davis, 1986).

Spherical variance: a measure of dispersion (1-Rbar) which increases with dispersion of sample set vectors about the mean vector direction.

Sampling

Samples for laboratory analysis were taken in many of the diamicton and gravel units of each described section. Bulk samples of diamictons were collected for textural analysis (providing the weight percentages of sand, silt, and clay, and coarser-than-sand fractions). These samples were analyzed at the Sedimentology Lab of the Terrain Sciences Division, Geological Survey of Canada, Ottawa, under the direction of Patricia Lindsay.

In order to determine provenance, a representative sample of ≥50 pebbles was collected by the author from some gravel units and all diamicton units at each section.

PALEOMAGNETIC SAMPLING AND DATING

Very fine sand, silt, clay, and diamicton matrix may record orientation and polarity of the earth's magnetic field at the time of deposition (Barendregt *et al.*, 1991). Samples for paleomagnetic analysis were taken at only one section: the Castle River Section (#1a). This section has been described in the past by Stalker (1963; Cowley Section 7), Wagner (1966; Section 15), and Alley (1973; his Fig. 10). Stalker considered that the lowest diamicton in the section is the Maunsell (Laurentide) till of possible Kansan time; Alley found the lowest till to be a Pre-Wisconsin montane till, which he correlated with Dawson and McConnell's (1895) Albertan stage.

The paleomagnetic sampling was carried out in order to test the possibility that the oldest Quaternary sediments in this area were deposited prior to the last magnetic reversal as implied by Stalker's (1963) and Alley's (1972). Oriented samples were taken from each Quaternary unit in the section by pushing plastic cylinders into a vertical face that had been cleaned of slumped sediments. The cylinders' orientation was measured by Brunton compass. A total of 59 samples were collected and analyzed. Samples were analyzed under the direction of R. Enkin, J. Baker, and R. Barendregt at the Paleomagnetism Laboratory in the Pacific Geoscience Centre of the Geological Survey of Canada, Patricia Bay, B.C. Stepwise alternating field demagnetization was carried out by treatment along three axes successively, using a Schonstedt GSC-5 for fields up to 100 mT, and Sapphire Instruments' SI-4 for fields up to 180 mT. Measurements of natural remanent magnetization were made on fully automated Schonstedt spinner magnetometers. All samples proved to record normal polarity. Hence, all deposition of Quaternary sediments at the Castle River Section (a near-complete stratigraphic sequence) occurred since the Matuyama-Bruhnes boundary, 780 ka (Appendix E).

CHAPTER 5

QUATERNARY STRATIGRAPHY

Interpretation of the Quaternary stratigraphy for the study area is based on the detailed descriptions of 24 stratigraphic sections observed at river bank exposures (two of which were described by Stalker, 1963, and could not be visited due to denial of access to the Peigan Indian Reserve). Several of the sections examined for this study have been previously described by Stalker (1963), Alley (1972) and Wagner (1966) (Fig. 6) (Appendix A, Section information table, Comments column). All sections are located on Map 4 (in pocket), and summarized by location in Table 3. All stratigraphic descriptions, three-dimensional fabric measurements, pebble lithologies, and bulk till textural information is presented in Appendices A, B, C, and D. A total of eight lithostratigraphic units were defined based upon field and laboratory analyses. They are described, and interpretation of their environments of deposition discussed, in the following sections. Stratigraphic sections are described for five geographic areas around the Oldman Reservoir (Fig. 1).

LITHOSTRATIGRAPHIC UNITS OF THE STUDY AREA

Eight Quaternary stratigraphic units can be traced laterally from section to section throughout the study area. These range from single lithology units to lithostratigraphic units containing several related sedimentary facies. These eight units were defined on the

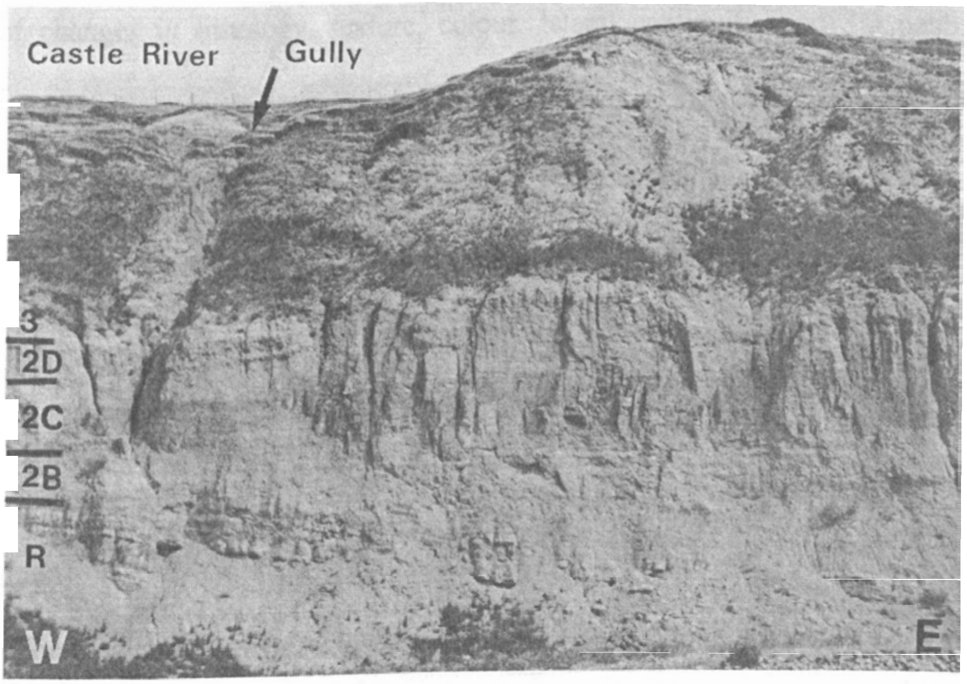


Figure 6: Castle River Gully. Cliff-bank exposure has been previously described by Stalker (1963), Wagner (1966), and Alley (1972). Samples for paleomagnetic analysis were collected 100 metres to the west of the gully. Numbers refer to unit numbers described in Chapter 6; W and E stand for west and east; R stands for bedrock.

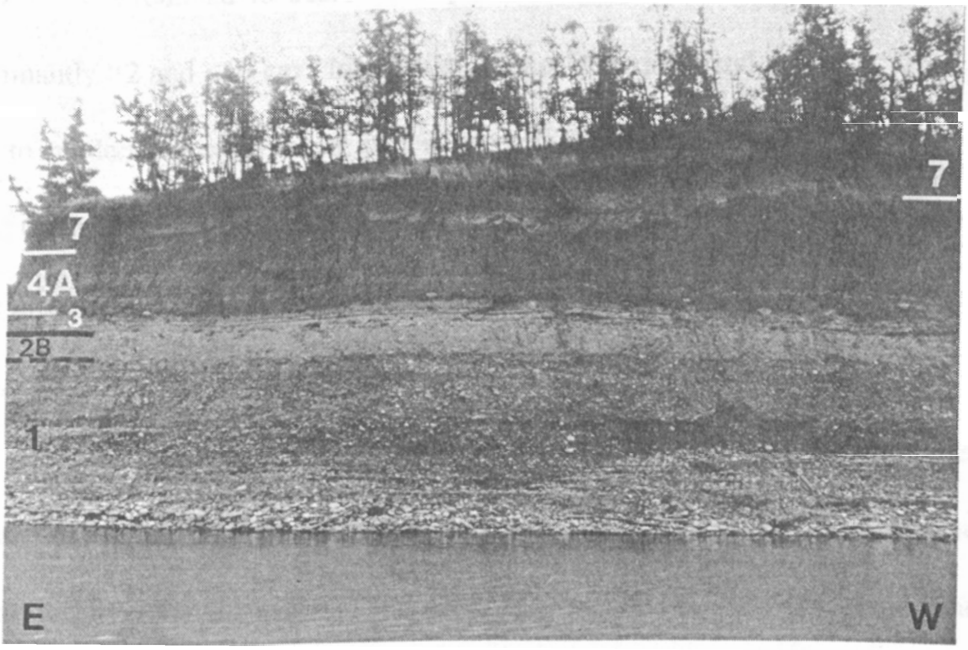


Figure 7: Northfork Section. A near-complete sequence of deposits consisting of proglacial basal gravel (Unit 1), montane till (Unit 2B), laminated silt and clay (Unit 3), to continental till (Unit 4A). Section is capped by glaciolacustrine sediments mapped extensilvely at the surface (Unit 7).

basis of changes in lithology, texture, colour, lateral continuity, and 3D pebble fabric direction, as well as unconformities or abrupt contacts marking unit boundaries. Section to section correlations are presented in the enclosed correlation chart (Map 4, in pocket). The units in the sections are arranged by age from bottom to top (oldest tc youngest).

UNIT 1 - BASAL GRAVEL

Description

The basal gravel is present in seven sections (Appendix A: Brocket, Cowley Bridge 2, Highway Bridge, Island View 1 and 2, Northfork, and Peigan sections), and overlies bedrock along an abrupt, erosional contact at all but two sections. It is clast-supported, and consists of well-rounded to subrounded pebbles and cobbles ranging up to 25 cm, but predominantly >2 and <10 cm. Interstitial sediments are sand and granules. The gravel is poorly to moderately well sorted, and is crudely stratified, occasionally containing sand lenses. Clasts within stratified layers are commonly imbricated, dipping up valley in the section locations. In most locations, the gravels become increasingly matrix-supported up-section, and are always overlain by Unit 2 (Fig. 7).

Along the upper and lower Oldman River, pebble and cobble lithologies are mainly carbonate and quartzite from the Livingstone Ranges, volcanic from the Crowsnest Pass area, and locally derived sandstone and siltstone (Appendix C: 33, 35). Along the Castle River, lithologies are mainly from the Lewis and Clark Ranges (Purcell Supergroup). Canadian Shield lithologies are absent at all locations.

Interpretation

The degree of rounding and sorting, and the large clast size of the cobbles indicates deposition in a moderate to high-energy fluvial environment. The predominance of massive or crudely horizontally bedded gravel with some imbrication of clasts suggests deposition in longitudinal bars or as fluvial lag deposits (Miall, 1978). Crude horizontal stratification, with coarse gravel layers separated by thin, finer-gravel layers may be the result of the aggradation of a series of diffuse gravel sheets in longitudinal and diagonal bars in a gravelly braided river (Hein and Walker, 1977). The lack of observed planar or trough cross-bedding is further indicative of a shallow water depositional environment (Church and Gilbert, 1975).

The basal gravel does not contain organic detritus. This may indicate that either: 1) this moderate to high energy fluvial environment did not permit the burial of woody detritus deposited during periods of low flow, or 2) the sediments were deposited under periglacial climatic conditions when flora and fauna were sparse. If the latter is true, this unit may be, entirely or in part, outwash from the oldest montane advance onto the plains recorded in the stratigraphy of this valley system, as originally proposed by Dawson and McConnell (1895), and later concluded by Wagner (1966).

The lack of Shield material precludes the possibility of a continental ice sheet advancing into this area prior to the deposition of Unit 1. This unit is correlated with the "Saskatchewan sands and gravels", described here and elsewhere in southwestern Alberta by McConnell (1885), Rutherford (1937), Westgate (1965), and Stalker (1968), and clearly predates continental glaciation.

UNIT 2 - MONTANE DIAMICTON COMPLEX

Description

This unit ranges in thickness from 50 cm to at least 13 m; it is found in 20 of the 24 sections included in this study (Appendix A, Sections 1-12 , 14, 15, 17-19a, and 21). This complex consists of one to four montane and Foothills provenance diamictons and interbedded stratified sediments. It occupies a stratigraphic position at, or near the base of the sections, and lacks any Canadian Shield lithologies (Fig. 8). It either directly overlies bedrock, or it is separated from it by the basal gravel of Unit 1. Where exposed, the lower contact of this unit is usually sheared or erosional. This complex has been subdivided into four subunits.

Subunit 2A

Subunit 2A always underlies subunit 2B. The subunit consists of sheared stratified sediments directly overlying bedrock or a comminution zone 2 to 20 cm thick of pieces of plucked and crushed bedrock that fines upward. Where it is composed of sheared stratified sediments, it ranges up to 50 cm thick, and consists of undulating and distorted laminations and beds of clay, silt, and sand with scattered pebbles and small lenses of pebbles. This subunit increases in stoniness upward, and generally exhibits plucked and sheared lenses of laminated clay toward the top.

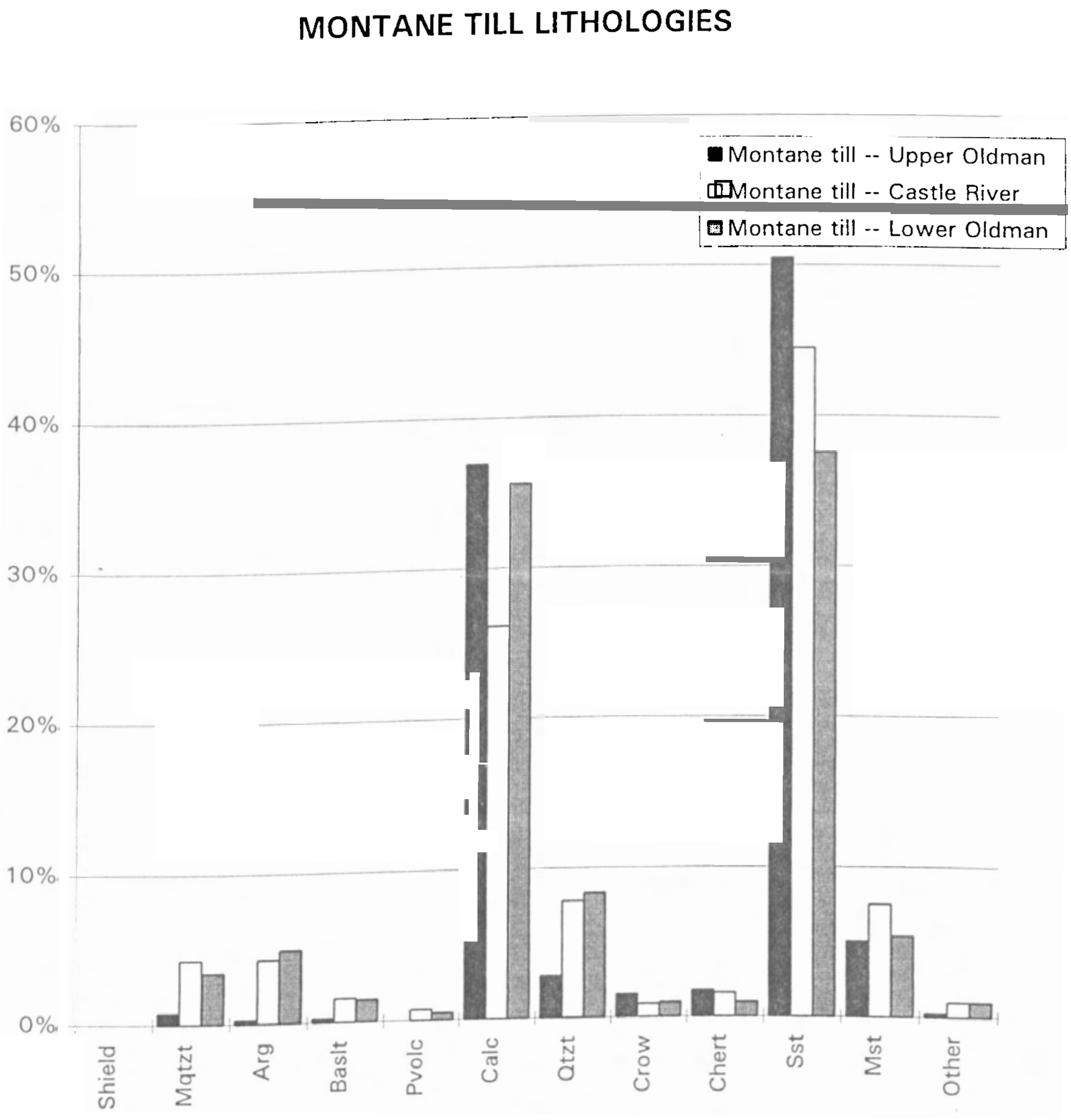


Figure 8: Pebble lithologies for montane diamictons (subunits 2B and 2D) in stratigraphic sections located in three geographically different regions of the study area.

Subunit 2B

This subunit forms the bulk of Unit 2; it is a massive, well consolidated diamicton. It is seen in all sections containing Unit 2. Colour of the sediment ranges from a pale tan where dry to medium to dark brown or grey where moist. The diamicton is moderately to very stony (15-20%) with a friable silty sand or slightly cohesive clayey silty sand matrix (Fig. 9). Clasts are usually <10 cm, but boulders over 1 m in size are common. Clasts, especially limestone and argillite, are commonly striated and faceted. This subunit is generally massive, but locally contains small lenses of clay or thin silt or fine gravel beds that are continuous over several metres. The top of the subunit at Bird Reserve, Brockwell, Logboom, and Brocket Sections contains rows of boulders spaced at several-metre intervals (Fig. 10). At Island View Section 1, the base of the subunit contains shear planes up to 5 m long. Although colour and texture differences are noted within subunit 2B (especially at Bail-out Bluff, Fig. 11; Appendix A), no evidence for a hiatus in deposition was observed at these boundaries

Fabrics obtained from this unit are all moderately to strongly asymmetric. Preferred orientations for rod-shaped pebbles range with valley orientation. Along the upper Oldman and Crowsnest rivers, fabrics indicate an ice flow direction from the southwest (Appendix B: 13, 17) (Fig. 12), and pebble counts indicate an ice source in the Livingstone Range (Appendix C: 14, 15). Along the main body of the reservoir, nailhead striations and fabrics indicate an ice flow direction from the west (Appendix B: 24, 25; Appendix A: Island section, Unit A), and pebble counts include clasts from both the Lewis and Clark Ranges and the Livingstone Range. (Appendix C: 30, 40-42).

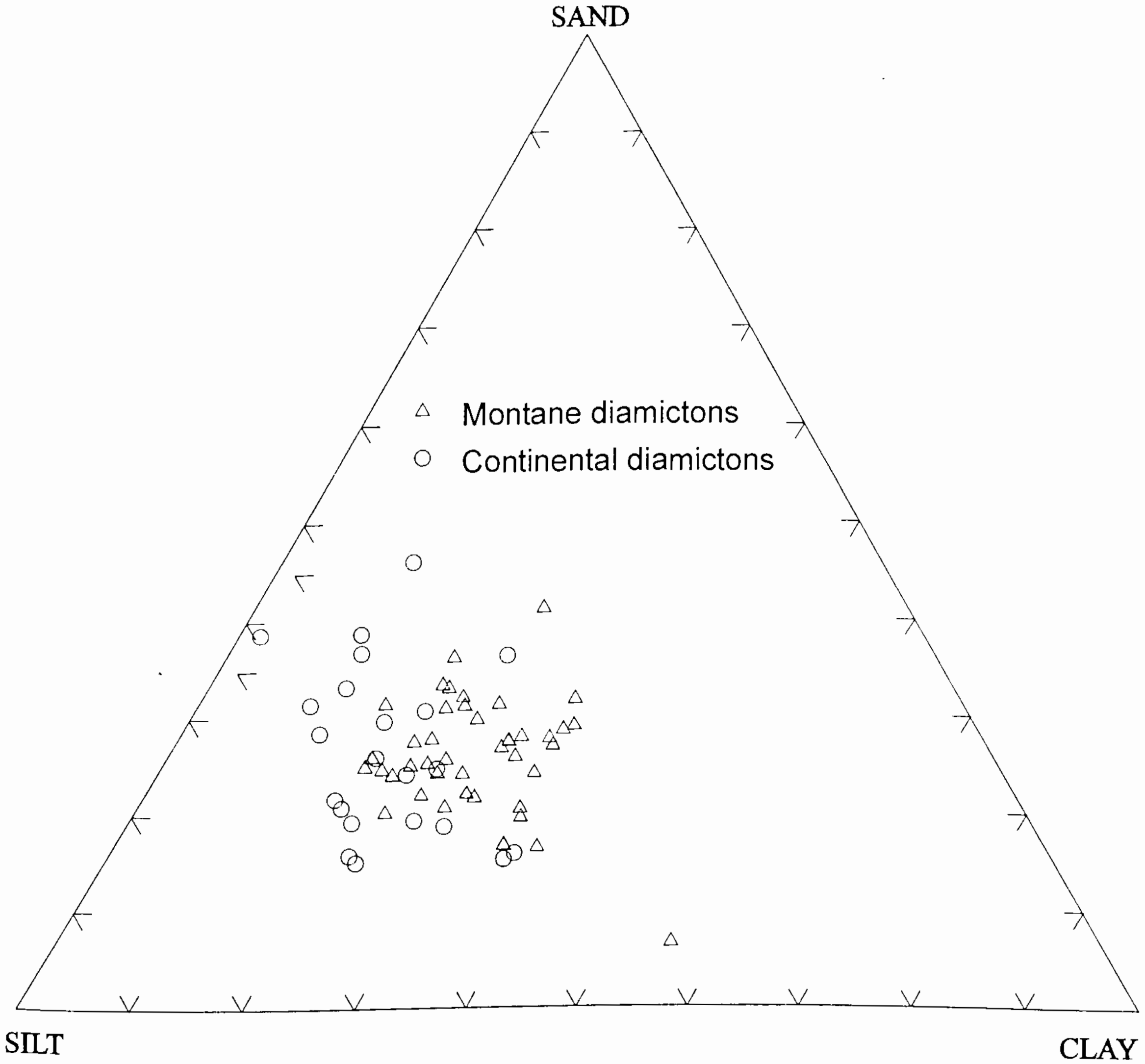


Figure 9: Sand, silt, and clay percentages for bulk samples from montane diamictons (Units 2B and 2D), and continental diamictons (Unit 4A).

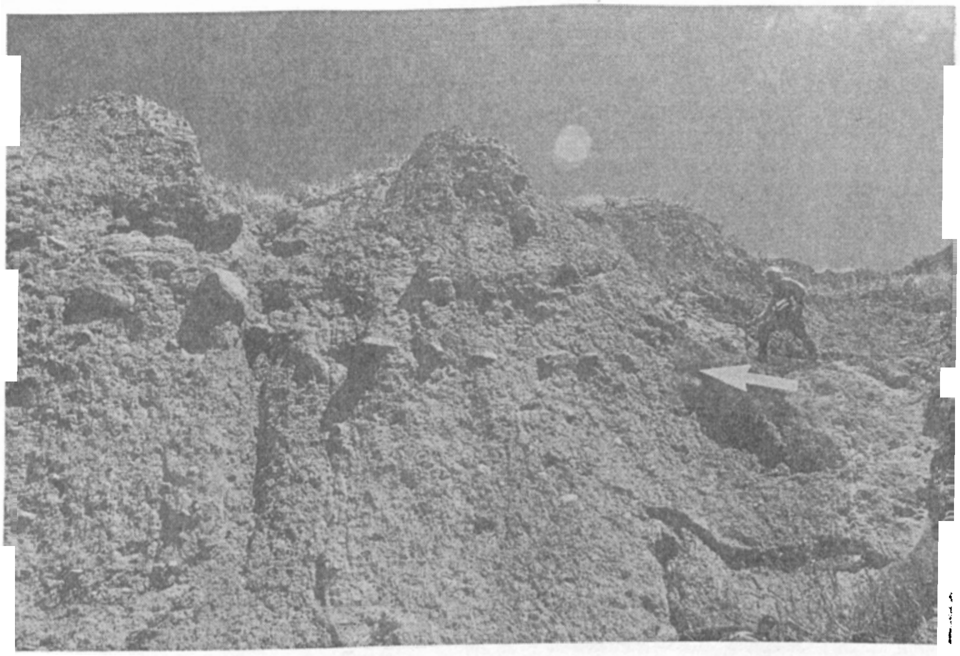


Figure 10: Bird Reserve Section (looking east). A "boulder pavement" within montane till (subunit 2B) indicates deposition under lodgement conditions.

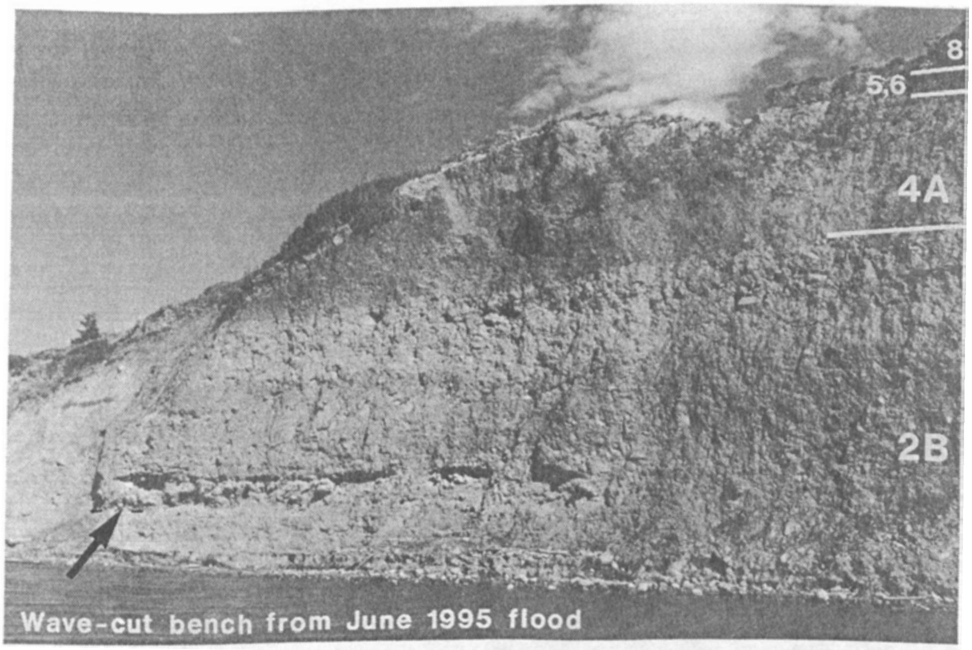


Figure 11: Bail-out Bluff (looking east). A good exposure of montane till (subunit 2B) showing the texture and colour variation within this unit.

Figure 12: A long exposure along the upper Oldman River containing the Brockwell Gully. A fabric obtained in subunit 2B indicates ice flow from the southwest. Abrupt horizontal change in colour marks the boundary between continental till (subunit 4A) and glaciolacustrine sediments mapped extensively at the surface (Unit 7). S and N stand for south and north.

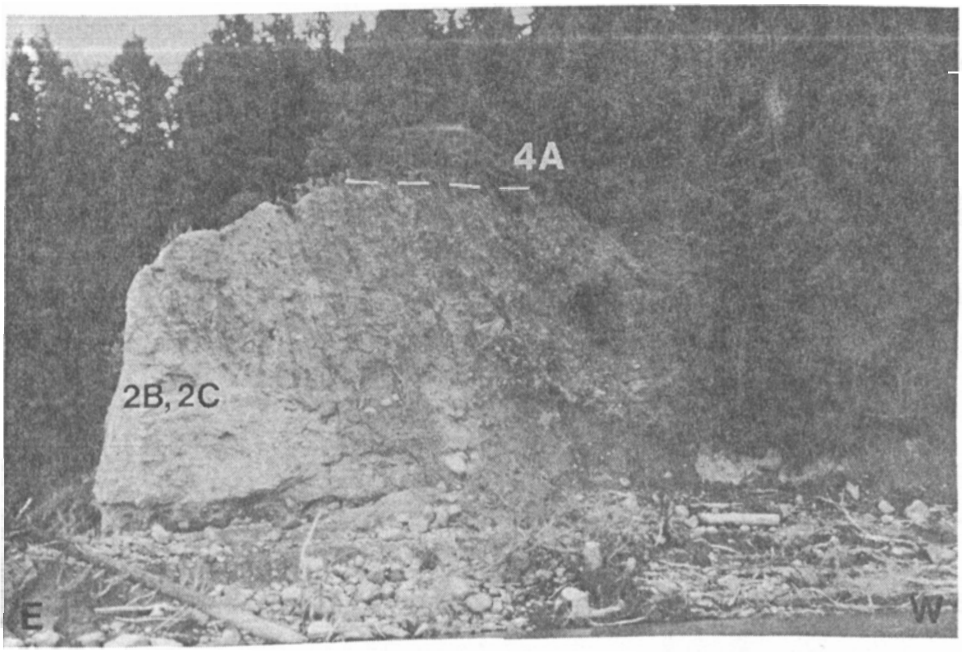


Figure 13: Numbum Bluff consists almost entirely of montane tills and interbedded stratified sand (subunits 2B and 2C). Continental till (subunit 4A) forms the dark unit at top right.

Along the drowned Castle River valley, fabrics, bullet-shaped boulder long axis orientations, and striation measurements are somewhat variable. At Bail-out Bluff, Three Rivers Roadcut, and Highway Bridge Section, fabrics and a bullet boulder indicate ice flow from the north or northwest (Appendix B: 2-5, 19, 30; Appendix A: Bail-out Bluff, Unit A); at the Vogelaar, Driftwood, Highway Three, and Castle River Sections, fabrics and striations indicate an ice-flow direction from the Lewis and Clark Ranges to the southwest or west-southwest (Appendix B: 15, 16, 18, 20, 32; Appendix A; Driftwood Section, Unit B). At Bail-out Bluff, however, pebble lithologies are exclusively from the Front Ranges north of Crowsnest Valley (Appendix C: 2-4). At all other sections along the Castle River arm, pebble counts include anywhere from 2-24% clasts from the Lewis and Clark Ranges in the southwest.

The lower contact of subunit 2B is dependent on the underlying lithology. Where subunit 2B overlies the gravel of Unit 1, the basal contact is gradational with a very high stone content at its base. The stone content decreases upward over 25-50 cm. Where subunit 2B overlies subunit 2A, sheared structures underlie the contact. Where subunit 2B overlies bedrock, the contact is also sheared, as evidenced by a comminution zone and/or striated bedrock.

Subunit 2C

This subunit is seen in six of the twenty sections that contain Unit 2 (Appendix A: Castle River and Vogelaar sections, Island View Section 1, Numbum Bluff, and Castle River and Vogelaar gullies) (Fig. 13). It is an extremely heterogeneous unit, characterized by distorted and disorganized bedding, that includes stratified sediments contained within subunit 2B or between subunits 2B and 2D (Fig. 14).

This subunit is up to 2.5 m thick, but is generally less than 1 m thick. The grain size varies from stoneless or pebbly clay to coarse sand and granules. Some thin diamicton layers or rows of boulders are mixed with finer sediments. All sediments are arranged in beds and lenses that are of variable thickness and length, and are highly contorted and include ptygmatic-like structures and lenses. Many layers pinch out over very short distances (<1 m). The contact with the underlying diamicton is generally abrupt, but it is occasionally marked by a concentration of cobbles. The upper portion of this subunit is marked by sheared sediments or a gradational contact with either a diamicton of subunit 2B or 2D above.

Subunit 2D

This subunit is an unconsolidated diamicton, and is characterized by stratification and/or a bouldery texture. The diamicton is non-compact and very stony with a silty matrix, and it also contains lenses or layers of coarse sandy gravel, sand, and stony silt, that are discontinuous over more than 2 m. The sand may have loading structures injected into overlying diamicton. Discontinuous silt and clay laminations may be deformed around the base of overlying clasts.

Subunit 2D is seen at Island View Section 1, Numbum Bluff, Vogelaar Section, and Castle River Gully (Appendix A), and ranges in thickness from 1 to 4 metres. Its stratigraphic position is generally near the top of Unit 2. In two cases, the lower part of the

Figure 14: Vogelaar Section. Laminated silt of subunit 2C, seen between subunits 2B and 2D.

Figure 15: Island Section. Draped clay laminae of Unit 3.

subunit is gradational from the underlying subunit 2B, and otherwise, its lower contact with subunit 2C is abrupt. The upper contact is gradational with the overlying Unit 3, or is abrupt or marked by a boulder pavement.

Boulders occur either throughout the subunit (Vogelaar Section), or are concentrated at the contact with the overlying unit. A fabric taken at the Vogelaar Section shows that pebbles tend to lie very close to horizontal, although along a preferred southwest/northeast azimuth (see Appendix B; 31).

Interpretation

The fine, stratified sediments of subunit 2A were deposited in a quiet-water depositional environment. Scattered pebbles within laminae suggest a lake with glacial ice at one of its margins. Its stratigraphic position beneath subunit 2B and its sheared state are consistent with either deposition in water ponded before an advancing glacier, and subsequently overrun by it, or perhaps, subglacial lacustrine deposition (Shaw, 1985). Comminuted bedrock also reflects glacigenic shearing.

The dense matrix-supported diamicton of subunit 2B is interpreted to be a lodgement till of montane origin, based upon over-consolidation, strong unimodal pebble fabric, and sheared or eroded lower contacts (Dowdeswell and Sharp, 1986, and Mills, 1977). The presence of faceted and striated clasts, as well as "bullet boulders" that are striated and embedded parallel to clast fabrics, and "pavements" of boulders also indicate lodgement till deposition (Krüger, 1979 and 1984). Shear planes, a basal comminution zone, bimodal particle size distributions with poor sorting, and a high percentage of local lithologies near the till base are also good indicators of deposition at the base of an active glacier (Dreimanis, 1988).

The till matrix is a silt loam or loam, which reflects the sandy and silty nature of the local rocks of the Foothills belt. However, pebble lithologies indicate flow from the mountains, either from the Lewis and Clark Ranges (Purcell Supergroup) to the southwest, or from the Paleozoic and Mesozoic carbonate, clastic, and pyroclastic rocks of the Livingstone Range and Crowsnest Pass areas to the west and northwest. Pebble orientation fabrics parallel striations on bedrock which indicate flow from the mountains. Together, these factors indicate deposition at the base of ice advancing from the mountains. Several local montane provenances are reflected in this unit. From these, it can be concluded that ice advanced east down the Crowsnest River valley, pushed up the upper Oldman River valley as far as the Brockwell Gully, and pushed a short way south into the Castle River valley to Bail-out Bluff before encountering ice flowing down each of these valleys from the Livingstone Range and the Lewis and Clark Ranges, respectively.

Subunit 2C was deposited in a range of subaqueous sedimentary environments ranging from glaciolacustrine to moderate and high energy fluvial environments. In its stratigraphic position within subunit 2B, it represents local interruption of lodgement processes by sub-ice meltwater erosion and deposition (Dreimanis, 1988; Shaw, 1985; Shaw *et al.*, 1996). Its stratigraphic position between subunits 2B and 2D likely marks the termination of the lodgement till deposition phase, and a transition to the ablation and resedimentation processes of a less active glacier. Meltwater issuing from the ice front would be responsible for the winnowing of fines and the deposition of gravel and sand layers. The ponding of sediment-laden water in depressions and areas still underlain by ice, and the flow of saturated sediments into these waters, would result in the deposition of contorted laminations of fine sediments mixed with pockets of coarser grains.

Subunit 2D has a non-compact nature which implies that it was not deposited by lodgement processes under active, advancing ice. Its general stratigraphic position succeeding the lodgement till of Subunit 2B indicates it was deposited following the major advance of montane ice. The subunit shows strong stratification associated with water-lain, sorted fine gravel, sand, and silt, some of which exhibit soft-sediment loading structures. These criteria are all indicative of an environment dominated by sediment gravity flow activity (De Jong and Rappol, 1983). A fabric taken from diamicton within this unit shows clast axes to be close to horizontal with a slight preferred orientation; this type of fabric is commonly characteristic of sediment gravity flows (Dowdeswell and Sharp, 1986). Variability within sediment gravity flow deposits are characteristic, as are sheared or deformed sediments beneath them (Lawson, 1988). Both are commonly observed in subunit 2D. It should be cautioned that the interstratification of diamictons and sorted sediments produced by the interaction of sediment flow and water transport is not uniquely diagnostic of sediment flow deposits; melt-out may also produce similar results (Haldorsen and Shaw, 1982). However, an ice environment dominated by sediment gravity flow activity is favoured for subunit 2D because the limited horizontal distribution of each stratum within it, as well as its limited areal distribution which is characteristic of flow tills (Marcussen, 1975). The margin of a weakened and receding montane glacier is envisioned as a likely environment.

The entire succession of subunits within Unit 2 appears to represent a near-complete cycle of advance and retreat of montane ice with continental ice influencing sedimentation during retreat stages (see Glacial History, Ch. 7).

UNIT 3 - MIXED PROVENANCE SAND, SILT, CLAY, AND DIAMICTON

Description

This unit is composed of laminated or bedded silt and clay, but ranges widely in texture, sedimentary structure, and thickness. It is uniform in texture in some sections, and ranges from heavy, laminated clay, to massive sand with scattered stones of both montane and Canadian Shield provenance. The entire range of sediments are assigned to one unit for two reasons: their systematic stratigraphic position between a montane till (Unit 2), and a continental till (Unit 4); and as a method of grouping laterally discontinuous beds.

Unit 3 typically overlies an abrupt contact that exhibits laminations or beds of clay draped over the underlying sediments (Fig. 15). At six sections along the Castle River (Appendix A: Vogelaar, Logboom, Driftwood, Castle River, and Bird Reserve sections, and Castle River Gully), and at the Peigan Section, the unit is characterized by a succession of rhythmically bedded silt and clay with scattered clasts, in which rhythmites range from 2.5 to 50 cm, with thicknesses increasing upward at the Castle River Gully, and decreasing upward at the Vogelaar Section. In most occurrences, the lower portions of the unit contain thin, discontinuous layers of diamicton or gravelly sand interbedded with silt and clay. In several sections, the uppermost portion of this unit is distorted and sheared. In the Castle

River Gully section, clay beds in the uppermost part of the unit are brecciated into small angular clay flecks in a silt matrix.

In the stratigraphic sections observed, this unit consistently overlies either a depositional or erosional contact with the diamicton of Unit 2. It may be overlain by Units 4, 5, or 6.

Interpretation

Unit 3 is interpreted to be a glaciolacustrine deposit. However, facies variation reflect a wide variability in local environments. Lenses of diamicton or gravel mixed with clay, silt, and sand with dropstones near the base of the unit are consistent with deposition by sediment gravity flows off a glacier margin into a lake, by ice-raft deposition, or deposition by subglacial fluvial discharge into a glacial lake. Unit 3 represents a continuation of the ice-recessional environments in which subunit 2D was deposited with the important distinction that Canadian Shield clasts are present in Unit 3.

The nearly stoneless, laterally persistent rhythmically bedded silt and clay facies of Unit 3 indicate a distal, glacial lake bottom environment dominated by seasonal fluctuations in sediment input, whereas the siltier and sandier facies reflect a more proximal glacio-lacustrine environment (Ashley, 1988). The distorted character of the bedding of Unit 3 near its upper contact suggests shearing during the deposition of the succeeding Unit 4. Brecciated clay beds near the top of Unit 3 at Castle River Gully appear to have been formed by ice advancing over frozen, previously interbedded clay and silt (Pederson, 1989).

In summary, this unit was deposited following the retreat of montane ice from the area, and during the advance of continental ice from the east. A glaciolacustrine environment predominated at this time as a lake was created by the ponding of meltwater issuing from the retreating montane ice. The variability in clast provenance within this unit documents the concurrent and co-lateral influence of montane and continental glaciers on lacustrine sedimentation.

UNIT 4 - CONTINENTAL DIAMICTON COMPLEX

Description

This unit is a diamicton containing Canadian Shield material and associated sand beds (see Appendix A; Bitango, Brocket, Peigan, and Pincher Creek Sections). The diamicton, in places, can be differentiated into at least five separate beds by changes in colour, or the presence of stratified sediments or shearing at contacts between them. Thickness ranges from <1 m to >25 m. The lower contact of this unit is highly variable; it ranges from abrupt and erosional (Vogelaar Gully) to gradational, to sheared and brecciated (Castle River Gully). The upper portion of the unit may exhibit inter-stratification of silty clay or clay layers throughout a gradational contact with the unit above, and may be topped by a band of boulders (Brockwell Gully). Unit 4 has been divided into two subunits: 4A (diamicton) and 4B (stratified sediments).

Subunit 4A

This subunit of the continental diamicton complex is the dominant lithofacies of this association. It consists of generally massive diamicton, characterized by a prismatic fracture pattern with vertical jointing. It is locally slightly fissile, or may contain thin (<20 cm thick) sand and pebble gravel beds that pinch out over a few m. It has a matrix ranging from clayey silt to sandy silt (Fig. 9), and a stone content of only 5-10%; it is always more cohesive and less stony than Units 2B and 2D. Clasts are generally smaller than 5 cm, but rare boulders up to 40 cm long were observed. Many clasts are friable sandstone and mudstone. Although Shield stones are visually obvious in exposures, they only account for less than 5% of the total clasts in the unit (Fig. 16). The colour of this unit ranges from a dark greyish brown to a light olive brown.

On the Crowsnest River arm, at Cowley Bridge Section 1, the continental diamicton is stratified; bands of slightly cohesive sandy silt matrix diamicton are separated from each other by thin layers of siltier diamicton which are paler in colour. These thin bands have a gradational lower contact with the darker diamicton, and an abrupt upper contact with the next band in the succession. These paired layers are not continuous over the exposure, and the layers of darker diamicton increase in thickness upward through the unit. This stratified portion of the unit is capped by a very stony continental diamicton containing discontinuous layers and pockets of silt, sand, and gravel.

Sixteen pebble fabrics from this subunit (Appendix B; 1, 6-12, 14, 21-23, 26-29) indicate two general trends: along the Castle River and upper Oldman River arms of the reservoir, ice flow was from the southeast. At the Bitango section near the eastern edge of the study area, fabrics obtained from the lowest of stratified diamictons composing subunit 4A both indicate flow from the northeast. Ice flow alternated between northeast and

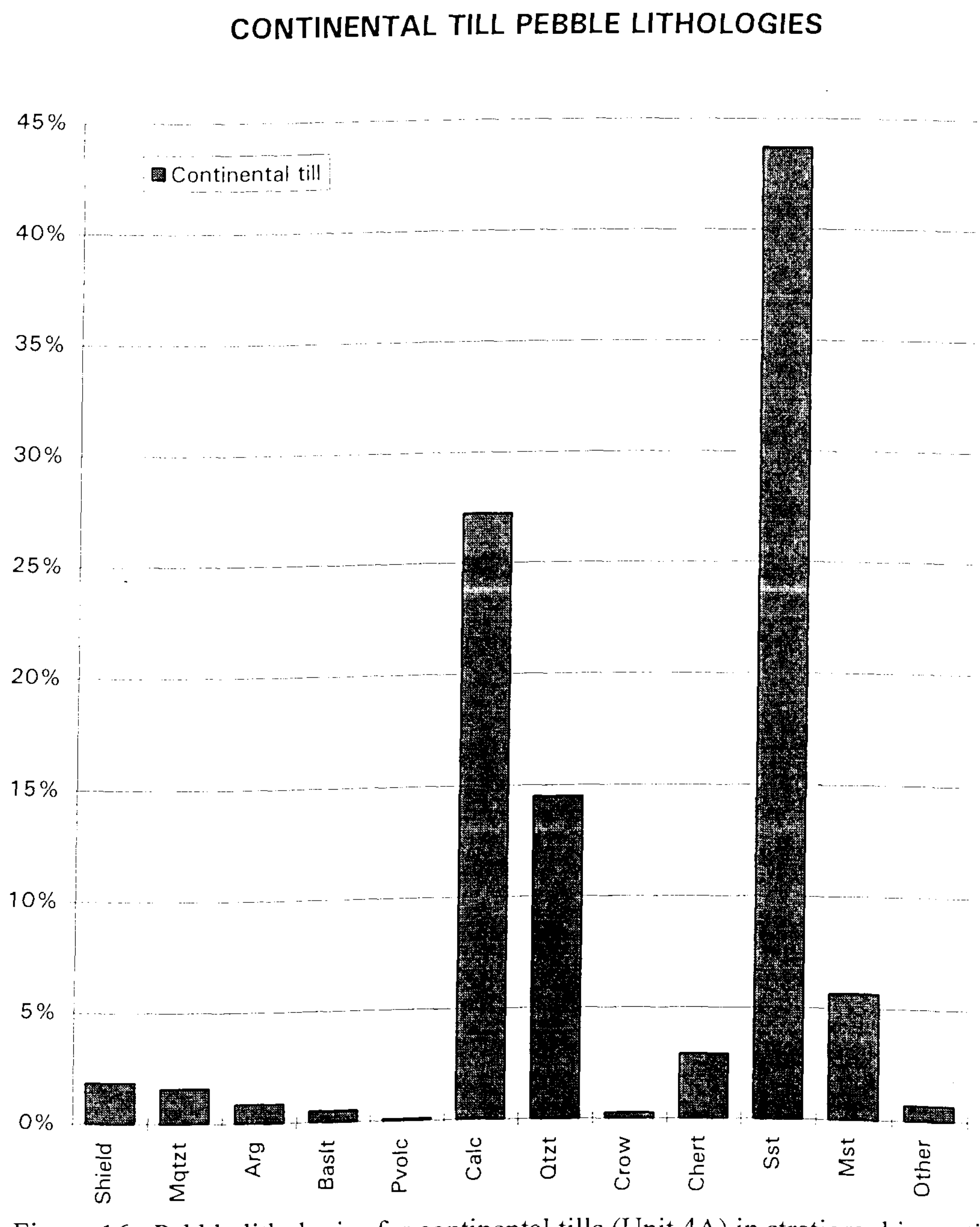


Figure 16: Pebble lithologies for continental tills (Unit 4A) in stratigraphic sections (data in Appendix C).

southeast in successive stratified diamictons at this section.

Subunit 4B

This subunit is present only at Pincher Creek, Brocket, Peigan, and Bitango sections (Appendix A); it consists of layers of stratified sediments up to 4 m thick which separate the diamictons of subunit 4A. More than one subunit 4B may exist in a section. Subunit 4B sediments range widely from poorly sorted, contorted pebble gravel of varying thickness, to layers of fine sand and silt with scattered pebbles, to stratified zones of typical continental diamicton (as in subunit 4A) separated by thin sheared and contorted sand layers, or massive sand containing unstructured diamicton blebs.

The upper contacts of each subunit 4B is often marked by rip-ups of fine sediments incorporated into the base of a massive diamicton (subunit 4A) above.

Interpretation

The massive, consolidated diamictons of subunit 4A are interpreted to be lodgement tills: they are over-consolidated, have moderate to strong unimodal pebble fabrics, have sheared or eroded lower contacts and internal shear planes, and contain faceted and striated clasts. The presence of Canadian Shield material, in combination with pebble fabric data, indicates that ice flow responsible for these deposits was from the east, confirming its identification as a continental till.

At the Bitango Section, on the plains of the eastern side of the study area, the lowest subunit 4A was deposited by the main advance of ice from the northeast, flowing unimpeded up the regional gradient. Alternating flows from the northeast and southeast, depositing up to four more 4A subunits, are likely due to the fluctuation of the ice margin out of, and back onto, the eastern portion of the study area. Southeast flow recorded in sections along the Castle River arm of the reservoir is attributed to deflection of continental ice around the Porcupine Hills and perhaps around local Foothills ridges.

Subunit 4B sediments were deposited during breaks in the lodgement process when continental ice waned from the study area. As the ice margin retreated, east-flowing meltwater ponded against the retreating ice margin, forming fluvial and lacustrine environments that were highly variable in space and time. Stratified fine sediments, gravel, and sediment gravity flow diamictons were deposited in these short lived ice-proximal environments. Each deposit was sheared by a subsequent episode of readvancing ice, as evidenced by rip-ups at the base of lodgement tills overlying subunit 4B deposits.

The ice responsible for the deposition of Unit 4 was not highly erosive; in most cases, much of the sediment deposited prior to Unit 4 still remain, as do many of the sheared inter-till deposits of subunit 4B.

UNIT 5 - RHYTHMICALLY BEDDED SILT AND CLAY

Description

This unit is seen only at Vogelaar Gully, Bail-out Bluff, and Bird Reserve Section (Appendix A), and ranges in thickness from 50 cm to 3 m. It overlies Unit 4 along an abrupt contact, and underlies Unit 6 along another sharp contact. The sediments are rhythmically bedded fine sand and clayey silt, or rhythmically bedded silt and laminated clay grading up to faintly laminated clayey silt or massive heavy clay with scattered clasts.

Interpretation

The rhythmically bedded silt and clay seen within this unit, as well as the almost ubiquitous presence of clasts of varying sizes within a matrix of much finer sediment, are indicative of a glaciolacustrine environment. The absence of poorly sorted sediment or sand ripples, and the presence of dropstones, laminated and graded beds of sand and silt, and rhythmites of clay suggest that these sediments were deposited in an intermediate to distal environment within the glacial lake basin (Ashley, 1988).

The position of Unit 5 directly above a continental till complex (Unit 4) indicates that the glaciolacustrine environment developed following the final retreat of the continental ice sheet from the immediate area. Although it had retreated, continental ice still impeded eastward drainage and dammed the lake. It is difficult to assess from the available stratigraphic information how long this environment existed; although the unit is relatively thin, one cannot ascertain if this is due to a short-lived proglacial lake, or due to erosion by the succeeding period of fluvial activity which resulted in the overlying Unit 6 (see below).

UNIT 6 - GRAVEL CONTAINING SHIELD LITHOLOGIES

Description

This unit is a clast-supported, poorly to moderately-well sorted pebble or cobble gravel with a sandy matrix. Clasts are generally rounded to sub-angular, and may range up to 20 or 30 cm in diameter. The unit ranges from massive and disorganized to horizontally stratified with lenses of silty sand, and stratified imbricated clasts. In some exposures, it fines upward from a boulder lag at its base, through a cobble gravel, to a pebble gravel with a coarse sand matrix. Along Castle River, the apparent clast imbrication indicates a flow direction from the south, which is the same flow direction of the present-day Castle River. At the Peigan section, 25 km east of the Castle River arm, it has a different texture: there, the unit consists of medium sand with gravel lenses capped by poorly sorted coarse gravel with stones up to 60 cm long (most 2-10 cm) that grade laterally into ripple-stratified sand.

Wherever the lower contact of this unit is exposed, it is an abrupt contact, occasionally marked by a lag of boulders (as at Island View Section 2 and Highway Three Section). It overlies either a montane diamicton (Unit 2B), a continental diamicton (Unit 4A), or rhythmically bedded silt and clay (Unit 5). The clasts within this unit include lithologies from all identifiable sources: the Canadian Shield, the Lewis and Clark Range (Purcell Supergroup), Crowsnest Pass (Crowsnest Volcanics), the Livingstone Range (limestone, dolostone, and white orthoquartzite), and the local Foothills clastics (Appendix C; 34, 36, 48).

Interpretation

A moderate to high-energy fluvial environment is interpreted for this gravel unit. The absence of strong stratification or cross-bedding suggests that this deposit was laid down in the coarse bed proximal zone of a wide and shallow glacial outwash plain, where stratification is predominantly massive to crudely horizontal, with only a subordinate amount of cross-stratification (Smith, 1985).

The stratigraphic position of this unit above the continental diamicton and rhythmically bedded silt and clay indicates that it was deposited following the retreat of continental ice from the area, and following the draining of a proglacial lake dammed by the retreating ice. The ubiquitous abrupt contact with each of several different units suggests that east-flowing, glacially fed streams extensively eroded and incised their beds during deposition of this gravel. This erosion of underlying sediments incorporated clasts of all lithologies, including Shield lithologies, although the source of the meltwaters was to the west and south within the Foothills or Rocky Mountains.

UNIT 7 - MASSIVE TO BEDDED SAND, SILT, AND CLAY

Description

This unit is found at the top of all exposures that extend up to the plains level (Appendix A: Sections 1, 4-6, 14-21), and forms the extensive lake plain that is mapped at the surface on the Brocket, Blairmore, and Pincher Creek maps. Sediments within this unit range between fine sand, sandy silt, silt, silty clay or heavy clay. This unit yields more sand near the eastern border of the study area. Sedimentary structures can be massive or may exhibit one or several of the following structures: faint horizontal stratification; laminated clay; rhythmites varying in thickness from less than one cm to over ten cm; convoluted bedding; ball-and-pillow or flame structures; lenses of diamicton near unit base (Brockwell

Gully). Sediments are locally stone-free, but commonly contain scattered clasts of varying sizes; lithologies of these clasts include metamorphic or granitic rocks from the Canadian Shield.

The texture and stratification within this unit is vertically and horizontally variable. The lower contact is always an abrupt and depositional contact. Unit thickness can only be estimated, because in most sections it has slumped heavily near the top, or exposures do not continue to the surface. However, these fine sediments are 15 m thick at Brocket Section, and 17 m thick at Cowley Bridge Section 1. The maximum thickness of this is, therefore, at least 17 metres.

Interpretation

The texture and sedimentary structures of this unit are indicative of a distal glacial lake environment (Ashley, 1988). Soft-sediment deformation structures such as flame structures, ball-and-pillow structures, and convoluted beds indicate rapid deposition and loading of water-saturated sediments, and are hallmarks of glaciolacustrine sedimentation.

The surface distribution of this unit (Chapter 6), as well as its stratigraphic position at the top of the Quaternary column suggests that these sediments were deposited in an extensive proglacial lake. The ice margin, which had retreated far enough to the east to permit the subaerial deposition of Unit 6, readvanced once more toward the west, although not onto the study area, and blocked drainage. The considerable thickness (up to twenty m) of this unit suggests that this glacial lake was extensive and long-lived relative to the glaciolacustrine environments responsible for the deposition of Units 3 and 5.

UNIT 8 - MASSIVE SANDY SILT

Description

This is the uppermost unit of several sections along the Castle River arm of the reservoir (Appendix A: Bail-out, Bird Reserve, Castle River, Highway Bridge, Highway Three, and Vogelaar sections). It is generally less than 1 m thick, and is a massive, uniform silt or sandy silt, occasionally burrowed by animals or containing small plant roots or bones from *Bison* sp. In some sections, the otherwise massive sediment contains faint, thin layers of coarse sand, granules, and occasionally pebbles that roughly parallel the ground surface slope. This unit overlies an abrupt contact with Unit 6 or Unit 7.

Interpretation

The uniform silty texture and non-stratified nature of the sediment points to deposition by wind. The high winds prevalent in the study area are conducive to the entrainment and transport of fine sediment, and cliff-top dunes are forming today. The stratigraphic position of Unit 8 at the top of the sections, and its superposition on many stratigraphic units, suggests that this deposit was laid down following the complete retreat of ice from the study area (Ashley, 1985). The incorporation of *Bison* sp. bones into the unit indicates that this process had been occurring during Holocene time.

The coarser layers paralleling the slope surface within otherwise massive silt are found in the Vogelaar and Bird Reserve sections. The ground surface at the top of these sections slopes toward the former river valley; this results in the winnowing of fine sediments by slope-wash, leaving distinct layers of coarse sand and granules and clasts that were originally present in the uppermost Unit 7. Contemporaneous eolian deposition lead to the interstratification of massive silt and sandy silt between coarse layers.

CHAPTER 6

SURFICIAL GEOLOGY

The surficial geology of the Blairmore, Brocket, and Pincher Creek map areas was mapped at the detailed scale of 1:50 000 for the first time as a part of this project (in pocket). Previous maps were at a reconnaissance scale (Wagner (1966), 1:150 000; Stalker (1962a and b), 1:250 000). This chapter describes the limits of the continental and montane ice sheets and the former extents of glacial lakes documented on these maps, and discusses glaciofluvial deposits and features which dominate several portions of the map areas.

GLACIAL LIMITS

Establishment of glacial limits are one of the most significant criteria for reconstructing the glacial history of this study area. The following is a description of the distribution of till deposits, constructional ice limit features, and the upper limits of erratics associated with montane and continental glaciers (Figs. 17 and 18).

Montane till

Montane till does not directly underlie the surface in the immediate Oldman Reservoir area; it does so only in the western two-thirds of the Blairmore map area, and in the extreme southwest corner of the Pincher Creek map area (which is outside Three Rivers study area; Fig. 1).

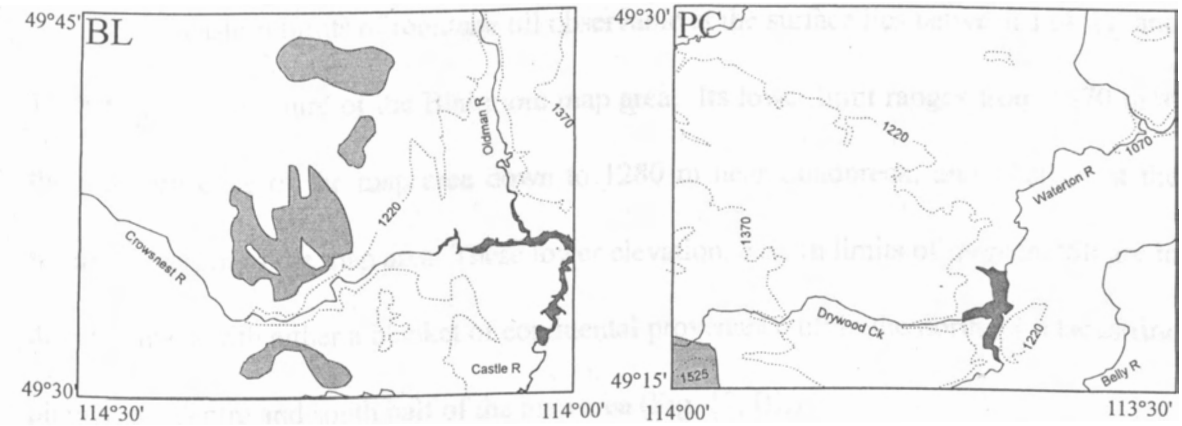


Figure 17: Distribution of montane till at the surface within the Blairmore (BL) and Pincher Creek (PC) map areas.

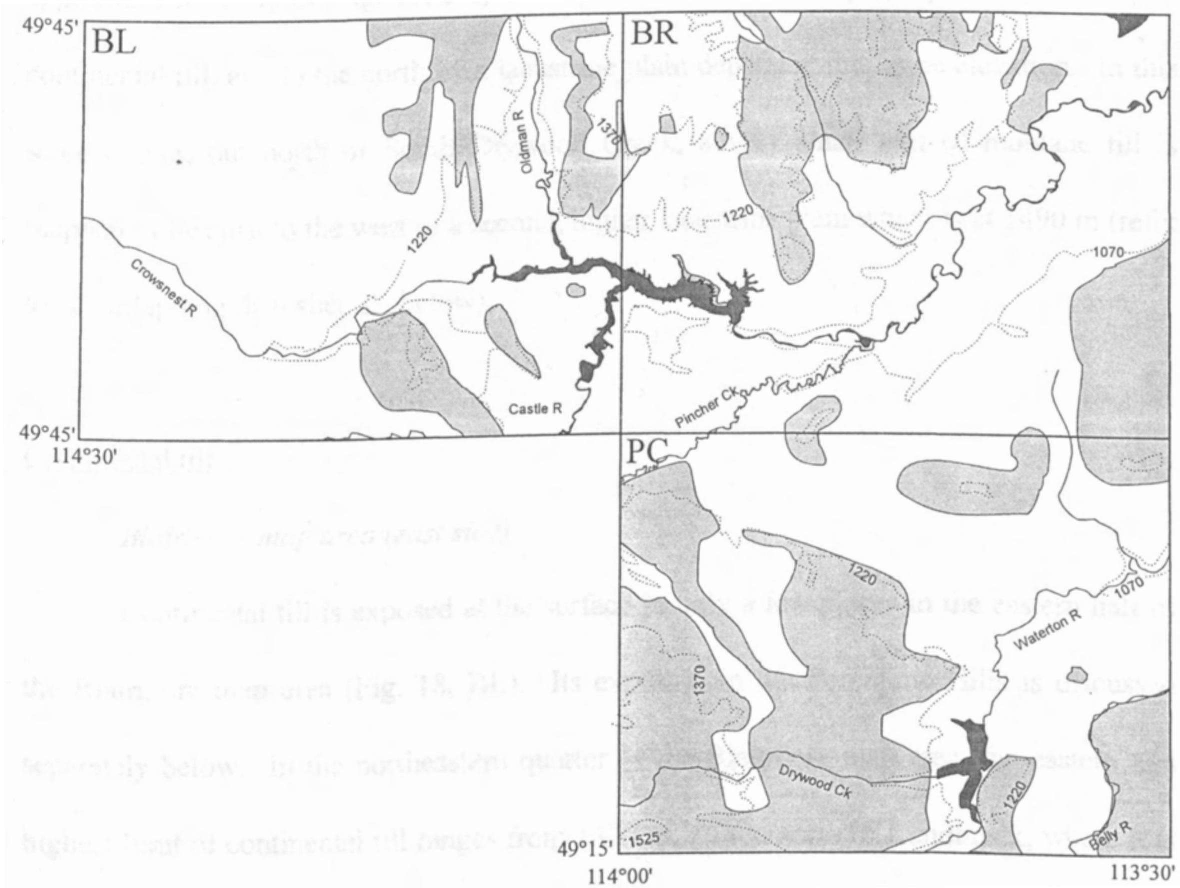


Figure 18: Distribution of continental till at the surface within the Blairmore (BL), Brocket (BR), and Pincher Creek (PC) map areas.

The eastern limits of montane till observable at the surface lies between 114°11' and 114°06', near the centre of the Blairmore map area. Its lower limit ranges from 1370 m at the northern edge of the map area down to 1280 m near Lundbreck, and 1220 m at the southern margin of the map area. These lower elevation, eastern limits of montane till are in direct contact with either a blanket of continental provenance till in the north, or a lacustrine plain at the centre and south half of the map area (Fig. 17, BL).

In the southwestern corner of the Pincher Creek map area, south of South Drywood Creek, a lobe-shaped area of montane till forms a localized blanket that descends to approximately 1480 m (Fig. 17, PC). It is bounded to the east by a deposit of hummocky continental till, and to the north by a lacustrine plain deposit at this same elevation. In this same corner, but north of South Drywood Creek, a very small unit of montane till is mapped; it lies just to the west of a second, higher lacustrine plain which is at 1490 m (refer to "Overlapping drift sheets", below).

Continental till

Blairmore map area (east side)

Continental till is exposed at the surface in only a few places in the eastern half of the Blairmore map area (Fig. 18, BL). Its exposure in the Porcupine Hills is discussed separately below. In the northeastern quarter of the Blairmore map area, the eastern and highest limit of continental till ranges from 1370 m, 10 km north of Lundbreck, where it is bordered to the west by a montane till veneer (<1 m thick), to 1400 m at the northernmost edge of the map, where it is bordered to the west by colluvium and rock outcrops.

Continental till does not exist at the surface at this elevation in the south half of the map; rather, the highest outcrop of continental till covers Cowley Ridge at 1250 m. This unit disappears beneath a lacustrine plain on all sides of Cowley Ridge.

Porcupine Hills

Till containing erratic pebbles from the Canadian Shield forms a continuous veneer up to 1400 m on the west side of the Porcupine Hills. A similar till was found in a continuous veneer up to an elevation of 1490 m along the southern margin of the Porcupine Hills at the boundary of the Brocket and Blairmore map areas. A discontinuous belt of hummocky, pitted continental till between 1340 and 1370 m surrounds the southern margin of the Porcupine Hills and spans the border of Blairmore and Brocket map areas. Some valleys below this hummocky terrain contain local patches of glaciolacustrine sediments at about 1370 m.

Although no continuous or discontinuous drift cover exists above 1490 m, discontinuous colluvium formed by weathering of local sandstone bedrock contains clasts of erratic lithologies. These lithologies are from the Canadian Shield and Rocky Mountains. Canadian Shield erratics occur to an elevation of 1590 m, whereas erratics from the Rocky Mountains are present to 1620 m. Above the 1620 m limit of erratics, bedrock outcrops have a tor-like appearance where they project above weathered sandstone colluvium at their bases.

Brocket map area

Continental till is extensively exposed at the surface over the west half of the Brocket map area (Fig. 18, BR). Continental till veneers and blankets (≥1 m thick) are mapped above an elevation of 1170 m immediately south of the reservoir. East of the Porcupine Hills, continental drift extensively covers the land surface from approximately 1170 m to the very tops of the mesa-like plateaux on the north edge of the map sheet at over 1370 m. The till veneer at the tops of these plateaux are commonly separated laterally from till blankets at lower elevations by a colluvial veneer on the hillsides.

Scattered patches of continental till occur in the northeastern corner of the Brocket map area. The lowest patches, situated at approximately 1070 m, are associated with numerous boulders of pebbly quartzite of the Foothills Erratics Train (Stalker, 1956). The balance of this area is dominated by lacustrine plain, alluvial, and glaciofluvial sediments.

Pincher Creek map area (northern and eastern areas)

Continental till is exposed in the northern half of this map area on hills and ridges that rise above 1190 in the west and 1140 m in the east (Fig. 18, PC). None of these areas is at a high enough elevation to exceed the limit of continental glaciation. In the southeast corner, continental till crops out above approximately 1170 m; below this elevation, continental till is covered by a blanket of lacustrine sediments.

<u>Overlapping till sheets and associated glaciolacustrine sediments</u>

Several overlapping till sheets exist in the Drywood Creek area in the extreme southwest corner of the Pincher Creek map area. Hummocky continental till (map unit Th^{C}) marking the position of a former ice margin, lies between 1480 m and 1490 m. Immediately to the south of this margin, on the north side of South Drywood Creek between 1490 and 1510 m there is a glacial lake plain. A related glacial lake plain exists 3 km to the north, between the same elevations. Relief of the continental till is subdued compared with hummocky continental till further to the southeast, and most stones within the unit are largely disaggregated to depths of 1 m or more. The upper, western belt of hummocky continental till is in contact to the west with an extremely bouldery till of montane provenance at the foot of the Rocky Mountains (unit Tb^{M}).

Topography within the montane till is composed of numerous high hills and deep swales, and the relief is approximately 30 m vertical over 100 horizontal metres (Fig. 19). Hillsides are dotted with large erratics of red quartzite, amygdaloidal basalt, and red and green argillite from the Purcell Supergroup rocks in the adjacent Rocky Mountains.

The nature of the contact of the belt of high-elevation continental till and the belt of montane till is apparent along South Drywood Creek. Here, extremely bouldery, poorly sorted ice-contact gravel fills channels cut into the hummocky continental till and associated lake sediments. The bouldery montane till and gravel, and the topographically subdued continental till are buried at the limit of a second belt of hummocky and pitted continental till trending generally northwest across the southwest corner of the Pincher Creek map area (Fig. 20). The upper limit of this younger, higher relief continental till is at approximately 1480 m, and is marked by a plain of heavy clay on the south side of the Pincher Creek map area. The upper limit of this younger, higher relief continental till is at

Figure 19: Typical hill-and-swale topography of montane till in the southwest corner of the Pincher Creek map area.

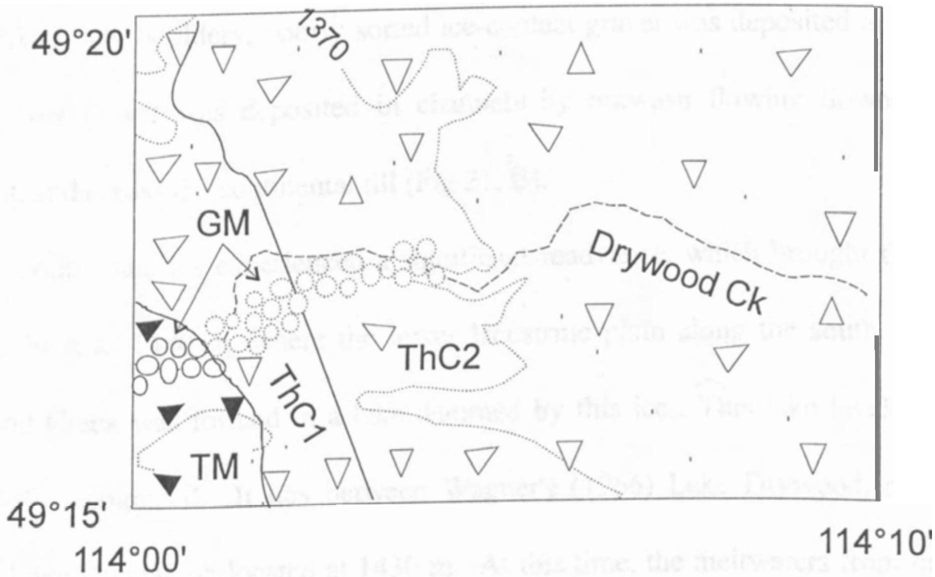


Figure 20: The nature of the contacts between units at the surface in the southwest corner of the Pincher Creek map area. Units are montane till (TM), Horberg's (1954) Outer Drift (hummocky continental till, ThC1, up to 1490 m), and Horberg's (1954) Kimball Moraine (hummocky continental till, ThC2, up to 1480m). The gravel GM symbolizes the position of ice contact gravels exposed in Drywood Creek valley, and the dotted GM circles represent the assumed position of the buried montane meltwater channel.

approximately 1480 m, and is marked by a plain of heavy clay on the south side of South Drywood Creek. The creek is diverted to the north from its former course down the northeast regional gradient at the western edge of this hummocky topography.

The sequence of events leading to the superposition and juxtaposition of morainal deposits can be reconstructed.

The upper lake plain was formed when continental ice reached an elevation of at least 1510 m and blocked drainage, ponding a large, high elevation lake. This lake was previously recognized by Wagner (1966), who called it Glacial Lake Drywood. This ice stagnated and retreated, leaving in its place a zone of hummocky and pitted terrain (Fig. 21, A), which correlates with Horberg's (1954) Outer Continental Drift.

Concurrently, a lobe of montane ice advanced down-valley from the southwest, depositing the bouldery diamicton observed in the southwesternmost corner of the map area. Extremely bouldery, poorly sorted ice-contact gravel was deposited at the toe of the lobe. This gravel was deposited in channels by outwash flowing down the regional gradient, and across the continental till (Fig 21, B).

Continental ice experienced a significant readvance, which brought the ice margin back as high as 1480 m, where the lower lacustrine plain along the south side of South Drywood Creek was formed in a lake dammed by this ice. This lake level has not been previously recognized. It lies between Wagner's (1966) Lake Drywood, and Horberg's (1954) Lake Dungarvan located at 1430 m. At this time, the meltwaters from the retreated montane glacier were diverted north along the ice margin (Fig. 21, C).

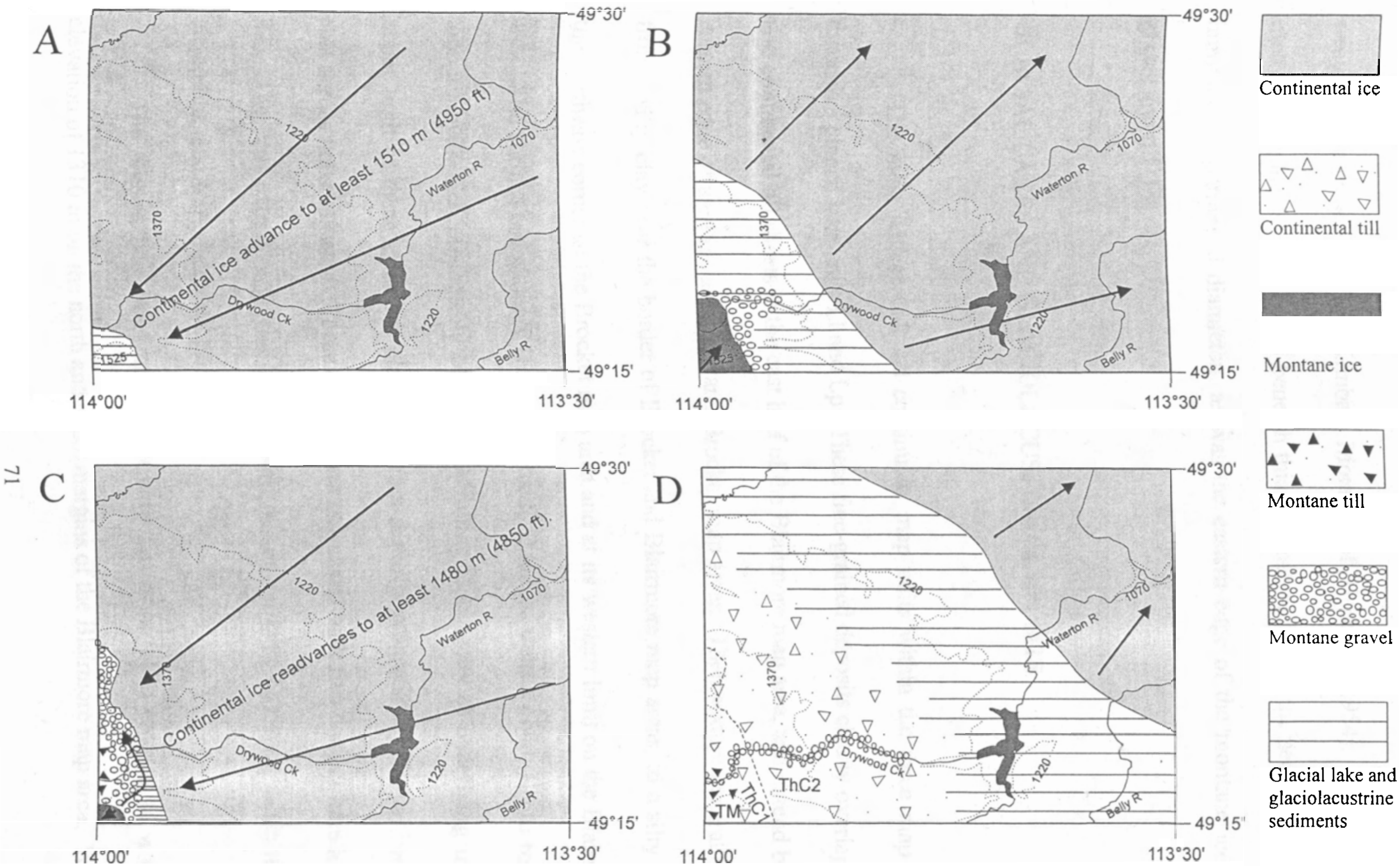


Figure 21: Events responsible for the formation of overlapping till sheets and associated lacustrine sediments in the southwest corner of the Pincher Creek map area: 23A (maximum advance of ice into area); 23B (retreat of ice from maximum position); 23C (readvance of ice to 1480 m); and 23D (final retreat of ice from area).

This continental readvance resulted in a second belt of hummocky and pitted till, a western continuation of the Kimball Moraine of Horberg (1954). Former montane meltwater channels were buried beneath this continental till, by the second, lower belt of hummocky continental diamicton, as was the eastern edge of the montane ice-proximal gravel and till (Fig. 21, D).

GLACIAL LAKES AND GLACIOLACUSTRINE DEPOSITS

The most widespread and continuous map units within the three map areas are extensive glacial lake units Ll and Lp. These fine-grained deposits clearly overlap montane and continental till sheets in the east half of the Blairmore map area, and extend beyond the eastern edge of the Pincher Creek and Brocket map areas. Their texture generally coarsens from a silty clay near the border of Brocket and Blairmore map areas, to a silty sand near the northeast corner of the Brocket map area and at its western limit on the Blairmore map area. The surface morphology is very subdued: it ranges from a plain (Ll) to rolling (Lp) topography, which presumably blankets the rolling topography of underlying units. The upper limit of these extensive glaciolacustrine deposits progressively drops from west to east across the study area. These deposits are associated with five distinct lake levels (Fig. 22). The less extensive glacial lake deposits of Glacial Lake Drywood attain the highest elevations, and were described previously.

The highest lake level of the extensive lacustrine plain extends to a maximum elevation of 1310 m on the north and south margins of the Blairmore map area. Within the

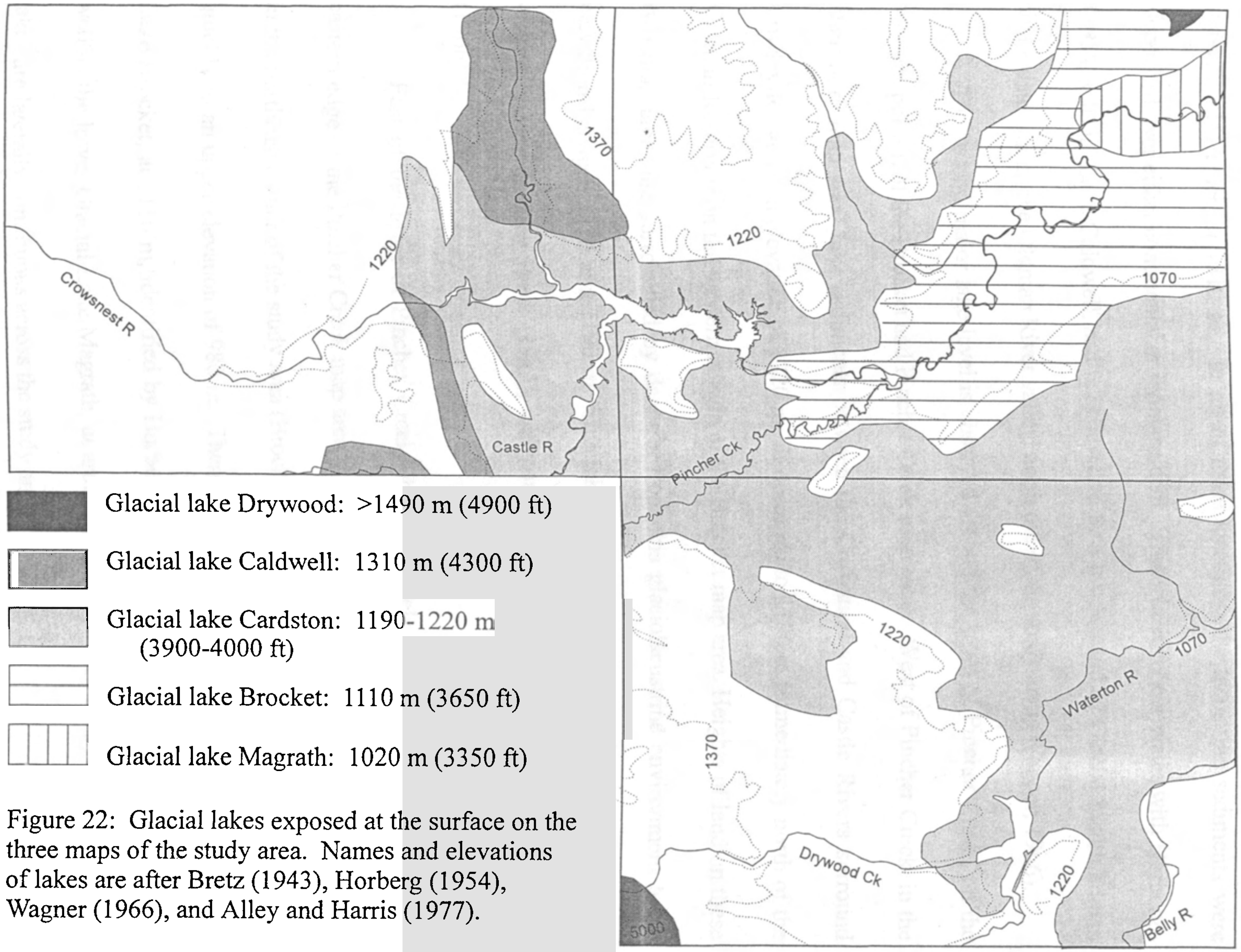


Figure 22: Glacial lakes exposed at the surface on the three maps of the study area. Names and elevations of lakes are after Bretz (1943), Horberg (1954), Wagner (1966), and Alley and Harris (1977).

high-relief areas of the western side and southern end of the Porcupine Hills, the lacustrine deposits also reach to 1310 m. In all of these locations, the lacustrine sediments were deposited over either continental or montane drift. This lake level correlates with Horberg's (1954) Glacial Lake Caldwell, and is believed to be a lower stand of Glacial Lake Oldman that existed along the Oldman River valley, north out of the study area (Wagner, 1966).

The second major lake level is observed around the town of Pincher Creek, on the western portion of the Brocket and Pincher Creek map areas. West of Pincher Creek, in the Blairmore map area, lake sediments between the Crowsnest and Castle Rivers surround Cowley Ridge to an elevation of 1220 m. It descends to 1190 m immediately north of the Oldman Reservoir on the western margin of the Brocket map area. Heights of land on these two map areas are surrounded by deposits from this glaciolacustrine environment to an elevation between 1170 and 1190 m This lake level, called Glacial Lake Cardston, was originally identified by Bretz (1943), and corroborated by Horberg (1954) and Wagner (1966).

East of the town of Pincher Creek, the lake levels progressively drop. On the eastern edge of the Pincher Creek map area, the lake level extends only up to 1140 m, and in the northeast corner of the study area (Brocket sheet), the glaciolacustrine sediments drop quickly to an upper elevation of 980 m. These lacustrine deposits include those of Glacial Lake Brocket, at 1110 m, identified by Horberg (1954), and named by Wagner (1966), as well as the lower Glacial Lake Magrath, at around 1020 m (Bretz, 1943). However, these lakes are laterally continuous across the study area.

In addition to a continuous lake plain, much of the hummocky till at the northeastern margin of continental drift is buried by a veneer of glaciolacustrine deposits in the Pincher Creek map area. Furthermore, continental till is buried by only a thin veneer of glaciolacustrine deposits below 1170 m in the southeasternmost corner of the Pincher Creek map area.

GLACIOFLUVIAL DEPOSITS AND FEATURES

Glaciofluvial deposits and their associated meltwater channels, water-cut notches, and outwash plains dominate parts of the three map areas. Three categories of glaciofluvial deposits exist at the surface: 1. glaciofluvial features and deposits resulting from the diversion of regional gradient directed flow by ice dams, 2. ice contact environments, and 3. outwash. These features and their related glacial drainage patterns and drainage changes are summarized in Table 3.

Topographic features and glaciofluvial deposits of category 1 are the direct result of regional drainage being dammed by continental ice to the east and northeast. These landforms and related deposits include diverted stream courses and water-cut notches that provide evidence for former ice margin positions.

Items in Category 2 result from deposition directly in contact with the continental or montane glacial ice, either subglacially, supraglacially, or proglacially. They are dominated by landforms indicating deposition in ice stagnation environments that prevailed during the waning of the continental ice: eskers, hummocks, kames and kettles. Sedimentary structures and textures, where exposures exist, further support ice stagnation: distorted stratification of coarse sediments, and a chaotic mixture of boulders, gravel, and fine sediments, indicating rapid deposition adjacent to glacial ice.

Category 3 is the result of the final waning of ice and glaciolacustrine waters from the study area, during which time subaerial, fluvial conditions could establish themselves, and integrated drainage systems began to form. Features of this category include deltas, where outwash streams emptied into downstream glacial lakes, and glaciofluvial outwash plains and terraces.

Table 3: Examples and significance of glaciofluvial features within the study area.

Feature	Example locations	Description	Formation/Significance
CATEGORY 1			
Cross-ridge notches	Southwest end of Porcupine Hills, Brocket map sheet UTM: 284500, 5507000 and 301000, 5509000	Notches up to 30 m deep cut through ridges at 1310, 1325, 1340, 1420, 1450, and 1490 m. Floors of notches covered by colluvium containing erratics.	During retreat of continental ice, water drainage was blocked by the presence of ice downslope, and was forced to drain away from the ice, across a lower-elevation, recently deglaciated ridge. Meltwater cut a channel, indicating that ice was present at least to the level of the notch.
Notches paralleling topographic contours	Southeast end of Porcupine Hills, Brocket map sheet UTM: 310000, 5512500 Southwest corner of Pincher Creek map sheet UTM: 282500, 5468000	Notches up to 30 m deep and 100 m wide cut along the topographic contours at 1067 m, where the base of Porcupine Hills meets Interior Plains; at 1570 m along small knoll north of North Drywood Creek.	During retreat of continental ice from the uplands of the Porcupine Hills, water drainage was blocked by the presence of ice downslope, and meltwaters were forced to flow along the glacier margin until they found a lower drainage route. Indicates ice margin elevation remained a sufficient time for a channel to form.
Meltwater channels (parallel to topographic contours)	West edge of Pincher Creek map sheet UTM: 288000, 5472000 Northeast corner of Pincher Creek map sheet UTM: 312000, 5480000	Large channels between 7-10 km long and up to 800 m wide aligned southeast and south across regional gradient. Contain underfit streams or bogs.	Continental ice created a barrier to drainage, and caused meltwaters or draining glaciolacustrine waters to flow along its margin, paralleling topographic contours.
Diverted river courses	Southwest corner, Pincher Creek map sheet. UTM: 284000, 5463000	South Drywood Creek, flowing east-northeast, jogs to the north for a distance of 2.5 km before turning east again.	Meltwaters issuing from a waning montane glacier flowed down-gradient until reaching the continental ice margin to the east. Water was diverted, and forced to flow along the margin, seeking a lower outlet. Previous course is now filled with drift.
CATEGORY 2			
Glaciofluvial complex (map unit Gx)	Southwest corner of Pincher Creek map sheet UTM: 291000, 5464000	Complex area of hummocks, gravel, diamicton, and eskers.	Result of glaciofluvial sedimentation above and beneath downwasting and stagnating continental ice near its western margins. Geomorphic features include eskers, and kame and kettle topography.

Feature	Example locations	Description	Formation/Significance
CATEGORY 3			
Glaciofluvial plain (map unit Gp)	Northeast corner, Brocket map sheet UTM: 315000, 5510000 (Oldman R)	Extensive sheet of coarse gravel slightly inset into lacustrine plain north of the Oldman River, containing all identifiable lithologies.	Prior to incision of modern-day river channels, montane meltwaters flowed in sheets down the regional gradient following the retreat of continental ice and the draining of Glacial lakes Cardston, Brocket, and Magrath.
Glaciofluvial terraces (map unit Gt)	Along water courses. UTM: 283000, 5459500 (Yarrow Ck) UTM: 310500, 5502500 (Oldman R) UTM: 712000, 5597500 (Crowsnest)	Flat, coarse gravelly terraces well above modern day active stream courses, inset into surrounding glacial deposits.	Outwash from glaciers established water courses, and deposited massive amounts of coarse sediment. Rivers progressively cut down from plains surface to modern-day river levels.
Meltwater channels (down regional gradient)	Ridge south of Pincher Creek UTM: 295000, 5479000 East side, Brocket map sheet UTM: 317000, 5501500	Channels are narrow relative to their length, and are generally aligned to the east or northeast. Cut through bedrock ridges or down through till and lacustrine plains.	Montane glaciofluvial and glaciolacustrine waters drained down regional gradient once the ice barrier to east retreated and lake waters drained through lower outlets.
Deltas (map unit Gd)	Brocket map sheet UTM: 702000, 5504000 (Ross Ck) UTM: 703000, 5498000	Sand and gravel deltas at 1311 m, and 1219 m	During existence of Glacial Lake Caldwell (1310 m), and Glacial lake Cardston (1219 m), meltwater streams flowed into the lakes, and formed a delta at each lake level.

CHAPTER 7

GLACIAL HISTORY

This chapter discusses the pattern and timing of interaction between montane and continental glaciers in the Three Rivers Region. Quaternary stratigraphy and surficial geology from this study is integrated with the work of previous authors. Figures 23 and 24 show the stratigraphic pattern repeated throughout the study area (continental till always overlying montane till). Figure 25 presents idealized stratigraphic columns for the confluence of the Crowsnest, Castle, and Oldman rivers, and the northeast corner of the Brocket map area.

PRE-WISCONSINAN MONTANE GLACIATION

Evidence for montane advances prior to the Wisconsinan Stage has been described immediately south of the study area. This evidence includes a montane till overlain by a paleosol on Cloudy Ridge, and five interstratified tills and associated paleosols on Mokowan Butte (Alden, 1932; Horberg, 1954; Wagner, 1966; Barendregt *et al.*, 1991; Little, 1995). The uppermost till in the sequence, the Kennedy Drift, has all the characteristics of a glacial till derived from the Lewis and Clark Ranges, but differs significantly from Unit 2 till observed in valley bottoms in that it has been extensively weathered. It has been dated at between 0.5 Ma and 65 ka by Karlstrom (1988), based on time required for soil profile development. The two tills beneath the Kennedy drift have

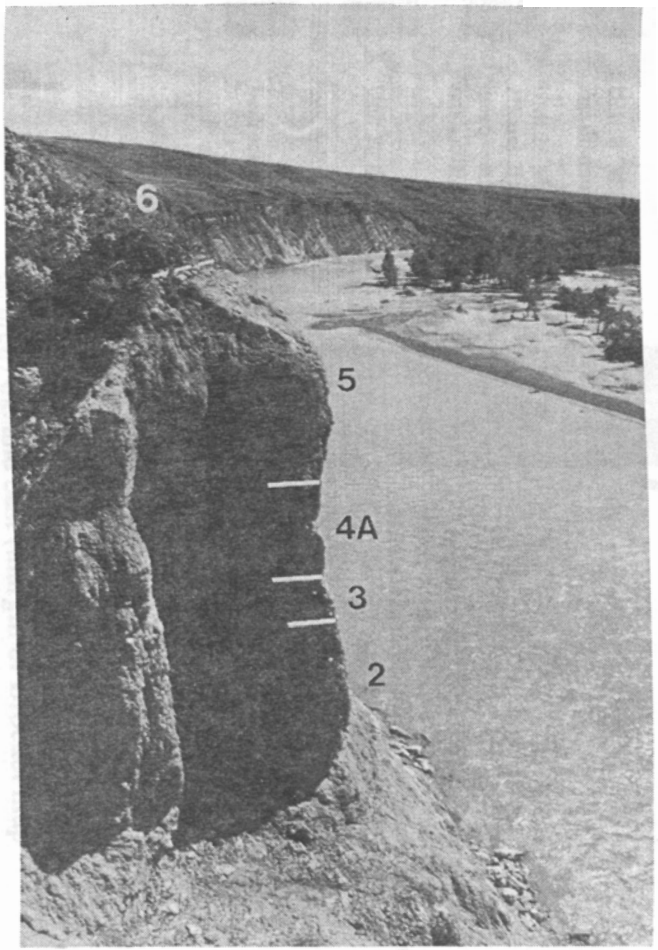


Figure 23: Bird Reserve Section (looking south down Castle River). Laminated silt and clay at top of cliff is Unit 5.

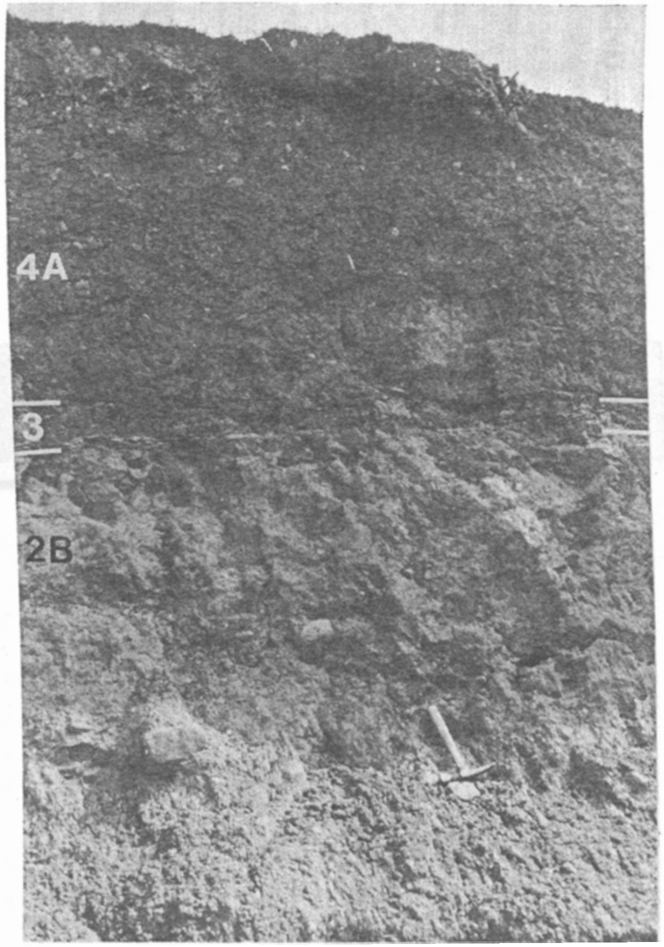


Figure 24: Island Section. Typical stratigraphic pattern observed throughout study area: montane till (subunit 2B) beneath continental till (subunit 4A), separated by laminated silt and clay (Unit 3).

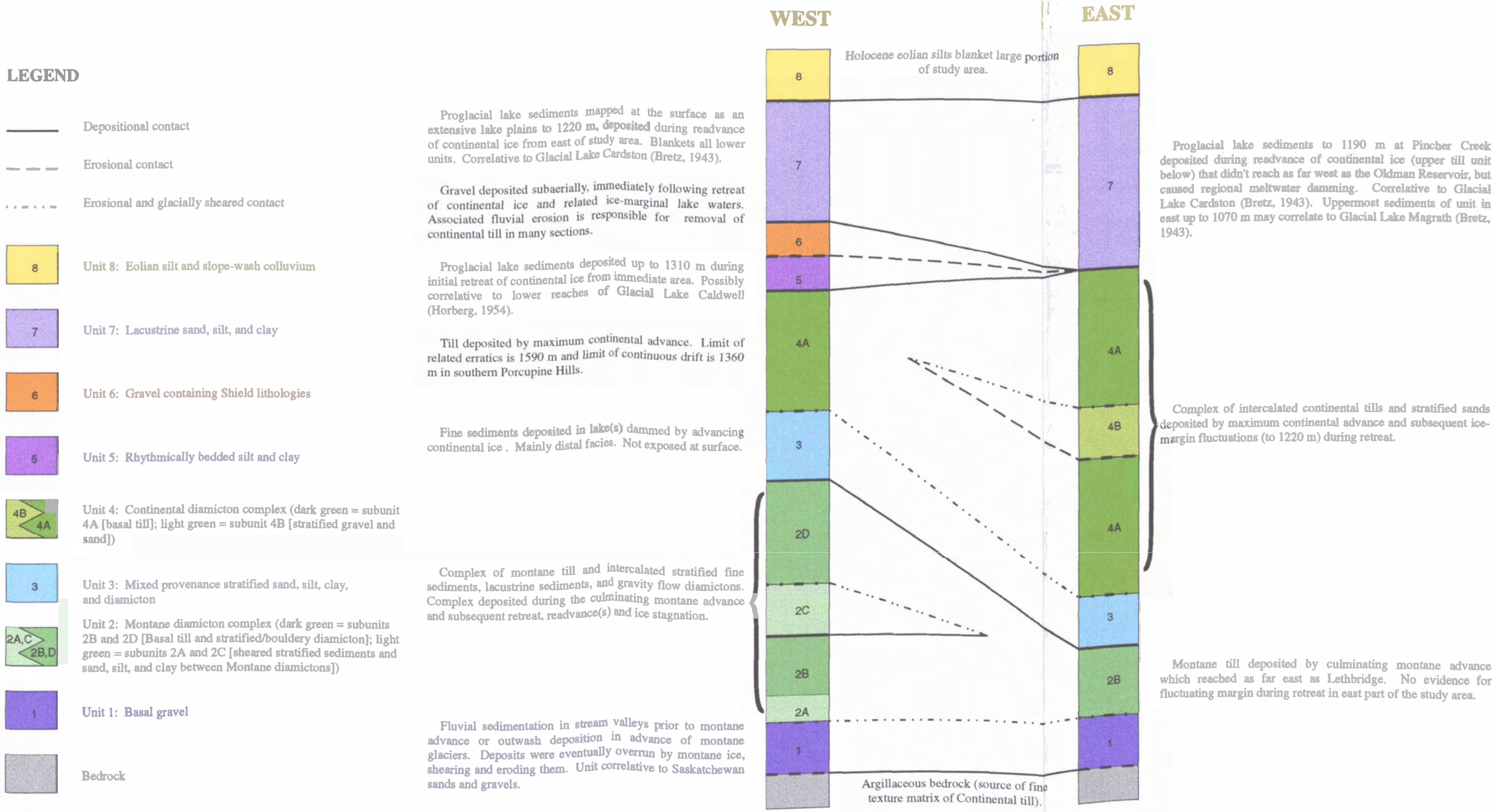


Fig 25: Ideal schematic stratigraphic columns for the drift fill of the Oldman River Valley at the west (Three Rivers confluence area) the and east (margin of Brocket map area) sides of the study area. Stratigraphic columns are not to scale. Except for Holocene silt at the top, all units are late Wisconsinan in age.

reversed geomagnetic polarity, and therefore pre-date the Bruhnes chron.

The pre-Wisconsinan montane till units were likely deposited prior to the cutting of the contemporary valley systems that now contain the basal gravel of Unit 1, and all younger deposits identified in this thesis (Chapter 5: Quaternary Stratigraphy). Glacial limits in the Foothills indicate that glacial ice was never thicker than 300 m above the floors of contemporary valleys (Jackson *et al.*, 1996). The drift on Mokowan Butte and Cloudy Ridge is an erosional remnant of a former drift-covered landscape.

THE LAST GLACIATION

Proglacial fluvial processes dominated the valleys of the Crowsnest, Oldman, and Castle rivers at the onset of the last glaciation. Water and sediment were supplied from glacier ice expanding in the west and south along the Great Divide, and were responsible for the deposition of the basal gravel of Unit 1.

Montane glaciation culminated in an advance that spread out onto the Plains east of the study area, reaching as far east as Lethbridge (Stalker, 1963; Wagner, 1966, Jackson *et al.*, 1996). This deposited the basal till and related sediments of subunits 2A, 2B, and 2C. The lodgement process beneath the advancing ice was interrupted occasionally, and replaced by subglacial meltwater erosion and deposition. The lack of any erratics from the Canadian Shield within the sediments indicates that no advances of continental ice preceded this montane advance. Erratics as high as 1620 m in the southern Porcupine Hills may either mark the limit of montane ice as it blanketed the area or the limit of later continental ice, which reworked montane drift.

Continental ice advanced westward toward the Foothills when montane ice was in recession. This created a barrier to drainage for meltwaters issuing from glaciers of both provenances. A glacial lake came into existence between the ice margins. An ice-proximal glaciolacustrine environment developed in the western portion of the study area, near the margin of retreating montane ice (Fig. 26). The stratified fines and sediment gravity flow diamictons of subunits 2C and 2D were deposited during this period. The depositional environment in the upper Oldman and Castle River valleys on the west half of the study area, changed from an ice-proximal to a more distal glaciolacustrine environment as montane ice retreated further west and south. Continental ice continued to advance westward toward the study area, and began to have a more direct influence on the sedimentation occurring in the lake ponded before it. The appearance of Shield stones in the silt and clay rhythmites of Unit 3 reflect this continental ice advance.

Continental ice eventually overrode the Oldman Reservoir area, and the glaciolacustrine deposits of Unit 3. This glacier advanced, and deposited a basal till bearing abundant Shield stones (subunit 4A). This advance apparently involved a coalescence of continental and montane ice (Fig. 27). Continental and montane tills are mapped at the surface immediately adjacent to one another in the middle of the Blairmore map area. Furthermore, continental till reaches up to 1400 m on the north edge of the Blairmore sheet, but only 10 km further south, where it lies adjacent to montane till, it only rises to 1370 m, and at the south edge of the sheet, it does not reach that elevation. This distribution of continental till and erratics indicates that montane ice was present in major Foothills valleys

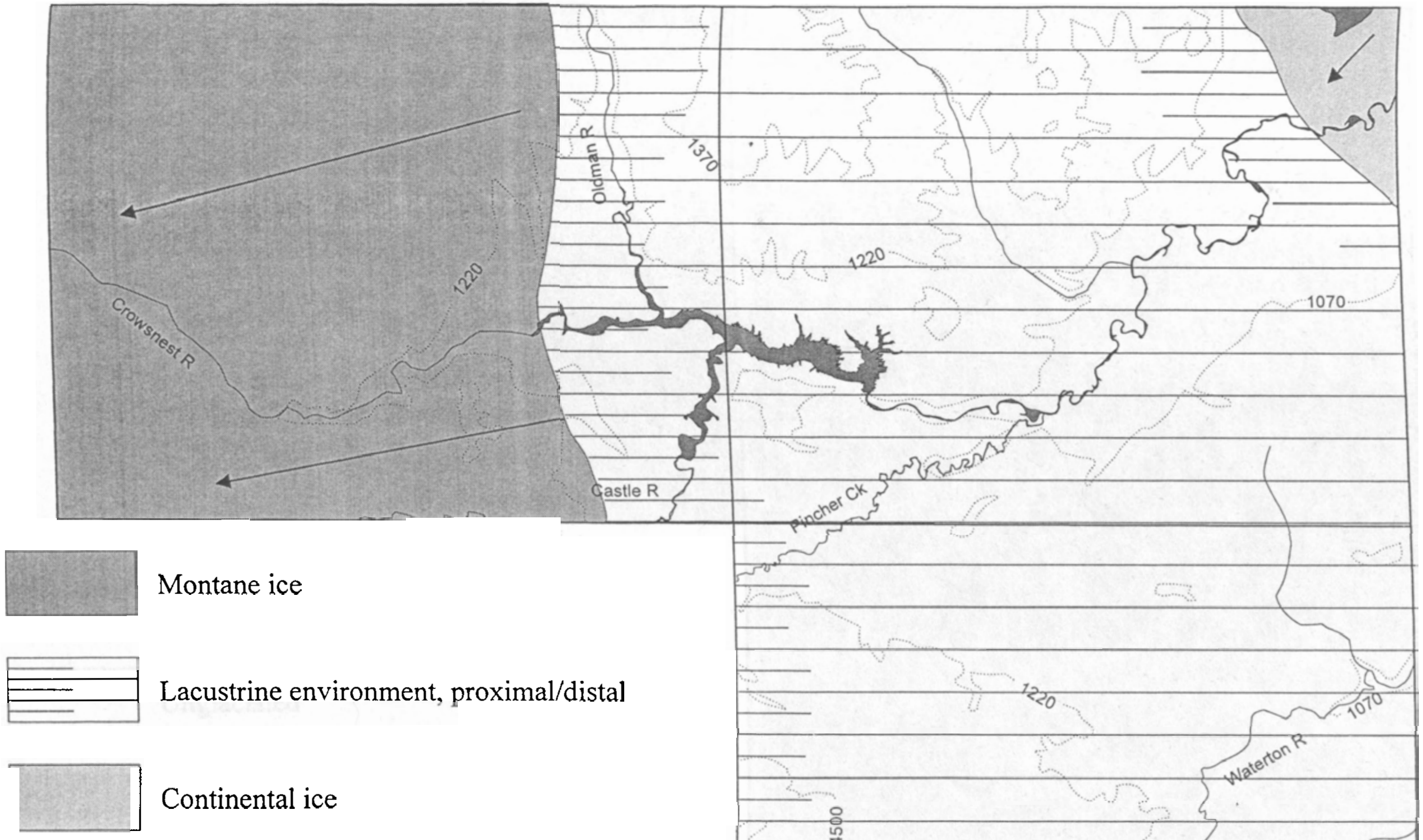
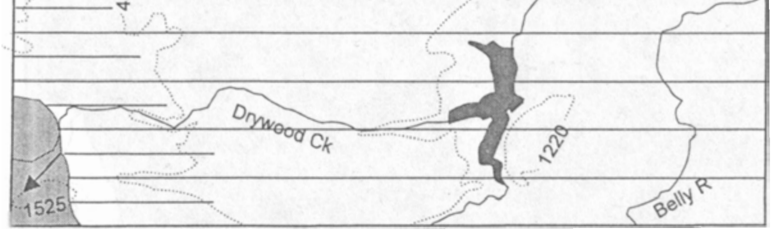



Figure 26: Approximate location of ice margins during retreat of montane ice out of, and advance of continental ice into the Three Rivers study area.

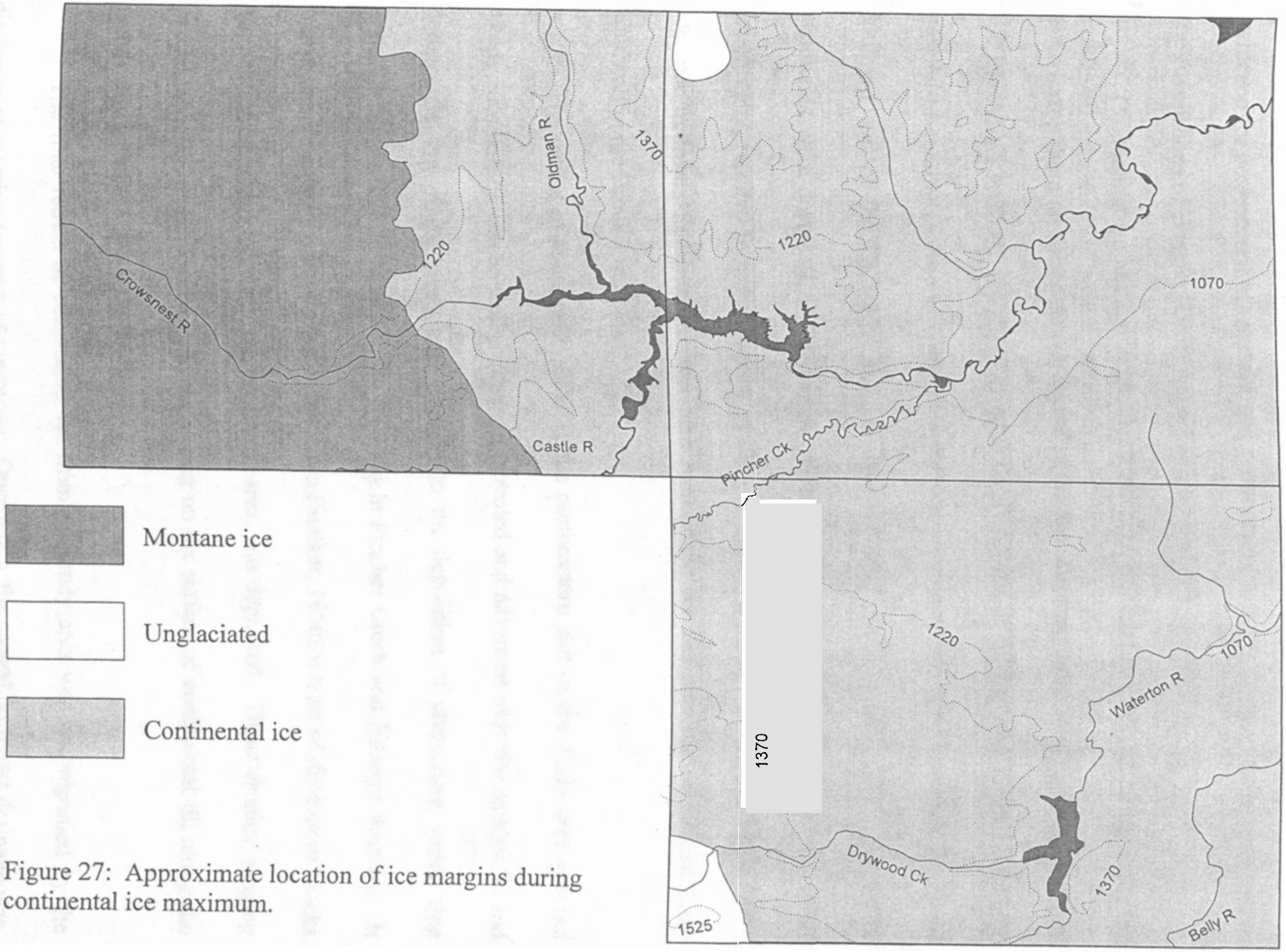


Figure 27: Approximate location of ice margins during continental ice maximum.

and prevented continental ice from pressing further west or south. The overwhelming evidence for coalescence of montane and continental ice in the Oldman basin corroborates the conclusions of Wagner (1966) and refutes those of Alley (1973).

Continental ice reached as high as 1590 m in the southern Porcupine Hills, but did not overtop them on the northwest corner of the Brocket map area. During its retreat from the immediate area, the ice experienced several still-stands during which cross-ridge and parallel-to-contour meltwater channels were cut. A major still-stand occurred along the southern end of the Porcupine Hills at approximately 1370 m (Fig. 28). Lacustrine sediments were deposited where valleys were blocked, and a belt of hummocky, pitted topography, resulted from ice wasting in situ. This still-stand and the progressively lower ice margin levels following it were also responsible for the ponding of Glacial Lake Caldwell in the Brocket map area.

The retreat of continental ice from the northeastern part of the study area was not steady. Rather, the continental ice margin retreated and advanced over the eastern 20 and perhaps 35 km of the study area, leading to the deposition of alternating sorted fine sediments and basal till (subunits 4A and 4B) in Pincher Creek and Bitango Sections. It was at this time that the Foothills Erratics Train (Stalker, 1956), a train of distinctive blocks of pebbly quartzite originally from the Jasper area, was deposited. These erratics, ranging in size from 0.5 to 5 m, were observed resting on the surface of continental till along the eastern margin of the Brocket map area.

The final retreat of continental ice from the study area was accompanied by the discharge of massive amounts of meltwater. Once again, the natural northeast drainage was

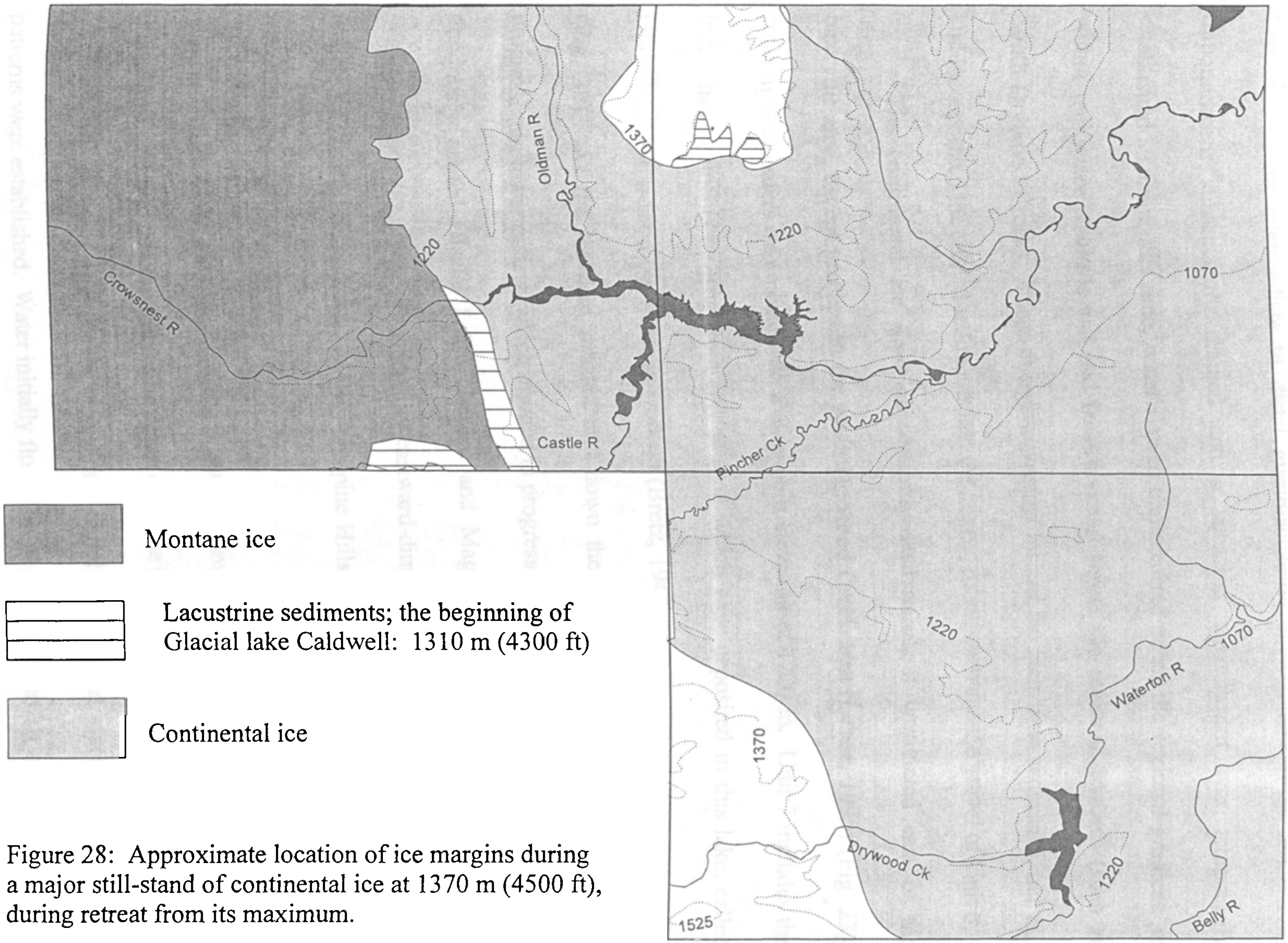


Figure 28: Approximate location of ice margins during a major still-stand of continental ice at 1370 m (4500 ft), during retreat from its maximum.

blocked by the waning ice front. The bedded fine sediments of Unit 5 were therefore deposited in an intermediate to distal glaciolacustrine environment (Fig. 29). This impoundment subsequently drained and a subaerial environment was temporarily established. During this time, water flowed unobstructed down the regional gradient, or within meltwater channels that had been diverted across the regional gradient (such as South Drywood Creek). These energetic streams incised the lacustrine sediments and till, and incorporated the eroded sediments into the coarse, mixed-provenance gravel of Unit 6.

The continental ice sheet subsequently readvanced; it terminated east of the reservoir area, except perhaps in the south Drywood Creek area (Leboe, 1995) (Fig. 23), ponding meltwaters into a lake with a maximum elevation of 1220 m. Unit 7 includes the lacustrine sediments ranging from clay to sand which were deposited in this lake, called Glacial Lake Cardston by previous workers (Bretz, 1943; Horberg, 1954; Wagner, 1966) (Fig. 30). As the ice dam receded east down the regional slope, lake waters found progressively lower outlets, which resulted in progressively lower lake levels, including the previously named Glacial Lakes Brocket and Magrath (Bretz, 1943; Horberg, 1954; Wagner, 1966) (Fig. 24). This steadily eastward-diminishing lake level is evident in the limits observed around the base of the Porcupine Hills and other prominent uplands within the study area.

The lower-to-the-east migration is also documented by deltas (Table 4) formed by meltwaters draining into the lake. The deltas decrease in elevation eastward.

As lacustrine environments waned, sub-aerial, fluvial, and glaciofluvial, drainage patterns were established. Water initially flowed in wide sheets, leaving a large outwash

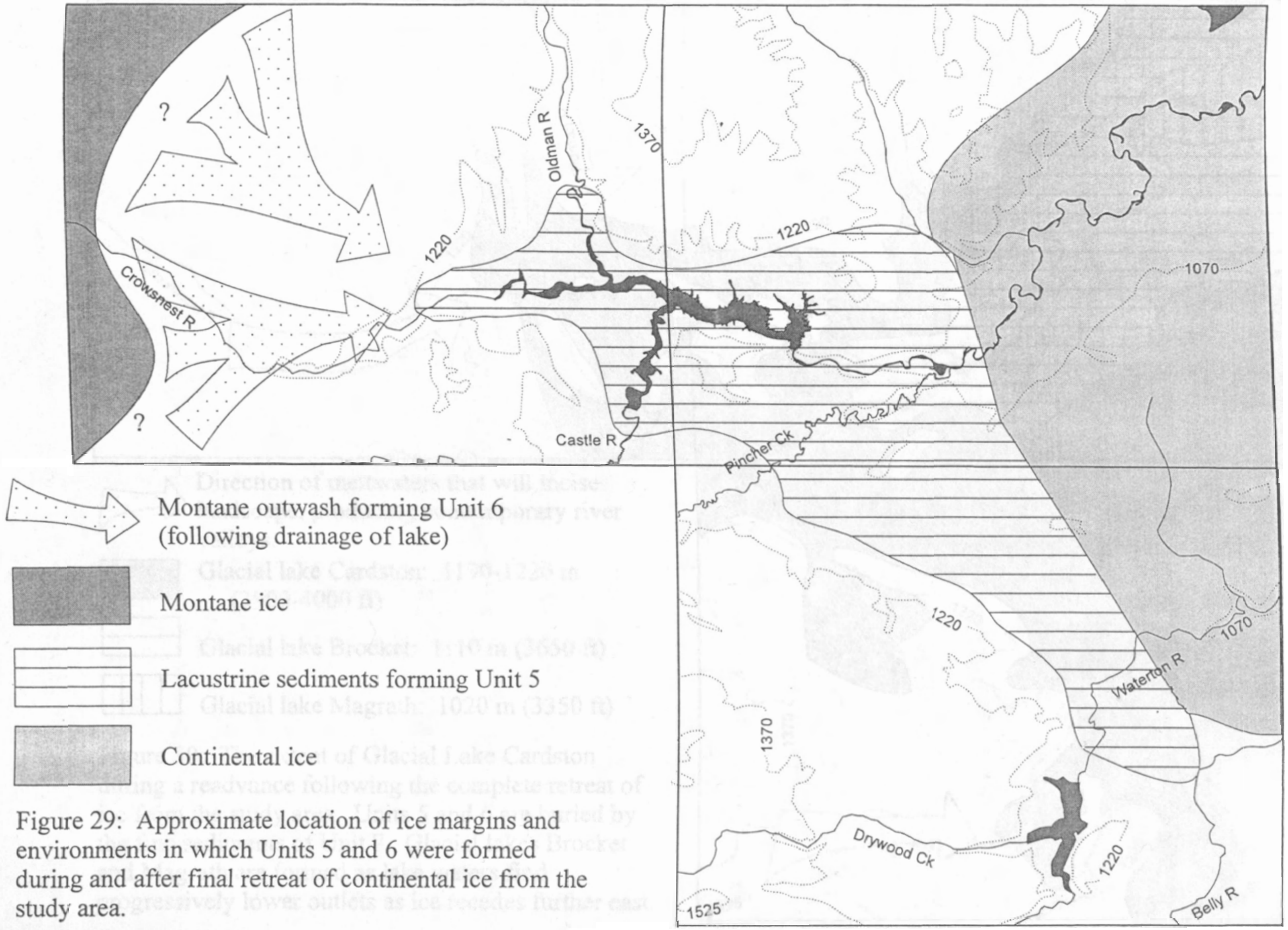
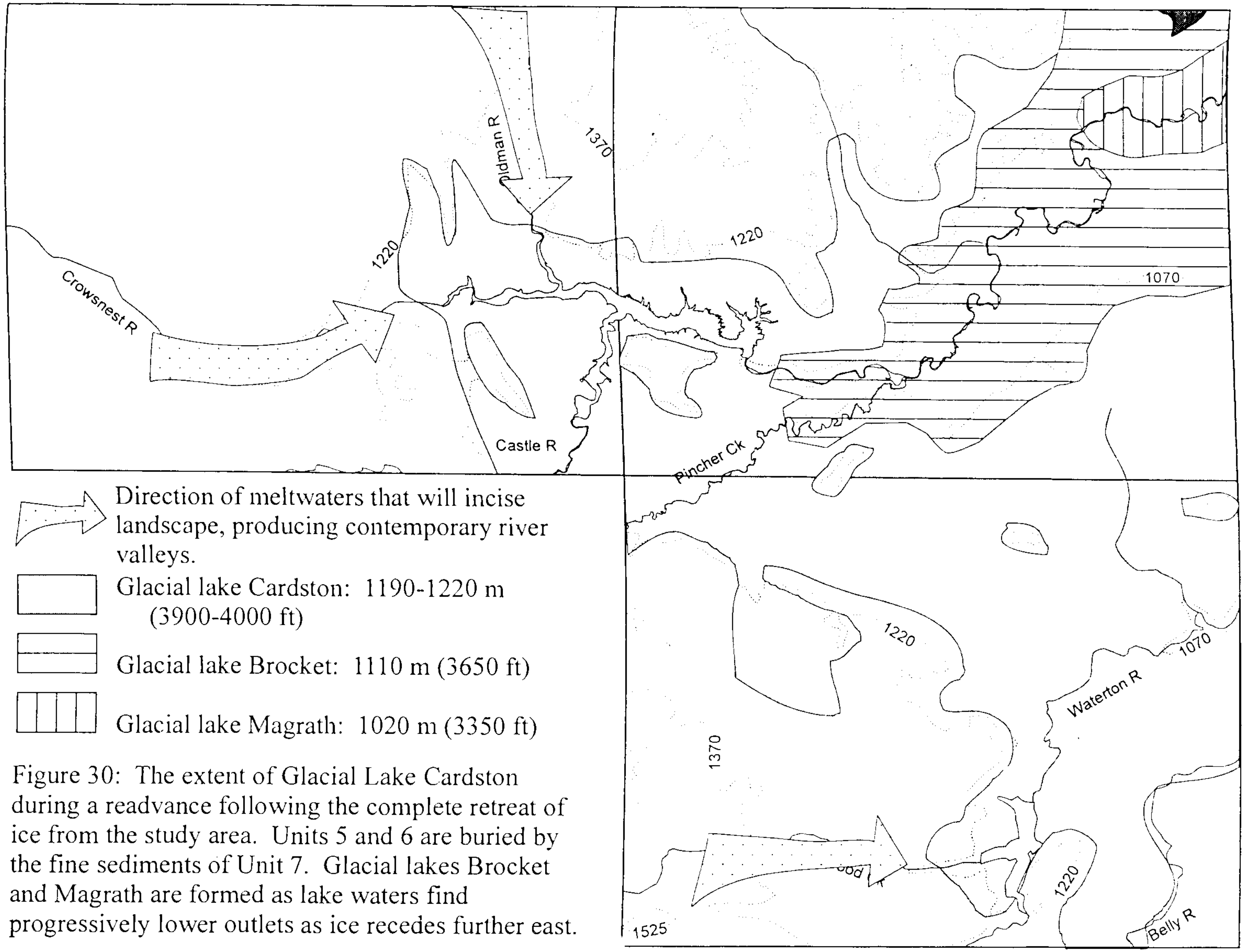


Figure 29: Approximate location of ice margins and environments in which Units 5 and 6 were formed during and after final retreat of continental ice from the study area.



Direction of meltwaters that will incise landscape, producing contemporary river valleys.

Glacial lake Cardston: 1190-1220 m (3900-4000 ft)

Glacial lake Brocket: 1110 m (3650 ft)

Glacial lake Magrath: 1020 m (3350 ft)

Figure 30: The extent of Glacial Lake Cardston during a readvance following the complete retreat of ice from the study area. Units 5 and 6 are buried by the fine sediments of Unit 7. Glacial lakes Brocket and Magrath are formed as lake waters find progressively lower outlets as ice recedes further east.

plain near Fort Macleod. As valleys were cut, outwash plains were succeeded by flights of terraces.

During the development of an integrated drainage pattern, some rivers created new stream courses. The Crowsnest River, and the Oldman River upstream of Brocket have cut down through bedrock, creating steep, near-vertical-walled gorges. The buried original trunk valley that carried the combined flows of the Oldman, Crowsnest, and Castle rivers is now occupied by Pincher Creek between Brocket and the town of Pincher Creek (Stalker, 1961). Up to 40 m of unconsolidated valley fill form cliff-banks in this partly exhumed valley.

Since the final retreat of continental ice and its associated meltwaters from the study area, subaerial processes of erosion and deposition have been steadily occurring. Immediately upon the establishment of these new conditions, strong winds typical of the Foothills and western Interior Plains began transporting and depositing silt, blanketing the landscape with an eolian cover ranging from a thin veneer to about a metre of massive silt. On inclined land and river banks, eolian processes were interrupted by slope-wash processes, resulting in the interstratification of silt and coarser layers within Unit 8.

AGE OF GLACIATION

The results of paleomagnetic sampling from a complete stratigraphic section at the Castle River Section show that all glacial sediments were deposited following the last magnetic reversal, 780 ka (Barendregt *et al.*, 1991), confirming that no stratigraphic evidence for ancient montane glaciations exists in the Three Rivers study area. To reiterate, the montane and continental advances recorded within the study area were events of the same glaciation: there is no indication of a significant hiatus between deposition of montane and continental tills where they are superposed, or between any other units exposed in the study area. Furthermore, the elevation range of continental drift and erratics necessitate the simultaneous existence of montane ice in the Foothills area (see above). This single continental glaciation of the region corroborates the conclusions of Horberg (1952), Wagner (1966), Bayrock (1969), Liverman *et al.* (1989), Young *et al.* (1994), and Little (1995).

The succession of continental basal tills (subunit 4A) separated by sorted fine sediments and thin diamicton units (subunit 4B) can be explained by a single continental ice advance followed by a fluctuating retreat from the study area. This uncomplicated hypothesis was first proposed by Wagner (1966) and is supported by this study.

The faunal evidence of Bayrock (1969), and series of radiocarbon ages of Liverman *et al.* (1989), and Young *et al.* (1994) limit the only incursion of continental ice in southern Alberta to the late Wisconsinan. This has recently been corroborated by direct dating of the Foothills Erratics Train as late Wisconsinan by the cosmogenic ^{36}Cl exposure dating technique (Jackson *et al.*, in press).

Stratigraphic and absolute dating conclusively demonstrates that there has been a single continental glaciation, that at its maximum, was coalescent with waning montane ice.

CHAPTER 8

SUMMARY AND CONCLUSIONS

For the purposes of this study, detailed stratigraphic investigations of 24 sections along the Castle, Crowsnest, and Oldman rivers, Oldman Reservoir, and Pincher Creek were conducted, and sequences explained using modern (post-1970) sedimentological theories. Surficial geology, mapped at a scale of 1:50 000, over 2 500 km^2 in the Foothills and adjacent Plains of southwestern Alberta was interpreted, and linked to the sediments observed in stratigraphic column. Paleomagnetic investigation was conducted in the Quaternary sediments of a complete stratigraphic section along the Castle River.

The results of these investigations lead irrefutably to the conclusion that this area has been glaciated only once by continental ice, which reached its acme shortly after ice from the Rocky Mountains climaxed and began its westward retreat. In the northwest portion of the study area, continental ice was blocked from further advance westward and up valleys by the presence of retreating montane ice. During the fluctuating retreat of continental ice from the study area, glaciolacustrine and glaciofluvial processes dominated the region and produced relict lake plains, raised deltas, and meltwater channels.

No Quaternary sediments in the study area were deposited prior to the last magnetic reversal of the geomagnetic pole, 0.78 M years ago. Based on the lack of evidence for a significant hiatus between deposition of any tills observed, the ability to explain all sediments observed by a single glaciation, and the absolute dating work of other scientists (see "Glacial History", Ch. 7), it is apparent that the glaciation of the study area by continental ice occurred only once, during the late Wisconsinan, and that at its maximum, it was coalescent with waning montane ice.

These conclusions are consistent with those of Horberg (1954), Wagner (1966), Bayrock (1969), Liverman *et al.* (1989), Young *et al.* (1994), Little (1995), and Jackson *et al.* (1996). However, the stratigraphic interpretations and chronologies of Stalker (1963), Alley (1973), Alley and Harris (1974), and Stalker and Harrison (1977) are not supported by the conclusions of this study.

The stratigraphic nomenclature for mid-continent and Great Lakes regions, to which many studies have attempted to correlate stratigraphic units in southwestern Alberta, has been modified numerous times over the years. No evidence exists to show that the sequence of Wisconsinan events in southern Alberta are time-equivalent to those events determined for the Great Lakes region, or mid-continental United States region. Correlations over such great distances are tenuous at best, and therefore such correlations will not be attempted. However, if maxima are correlated, then the Woodfordian stage of mid-continent United States (Frye and Willman, 1960) corresponds to the glacial maximum that deposited Unit 4 within the study area (Wagner, 1966).

The glacial stratigraphy in the Rocky Mountains of Glacier National Park (Richmond, 1960) can now be correlated to the study area: the maximum montane glaciation of the region clearly occurred during the Pinedale Stage (Jackson *et al.*, 1996).

APPENDICES

Appendix A: Stratigraphic sections

Appendix B: Till fabrics

Appendix C: Pebble sample data

Appendix D: Till matrix textural data

Appendix E: Paleomagnetic data

APPENDIX A

STRATIGRAPHIC SECTIONS

a. Table of section information (name, location, comments)

b. Legend of symbols used in section descriptions

c. Sections (in alphabetical order)

Table 3: Section information (name, location, comments). (#) refers to the section number on the Correlation chart (Map 4).

SECTION NAME (#)	LOCATION	BEDROCK EXPOSED?	COMMENTS
	CASTLE RIVER ARM		
Castle River Gully (#1) (Figure 6)	A near-vertical cliff face approximately 250 m long and between 20 and 60 m high exists on the right bank at the confluence of the Castle River arm with the main reservoir. The section was described in a narrow gully cutting through the east end of this long section. UTM: 714700, 5490300	YES	Exposure previously described by Stalker (1963; Sec.7), Wagner (1966; Sec. 15) and Alley (1973), and they proposed multiple glaciations in the area based upon the stratigraphy exposed here.
Castle River Section (#1a)	Approximately 100 m west of the Castle River Gully. UTM: 714500, 5490250	YES	A composite of three partial sections within 30 m along the cliff.
Bird Reserve Section (#2) (Figure 23)	On the right (east) bank of Castle River arm, approximately one km downstream from the Castle River Sections. UTM: 715200, 5491200.	YES	Described previously by Stalker (1963; Sec.6) and Wagner (1966; Sec. 14).
Highway Bridge Section (#3)	On the right (east) bank of Castle River arm, immediately south of the crossing of the reservoir by Alberta Highway 3, at the north end of a 100-m-long exposure. UTM: 715600, 5491800	YES	Bottom 7 m are well exposed; a steep slope of silty clay continues up to the plains level. Described by Wagner (1966; Sec. 13).
Highway Three Section (#4)	Located at the intersection of Alberta Highway 3 with an unnamed creek one km west of Castle River arm. The exposure begins approximately 4 m up from the base of the ravine and is about 20 m long. UTM: 714250, 5492650	YES	
Three Rivers Roadcut (#5)	Located on the south shore of the reservoir just west of the CP Railway bridge across Castle River arm. The sloping roadcut is only 2 m high, but is approximately 50 m long and descends through the section. UTM: 715300, 5482500	YES	35 m of vertical Quaternary deposits are continuously exposed along this roadcut.
Vogelaar Gully (#6)	Located on the right (east) bank of Castle River arm at the easts end of a 500-m-long exposure. UTM: 715700, 5492550	YES	Upper 12 m are heavily slumped.
Vogelaar Section (#7)	At the west end of the exposure described above. UTM: 715600, 5492650	YES	Upper 5 m are partially slumped.
Logboom Section (#8)	On the south end of a 500-m-long exposure on the right (east) bank of Castle River arm, around a point of land north of the Vogelaar sections. UTM: 715900, 5492900	NO	Uppermost portion of vertical exposure is 10 m below the plains level.

SECTION NAME (#)	LOCATION	BEDROCK EXPOSED?	COMMENTS
Driftwood Section (#9)	300 m to the north of the Logboom Section, on the same cliff bank exposure. UTM: 715800, 5493350	YES	
Bail-out Bluff (#10) Fig. 11	Immediately south of the confluence of the main reservoir and the right (east) bank of the Castle River arm. UTM: 716300, 5496450	NO	Section is vertical to overhanging and was formed during the June 1995 flood.
	RESERVOIR & LOWER OLDMAN RIVER		
Island Section (#11) (Figure 24)	On the northeast side of an island one km east of the confluence of the upper Oldman River arm with the main reservoir. UTM: 714350, 5498300	NO	
Numbum Bluff (#12) (Figure 13)	A 20-m-long exposure located on the south side of the reservoir, one km west of the Oldman Dam. UTM: 288800, 5495000	NO	Heavily slumped above the lower 14 vertical m.
Bitango Section (#13)	Located on the north side of the Oldman River at the west end of a very large exposure almost two km long and over 50 m high just west of the Peigan Indian Reserve boundary. This exposure is visible from Alberta Highway 3. UTM: 297500, 5493700	NO	The lower 25 m are vertical; the upper 25 are a steep grassy slope from the cliff-top to the plains. Described by Wagner (1966; Sec. 11).
*Brocket Section (#14) (Figure 4)	Located on the left bank of a very large bend in the Oldman River, six km northeast of Brocket, on the Peigan Indian Reserve. UTM: 303700, 5497500	YES	Described by Stalker (1963; Sec. 5), Alley (1972), and Wagner (1966; Sec. 10). Included for correlation purposes using Stalker's 1963 description.
*Peigan Section (#15)	Located on the right bank of the Oldman River, 15 km downstream from the Brocket Section, on the Peigan Indian Reserve. UTM: 312700, 5503700	NO	Described by Stalker (1963; Sec. 4). Included for correlation using Stalker's 1963 description.
Van Santen Section (#16)	Located on the eastern border of the study area on a meander of the Oldman River that was reactivated during the flooding of June, 1995. UTM: 318950, 5507700	NO	The bottom five m of section are heavily slumped and overgrown.
	UPPER OLDMAN RIVER ARM		
Brockwell Gully (#17) (Figure 12)	Cuts down through a one-km-long vertical cliff on the right bank of an entrenched meander in the upper Oldman River. UTM: 710950, 5503900	YES	Minor slumping near the top. Previously described by Stalker (1963; Sec 9).

SECTION NAME (#)	LOCATION	BEDROCK EXPOSED?	COMMENTS
Northfork Section (#18) (Figure 7)	A 500-m-long cliff at the southern end of the right bank of the upper Oldman River, immediately north of the main body of the reservoir. UTM: 713000, 5498700	NO	Upper 5 m are heavily slumped in most places.
Island View Section 2 (#19)	Along a 300-m-long cliff at the southern end of the right bank of the upper Oldman River, immediately north of the main body of the reservoir. UTM: 713450, 5498700	YES	Lowest 10 m are well-exposed; 35 m of gently sloping, silty clay cap the section.
Island View Section 1 (#19a)	Located 100 m to the south of Island View Section 2. UTM: 713450, 5498600	NO	See Island View Section 2.
	CROWSNEST RIVER ARM		
Cowley Bridge Section 1 (#20)	A one-km-long exposure located on the left bank of the drowned Crowsnest River, immediately west of the reservoir crossing of Alberta Highway 510. A series of gullies separates vertical faces of Quaternary sediments. The described section is on the west end of this exposure. UTM: 710450, 5498400	YES	
Cowley Bridge Section 2 (#21)	On the east end of the exposure described above. UTM: 710650, 5498300	YES	Contains a more complete stratigraphic record than Cowley Bridge Section 1.
	PINCHER CREEK		
Pincher Creek Section (#22)	Located three km upstream from the town of Pincher Creek, on the left bank of Pincher Creek. The exposure is fifty m long. UTM: 283400, 5484900	YES	Upper five m are on a slope that extends to the plains surface.

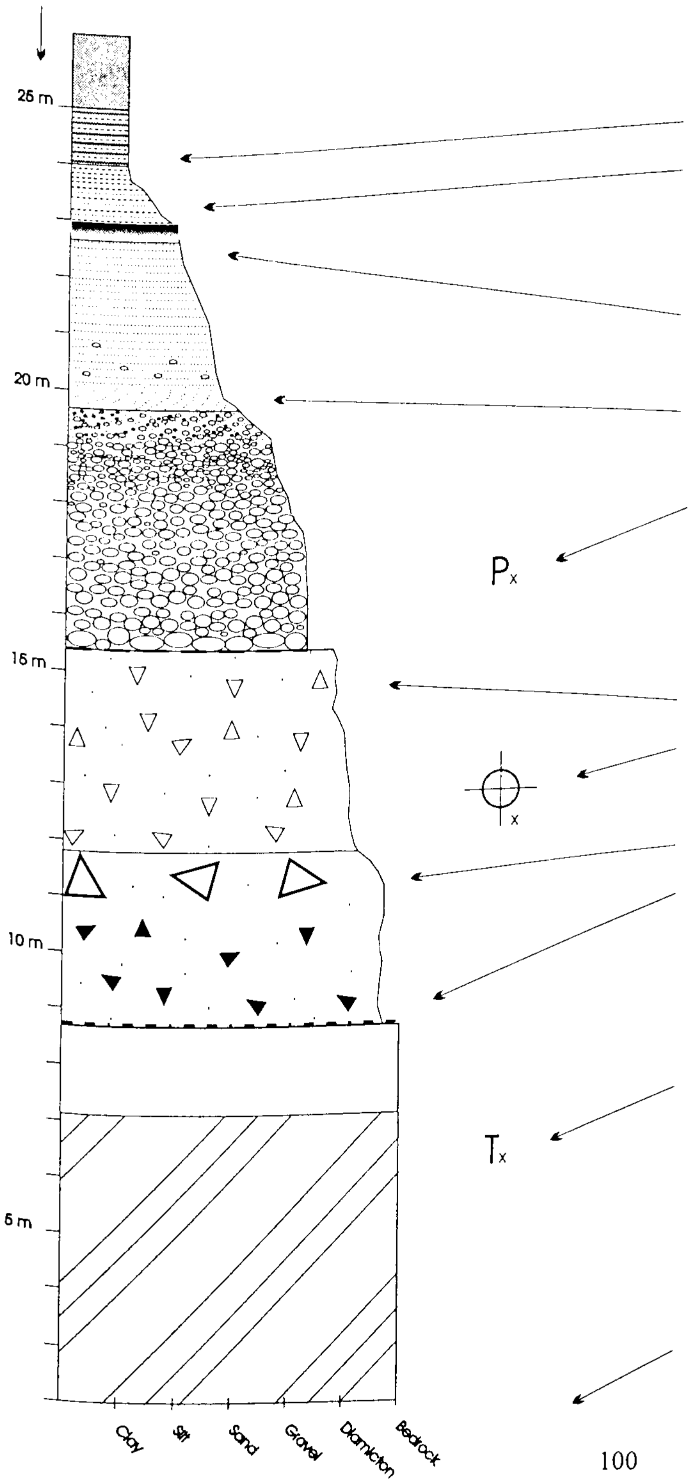
* denotes sections not redescribed for this study.

LEGEND FOR SECTION DESCRIPTIONS IN THIS APPENDIX

SECTION NAME (# on Map 4)(listed alphabetically)

NTS map sheet (map name): UTM grid coordinates

Height above base of section
(usually water level of river or reservoir)



Field descriptions

Massive or laminated clay or silty clay

Rhythmically bedded clay and silt

Depositional contact

Silts

Sandy silts

Paleosol

Sand

Dropstones

Cross-bedding in sands/gravels

Pebble gravels

Pebble sample #X taken at this height: see Appendix C

Cobble gravels

Erosional contact

Continental diamicton

3D pebble fabric #X taken at this height: see Appendix B

Boulder lag or pavement

Sheared contact

Montane diamicton

Colluvium/slumped material

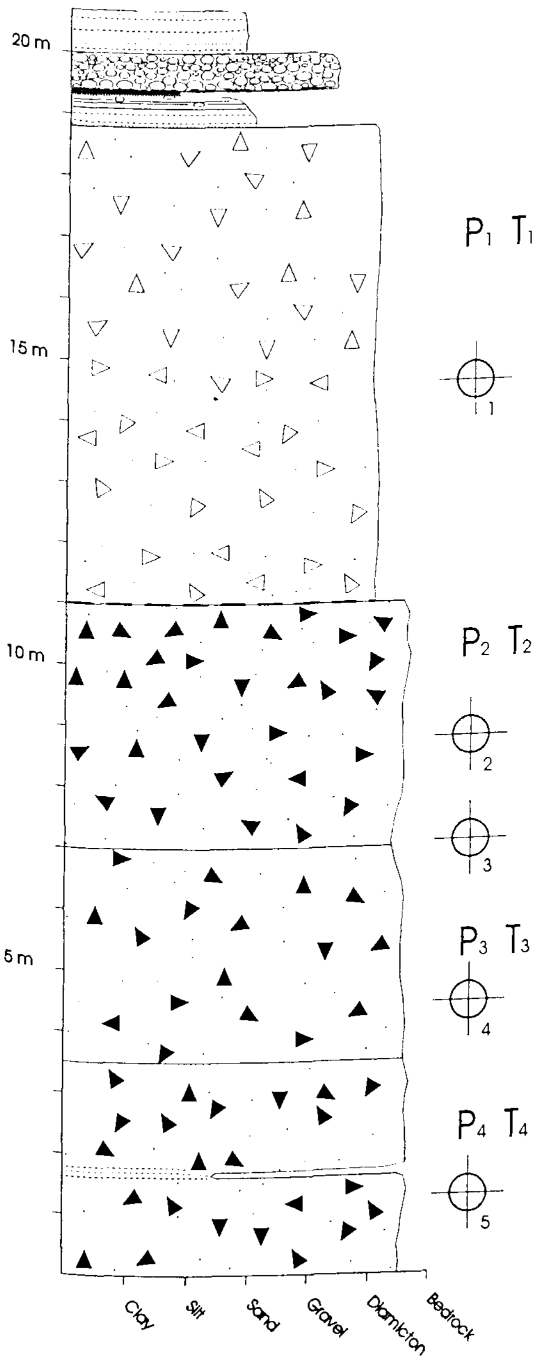
Diamicton sand/silt/clay texture sample #X taken at this height: see Appendix C

Bedrock

Dominant texture/grain size of unit

BAIL-OUT BLUFF (10)

82 G/9 (Blairmore): 716300, 5496450



G. Massive silty sand; cliff-top dune. (Unit 8)

F. Poorly sorted pebble and cobble gravel. (Unit 6)

E. Rhythmically bedded fine sand and clayey silt (30cm) topped by faintly laminated clayey silt with dropstones. (Unit 5)

D. Laurentide diamicton. About 10% stone content; contains Shield stones. Lower contact is abrupt. Fabric and bullet boulder indicate flow from SE. (Unit 4A)

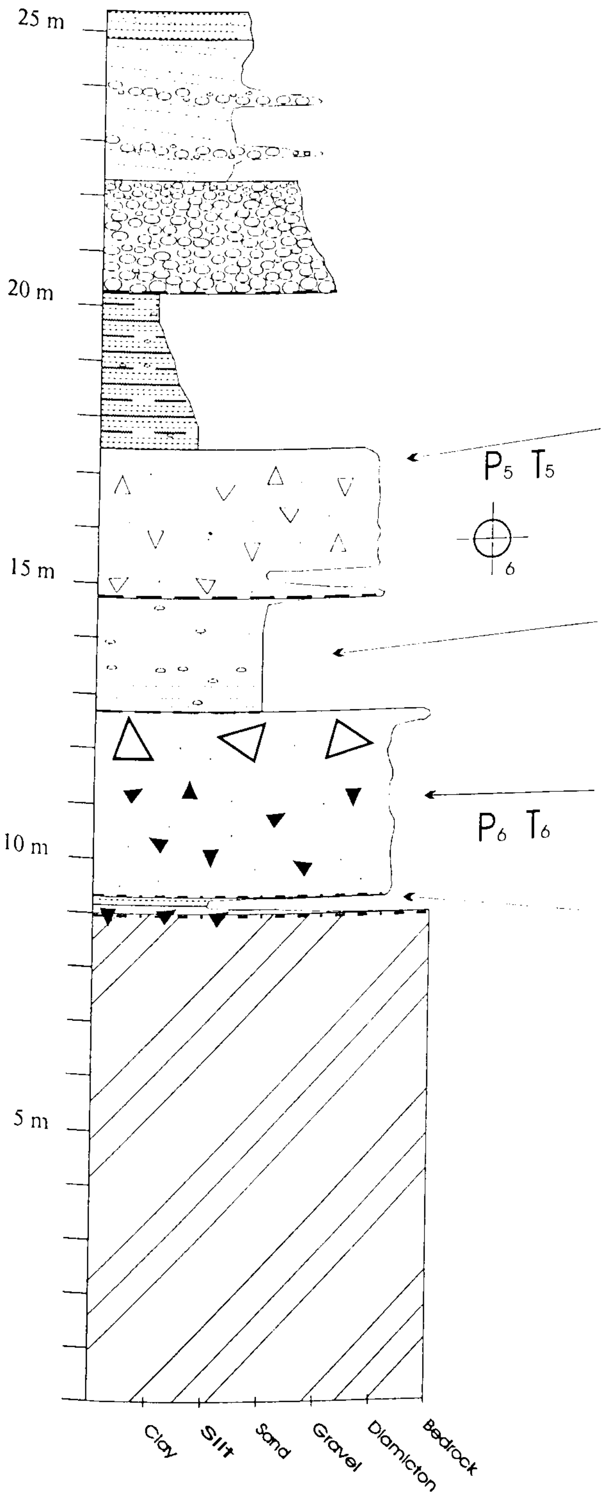
C. Montane diamicton. Colour is light brown. Matrix is sandy silt with 10-15% stone content; stonier at top than at base. Lower contact is gradational over 30cm. Fabrics both at middle and base of unit indicate ice flow from N. (Unit 2B)

B. Montane clayey diamicton. Colour is dark grey. Matrix is cohesive, with 10-15% stone content. Fabric indicates ice flow from NNW. Lower contact is abrupt. (Unit 2B)

A. Montane diamicton. Colour is a light grey-tan. Matrix is friable silty sand with 15-20% stone content. Diamicton exhibits some fissility, but is generally massive. Some stratification exists in the form of horizontal silty beds about 2cm thick, continuous over several metres. Lithologies are mainly weak sandstone and mudstone, limestones, quartzites, and some from the Purcell group. Fabric indicates ice flow from NW; bullet boulders lie along the N-S axis. (Unit 2B)

BIRD RESERVE SECTION (2)

82 G/9 (Blairmore): 715200, 5491200



I. Fine sand and silt. (Unit 8)

H. Silt with gravelly layers that parallel slope. (Unit 8)

G. Gravel. Poorly sorted pebble- and cobble-gravel with sand. Coarsest at base; cobbles up to 20cm. Apparent imbrication indicates flow from the south, the flow direction of present-day Castle River. (Unit 6)

F. Rhythmically bedded silt and clay grading up to massive heavy clay with a few dropstones. (Unit 5)

E. Continental till. Medium brown where damp, tan/buff where dry. Not very stony, massive diamicton with a clayey silt matrix. Shield stones present. Lowest 15cm are stratified. Lower contact is gradational. Fabric indicates ice flow from SSE. (Unit 4A)

D. Fine, slightly stratified sand that contain some clasts, mixed with a moderately stony, silty matrix diamicton. Lithologies are montane. Many clasts are well-rounded, some subrounded or subangular. (Unit 3)

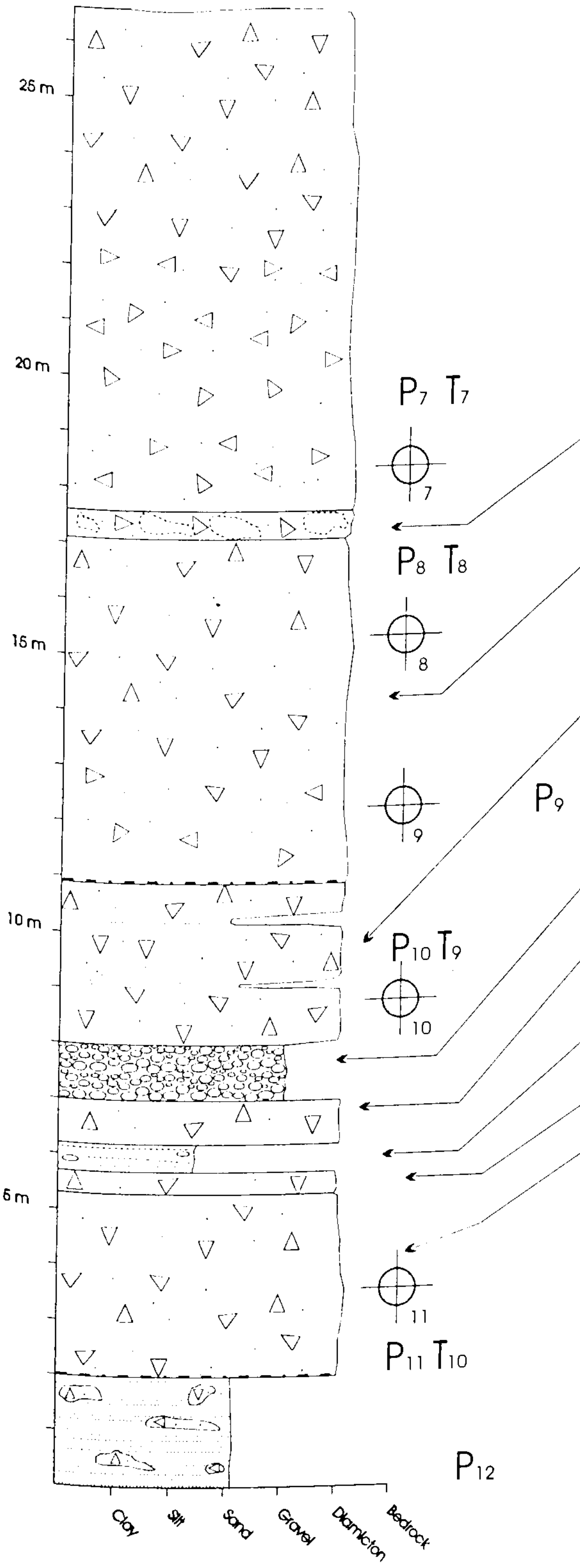
C. Massive Montane diamicton. Stony and well indurated with a sandy silt matrix. Top is marked by a lag of faceted boulders; striations on boulders trend between 60-85 degrees. (Unit 2B)

B. Contorted and discontinuous laminated silt with some lenses and bands of silty diamicton. 2cm of laminated silt lie along an abrupt lower contact. Comminution zone of sandy silt with numerous 20cm blocks of sandstone lodged at base. Striations and bullet boulder indicate ice flow direction from the SW. (Unit 2A)

A. Bedrock

BITANGO SECTION (13)

82 H/5 (Brocket): 297500, 5493700



J. Continental diamicton. Sandy silt matrix. Fabric indicates ice flow from SE. (Unit 4A)

I. Sand intraclast layer. Intraclasts up to 10cm of fine light grey sand are angular and irregular in shape within diamicton. (Unit 4B)

H. Diamicton with a cohesive matrix and 5% stone content. Contains Shield stones. Lower contact is gradational and marked by rip-ups of sand from layer below. Fabrics indicate ice flow from SE at base and NE at top of unit. (Unit 4A)

G. Stratified zone characterized by diamictons containing Shield stones interstratified with thin sheared and contorted sand layers. Lower contact is abrupt. Fabric at base indicates ice flow from NE. (Unit 4B)

F. Poorly sorted pebble gravel. Contorted and varies in thickness from 0.1 to 1.2m. (Unit 4B)

E. Diamicton with sandy silt matrix and clasts up to 5cm with some silt beds. (Unit 4A)

D. Alternating layers of fine sand and silt with pebbles. (Unit 4B)

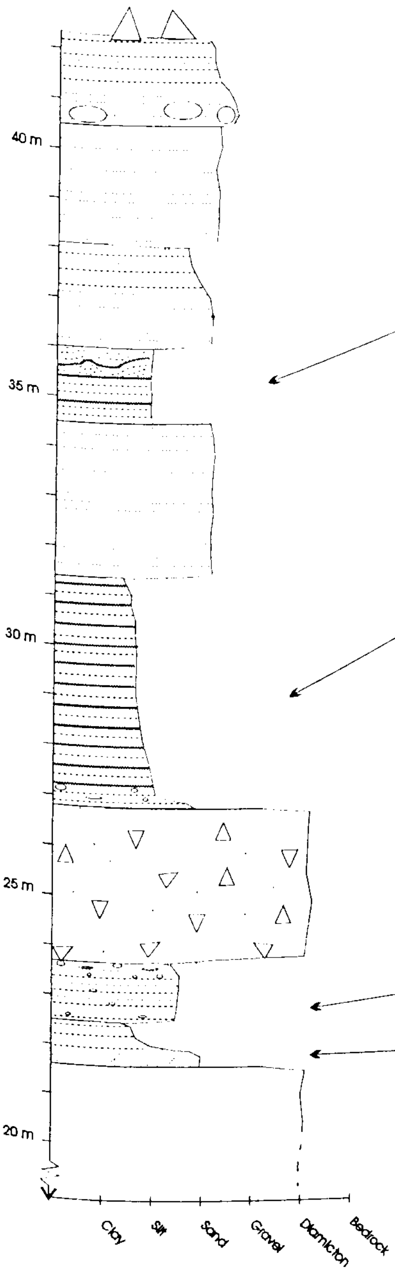
C. Stony silt or silty diamicton. (Unit 4A)

B. Continental diamicton. Light grey where dry and dark greyish brown where moist. Cohesive silty clay matrix with 10% stone content that decreases upward. Contains numerous Shield stones. Uppermost 70cm contains some interstratified silt beds. Lower contact is abrupt and somewhat sheared; some thin sand beds are injected upward. Fabric indicates ice flow from NE. (Unit 4A)

A. Massive fine sand with some thin diamicton lenses. Extremely consolidated unstructured blobs of diamicton up to 50cm long with ragged edges and a cohesive silty clay matrix with clasts to 7cm. Lithologies include Shield granites. (Unit 4B)

BROCKET SECTION (top half) (14)
Described by A. MacS. Stalker (1963)

82 H/12 (Brocket): 303700, 5497500



P. Lower contact obscured. Massive sand with boulders to 60cm in lower 60cm of unit. Silt and sand with scattered stones in rest of unit. Surface has scattered large boulders. (Unit 7)

O. Lower contact obscured. Slumped sand. (Unit 7)

N. Gradational lower contact. Stoneless fine sand grading to silt and sand in upper 60cm of unit. (Unit 7)

M. Lower contact obscured. Varves of mainly silt with some clay, generally 8cm thick. Upper part of unit is contorted. (Unit 7)

L. Lower contact obscured. Stoneless fine sand. (Unit 7)

K. Gradational lower contact. Stony silt in bottom 60cm, grading into silt and clay varves 7-10cm thick with scattered stones. Stones more rare toward top. (Unit 7)

J. Laurentide diamicton, much slumped. Lower contact is gradational. Light brown colour. Moderately stony with a silty matrix that breaks into small, irregular pieces. Poorly consolidated. Lithologies include Precambrian Shield stones and Crowsnest volcanics. Stone orientations indicate glacier movement from SW or NE. (Unit 4A)

I. Extremely stony silt and fine sand. Increasing stoniness upward. Light grey colour. Beds about 1 foot thick. Sharp lower contact. (Unit 4B)

H. Light grey silt and fine sand with bedding and current ripples. Numerous stones include Precambrian Shield types. Volcanic ash parting near bottom. Grades upward into silt and then clay. Sharp lower contact. (Unit 4B)

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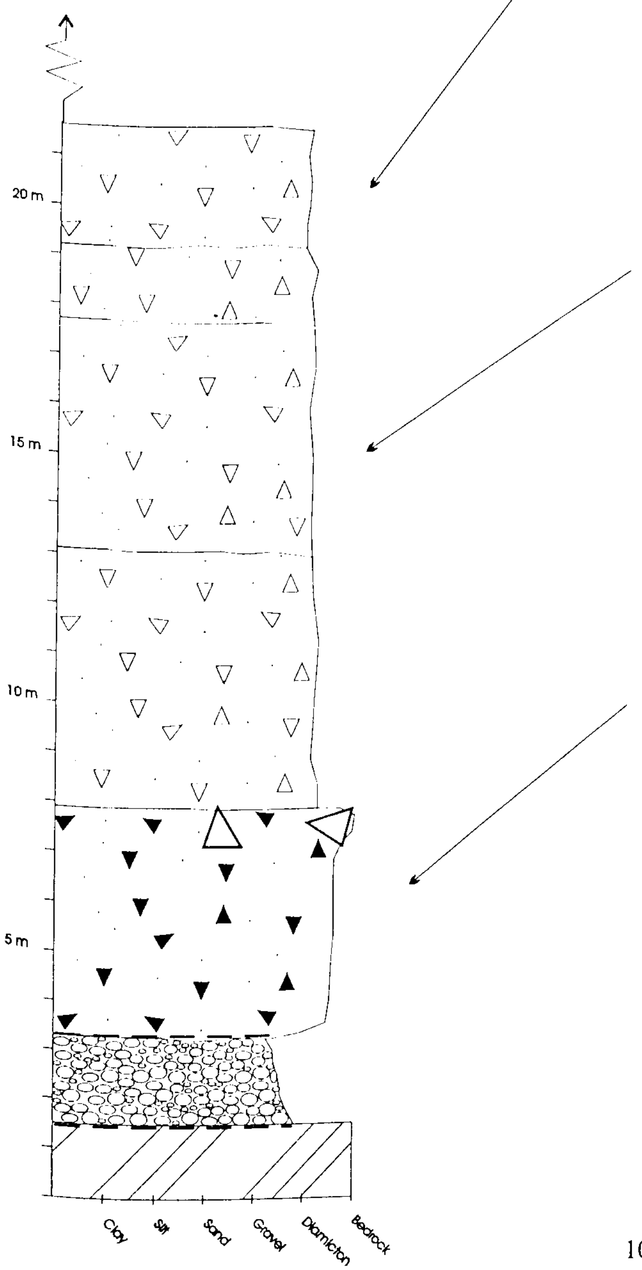
BROCKET SECTION (continued)



G. Laurentide diamicton. Light brown with many rusty streaks. Silty and unconsolidated and does not form a prominent vertical cliff face. Contains Precambrian Shield stones. Lower contact is gradational. (Unit 4A)

F. Laurentide diamicton. Dark brown. Silty and poorly consolidated, though more compact and better indurated than overlying till and forms a steeper cliff face. Displays vertical structure, tending towards columns. Moderately stony with Precambrian Shield stones and Crowsnest volcanics. Stone orientations indicate glacier movement from SW or NE. Lower contact is generally sharp, locally appears gradational. (Unit 4A)

E. Laurentide diamicton. Light bluish grey, somewhat darker at top. Indurated, compact clayey and silty diamicton with columnar structure. Moderately stony with Precambrian Shield stones and Crowsnest volcanics. Stone orientations indicate glacier movement from SW or NE. Lower contact is sharp. (Unit 4A)

D. Laurentide diamicton. Dark brown or grey to black. Clayey indurated, compact, massive diamicton that does not form a steep cliff face. Breaks into small, angular pieces 2-8cm long. Contains Precambrian Shield stones and Crowsnest volcanics. Stone orientations indicate glacier movement from SW or NE. Lower contact is sharp. (Unit 4A)

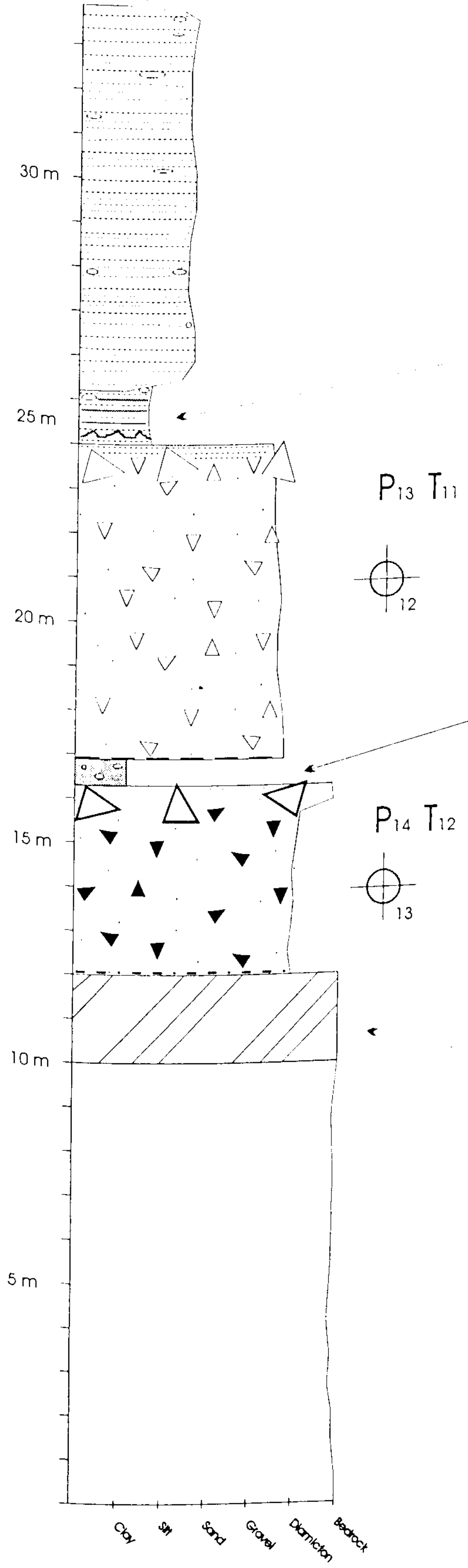
C. Diamicton. Light grey where dry, dark brown where moist. Indurated, resistant, silty diamicton with tendency to columnar structure, and forms a nearly vertical cliff face. Very stony. No Precambrian Shield stones, but contains Crowsnest volcanics. Stone orientations indicate glacier movement from SW or NE. Locally, there is a well-striated boulder pavement at top of this diamicton, with soled boulders to 60cm long. Lower contact is gradational. (Unit 2B)

B. Gravel. Well rounded to subrounded stones averaging between 5 and 8cm, but ranging up to 25cm long, with a brown silt or fine sand matrix. Decreasing number of stones and increasing content of matrix toward top of unit. No Precambrian Shield stones. Top foot of gravel is weakly cemented with lime. Sharp lower contact. (Unit 1)

A. Bedrock. Willow Creek Formation.

BROCKWELL GULLY (17)

82 G/9 (Blairmore): 710950, 5503900



G. Sandy silt with some faint thin bedding and dropstones. Lower contact is abrupt. (Unit 7)

F. Laminated clay and silt. Upper half consists of laminated clay and silty clay with numerous dropstones. Lower half is dominated by interstratified, contorted beds with prominent soft-sediment deformation structures. Contains some diamicton lenses. Lower contact is abrupt. (Unit 7)

E. Massive Continental diamicton. Dark greyish brown in colour. Clay-rich matrix with 10% stone content. Shield stones present. Top 40cm contains a prominent layer of boulders, and a few stratified layers of silty clay or clay. Lower contact is gradational over 15cm. Fabric indicates ice flow along a N-S axis. (Unit 4A)

D. Heavy clay and pebbly clay. Top 30cm is massive heavy clay with some dropstones. Lower part is laminated clay and silt that grades upward into pebbly silt with small clay blebs about 1mm in size. Lower contact is abrupt. (Unit 3)

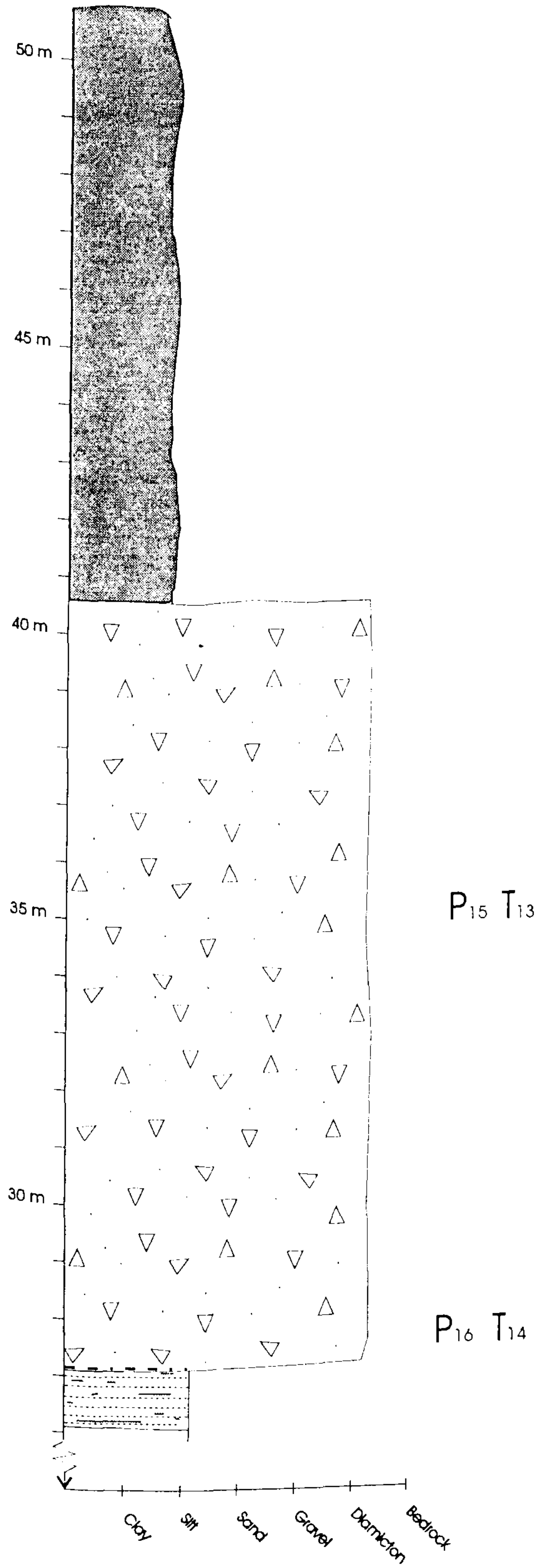
C. Montane till. Colour is medium brown. Silty matrix, with 15% stone content and numerous boulders >1m. Top 15cm contains some sand lenses and faint stratification, and upper contact is marked by a horizontal line of boulders. Lower contact is abrupt; comminuted sandstone within the basal 5cm. Striations on lodged stones at contact trend 215-25 and 170-350 degrees. Fabric indicates ice flow from SW. (Unit 2B)

B. Sandstone bedrock.

A. Colluvium.

CASTLE RIVER GULLY (top half) (1)

82 G/9 (Blairmore): 714700, 5490300

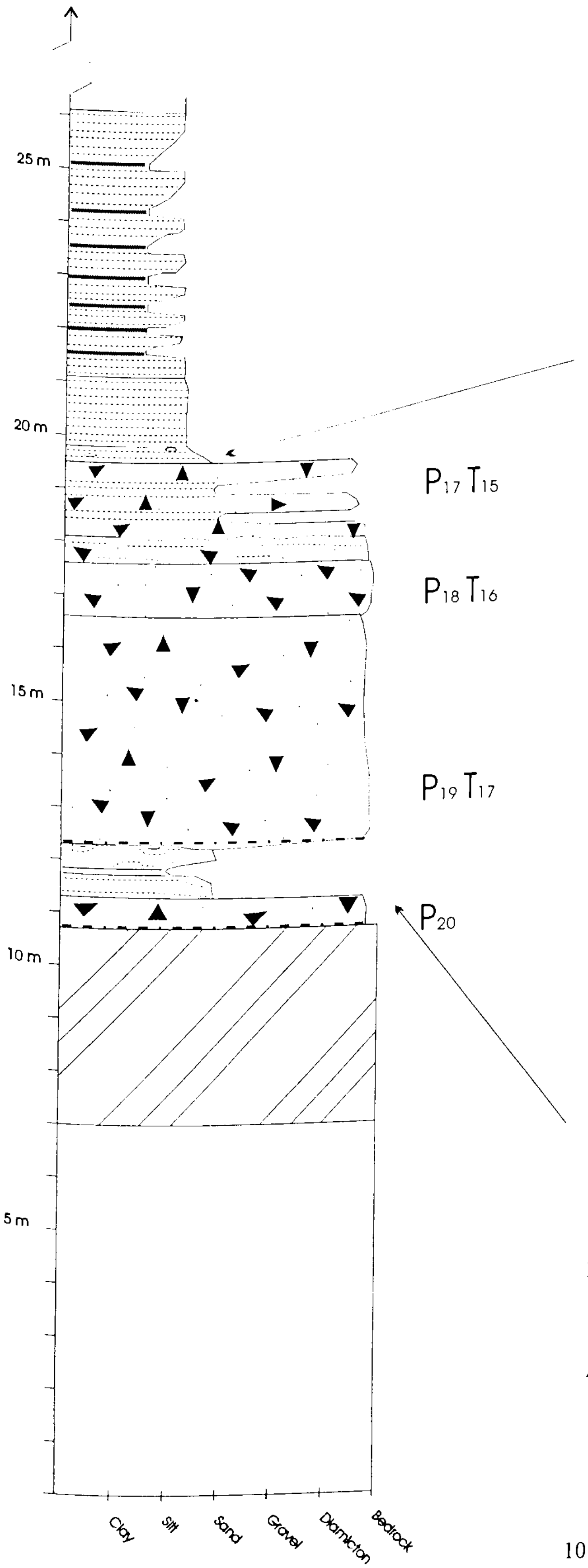


M. Silt and clay. Lower contact is abrupt. (Unit 7)

L. Continental diamicton. Dark greyish brown where moist and pale brown where dry. Moderately stony with a fine sandy silt matrix. Clasts range in size up to 10cm. Contains Shield stones. Lower contact is gradational and sheared over about 10-15cm. (Unit 4A)

K. Silt with some thin bands and small flecks of clay no more than 5mm in size that give the unit a speckled appearance. Also contains some small pebbles and granules. (Unit 3)

CASTLE RIVER GULLY (continued)



J. Rhythmically bedded silt and clay with scattered pebbles. Rhythmites range from 5cm to 50cm increasing in thickness toward the top. The amount of clay in each couplet increases, and silt decreases upward. (Unit 3)

I. Structureless silt with rare pebbles. (Unit 3)

H. Stony silt with numerous clasts of all sizes at base, grading upwards into stoneless, faintly laminated silt with some coal flecks. (Unit 3)

G. Stratified silty diamicton and stony silt in discontinuous, lensoidal beds. Dark-coloured diamicton is montane, and is very stony with clasts up to boulder size. Silt is lighter in colour. Upper half is chaotic; contains pockets and lenses of coarse sandy gravel and stratified silt. Basal contact is a gradational zone 50 cm thick between diamicton below to the stratified silty diamicton above. Some Purcell clasts. (Unit 2D)

F. Diamicton. Lower contact is abrupt and is marked by a colour and texture change. Dark brown where damp. Diamicton is moderately stony with a fine sandy silt matrix. (Unit 2B)

E. Diamicton. Dark brown where damp, grey-tan where dry. Moderately stony with a matrix of clayey silt. Clasts up to about 10cm. Within the matrix, there are small lenses of clay. (Unit 2B)

D. Silts and sands. Lower contact is abrupt in places and jagged in others. Heterogeneous, disorganized, distorted silt and fine sand beds with irregular lenses of diamicton, clay, and coarse sands. Upper contact is sheared; ptigmatic structures in clay and sheared sand beds. (Unit 2C)

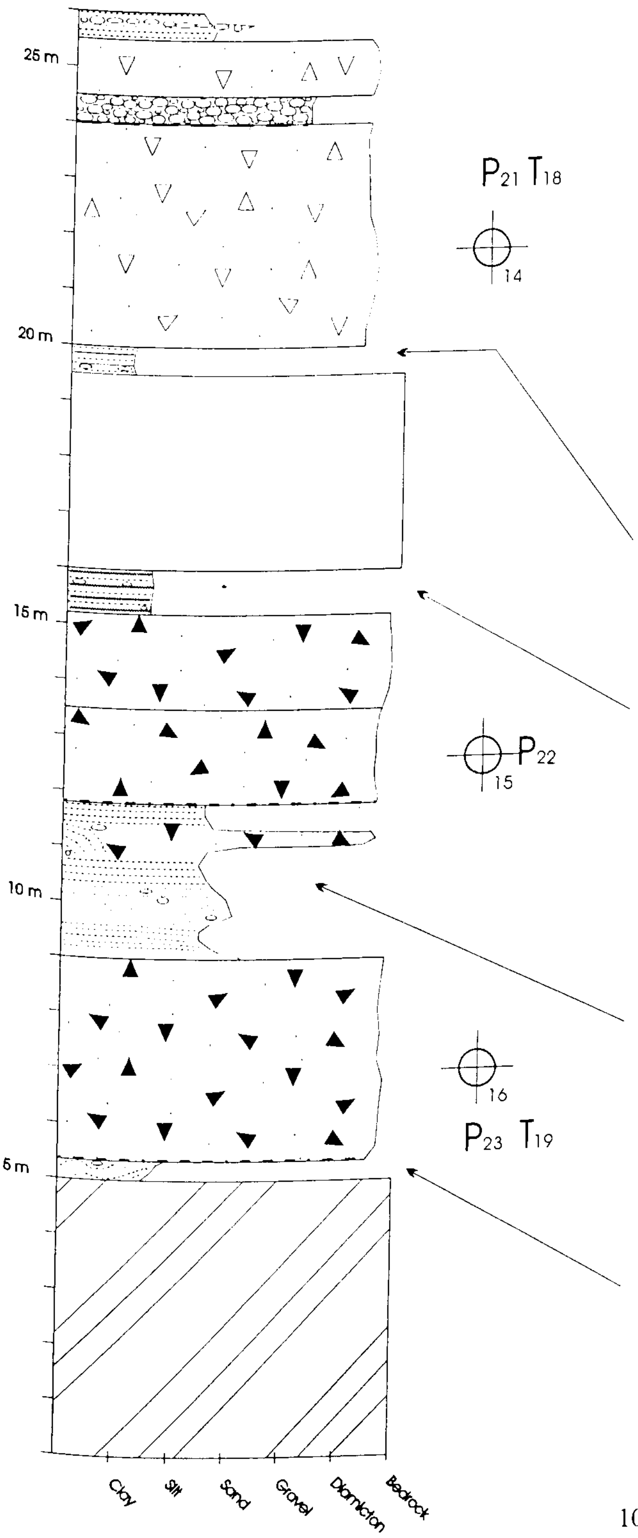
C. Diamicton. Contact with bedrock obscured. Medium to dark brown where damp. Diamicton is moderately to very stony with a slightly silty fine sand matrix. Clasts range up to 15cm in size. (Unit 2B)

B. Bedrock.

A. Colluvium.

CASTLE RIVER SECTION (1a)

82 G/9 (Blairmore): 714500, 5490250
(Compiled from three sections along 30 m of stream bank).



M. Silt with occasional stratified layers of pebbles. Slope-wash colluvium. (Unit 8)

L. Localized unit of stony diamicton of variable thickness. Stonier toward top. Clasts up to 50cm, and some are long-axis vertical. Lower contact is gradational. (Unit 4A)

K. Poorly sorted gravel. Most clasts between 3-5cm, all less than 10cm. (Unit 4B)

J. Continental diamicton. Medium brown where damp, yellowy tan where dry. Moderately stony with a clayey silt matrix. Fractures into small blocky columns. Clasts range up to 20cm. Contains Shield stones. Lower contact is abrupt. Fabric indicates ice flow from ESE. (Unit 4A)

I. Rhythmically bedded silt and clay with some dropstones. Also contains very stony silt bands. (Unit 3)

H. Slumped.

G. Rhythmically bedded silt and clay with some dropstones. Lower contact is abrupt. (Unit 3)

F. Diamicton. Moderately stony with a friable, silty matrix. Montane provenance. Lower contact is gradational over 50cm. (Unit 2B)

E. Diamicton. Moderately stony with a slightly cohesive, clayey silt matrix. Clasts range from granules to cobbles. Fabric indicates ice flow from SW. (Unit 2B)

D. Stratified thin beds of stony silt, fine sand, and silty diamicton. Some beds are distorted, others pinch out over short distances. (Unit 2C)

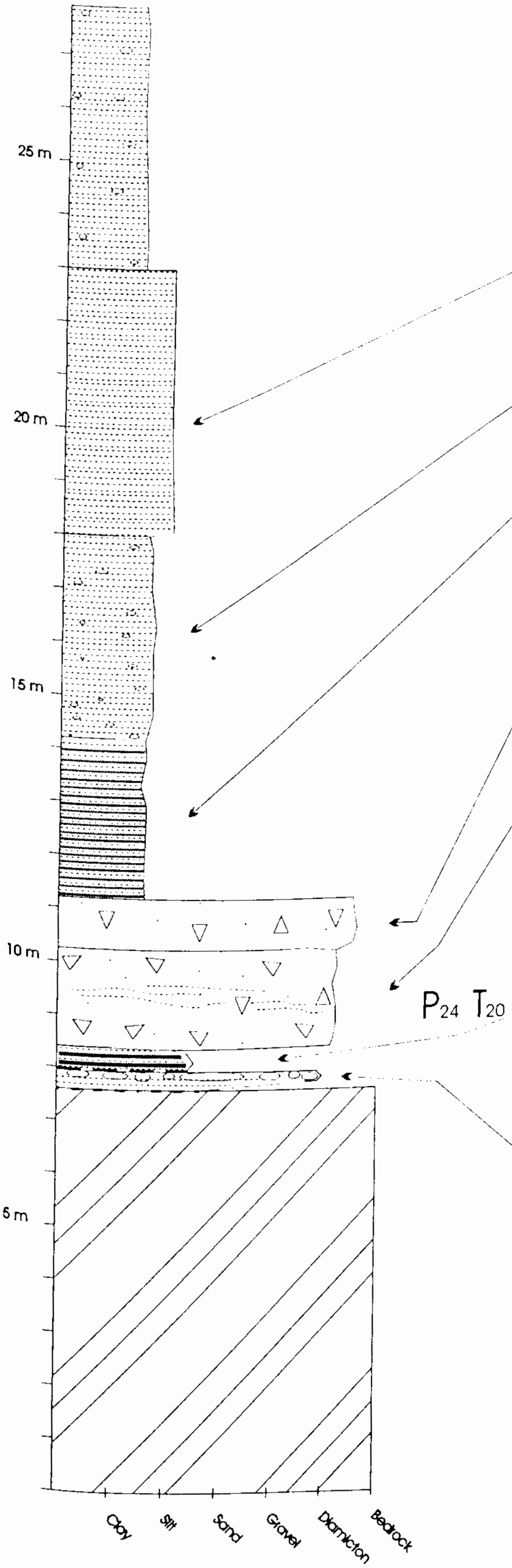
C. Diamicton. Pale tan where dry and medium brown where moist. Very stony with a fine sand and silt matrix. Clasts range up to boulders over 1m long. Fabric indicates ice flow from SW. (Unit 2B)

B. Undulating laminations and beds of silt and sand with scattered pebbles. Granules and small pebbles are concentrated into lenses in places. Increases in stoniness upward. (Unit 2A)

A. Sandstone bedrock.

COWLEY BRIDGE SECTION 1 (20)

82 G/9 (Blairmore): 710450, 5498400



I. Stony silty clay. (Unit 7)

H. Silt. (Unit 7)

G. Stony silty clay. (Unit 7)

F. Laminated silt and clay, near stoneless. (Unit 7)

E. Very stony diamicton with a silty matrix and irregular and discontinuous layers and pockets of sand, gravel, and silt. (Unit 4A)

D. Stratified Continental till. Generally, the diamicton is dark brown where moist and pale yellowy brown where dry. Slightly to moderately stony with a slightly cohesive sandy silt matrix. Clasts to boulder size. Shield stones present. Contains bands 2-3cm thick which are siltier and paler than the described diamicton, with a gradational contact at their bases, and an abrupt contact at their tops. Most bands are continuous, but some pinch out. Layers of darker diamicton increase in thickness up to 40cm toward the top. Abrupt lower contact. (Unit 4A)

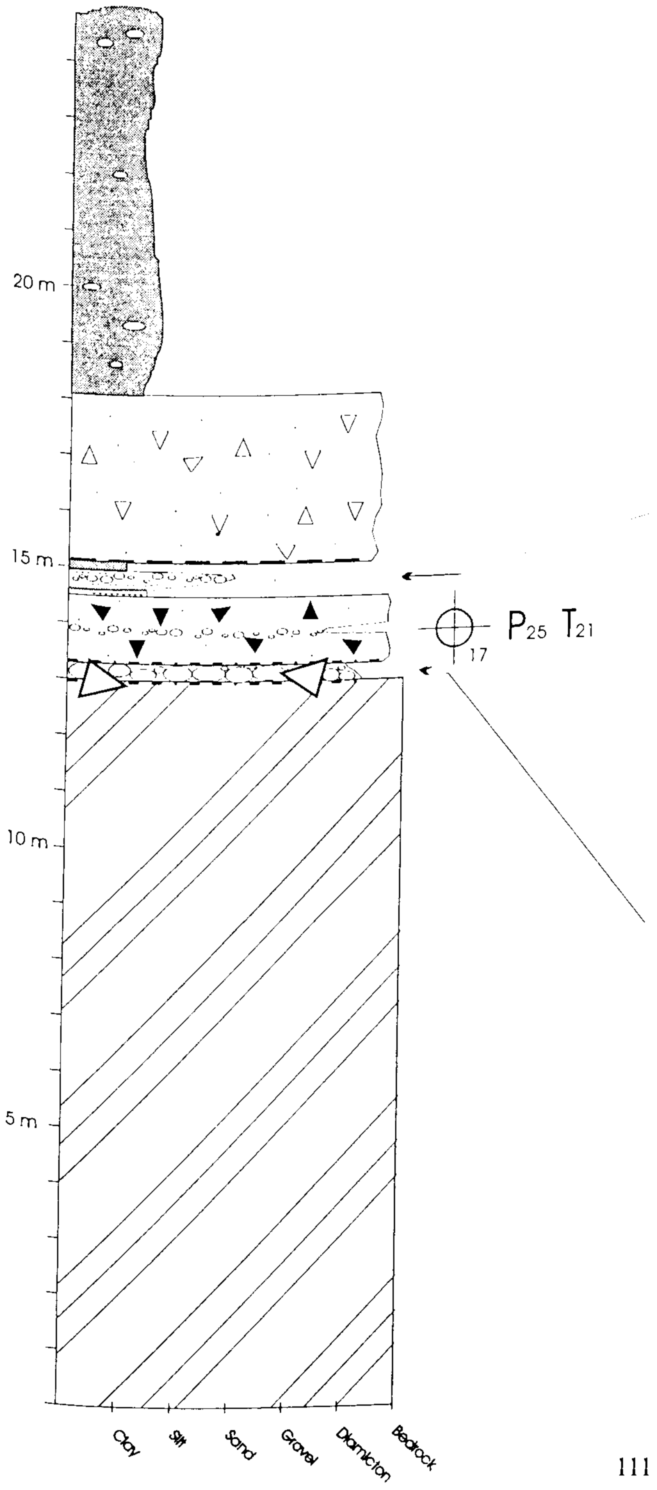
C. Interbedded silt, clay, and diamicton. Silt and clay layers range from 1mm-1cm thick, and contain clasts. Diamicton layers are between 2-10cm thick; they are yellowy brown and very stony with a sandy silt matrix. Occasional lenses of sands. Shield pebbles found. Lower contact is abrupt. (Unit 4B)

B. Comminution zone with a fine sandy silt texture with small pebbles of non-local origin as well as small blocks of ripped-up local bedrock. Upper contact is marked by a layer of cobbles which have been planed on top and have surface striations oriented at 055/235 degrees. (Unit 4A)

A. Bedrock.

COWLEY BRIDGE SECTION 2 (21)

82 G/9 (Blairmore): 710650, 5498300



F. Silty clay with stones, containing Shield pebbles. (Unit 7)

E. Continental diamicton. Medium yellowy brown. Moderately stony with a silty matrix. Contains Shield pebbles. Lower contact is gradational over 10-15cm. (Unit 4A)

D. Interstratified clay, silt and gravelly sand. Lower contact is abrupt and is marked by a layer 3cm thick of banded silt and clay. Middle of unit consists of alternating beds of thinly bedded silt and clay and beds of gravelly sand. The top 10cm of this unit is heavy clay. (Unit 3)

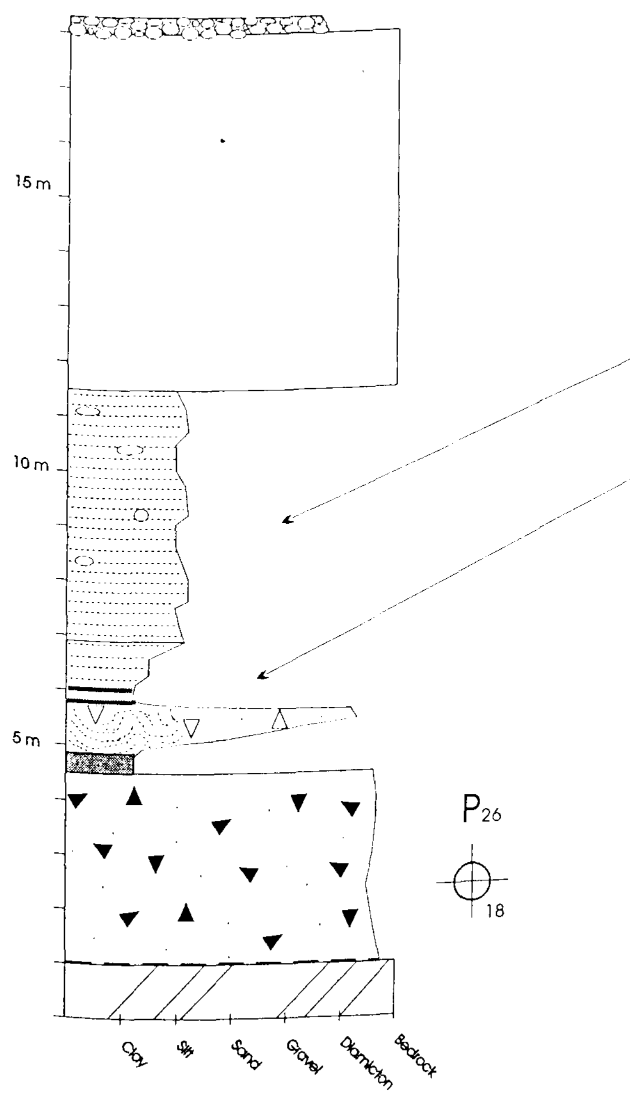
C. Very coarse diamicton. Colour is light to medium yellowy brown, and gets darker brown closer to the top. Moderately stony with some boulders in a fine matrix of fine and medium sand. Contains a 10cm layer of fine gravels. No Shield stones. Lower contact is jagged. Fabric indicates ice flow from the WSW. (Unit 2B)

B. Bouldery very poorly sorted gravel containing much plucked bedrock. Clast sizes range from granules to boulders with many fines in interstices. (Unit 1)

A. Bedrock.

DRIFTWOOD SECTION (9)

82 G/9 (Blairmore): 715800, 5493350



F. Poorly sorted pebble and cobble gravel. Not in vertical exposure. Lithologies include Shield stones and stones from the Purcell group. (Unit 6)

E. Colluvium.

D. Rhythmically bedded silt with few stones in graded beds averaging 2.5cm thick. Gradational lower contact. (Unit 3)

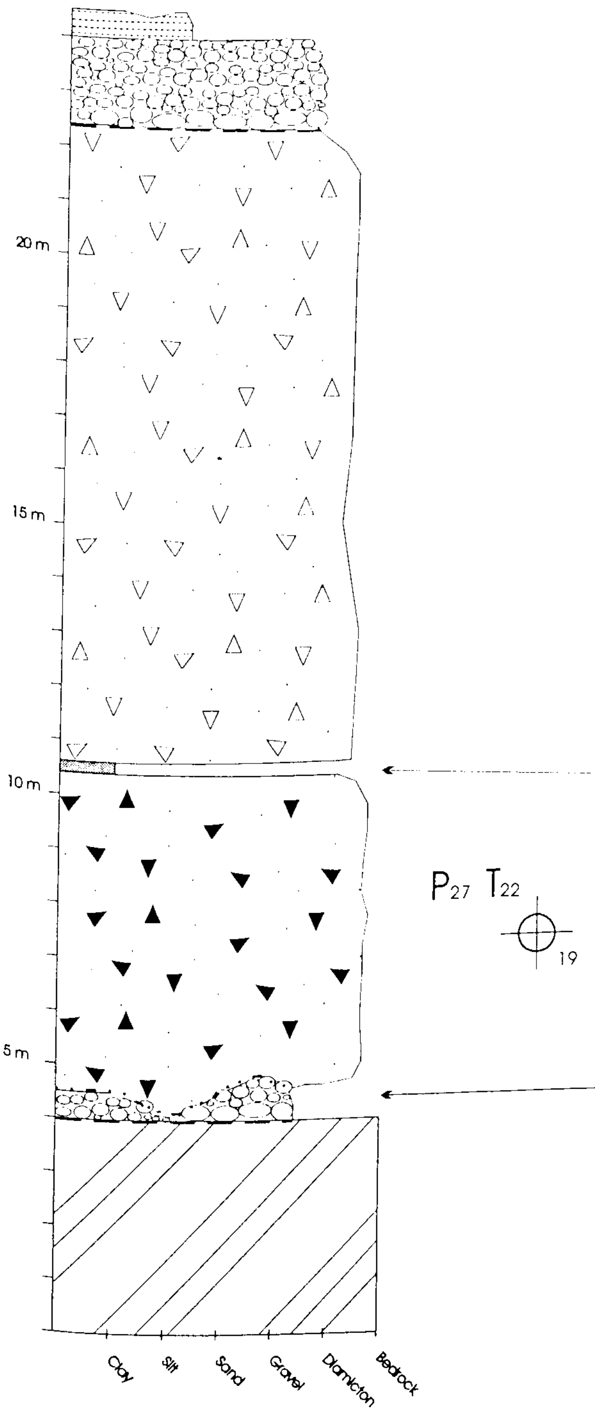
C. Silt with some clay and diamicton. Extremely variable: in general, the top 70cm is pebbly silt with faint stratification and gets less pebbly and more thinly bedded at the top; the middle is extremely distorted and chaotic; the lowest 40cm is alternating layers of laminated silt, clay, and pebbly silty diamicton in relatively horizontal and continuous beds. Contains Shield granites. Lower contact is abrupt and marked by a thin bed of laminated clay. (Unit 3)

B. Montane diamicton. Light brown/tan when dry, medium brown where moist. Extremely indurated. Matrix is silty sand with 15-20% stone content. Numerous Purcell group lithologies present. Massive throughout, except for a lens of silt at base over a horizontal distance of 4 metres. Fabric near top of unit indicates ice flow from SW; striations on bedrock trend between 260-315 degrees. (Unit 2B)

A. Bedrock.

HIGHWAY BRIDGE SECTION (3)

82 G/9 (Blairmore): 715600, 5491800



G. Silt. Aeolian dune deposit. (Unit 8)

F. Poorly sorted pebble and cobble gravel containing Shield erratics. (Unit 6)

E. Continental diamicton with a clayey matrix and Shield erratics. Not well exposed. (Unit 4A)

D. Heavy clay. Not well exposed. (Unit 3)

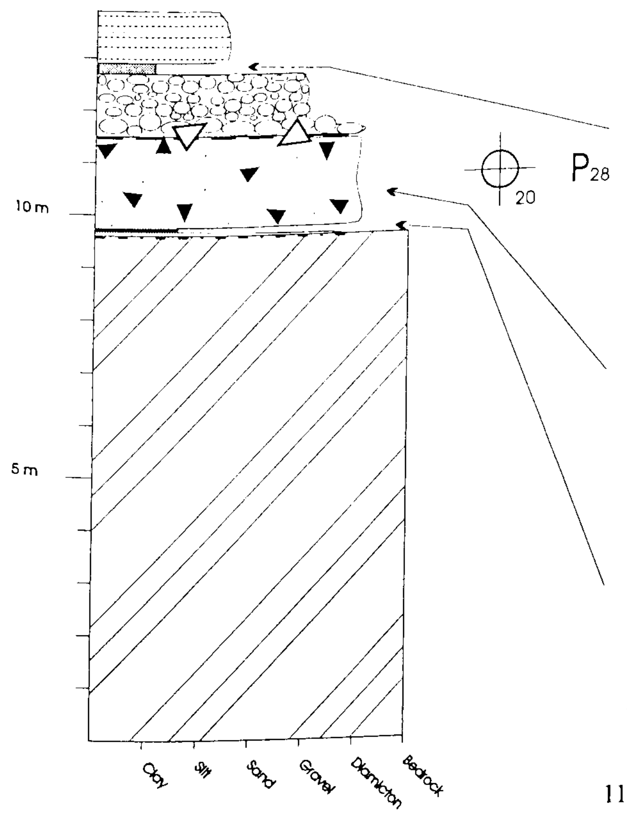
C. Montane diamicton. Very stony with a slightly cohesive matrix. Lithologies are mainly of Purcell provenance. Gradational contact with lower gravels, but sits directly on top of bedrock in some places. Fabric indicates ice flow from E; bullet boulders have parallel straie trending between 70-100 degrees. (Unit 2B)

B. Gravel. Discontinuous, up to 1 metre thick, and lies directly on top of bedrock. Poorly sorted pebble- and cobble-gravel with lithologies mainly of Purcell provenance. (Unit I)

A. Sandstone bedrock.

HIGHWAY THREE SECTION (4)

82 G/9 (Blairmore): 714250, 5492650



F. Massive sandy silt, extensively burrowed. Aeolian. (Unit 8)

E. Laminated dark grey clay, dropstones rare. (Unit 7)

D. Gravel. Ranges from imbricated and stratified to disorganized, and contains lenses of silty sand. Purcell group lithologies are common, as are Shield gneisses. Lower contact is abrupt and marked by large blocks of sandstone up to 1.2 m long. (Unit 6)

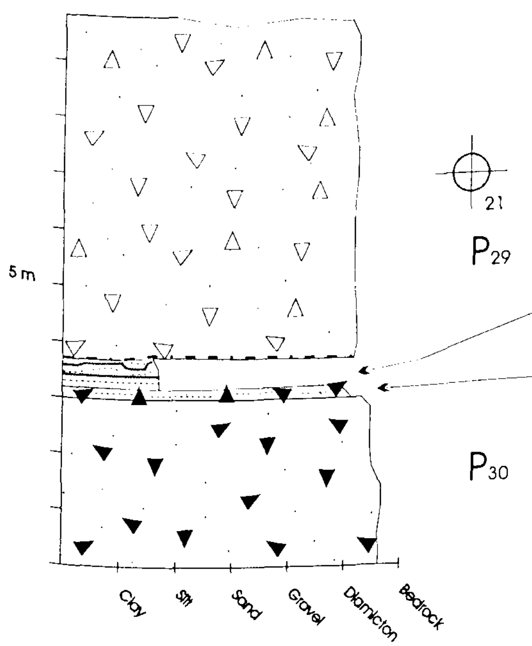
C. Montane diamicton. Grey colour. 5-10% stones. Lithologies are mainly from the Purcell Group; no Shield stones noted. Capped by a partly stratified zone of interfingering diamicton and poorly sorted pebble gravel lenses 2-20cm thick. Abrupt lower contact. Fabric indicates ice flow direction from the NE or SW. (Unit 2B)

B. Zone 10cm thick of plucked and sheared lenses of laminated clay. Straie on plucked sandstone trend 120-300 degrees. (Unit 2A)

A. Sandstone bedrock.

ISLAND SECTION (11)

82 G/9 (Blairmore): 714350, 5498300



D. Massive Continental diamicton. Dark brown. Clayey matrix with 10% stone content. Contains Shield stones. Lower contact is gradational. Fabric indicates ice flow from SE. (Unit 4A)

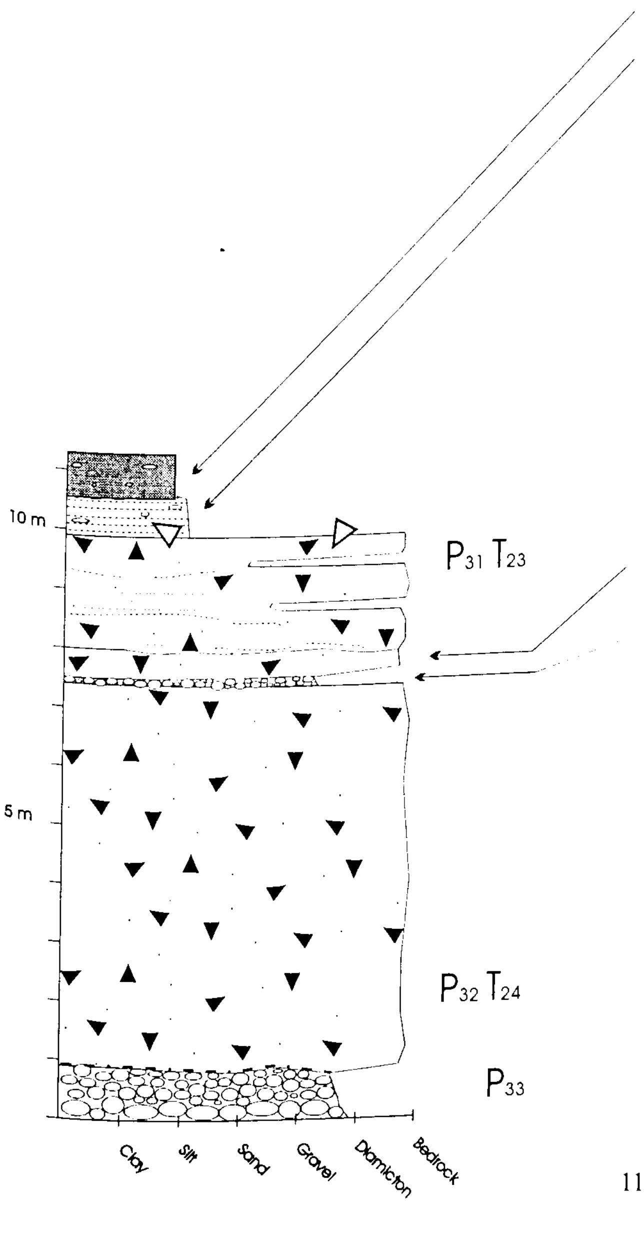
C. Silt and clay laminae interbedded with dark grey clayey diamicton. At top, beds and laminae are convoluted, vertical, or folded over. (Unit 3)

B. Stratified zone of grey diamicton interbedded with thin, near-horizontal silt beds with dropstones. Lower contact is abrupt in some places, and slightly gradational in others. (Unit 3)

A. Montane diamicton. Silty sand matrix with 15-20% stone content. Upper contact is abrupt in some places, and sightly gradational in others. Nailheads on lodged boulders point due east. (Unit 2B)

ISLAND VIEW SECTION 1 (19a)

82 G/9 (Blairmore): 713450, 5498600



G. Slightly pebbly, laminated clayey silt. (Unit 7)

F. Massive pebbly silt that grades upward into slightly laminated silt with a few dropstones. Thin beds of silt containing many dropstones at base. Lower contact is marked by beds draped over stones of lower unit. (Unit 7)

E. Stratified diamicton with fine sand, silt, and clay layers. Sand beds have an abrupt but undulating upper contact, and exhibit some loading structures that inject up into diamictons. Discontinuous silt and clay laminations that are deformed around the base of clasts up to 15cm. Diamictons are non-indurated and very stony with a silty matrix. Most clasts are between 2 and 4cm, but the top 20cm of the unit contains some boulders. Layers are not continuous over distances more than 2m. Lower contact is gradational. (Unit 2D)

D. Very stony massive diamicton. Matrix is sandy silt. Lithologies are of montane. (Unit 2B)

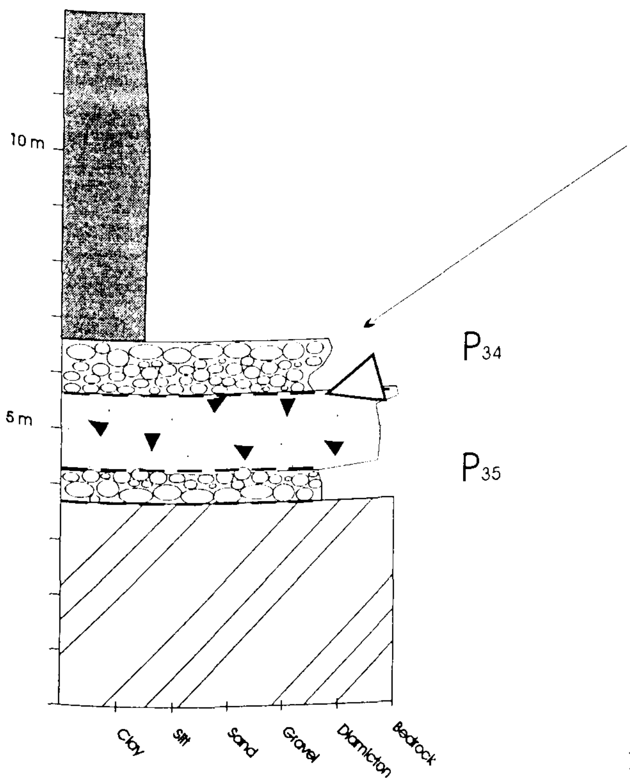
C. Granules and sand, with some weakly laminated silt and clay at base. Variable thickness. (Unit 2C)

B. Well-indurated diamicton. Colour is medium yellowy brown where moist and yellowy light brown where dry. Moderately stony with boulders in a sandy silt matrix. Lower part of diamicton has many 3-5m long shear planes. Lithologies are montane. Lower contact is gradational over 2m; stone content decreases upward. Bullet boulder is oriented at 323 degrees dipping to the north with parallel striations. (Unit 2B)

A. Faintly stratified, poorly sorted gravel up to 20cm. Individual layers range from slightly imbricated to disorganized. Contains some lenses of bedded medium sand 30cm thick. Lithologies are all montane. (Unit 1)

ISLAND VIEW SECTION 2 (19)

82 G/9 (Blairmore): 713450, 5498700



E. Slumping silty clay with some laminations; almost stoneless. (Unit 7)

D. Gravel with some stratification. Lithologies include Shield granites and clasts of mountain provenance. Upper half of unit is clast-supported pebble gravel, containing some clasts up to 30cm. Lower part is disorganized and poorly sorted sandy fine gravel with rounded clasts up to 20cm. Abrupt lower contact is marked by a huge sandstone boulder. (Unit 6)

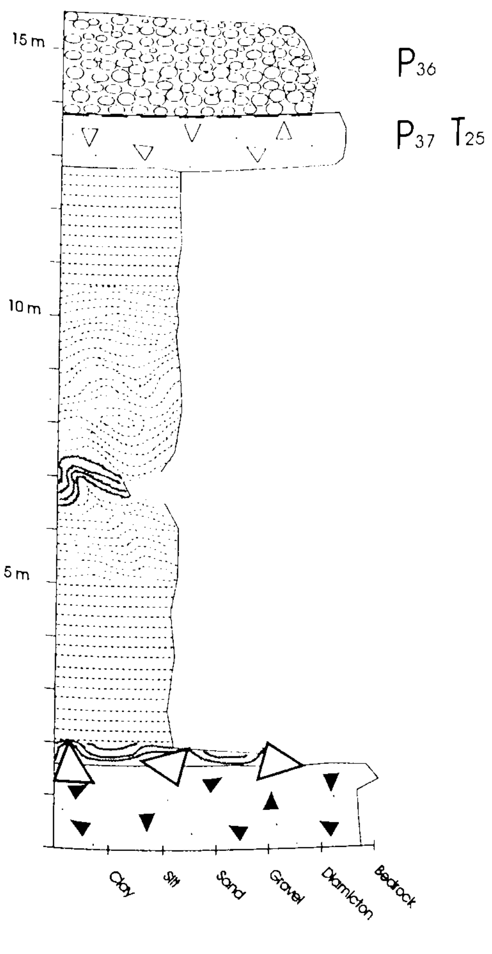
C. Diamicton. Yellowy medium brown where moist and yellowy-beige where dry. Moderately stony with a sandy silt matrix. Lithologies are montane. Gradational lower contact over 25cm. (Unit 2B)

B. Moderately sorted gravel. Clasts are rounded and subrounded and are pebbles and cobbles, but Some are up to 30cm. Lower contact is abrupt. (Unit 1)

A. Bedrock.

LOGBOOM SECTION (8)

82 G/9 (Blairmore): 715900, 5492900



D. Poorly sorted sandy pebble and cobble gravel. Clasts up to 30cm, most around 5cm. Lithologies are mainly from the Purcell group, but there are also sandstones, limestones and Shield stones. Lower contact obscured. (Unit 6)

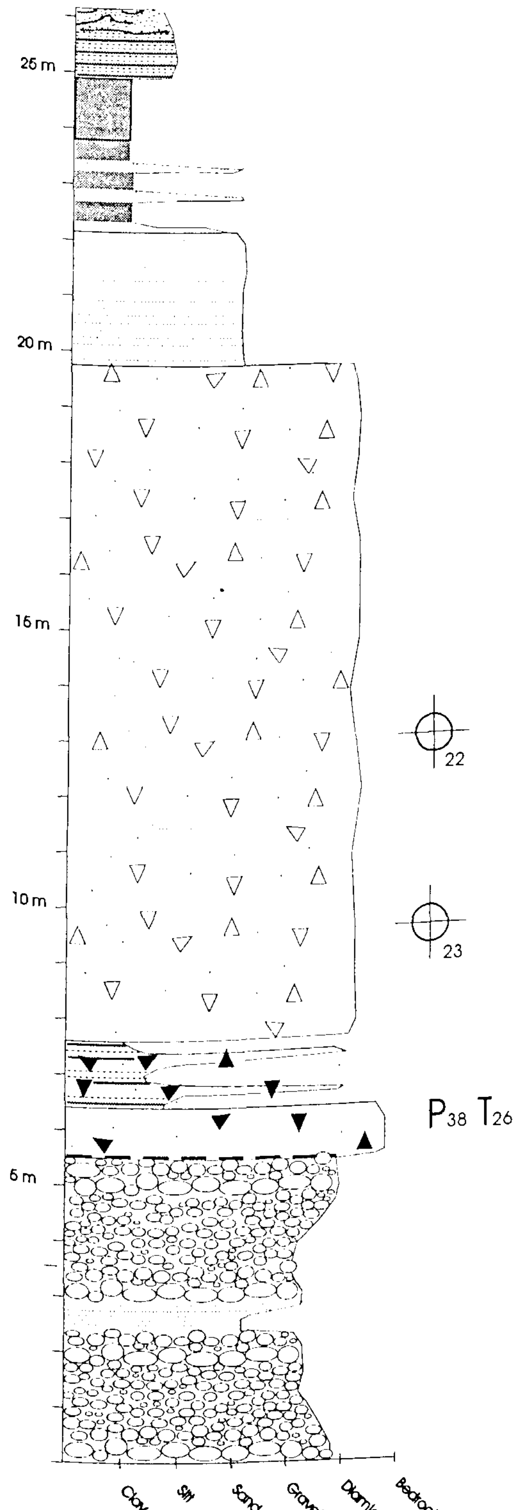
C. Laurentide till. Dark brown when moist. Fissile with a cohesive matrix and 5% stone content, many of which are incompetent and disaggregated. Lower contact obscured. (Unit 4A)

B. Bedded silt and some clay. Upper part is uniformly bedded silt with few stones. The middle few metres are very chaotic and contorted silt. Near the unit's base there are 10cm of well-consolidated silty/sandy pebble gravel over a horizontal distance of about 5m. Lower contact of this unit is very abrupt; clay laminae are draped over the boulders below. (Unit 3)

A. Massive montane diamicton. Light brown/tan when dry, medium brown when moist. Very indurated with a silty sand matrix. Stone content is 15-20%; most clasts are from the Purcell group. Upper contact is marked by a row of sandstone boulders, spaced at approximately every 5m, that extends over a horizontal distance of about 200m. (Unit 2B)

NORTHFORK SECTION (18)

82 G/9 (Blairmore): 713000, 5498700



H. Interbedded silt and laminated clay in bottom 10cm, topped by clayey silt containing undulating and distorted beds of dark clay. (Unit 7)

G. Massive clay; breaks into angular irregular blocks about 2cm in size. (Unit 7)

F. Interbedded and chaotic beds of fine sand and heavy stoneless clay. (Unit 7)

E. Fine sand. Lower contact obscured. (Unit 7)

D. Continental till. Only about 5% stones with clasts to boulder size (40cm). Lithologies include Shield stones. The matrix is silty clay, and in places contains small sand and granule beds that pinch out over a few metres. Lower contact is somewhat gradational--dark grey at base; dark brown above. Fabrics indicate ice flow along SE/NW orientation. (Unit 4A)

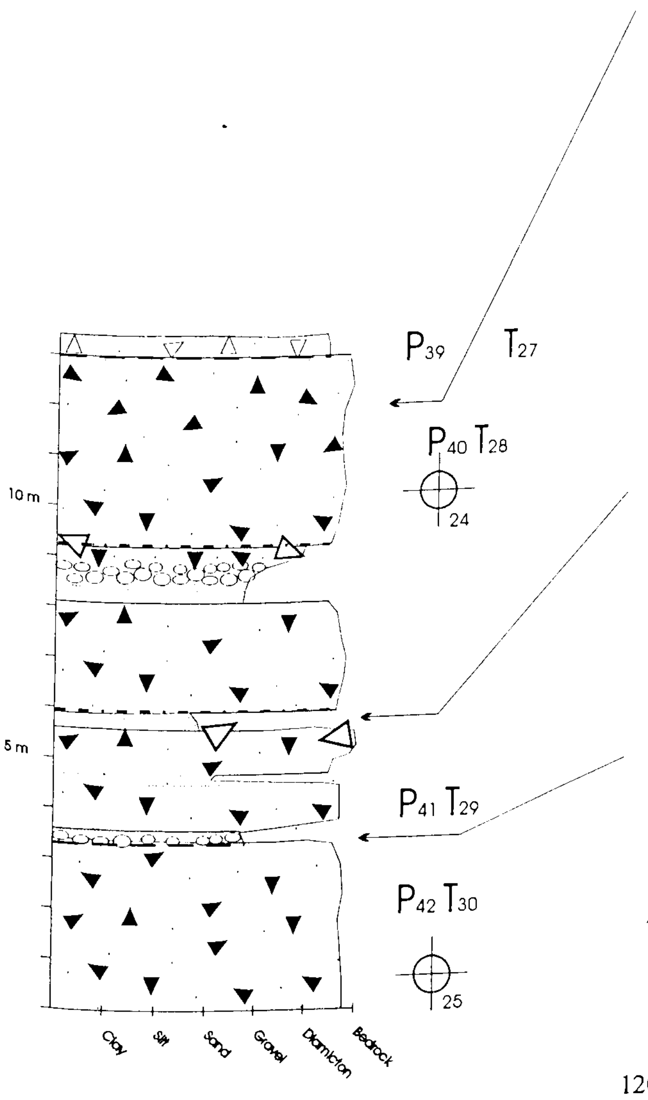
C. Bedded and laminated silt and clay containing dropstones, with interbeds 10cm thick of diamicton. Abrupt contact with unit below. (Unit 3)

B. Montane diamicton of variable thickness. Matrix is a fine sand or sandy silt. Medium brown where moist; light brownish grey where dry. Very indurated. Very stony (25%) at base; gradational lower contact due to incorporation of gravels below. (Unit 2B)

A. Stratified cobble gravel and pebble gravel with occasional lenses of medium sand. Lithologies are mainly grey and white quartzites, limestone, and conglomerates. Imbrication measurements indicate most clasts are dipping to the north. (Unit 1)

NUMBUM BLUFF (12)

82 H/12 (Brocket): 288800, 5495000



H. Continental till. Dark brown colour. Clayey matrix with 10% stone content. Abrupt lower contact. (Unit 4A)

G. Montane diamicton with a sandy silty matrix. Bullet boulders within unit trend 270 and 245 degrees° and fabric indicates ice flow from WNW. (Unit 2B)

F. Stratified and sheared sand and fine gravel beds that grade up into diamicton. Beds and lenses are contorted and vary in thickness along their length. Contains a line of boulders at 8.6m. Upper part of unit is a sandy diamicton containing angular blocks and fragments of bedded sand. Abrupt lower contact. (Unit 2C)

E. Montane diamicton with a sandy matrix and 15% stone content. Most stones less than 10cm, but some boulders are >1m. Limestones are striated, and many stones are faceted. (Unit 2B)

D. Silt and sand with faint contorted structures in bedding. Few clasts, but locally there are some cobbles and pebbles. (Unit 2C)

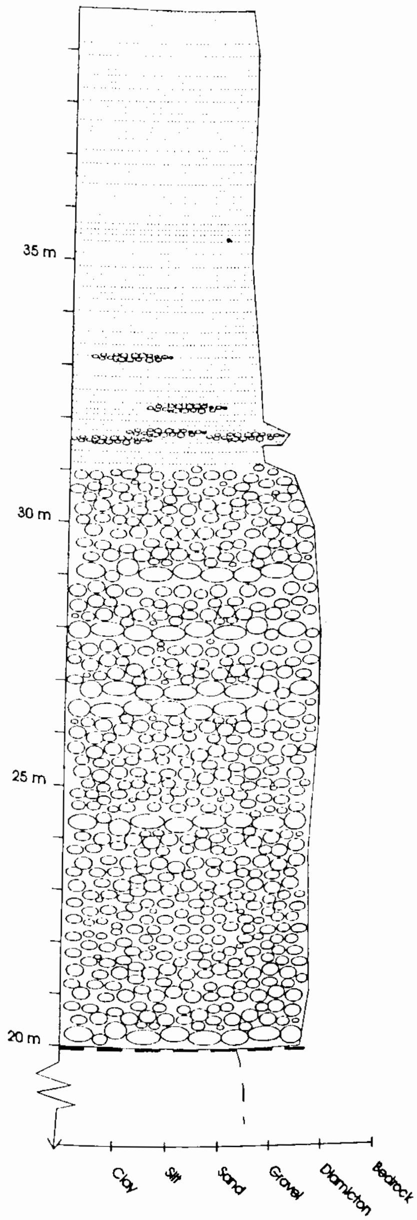
C. Montane diamicton with some thin beds of sand. Same texture as diamicton at base of section. Upper contact is gradational and is marked by a boulder pavement and a chaotic mixture of sand diapirs mixed with diamicton. (Unit 2B)

B. Stratified pebbly sand, sand, and sandy fine gravel. Lower contact is marked by a concentration of cobbles. Unit ranges in thickness from 20-30cm. All interstratified layers are thin and discontinuous. (Unit 2C)

A. Montane diamicton. Light to medium brown colour. Sandy matrix with 15-20% stone content. Numerous sandstone boulders larger than 1m. Lithologies are montane. Striations and nailheads on boulders near base of till indicate ice flow from SW and fabric indicates ice flow from WSW. (Unit 2B)

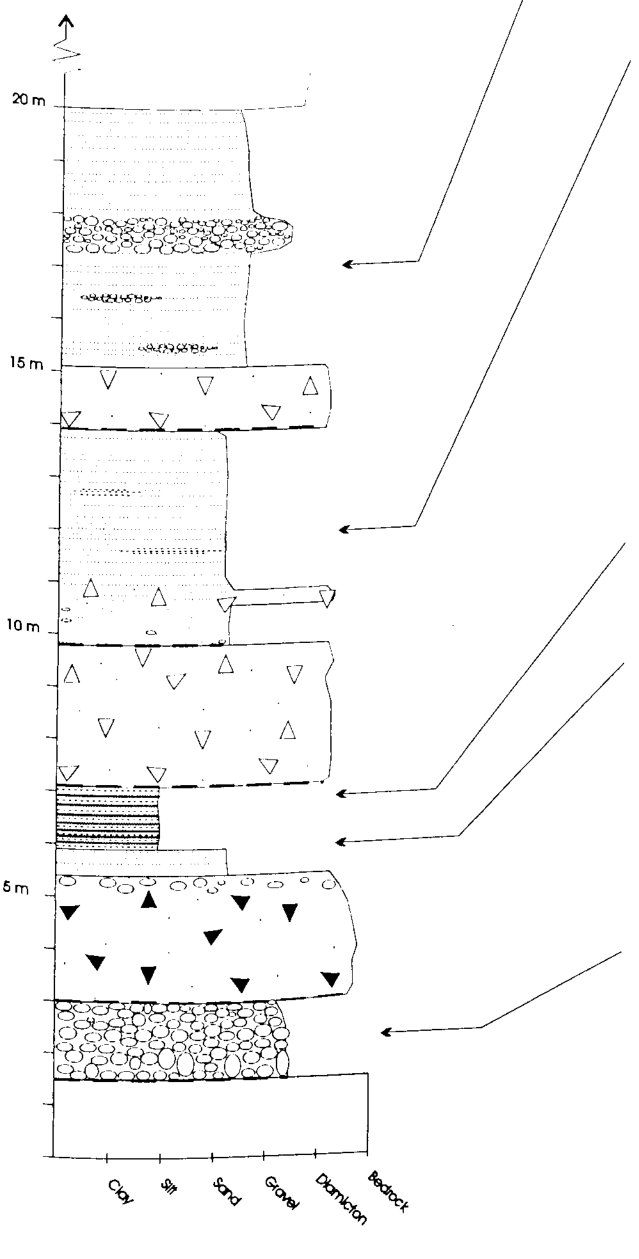
PEIGAN SECTION (top half) (15)
Described by A. MacS. Stalker (1963)

82 H/12 (Brocket): 312700, 5503700



J. Lower 12m is poorly sorted coarse gravel with stones up to 60cm long. Most stones are 2 to 10cm long. Sharp lower contact. Grades laterally into ripple-marked sand. Upper 8m is sand with scattered stones and lenses of gravel at base. (Units 6 and 7)

PEIGAN SECTION (continued)



I. Sharp and undulating lower contact. Lowest 2.5m of unit is medium sand with lenses of fine gravel. Middle of unit is gravel with stones 2-5cm long that grades into massive sand and grit with scattered stones. (Unit 4B)

H. Laurentide diamicton. Dark brown with oxidized, reddish-brown streaks. Silty. Generally massive but locally contorted into overlying sand. Contains Precambrian Shield stones. Sharp lower contact. (Unit 4A)

G. Sharp lower contact. Lowest 60cm is crossbedded grey sand, locally oxidized to yellow, with scattered stones. Above these is 30cm of poorly stratified moderately stony sandy diamicton. It is reddish brown, but is locally oxidized to yellow. Contains Precambrian Shield stones. Top 3m of unit is sand with minor silt and rare stones. Sand is in beds up to 1m thick, and the silt is contained in thin lenses. (Unit 4B)

F. Laurentide diamicton. Dark greyish brown where dry, dark grey to black where moist. Well-indurated, compact, mostly massive, but contains some oxidized sand and silt lenses. Moderately stony and contains Precambrian Shield stones. Breaks into irregular pieces 2-10cm long. Displays contortion and deformation. Sharp lower contact. (Unit 4A)

E. Stoneless silt with some clay in 17 varves that increase in thickness upward. Sharp lower contact. (Unit 3)

D. Reddish-brown stoneless sand with a sharp lower contact. Contains a pebble band and scattered stones near top. (Unit 3)

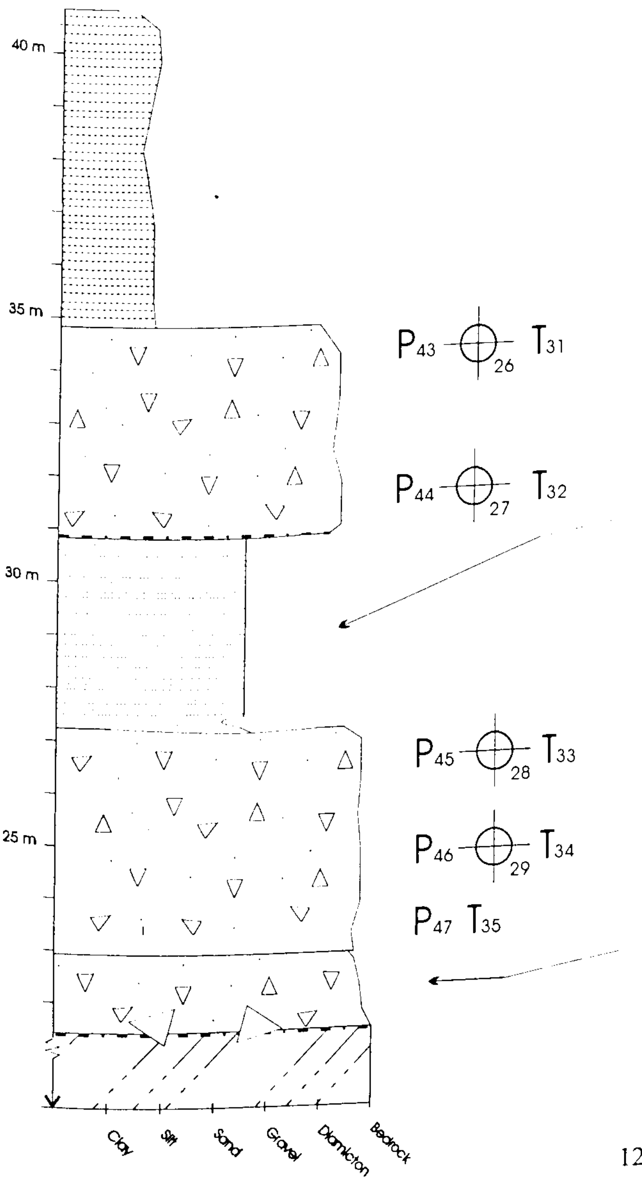
C. Diamicton. Light grey, except top and bottom metres are brown. Massive, except for pebble bands near top. Stones numerous near bottom, but become fewer upwards, some to 30cm long. No Precambrian Shield stones. Lower contact locally gradational, elsewhere sharp. (Unit 2B)

B. Gravel with a reddish sand matrix. Stones to 20cm long, but most are 2-8cm. Lithologies include quartzite, sandstone, limestone, dolomite, conglomerate, Crowsnest volcanics, but no Precambrian Shield stones. Gravel has been contorted, the bedding mostly destroyed, and long axes of many of the stones are now vertical. Lower contact obscured. (Unit 1)

A. Slumped.

PINCHER CREEK SECTION (22)

82 H/5 (Pincher Creek): 283400, 5484900



F. Clayey silt with scattered stones. Clasts are mostly disaggregated sandstone and mudstone, and decrease in quantity toward top. Much calcium carbonate veining within the sediments. (Unit 7)

E. Diamicton. Medium brown. Moderately stony with a cohesive fine sandy loam matrix and clasts to 10cm. Contains coal, disaggregated sandstones, coal, siltstones, and resistant lithologies including Shield pebbles. Clast orientation at base of unit is random. Lower contact is fairly abrupt and undulating, with evidence of a 3mm wide injection plume of sand, and faint bedding distortion in the sand below. Fabric near top of unit is steeply dipping from the NW. The top of this unit is interpreted based on trenches and augerholes bored at intervals on the slope above the vertical section. (Unit 4A)

D. Completely stoneless medium sand with a 10cm band of fine sand and a 2cm band of medium-coarse sand at the unit base. The uppermost part of the sand has very faint diagonal stratification, and faint bedding distortion. Lower contact is abrupt. (Unit 4B)

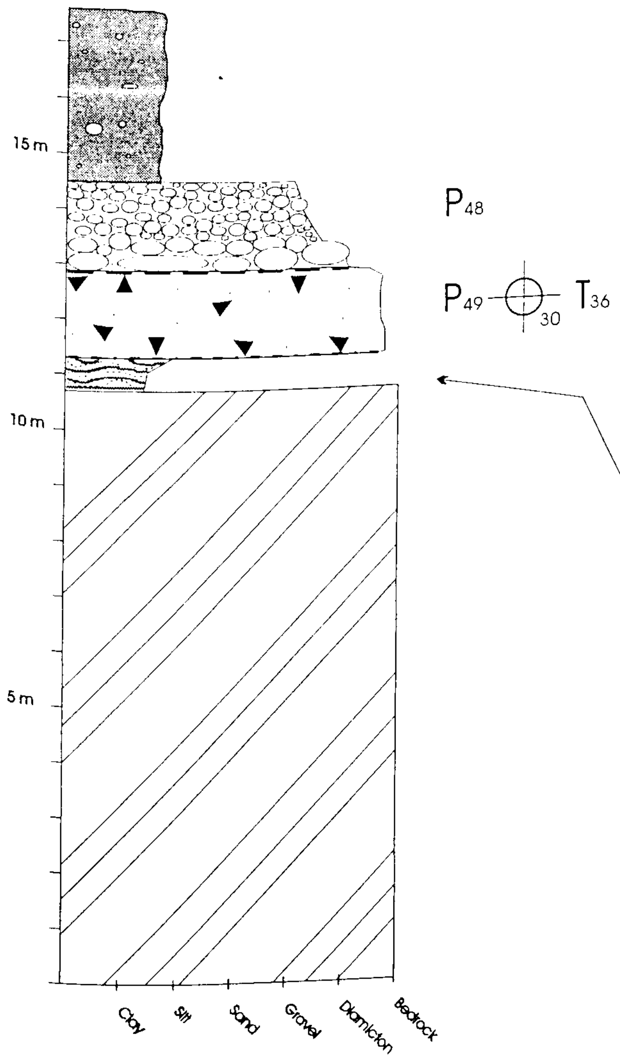
C. Very stony diamicton. Colour ranges from medium brown to dark grey-brown. Matrix ranges from friable silty sand near the base to more cohesive silty matrix containing some clay near the top. Has small blocky ped structure. Clasts are rounded to subangular granules to boulders larger than 40cm; some are flat-iron and keeled. Contains Shield pebbles. Two fabrics taken within this diamicton indicate flow from the east. (Unit 4A)

B. Gradational zone between bedrock and overlying diamicton. The number of local angular grey mudstone bedrock clasts within the diamicton decreases upward through this unit, while the amount of diamicton increases. (Unit 4A)

A. Bedrock. Extends 20 m above creek level.

THREE RIVERS ROADCUT (5)

82 G/9 (Blairmore): 715300, 5482500



E. Massive silty clay with dropstones up to 5cm. Contact with underlying unit is abrupt. These sediments continue up to the level of the plains, 20m above. (Unit 7)

D. Gravel. Mainly Purcell group lithologies, but include Shield granites. Clasts are smaller at near top. Lower part is moderately well-sorted, well-imbricated bouldery cobble gravel with a matrix of pebbles, granules and coarse sand. Boulders >1m form a lag at base, and lower contact is abrupt. (Unit 6)

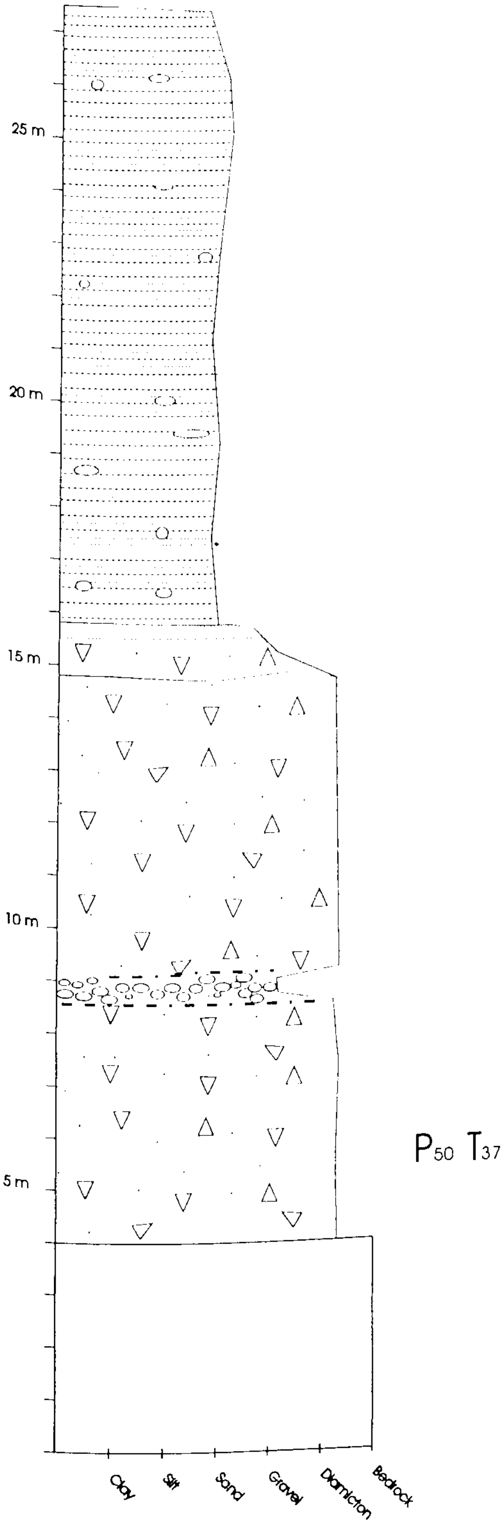
C. Diamicton. Moderately stony massive diamicton with a sandy, clayey silt matrix supporting clasts up to boulder size. Lithologies are mainly from the Purcell group. No Shield stones noted. Fabric indicates flow from the northwest. (Unit 2B)

B. Distorted clay and stony clay. Diamictons and stony clay overlie bedrock; middle is laminated clay and silt and a very distorted broken band of silts; top is slightly stony silty clay and grades into the diamicton above. (Unit 2A)

A. Bedrock.

VAN SANTEN SECTION (16)

82 H/12 (Brocket): 318950, 5507700



D. Sand and silt. Slight evidence of horizontal stratification. Loaded with randomly scattered stones, including Shield gneisses. (Unit 7)

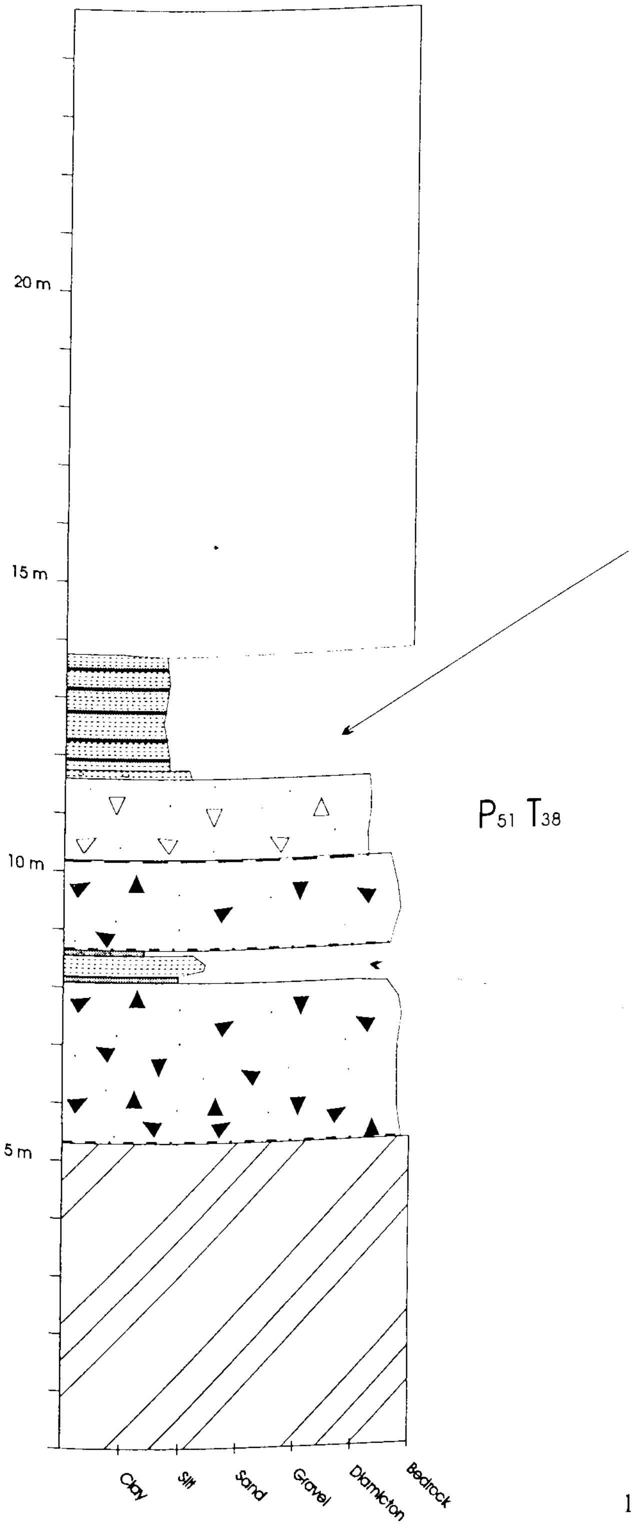
C. Gradational zone. Moderately stratified sandy diamictons and massive, well-sorted medium and fine sand with occasional stones. (Unit 4B)

B. Diamicton. Medium grey brown where wet; light yellowy brown where dry. Sandy/silty matrix has a prismatic fracture pattern with numerous oxidized vertical joints. Stone content less than <5%. Most stones are 5cm or less, and many are well-rounded. Lithologies include Shield stones. At 5.8m, there is a lens 1m long and 20cm thick containing poorly sorted pebble gravels that is bounded on upper and lower surfaces by shear planes. (Unit 4A)

A. Colluvium

VOGELAAR GULLY (6)

82 G/9 (Blairmore): 715700, 5492550



G. Colluvium. (Units 6 and 7)

F. Rhythmically bedded bands of silt (3-10cm thick) and laminated clays (1-3cm thick). The silt contains some stones, and the clay contains some granules. 10 cm of interbedded diamicton and pebbly silt at base. Basal contact is abrupt. (Unit 5)

E. Continental diamicton. Dark brown when moist, pale brown when dry. Slightly to moderately stony with a cohesive clayey silt matrix. Shield stones observed. Contact with unit below is abrupt. (Unit 4A)

D. Diamicton. Yellowy medium brown when moist, pale tan when dry. Moderately stony diamicton with a sandy silt matrix . Clasts are montane and range from granules to boulders. Lower contact is abrupt and undulating. (Unit 2B)

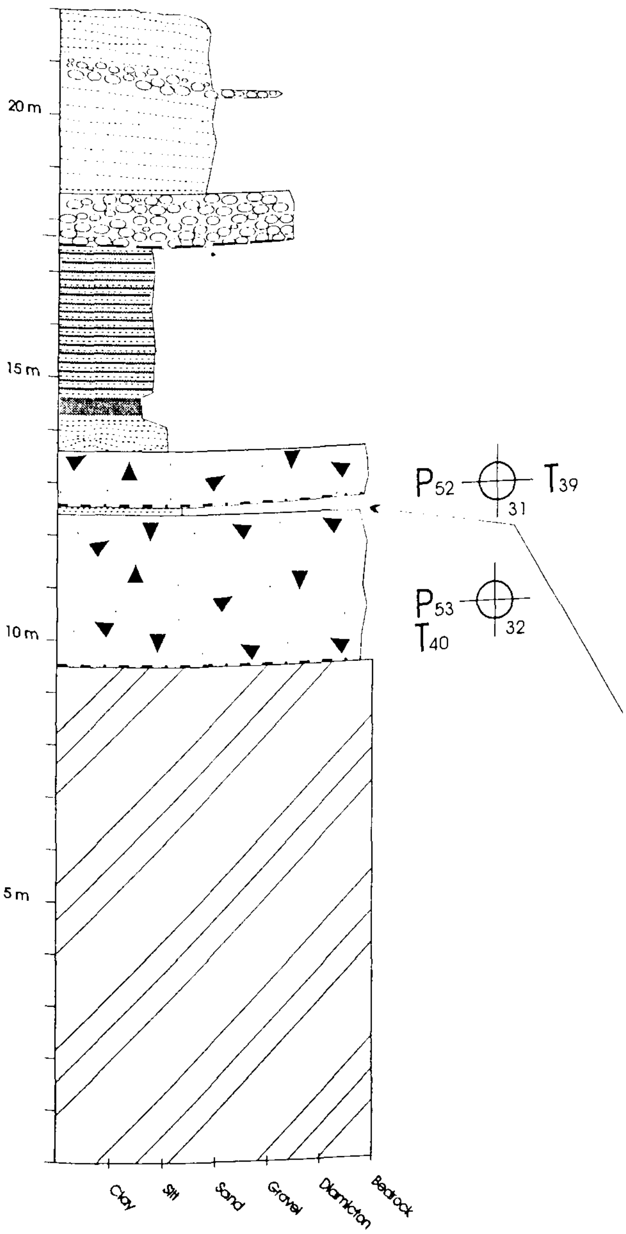
C. Wavy beds of silt and clay with some granules near top. Distorted beds of silt with stones with occasional clay or diamicton lenses in middle. Interlaminated silts and silty clay capped by a thin clay bed at base. Basal contact is abrupt and undulating. (Unit 2C)

B. Diamicton. Medium brown when moist, light tan when dry. Moderately stony with a sandy silt matrix with clasts ranging from granules to boulders. Lithologies are mainly from the Purcell group; no Shield granites. Bottom 60cm is very stony, and basal contact is abrupt. (Unit 2B)

A. Bedrock.

VOGELAAR SECTION (7)

82 G/9 (Blairmore): 715600, 5492650



G. Sandy silt containing bison bones and some pebbly layers that parallel the ground surface. (Unit 8)

F. Gravel, partially slumped. Top 20cm is a moderately well-sorted and partially imbricated pebble and cobble gravel with a very coarse matrix. Clasts are rounded to sub-angular. Lithologies include clasts from the Purcell group, the Front ranges, local sandstones, and Shield granites. Basal contact obscured by slumping. (Unit 6)

E. Rhythmically bedded silt and clay. Lowest metre of unit has undulating silt beds with no stones, topped by massive clayey silt with granules. The remainder of the unit is made up of clay and silt rhythmites containing dropstones. Rhythmites generally get thinner near the top of the unit. Lower contact is abrupt and wavy. (Unit 3)

D. Bouldery diamicton. Matrix is silty, and contains granules and pebbles. There is an abundance of clasts up to 50cm. The fabric for this unit is near random. Lower contact is sheared. (Unit 2D)

C. Pebbly silt. Thickness varies from 0-15cm. Silt is faintly bedded but no beds are continuous, and many pinch out over a few centimetres. There are thin lenses of diamicton within the silt. Basal contact is abrupt and sheared; there are small flame structures and overturned beds. (Unit 2C)

B. Diamicton. Medium brown. Moderately stony with a very fine sand and silt matrix. Contains granules and clasts up to boulder size of resistant lithologies. Lower contact is abrupt but irregular, and some pieces of bedrock are ripped up into the overlying diamicton in a thin comminution zone. Fabric indicates ice flow from the WSW. (Unit 2B)

A. Sandstone bedrock.

APPENDIX B

3-D TILL FABRICS

a. List of azimuth and plunge measurements

b. Fabric diagrams

Fabric 1		Fabric 2		Fabric 3		Fabric 4		Fabric 5		Fabric 6	
Section 10		Section 10		Section 10		Section 10		Section 10		Section 2	
Azimuth	Plunge	Azimuth	Plunge	Azimuth	Plunge	Azimuth	Plunge	Azimuth	Plunge	Azimuth	Plunge
182	21	290	9	46	15	1	4	285	4	246	23
165	22	254	15	315	15	152	15	245	44	181	16
126	31	23	7	316	35	132	11	275	18	177	30
160	21	314	21	115	17	240	11	285	6	139	15
162	16	294	22	298	29	340	11	323	6	152	23
34	10	326	26	39	10	352	17	303	28	185	28
136	21	314	16	14	30	359	10	311	36	38	13
112	3	298	13	41	10	338	30	350	7	132	26
152	28	16	2	112	13	115	34	82	24	90	13
122	34	9	32	344	20	340	14	314	12	50	11
326	8	22	26	351	13	310	14	250	34	131	8
114	18	162	42	18	5	206	9	298	28	136	20
308	6	304	10	244	21	88	45	140	24	42	7
179	10	181	23	278	31	90	36	330	23	159	30
21	19	50	24	322	12	326	16	101	1	141	29
173	30	33	70	215	7	0	11	322	23	141	10
155	14	310	31	231	19	352	34	315	35	272	12
219	27	244	29	101	15	141	8	18	13	134	22
137	36	42	1	18	33	345	22	113	23	231	33
142	15	26	26	199	5	274	27	213	16	198	20
331	13	33	14	22	28	324	15	290	21	150	16
200	18	34	13	222	19	61	22	347	55	214	29
130	14 •	256	36	314	10	20	5	272	7	153	10
332	11	32	0	112	7	168	34	340	8	154	11
315	16	212	0	175	35	337	18	250	23	139	27
31	9	352	12	359	15	158	9	112	8	140	9
18	9	350	36	18	25	159	13	278	15	167	49
292	13	4	11	180	9	173	40	144	8	238	49
186	10	318	9	155	16	164	16	307	14	190	17
164	17	325	31	25	47	38	30			118	15
334	12	321	35	351	13	120	7			73	24
163	12	338	11	51	28	345	12			200	1
131	28	342	14	15	26	336	9			212	6
128	15	336	13	254	7	155	24				
278	13	140	13	0	13	42	23				
130	15	340	6	335	0	318	20				
328	9	50	14	155	0	267	27				
127	19	338	7	287	24	312	54				
175	27	326	10	350	35	38	20				
		338	20	37	32	154	14				
		275	11	354	42	216	19				
						305	4				
						300	14				
						339	29				
						82	17				
						12	11				
						308	27				
						44	3				
						11	34				
						285	55				
						109	35				
						292	12				

Fabric 7		Fabric 8		Fabric 9		Fabric 10		Fabric 11		Fabric 12	
Section 13		Section 13		Section 13		Section 13		Section 13		Section 17	
Azimuth	Plunge	Azimuth	Plunge	Azimuth	Plunge	Azimuth	Plunge	Azimuth	Plunge	Azimuth	Plunge
184	24	52	29	152	10	41	28	45	15	340	17
122	15	146	41	198	54	43	24	349	40	220	9
90	80	50	30	227	10	224	16	130	12	168	3
270	5	197	28	128	31	140	17	359	13	93	67
65	78	32	38	130	20	86	34	135	31	336	16
116	23	44	30	132	25	74	12	54	9	54	2
116	18	346	11	102	20	59	13	175	15	142	30
87	6	138	57	190	24	45	7	16	20	215	4
201	56	47	22	4	6	68	26	49	41	343	35
110	30	29	24	190	27	309	26	58	17	102	9
196	4	46	35	194	18	42	14	31	35	4	42
112	14	274	6	146	32	29	20	170	16	56	6
2	35	46	17	148	19	302	24	43	17	185	3
170	9	58	26	12	81	269	48	75	9	95	10
214	33	359	22	116	9	354	27	252	10	154	18
126	23	209	9	145	29	112	39	160	8	342	23
242	5	188	21	179	22	48	10	245	17	238	27
0	3	282	6	162	3	141	35	214	25	311	35
226	3	229	10	176	19	49	22	254	41	29	7
250	2	14	29	94	14	50	24	163	7	13	26
180	28	51	25	108	18	49	2	24	34	185	22
326	7	92	14	122	20	31	30	346	33	154	27
170	15	125	60	141	27	240	10	250	34	340	13
70	5	44	57	208	4	29	26	258	42	190	28
300	4	350	14	222	13	250	9	243	13	335	17
46	33	73	30	145	23	200	14	76	20	270	26
146	5	63	27	52	42	64	34	49	21	198	36
186	11	48	21	124	8	170	7	9	14	311	23
184	10	261	11	80	26	222	5	65	17	124	16
162	32	141	21	120	35	55	14	65	19	306	17

Fabric 13		Fabric 14		Fabric 15		Fabric 16		Fabric 17		Fabric 18	
Section 17		Section 1a		Section 1a		Section 1a		Section 21		Section 9	
Azimuth	Plunge	Azimuth	Plunge	Azimuth	Plunge	Azimuth	Plunge	Azimuth	Plunge	Azimuth	Plunge
200	35	157	19	56	19	78	3	246	32	228	6
33	17	172	34	296	4	128	15	40	5	26	5
202	25	156	33	282	26	215	23	71	6	28	29
350	13	142	24	28	7	258	42	236	47	226	13
188	13	124	33	262	28	33	20	70	12	231	9
192	11	328	14	222	47	74	27	210	1	216	33
63	15	292	34	141	11	225	14	282	20	230	10
190	34	256	45	235	18	277	5	240	14	236	16
152	32	189	36	48	19	218	23	202	27	250	45
179	18	115	16	191	28	241	18	240	10	6	15
234	26	205	33	216	22	79	19	316	10	220	23
110	40	126	32	280	6	229	4	235	7	263	53
177	15	158	45	270	35	224	15	231	30	181	20
24	5	184	32	218	10	258	28	249	7	276	27
222	61	146	17	316	45	20	27	201	16	304	18
196	13	151	22	334	7	207	8	358	20	44	11
56	34	250	30	286	35	84	22	102	5	92	9
228	14	279	15	346	21	24	27	256	16	230	33
196	14	163	20	212	40	238	3	356	14	83	22
148	20	187	33	70	43	210	16	326	54	71	9
188	13	185	24	336	15	238	45	75	2	50	70
32	14	115	5	215	20	193	21	250	5	216	13
210	9	147	17	174	30	233	12	0	37	206	20
298	2	194	24	140	41	246	15	171	21	47	50
236	10	274	59	258	34	114	33	254	54	12	8
236	30	8	12	67	12	228	34	196	14	128	10
305	16	111	36	329	24	125	50	124	13	304	3
18	2	156	46	165	36	211	57	228	11	239	5
240	14	211	17	266	10	71	6	200	13	96	28
248	11	145	20	305	12	103	33	210	16	115	4
194	20	270	62	289	12	232	11			176	17
		128	34	290	10	1	25			238	40
		336	10	183	28	155	55			40	88
		102	23	143	2	87	20			270	13
		120	8	117	14	326	12			272	14
		267	36	267	9	182	41			7	4
		239	40	279	2	240	18			95	25
		8	40	221	53	298	13			59	11
		255	25	167	16	230	6			76	27
		274	25	143	24	352	47			340	29
		98	35	158	12	244	22			66	25
		176	25	280	20	224	47			236	11
		46	13	270	61	219	31			263	24
		302	48	280	31	71	54			260	9
		204	31	302	29	212	35			253	15
		320	27	174	14	5	26			358	7
		158	35	218	30	176	10			226	20
		135	15	189	8	218	44			136	41
		166	15	259	15	266	27			176	13
		135	32	320	12	29	3			234	7
		193	16							243	21

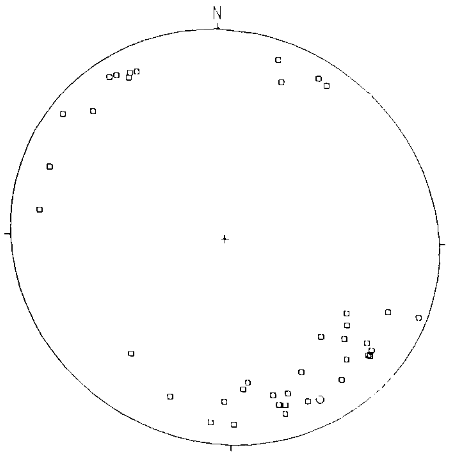
Fabric 19 Section 3		Fabric 20 Section 4		Fabric 21 Section 11		Fabric 22 Section 18		Fabric 23 Section 18		Fabric 24 Section 12	
Azimuth	Plunge	Azimuth	Plunge	Azimuth	Plunge	Azimuth	Plunge	Azimuth	Plunge	Azimuth	Plunge
260	7	236	24	124	22	290	5	250	23	100	15
252	8	224	35	308	3	85	10	110	2	280	16
250	21	76	7	146	9	297	7	272	20	280	22
98	21	145	11	132	20	144	28	260	13	232	17
259	10	228	21	210	44	76	38	90	34	39	45
323	9	97	14	185	24	322	9	64	12	41	28
133	12	146	6	151	17	149	7	318	2	285	15
54	13	286	18	346	43	278	14	339	12	125	18
289	6	167	14	126	10	298	34	75	12	302	28
343	14	151	13	220	4	254	15	344	53	315	30
295	9	128	35	116	12	45	9	68	9	315	19
312	6	222	27	139	37	76	42	96	33	318	32
122	11	76	37	4	37	191	13	280	14	118	15
298	12	256	10	143	34	267	52	156	3	290	40
130	4	50	9	102	14	334	27	129	11	294	14
288	3	290	3	156	4	350	15	330	20	90	19
310	10	220	16	309	39	340	38	130	21	242	15
238	14	122	22	115	23	208	7	126	21	330	23
272	27	227	2	188	23	271	26	60	29	335	25
112	30	251	27	103	9	182	15	80	17	280	15
125	19	240	50	286	31	277	32	88	24	318	15
132	30	272	7	116	17	86	10	268	18	9	35
89	13	136	10	78	8	312	23	290	13	290	18
262	21	176	51	298	10	57	26	42	20	95	29
268	54	247	14	70	12	126	5	149	21	42	9
280	12	229	25	119	4	54	24	100	12		
264	35	225	27	26	14	266	30	78	85		
67	21	95	8	80	9	231	5	62	10		
		216	47	292	26	118	29	48	26		
		136	13	224	11	142	10	106	16		
		29	53	101	14	284	11	282	14		
		25	12	35	25	264	39	283	12		
		302	43	55	17	292	12	338	20		
		100	34	157	16	142	6	234	5		
		196	47	314	13	281	35	150	5		
		301	10			269	40	82	30		
		59	8			356	20	154	21		
		154	37			36	68	314	31		
		101	16			40	24	10	17		
		70	5			320	45	80	35		
		135	12			326	16	306	4		
		10	4			256	13	138	19		
		84	16			0	6	287	10		
		28	4			80	25	68	8		
		44	7			280	42	310	22		
		265	5			342	9	55	6		
		76	10			188	25	165	1		
		230	20			268	33	140	5		
		227	30			269	24	34	18		
		68	17			280	54	295	12		

Fabric 25		Fabric 26		Fabric 27		Fabric 28		Fabric 29		Fabric 30	
Section 12		Section 22		Section 22		Section 22		Section 22		Section 5	
Azimuth	Plunge	Azimuth	Plunge	Azimuth	Plunge	Azimuth	Plunge	Azimuth	Plunge	Azimuth	Plunge
193	11	35	7	226	0	131	18	95	37	280	12
245	24	50	27	319	10	118	15	337	8	317	21
286	21	61	13	151	13	41	20	54	37	78	24
23	49	24	36	191	21	303	17	106	39	321	13
159	33	224	21	217	14	78	20	54	24	81	31
18	16	54	46	164	15	95	0	67	19	339	34
276	20	0	90	101	4	103	19	240	20	290	9
332	37	32	56	138	17	114	16	108	13	172	20
58	33	222	52	266	15	92	10	269	5	346	10
43	24	309	44	258	15	104	7	75	9	88	23
284	11	290	21	72	63	80	6	181	14	318	5
128	18	68	6	339	17	140	31	250	17	326	15
0	27	297	37	72	30	117	6	306	20	330	15
232	14	278	40	76	32	151	1	148	8	345	31
281	9	268	48	258	15	239	10	106	16	309	14
265	19	88	37	341	26	112	20	154	26	340	33
263	21	352	56	44	26	115	7	87	1	28	3
64	17	190	50	258	24	115	5	134	8	94	18
36	22	296	37	158	19	198	27	286	25	318	3
143	20	352	48	122	12	94	17	156	13	310	7
224	20	326	53	96	15	165	29	268	20	352	27
224	44	314	30	43	13	8	5	212	10	6	8
93	30	286	32	203	8	90	22	332	3	343	13
248	7	353	74	23	7	96	11	94	16	170	14
248	26	323	47	271	6	108	10	193	15	31	26
73	28	344	28	326	18	135	19	272	19	103	6
245	11	56	53	224	64	112	7	328	24	319	16
132	27	302	44	100	12	122	35	133	32	124	8
228	21	310	53	195	15	86	21	100	4	209	2
123	13	276	54	2	24	110	27	112	7	305	8
269	8	40	12	130	15	118	10	244	35	258	10
1	36	162	16	115	17	128	16	210	17	301	25
275	15	228	32	304	7	118	43	82	10	31	14
82	14	288	60	304	11	100	8	253	13	36	27
240	34	282	74	357	10	182	16	290	23	18	13
230	13	70	24	119	13	226	42	110	16	288	13
299	13	333	61	254	10	100	32	108	30	266	13
284	27	272	5	96	10	48	16	5	10	242	12
263	26	198	7	50	11	258	46	77	18	308	9
304	24	176	65	64	15	140	10	36	10	276	3
260	78	128	65	254	33	168	21	320	23	71	25
266	26	11	30	232	0	123	5	86	20	329	19
209	10	230	4	162	10	167	59	68	59	184	9
		16	48	38	10	282	27	243	18	340	5
		340	68	108	0	262	3	280	10	4	6
		342	53	198	11	134	15	76	30	26	35
		285	20	266	15	121	22	86	30	320	19
		355	55	118	0	137	16	168	31	280	13
		15	64	26	15	98	70	107	15	27	14
				35	8	353	17	203	13	316	27

Fabric 31		Fabric 32	
Section 7		Section 7	
Azimuth	Plunge	Azimuth	Plunge
260	21	260	34
349	15	232	18
252	52	281	10
57	15	3	37
289	7	278	26
147	28	101	17
134	33	271	25
278	6	284	30
180	3	88	5
198	13	96	33
268	0	226	15
88	0	266	30
267	29	250	6
195	17	261	11
235	2	230	28
234	13	78	8
92	14	258	7
139	26	228	26
264	16	356	24
193	9	228	24
58	4	33	15
263	58	252	67
145	23	242	11
69	14	16	19
69	17	270	17
16	26	227	30
34	28	284	42
250	14	56	18
79	8	266	17
256	28	223	23
88	14	284	41
118	24	216	22
256	15	320	10
245	30	275	38
245	11	240	29
29	23	238	24
276	10	226	16
214	17	289	14
46	10	280	28
148	14	40	3
186	20	2	10
186	13	216	20
102	26	94	21
114	5	92	17
20	16	0	43
236	5	274	5
42	26	57	20
222	10	258	6
78	13	256	22
290	5	25	18
148	6		

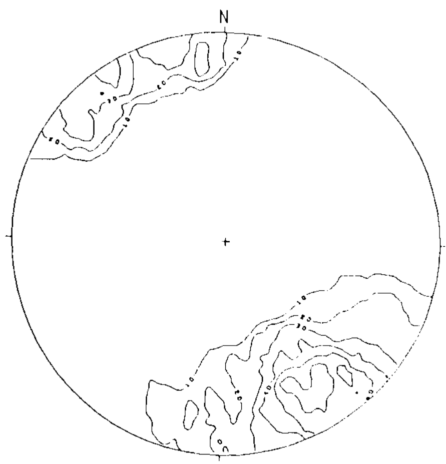
FABRIC 1: BAIL-OUT BLUFF

Laurentide till, unit D



Projection	Schmidt
Number of Sample Points	39
Mean Lineation Azimuth	151 2
Mean Lineation Plunge	12 1
1st Eigenvalue	0 724
2nd Eigenvalue	0 203
3rd Eigenvalue	0 073
LN (E1 / E2)	1 271
LN (E2 / E3)	1 017
(LN(E1/E2)) / (LN(E2/E3))	1 249
Spherical variance	0 5881
Rbar	0 4119

▫ Clast a-axis orientation

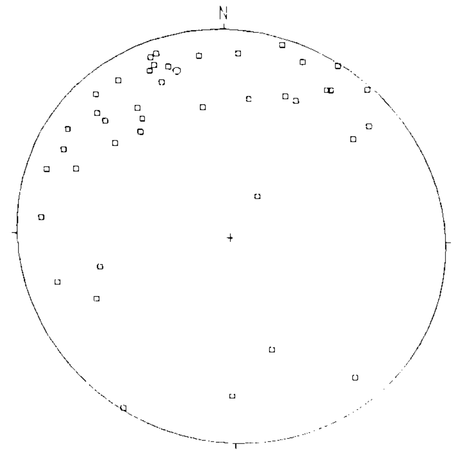


Step Function Grid
Number of Sample Points 39

Contour interval is 1 Sigma

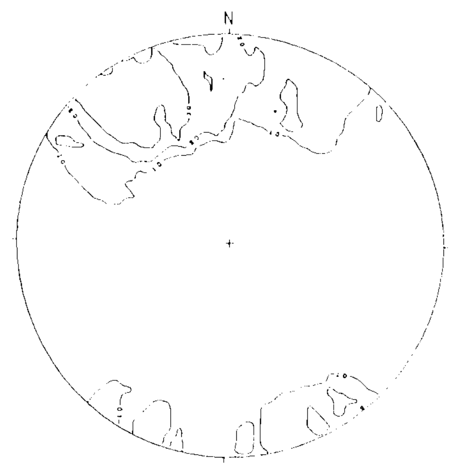
FABRIC 2: BAIL-OUT BLUFF

Unit C, montane



Projection	Schmidt
Number of Sample Points	41
Mean Lineation Azimuth	344 2
Mean Lineation Plunge	17 2
1st Eigenvalue	0 599
2nd Eigenvalue	0 315
3rd Eigenvalue	0 086
LN (E1 / E2)	0 641
LN (E2 / E3)	1 301
(LN(E1/E2)) / (LN(E2/E3))	0 493
Spherical variance	0 3796
Rbar	0 6204

▫ Clast a-axis orientation

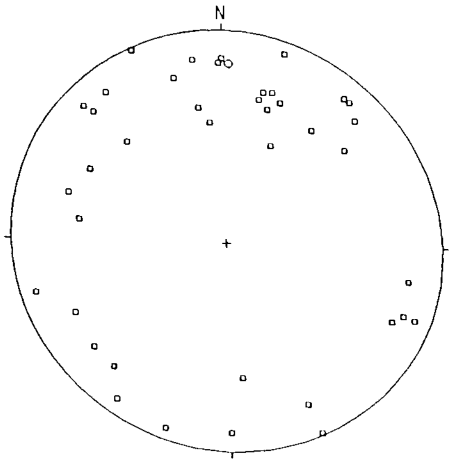


Step Function Grid
Number of Sample Points 41

Contour interval is 1 Sigma

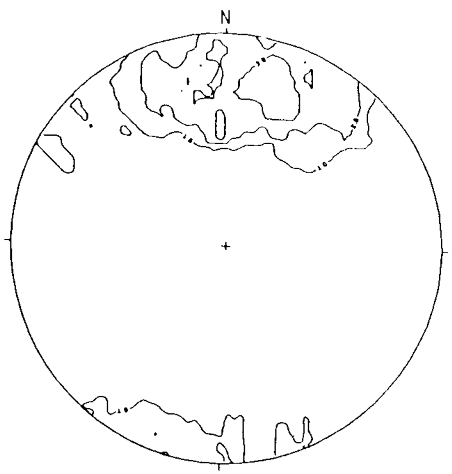
FABRIC 3: BAIL-OUT BLUFF

Contact between units B and C



Projection	Schmidt
Number of Sample Points	41
Mean Lineation Azimuth	2 2
Mean Lineation Plunge	15 4
1st Eigenvalue	0 575
2nd Eigenvalue	0 323
3rd Eigenvalue	0 102
LN (E1 / E2)	0 575
LN (E2 / E3)	1 155
(LN(E1/E2)) / (LN(E2/E3))	0 498
Spherical variance	0 5768
Rbar	0 4232

▫ Clast a-axis orientation

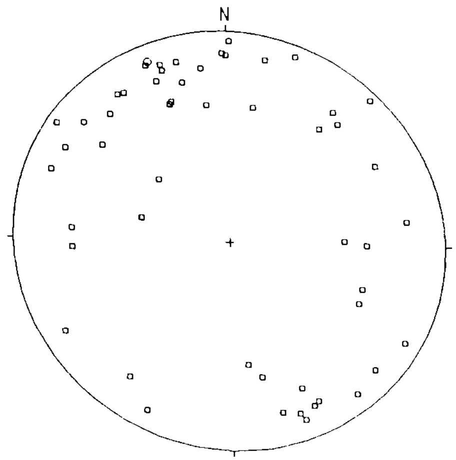


Step Function Grid	
Number of Sample Points	41

Contour interval is 1 Sigma

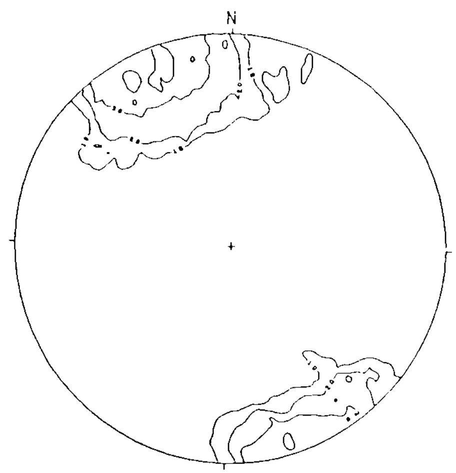
FABRIC 4: BAIL-OUT BLUFF

Unit B, montane



Projection	Schmidt
Number of Sample Points	52
Mean Lineation Azimuth	336 9
Mean Lineation Plunge	7 8
1st Eigenvalue	0 593
2nd Eigenvalue	0 272
3rd Eigenvalue	0 135
LN (E1 / E2)	0 780
LN (E2 / E3)	0 704
(LN(E1/E2)) / (LN(E2/E3))	1 108
Spherical variance	0 5942
Rbar	0 4058

▫ Clast a-axis orientation

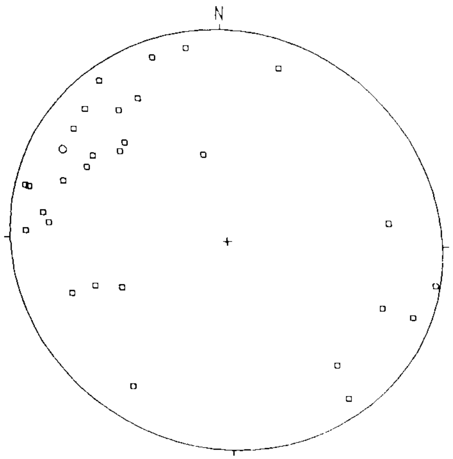


Step Function Grid	
Number of Sample Points	52

Contour interval is 1 Sigma

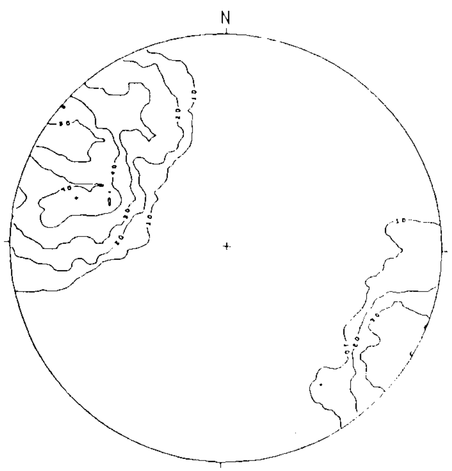
FABRIC 5: BAIL-OUT BLUFF

Unit A, montane



Projection	Schmidt
Number of Sample Points	29
Mean Lineation Azimuth	299 3
Mean Lineation Plunge	14 8
1st Eigenvalue	0 679
2nd Eigenvalue	0 215
3rd Eigenvalue	0 105
LN (E1 / E2)	1 148
LN (E2 / E3)	0 716
(LN(E1/E2)) / (LN(E2/E3))	1 603
Spherical variance	0 4866
Rbar	0 5134

□ Clast a-axis orientation

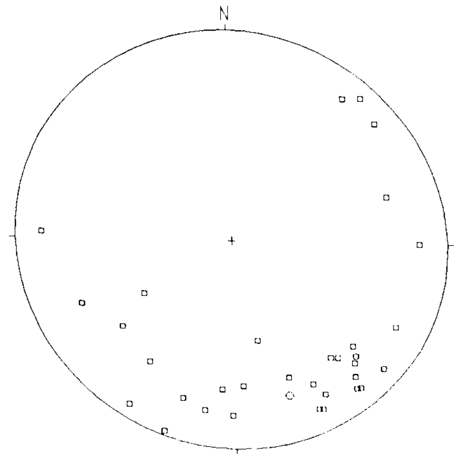


Step Function Grid	
Number of Sample Points	29

Contour interval is 1 Sigma

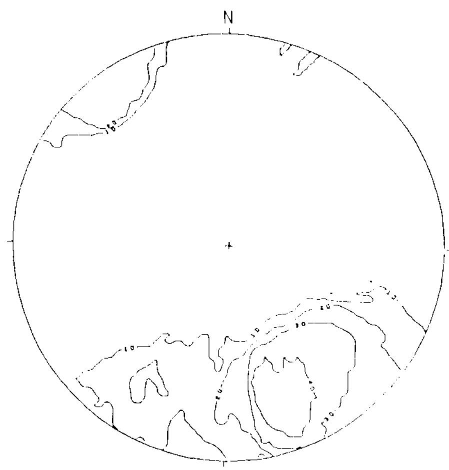
FABRIC 6: BIRD RESERVE SECTION

Laurentide till



Projection	Schmidt
Number of Sample Points	33
Mean Lineation Azimuth	161 0
Mean Lineation Plunge	22 2
1st Eigenvalue	0 612
2nd Eigenvalue	0 328
3rd Eigenvalue	0 059
LN (E1 / E2)	0 623
LN (E2 / E3)	1 709
(LN(E1/E2)) / (LN(E2/E3))	0 365
Spherical variance	0 3352
Rbar	0 6648

□ Clast a-axis orientation

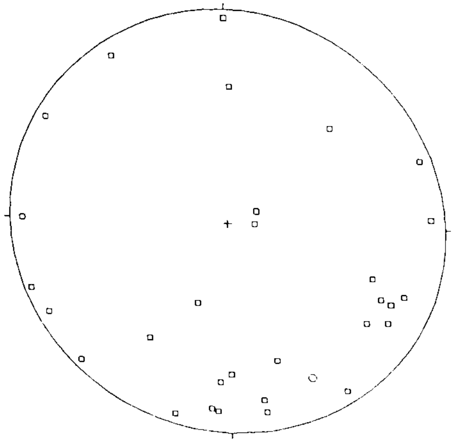


Step Function Grid	
Number of Sample Points	33

Contour interval is 1 Sigma

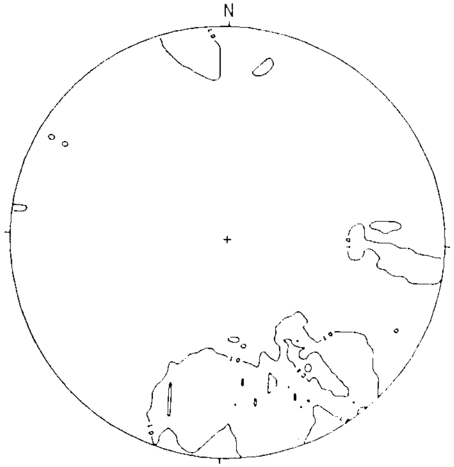
FABRIC 7: BITANGO SECTION

Top of upper till



Projection	Schmidt
Number of Sample Points	30
Mean Lineation Azimuth	152 9
Mean Lineation Plunge	19 0
1st Eigenvalue	0 500
2nd Eigenvalue	0 367
3rd Eigenvalue	0 133
LN (E1 / E2)	0 309
LN (E2 / E3)	1 014
(LN(E1/E2)) / (LN(E2/E3))	0 304
Spherical variance	0 5441
Rbar	0 4559

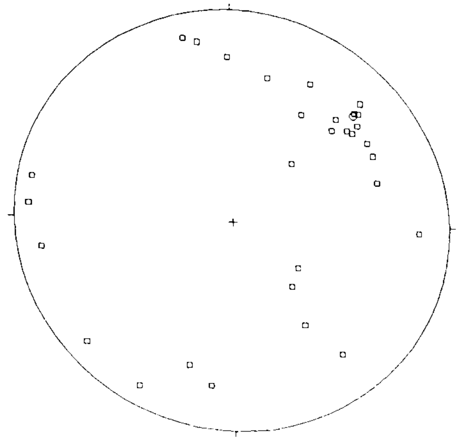
▫ Clast a-axis orientation



Step Function Grid
Number of Sample Points 30
Contour interval is 1 Sigma

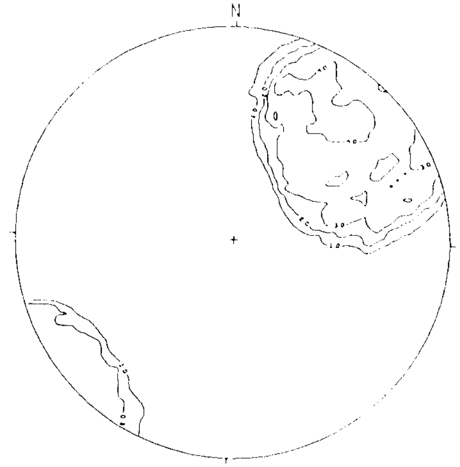
FABRIC 8: BITANGO SECTION

Middle of upper till



Projection	Schmidt
Number of Sample Points	30
Mean Lineation Azimuth	47 4
Mean Lineation Plunge	23 3
1st Eigenvalue	0 625
2nd Eigenvalue	0 255
3rd Eigenvalue	0 120
LN (E1 / E2)	0 895
LN (E2 / E3)	0 757
(LN(E1/E2)) / (LN(E2/E3))	1 182
Spherical variance	0 4787
Rbar	0 5213

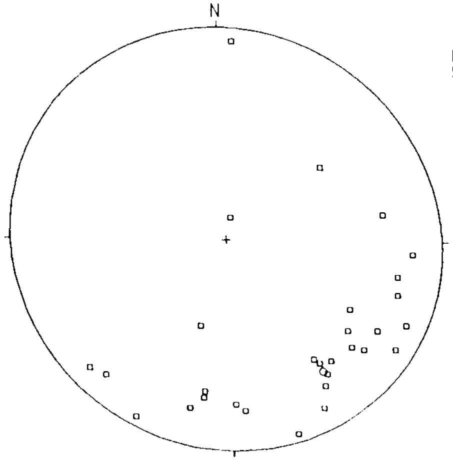
▫ Clast a-axis orientation



Step Function Grid
Number of Sample Points 30
Contour interval is 1 Sigma

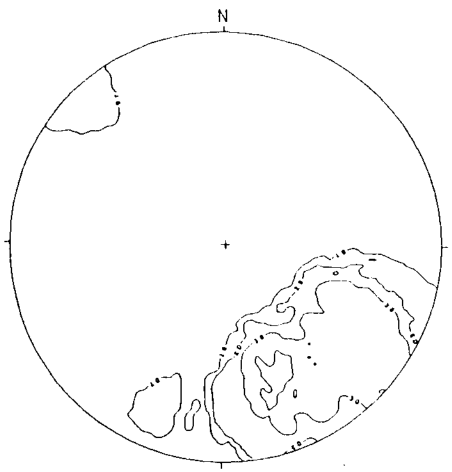
FABRIC 9: BITANGO SECTION

Base of upper till



Projection	Schmidt
Number of Sample Points	30
Mean Lineation Azimuth	145 7
Mean Lineation Plunge	25 3
1st Eigenvalue	0 639
2nd Eigenvalue	0 285
3rd Eigenvalue	0 076
LN (E1 / E2)	0 808
LN (E2 / E3)	1 314
(LN(E1/E2)) / (LN(E2/E3))	0 615
Spherical variance	0 2780
Rbar	0 7220

▫ Clast a-axis orientation

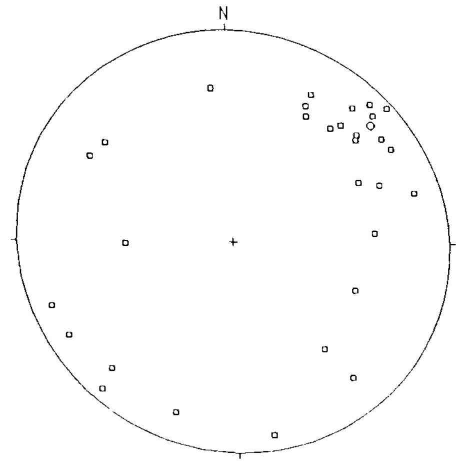


Step Function Grid
Number of Sample Points 30

Contour interval is 1 Sigma

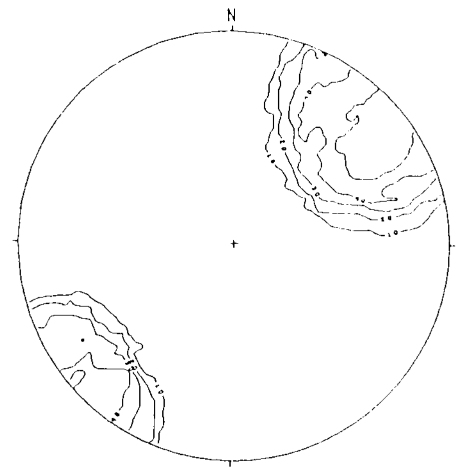
FABRIC 10: BITANGO SECTION

Till over gravel



Projection	Schmidt
Number of Sample Points	30
Mean Lineation Azimuth	49 7
Mean Lineation Plunge	14 0
1st Eigenvalue	0 672
2nd Eigenvalue	0 212
3rd Eigenvalue	0 116
LN (E1 / E2)	1 153
LN (E2 / E3)	0 603
(LN(E1/E2)) / (LN(E2/E3))	1 913
Spherical variance	0 5216
Rbar	0 4784

▫ Clast a-axis orientation

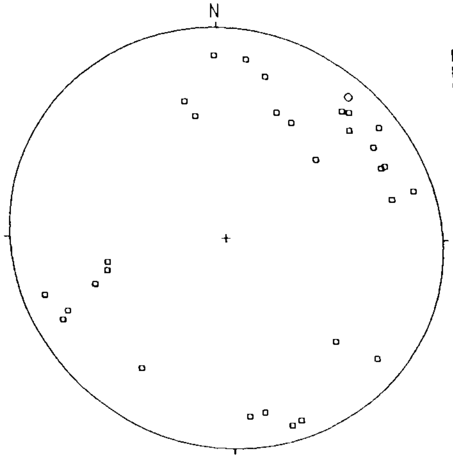


Step Function Grid
Number of Sample Points 30

Contour interval is 1 Sigma

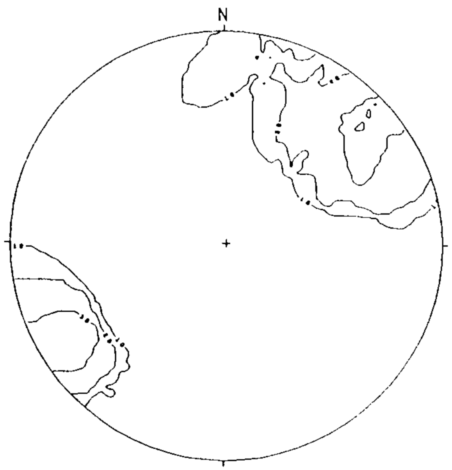
FABRIC 11: BITANGO SECTION

Labuma till



Projection	Schmidt
Number of Sample Points	30
Mean Lineation Azimuth	41 5
Mean Lineation Plunge	9 4
1st Eigenvalue	0 584
2nd Eigenvalue	0 271
3rd Eigenvalue	0 145
LN (E1 / E2)	0 766
LN (E2 / E3)	0 626
(LN(E1/E2)) / (LN(E2/E3))	1 224
Spherical variance	0 5844
Rbar	0 4156

▫ Clast a-axis orientation

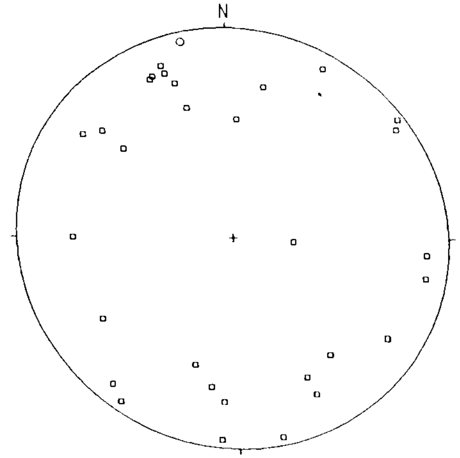


Step Function Grid
Number of Sample Points 30

Contour Interval is 1 Sigma

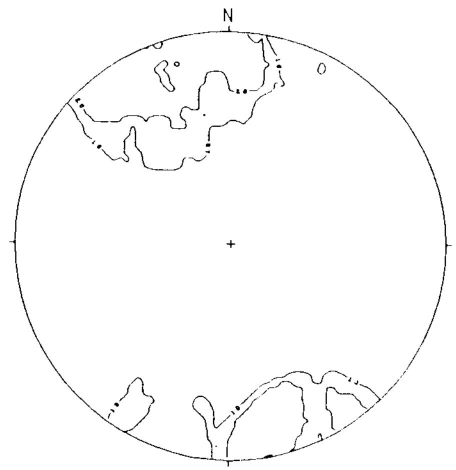
FABRIC 12: BROCKWELL GULLY

Laurentide till



Projection	Schmidt
Number of Sample Points	30
Mean Lineation Azimuth	347 5
Mean Lineation Plunge	3 9
1st Eigenvalue	0 547
2nd Eigenvalue	0 303
3rd Eigenvalue	0 150
LN (E1 / E2)	0 592
LN (E2 / E3)	0 698
(LN(E1/E2)) / (LN(E2/E3))	0 848
Spherical variance	0 6616
Rbar	0 3384

▫ Clast a-axis orientation

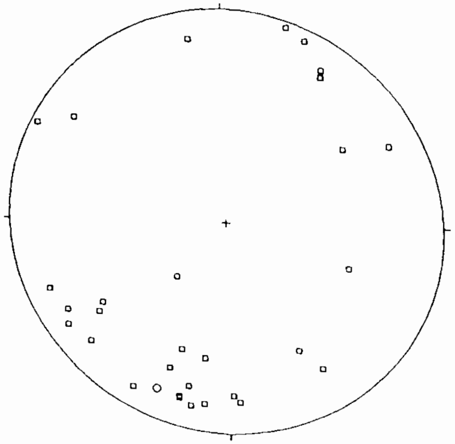


Step Function Grid
Number of Sample Points 30

Contour interval is 1 Sigma

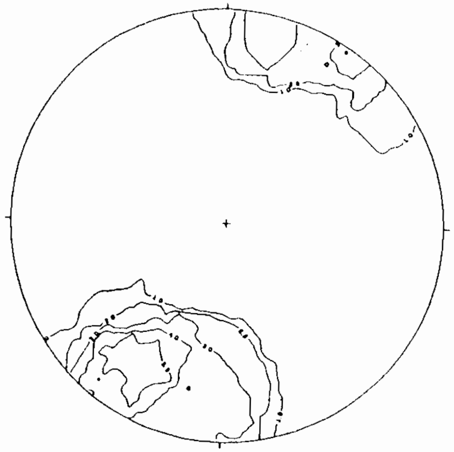
FABRIC 13: BROCKWELL GULLY

Mountain till



Projection	Schmidt
Number of Sample Points	31
Mean Lineation Azimuth	203 3
Mean Lineation Plunge	13 7
1st Eigenvalue	0 678
2nd Eigenvalue	0 223
3rd Eigenvalue	0 099
LN (E1 / E2)	1 111
LN (E2 / E3)	0 815
(LN(E1/E2)) / (LN(E2/E3))	1 364
Spherical variance	0 5299
Rbar	0 4701

▫ Clast a-axis orientation

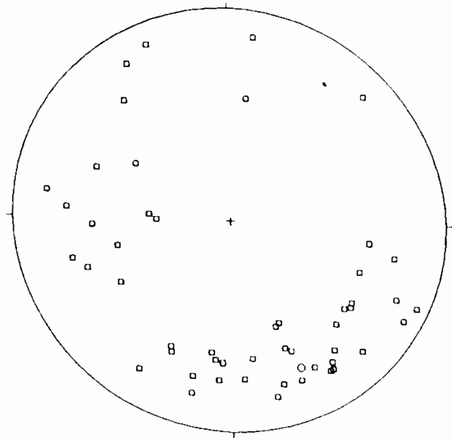


Step Function Grid
Number of Sample Points 31

Contour interval is 1 Sigma

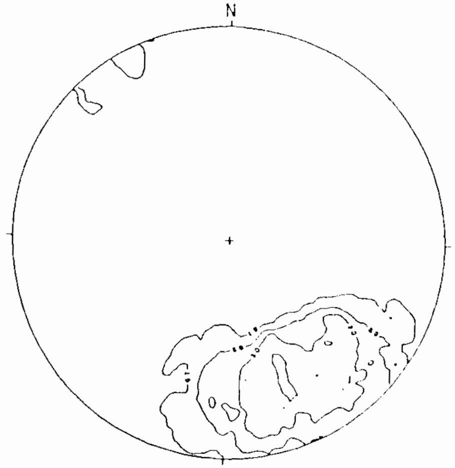
FABRIC 14: CASTLE RIVER SECTION

Laurentide till



Projection	Schmidt
Number of Sample Points	51
Mean Lineation Azimuth	155 3
Mean Lineation Plunge	24 5
1st Eigenvalue	0 573
2nd Eigenvalue	0 306
3rd Eigenvalue	0 121
LN (E1 / E2)	0 626
LN (E2 / E3)	0 928
(LN(E1/E2)) / (LN(E2/E3))	0 674
Spherical variance	0 411
Rbar	0 5889

▫ Clast a-axis orientation

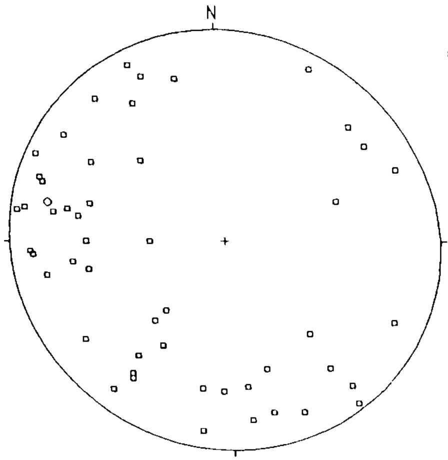


Step Function Grid
Number of Sample Points 51

Contour interval is 1 Sigma

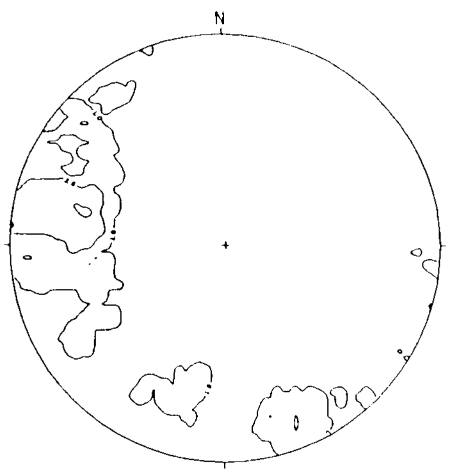
FABRIC 15: CASTLE RIVER SECTION

Middle till



Projection	Schmidt
Number of Sample Points	50
Mean Lineation Azimuth	283.1
Mean Lineation Plunge	16.6
1st Eigenvalue	0.491
2nd Eigenvalue	0.391
3rd Eigenvalue	0.118
LN (E1 / E2)	0.227
LN (E2 / E3)	1.202
(LN(E1/E2)) / (LN(E2/E3))	0.189
Spherical variance	0.5117
Rbar	0.4883

▫ Clast a-axis orientation

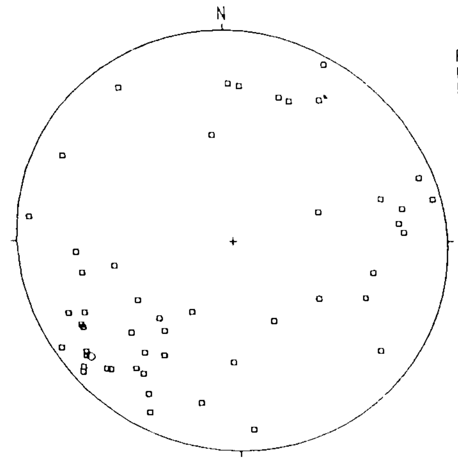


Step Function Grid	
Number of Sample Points	50

Contour interval is 1 Sigma

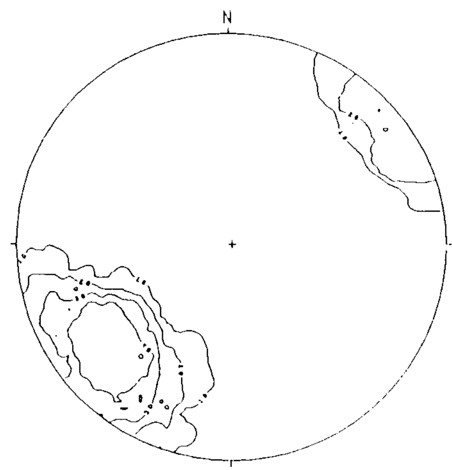
FABRIC 16: CASTLE RIVER SECTION

Lowest till



Projection	Schmidt
Number of Sample Points	50
Mean Lineation Azimuth	230.9
Mean Lineation Plunge	12.3
1st Eigenvalue	0.602
2nd Eigenvalue	0.234
3rd Eigenvalue	0.164
LN (E1 / E2)	0.947
LN (E2 / E3)	0.354
(LN(E1/E2)) / (LN(E2/E3))	2.678
Spherical variance	0.5297
Rbar	0.4703

▫ clast a-axis orientation

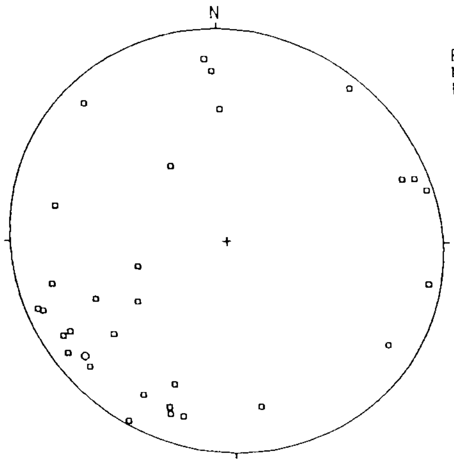


Step Function Grid	
Number of Sample Points	50

Contour interval is 1 Sigma

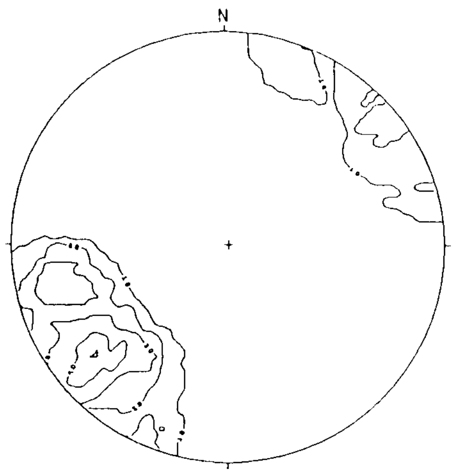
FABRIC 17: COWLEY BRIDGE SECTION

Mountain till



Projection	Schmidt
Number of Sample Points	30
Mean Lineation Azimuth	231 3
Mean Lineation Plunge	12 6
1st Eigenvalue	0 634
2nd Eigenvalue	0 264
3rd Eigenvalue	0 102
LN (E1 / E2)	0 878
LN (E2 / E3)	0 951
(LN(E1/E2)) / (LN(E2/E3))	0 923
Spherical variance	0 5678
Rbar	0 4322

▫ Clast a-axis orientation

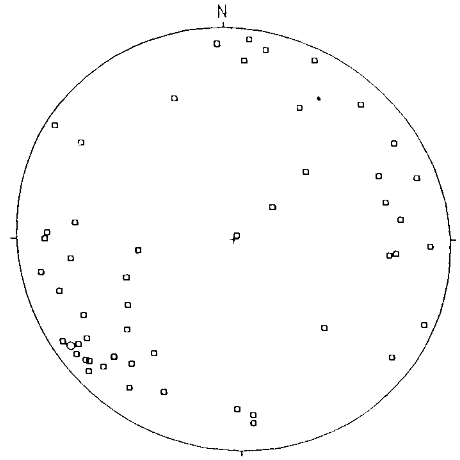


Step Function Grid
Number of Sample Points 30

Contour interval is 1 Sigma

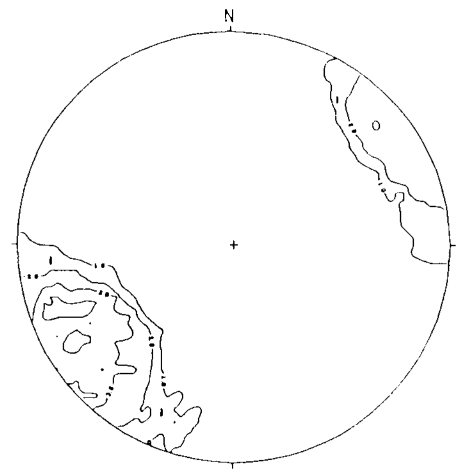
FABRIC 18: DRIFTWOOD SECTION

Mountain till



Projection	Schmidt
Number of Sample Points	51
Mean Lineation Azimuth	236 7
Mean Lineation Plunge	7 2
1st Eigenvalue	0 593
2nd Eigenvalue	0 249
3rd Eigenvalue	0 158
LN (E1 / E2)	0 867
LN (E2 / E3)	0 454
(LN(E1/E2)) / (LN(E2/E3))	1 908
Spherical variance	0 6170
Rbar	0 3830

▫ Clast a-axis orientation

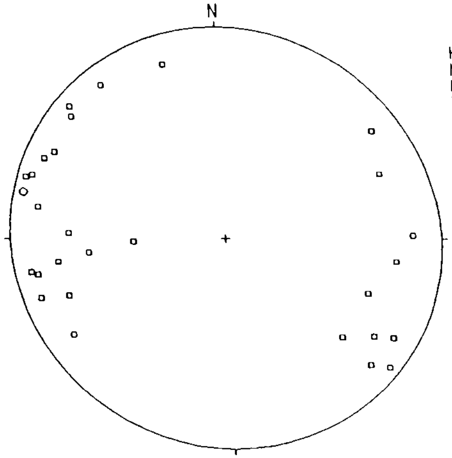


Step Function Grid
Number of Sample Points 51

Contour interval is 1 Sigma

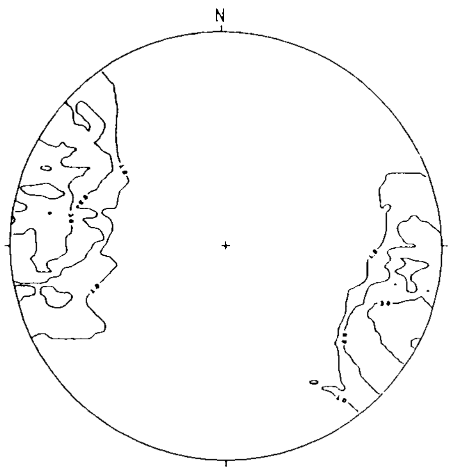
FABRIC 19: HIGHWAY BRIDGE SECTION

Montane till



Projection	Schmidt
Number of Sample Points	28
Mean Lineation Azimuth	283 6
Mean Lineation Plunge	3 8
1st Eigenvalue	0 723
2nd Eigenvalue	0 184
3rd Eigenvalue	0 093
LN (E1 / E2)	1 369
LN (E2 / E3)	0 680
(LN(E1/E2)) / (LN(E2/E3))	2 014
Spherical variance	0 6378
Rbar	0 3622

▫ Clast a-axis orientation

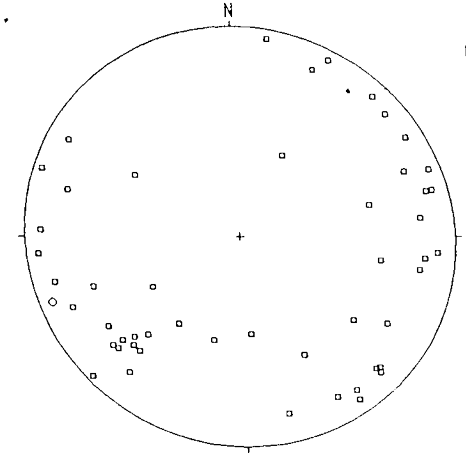


Step Function Grid
Number of Sample Points 28

Contour interval is 1 Sigma

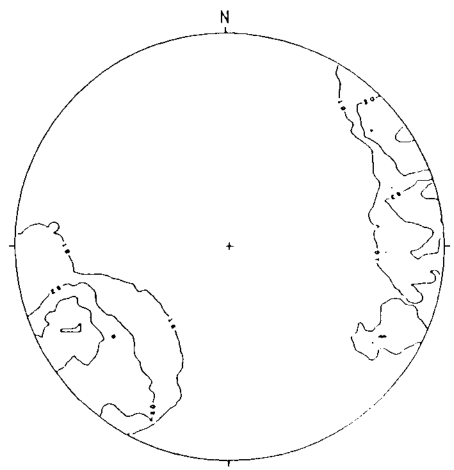
FABRIC 20: HIGHWAY THREE SECTION

Till



Projection	Schmidt
Number of Sample Points	50
Mean Lineation Azimuth	250 5
Mean Lineation Plunge	5 5
1st Eigenvalue	0 554
2nd Eigenvalue	0 334
3rd Eigenvalue	0 112
LN (E1 / E2)	0 507
LN (E2 / E3)	1 090
(LN(E1/E2)) / (LN(E2/E3))	0 465
Spherical variance	0 6224
Rbar	0 3776

▫ Clast a-axis orientation

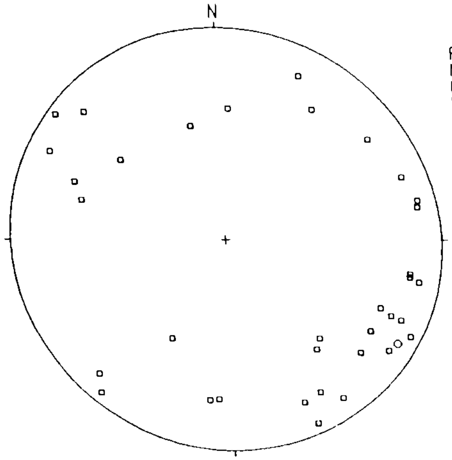


Step Function Grid
Number of Sample Points 50

Contour interval is 1 Sigma

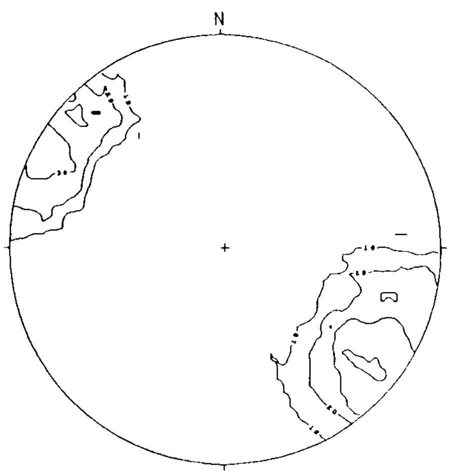
FABRIC 21: ISLAND SECTION

Laurentide till



Projection	Schmidt
Number of Sample Points	35
Mean Lineation Azimuth	122 9
Mean Lineation Plunge	8 2
1st Eigenvalue	0 585
2nd Eigenvalue	0 293
3rd Eigenvalue	0 122
LN (E1 / E2)	0 692
LN (E2 / E3)	0 878
(LN(E1/E2)) / (LN(E2/E3))	0 789
Spherical variance	0 5593
Rbar	0 4407

▫ clast a-axis orientation

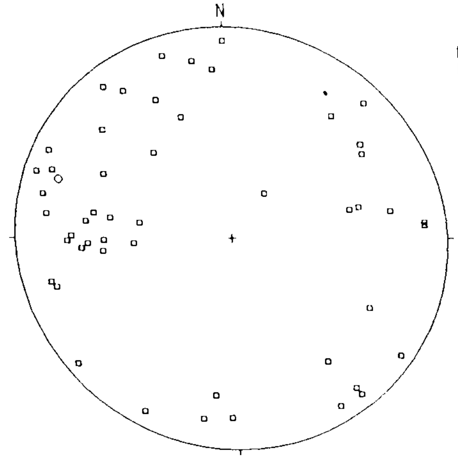


Step Function Grid
Number of Sample Points 35

Contour interval is 1 Sigma

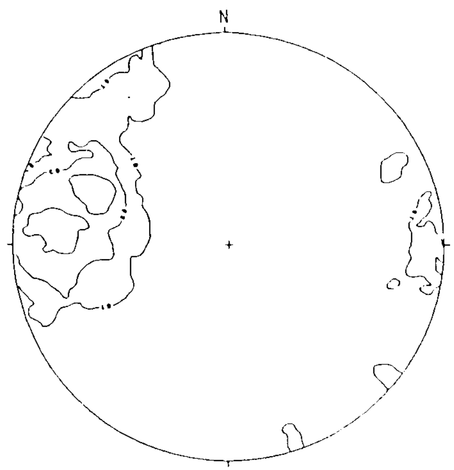
FABRIC 22: NORTHFORK SECTION

Laurentide till, 1994 measurements



Projection	Schmidt
Number of Sample Points	50
Mean Lineation Azimuth	289 7
Mean Lineation Plunge	16 1
1st Eigenvalue	0 536
2nd Eigenvalue	0 306
3rd Eigenvalue	0 158
LN (E1 / E2)	0 562
LN (E2 / E3)	0 661
(LN(E1/E2)) / (LN(E2/E3))	0 851
Spherical variance	0 5653
Rbar	0 4347

▫ clast a-axis orientation

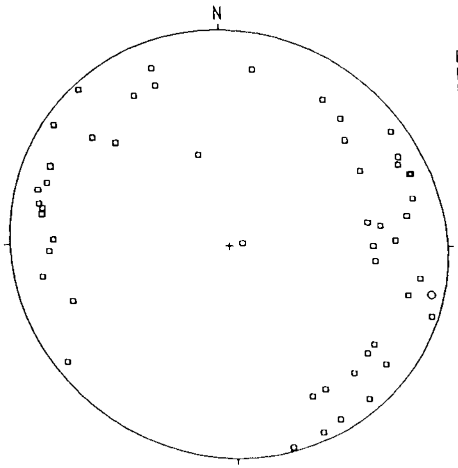


Step Function Grid
Number of Sample Points 50

Contour interval is 1 Sigma

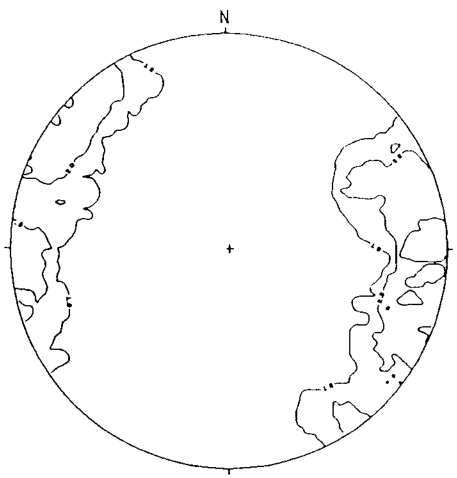
FABRIC 23: NORTHFORK SECTION

Laurentide till, 1995 measurements



Projection	Schmidt
Number of Sample Points	50
Mean Lineation Azimuth	104.1
Mean Lineation Plunge	5 1
1st Eigenvalue	0 602
2nd Eigenvalue	0 296
3rd Eigenvalue	0 103
LN (E1 / E2)	0 710
LN (E2 / E3)	1 058
(LN(E1/E2)) / (LN(E2/E3))	0 671
Spherical variance	0 6585
Rbar	0 3415

▫ clast a-axis orientation

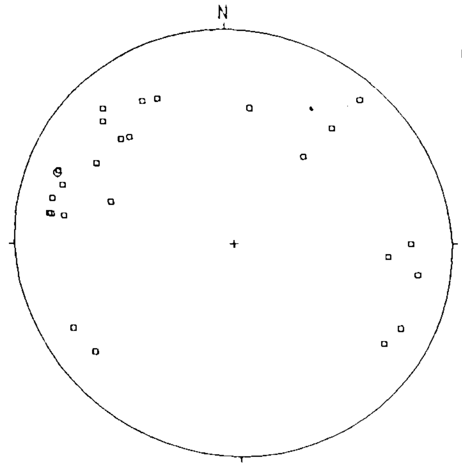


Step Function Grid
Number of Sample Points 50

Contour interval is 1 Sigma

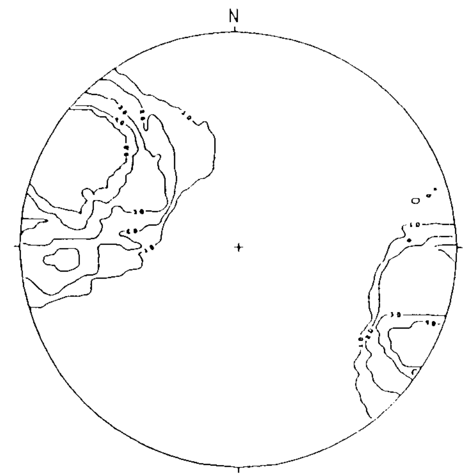
FABRIC 24: NUMBUM BLUFF

Unit G, montane



Projection	Schmidt
Number of Sample Points	25
Mean Lineation Azimuth	293 2
Mean Lineation Plunge	14 0
1st Eigenvalue	0 647
2nd Eigenvalue	0 276
3rd Eigenvalue	0 078
LN (E1 / E2)	0 853
LN (E2 / E3)	1 266
(LN(E1/E2)) / (LN(E2/E3))	0 674
Spherical variance	0 4816
Rbar	0 5184

▫ Clast a-axis orientation

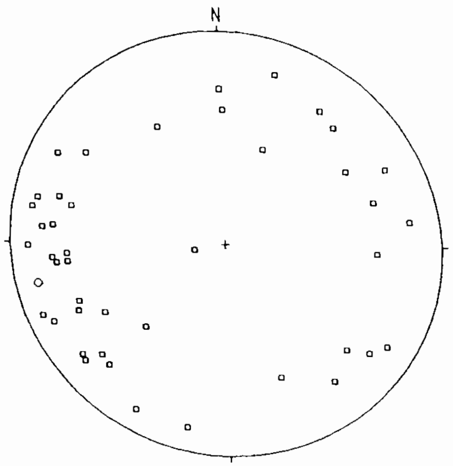


Step Function Grid
Number of Sample Points 25

Contour interval is 1 Sigma

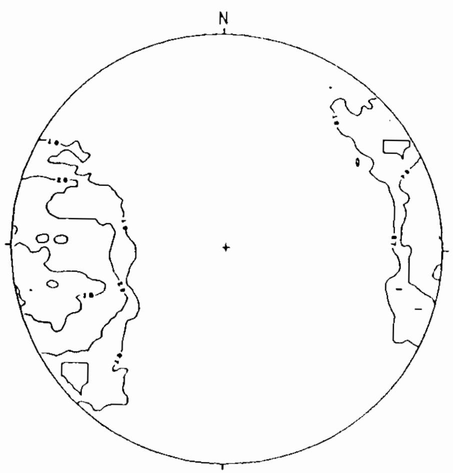
FABRIC 25: NUMBUM BLUFF

Unit A, montane



Projection	Schmidt
Number of Sample Points	43
Mean Lineation Azimuth	257 6
Mean Lineation Plunge	10 3
1st Eigenvalue	0 579
2nd Eigenvalue	0 262
3rd Eigenvalue	0 158
LN (E1 / E2)	0 792
LN (E2 / E3)	0 507
(LN(E1/E2)) / (LN(E2/E3))	1 562
Spherical variance	0 5314
Rbar	0 4686

▫ Clast a-axis orientation

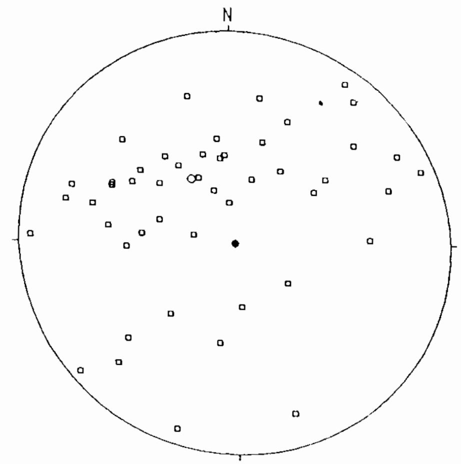


Step Function Grid
Number of Sample Points 43

Contour interval is 1 Sigma

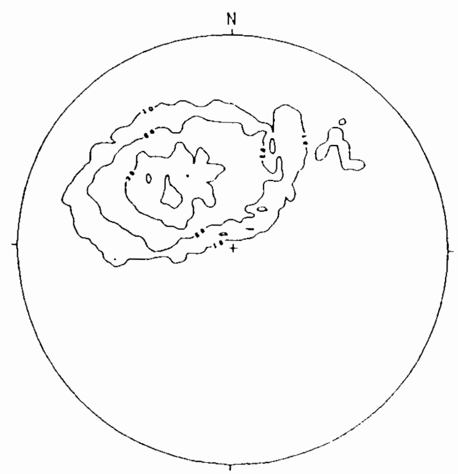
FABRIC 26: PINCHER CREEK SECTION

Upper part of upper till



Projection	Schmidt
Number of Sample Points	49
Mean Lineation Azimuth	327 7
Mean Lineation Plunge	60 2
1st Eigenvalue	0 547
2nd Eigenvalue	0 312
3rd Eigenvalue	0 141
LN (E1 / E2)	0 560
LN (E2 / E3)	0 796
(LN(E1/E2)) / (LN(E2/E3))	0 703
Spherical variance	0 3344
Rbar	0 6656

▫ clast a-axis orientation

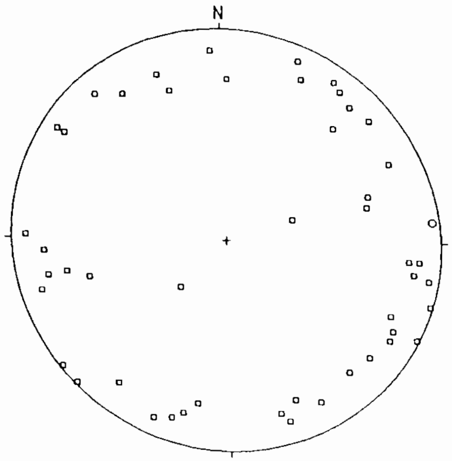


Step Function Grid
Number of Sample Points 49

Contour interval is 1 Sigma

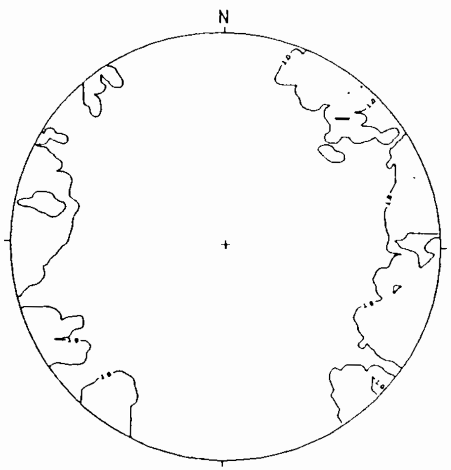
FABRIC 27: PINCHER CREEK SECTION

Lower part of upper unit



Projection	Schmidt
Number of Sample Points	50
Mean Lineation Azimuth	84.2
Mean Lineation Plunge	2.6
1st Eigenvalue	0.501
2nd Eigenvalue	0.399
3rd Eigenvalue	0.100
LN (E1 / E2)	0.227
LN (E2 / E3)	1.379
(LN(E1/E2)) / (LN(E2/E3))	0.164
Spherical variance	0.7238
Rbar	0.2762

▫ clast a-axis orientation

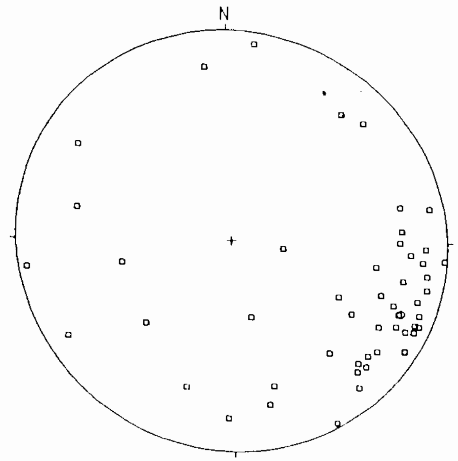


Step Function Grid
Number of Sample Points 50

Contour interval is 1 Sigma

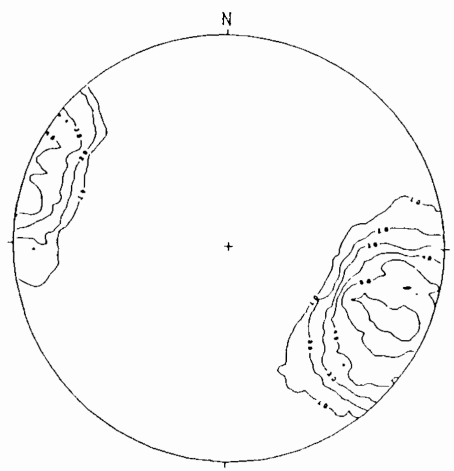
FABRIC 28: PINCHER CREEK SECTION

Upper part of lower till



Projection	Schmidt
Number of Sample Points	50
Mean Lineation Azimuth	113.6
Mean Lineation Plunge	15.4
1st Eigenvalue	0.693
2nd Eigenvalue	0.217
3rd Eigenvalue	0.090
LN (E1 / E2)	1.164
LN (E2 / E3)	0.876
(LN(E1/E2)) / (LN(E2/E3))	1.328
Spherical variance	0.3441
Rbar	0.6559

▫ clast a-axis orientation

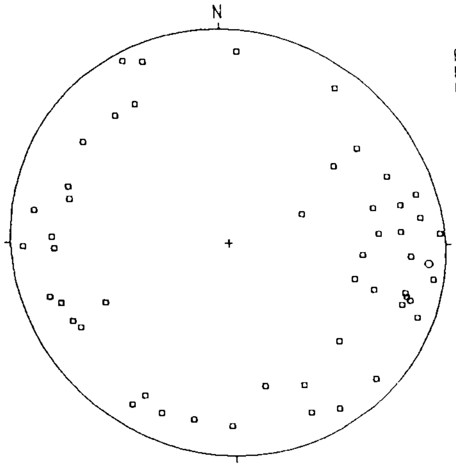


Step Function Grid
Number of Sample Points 50

Contour interval is 1 Sigma

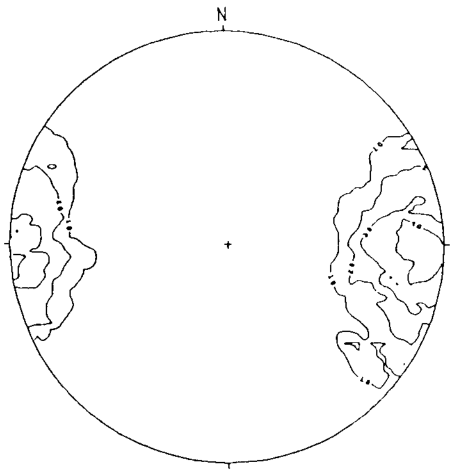
FABRIC 29: PINCHER CREEK SECTION

Middle of lower till



Projection	Schmidt
Number of Sample Points	50
Mean Lineation Azimuth	95 6
Mean Lineation Plunge	7 1
1st Eigenvalue	0 587
2nd Eigenvalue	0 295
3rd Eigenvalue	0 118
LN (E1 / E2)	0 689
LN (E2 / E3)	0 911
(LN(E1/E2)) / (LN(E2/E3))	0 756
Spherical variance	0 6399
Rbar	0 3601

▫ Clast a-axis orientation

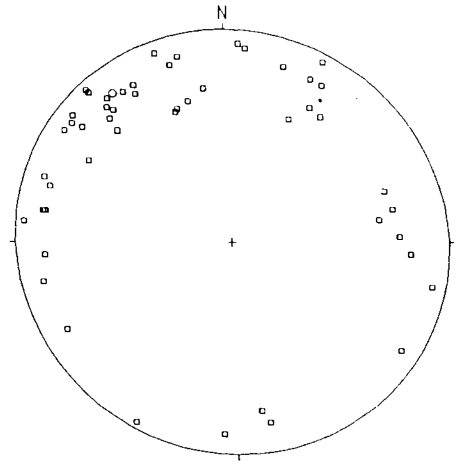


Step Function Grid
Number of Sample Points 50

Contour interval is 1 Sigma

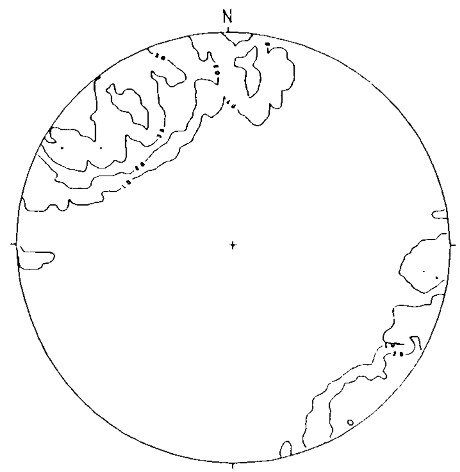
FABRIC 30: THREE RIVERS ROADCUT

Till



Projection	Schmidt
Number of Sample Points	50
Mean Lineation Azimuth	323 3
Mean Lineation Plunge	12 7
1st Eigenvalue	0 599
2nd Eigenvalue	0 345
3rd Eigenvalue	0 056
LN (E1 / E2)	0 552
LN (E2 / E3)	1 823
(LN(E1/E2)) / (LN(E2/E3))	0 303
Spherical variance	0 4715
Rbar	0 5285

▫ Clast a-axis orientation

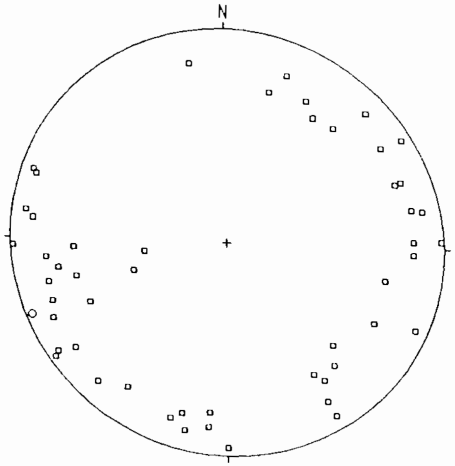


Step Function Grid
Number of Sample Points 50

Contour interval is 1 Sigma

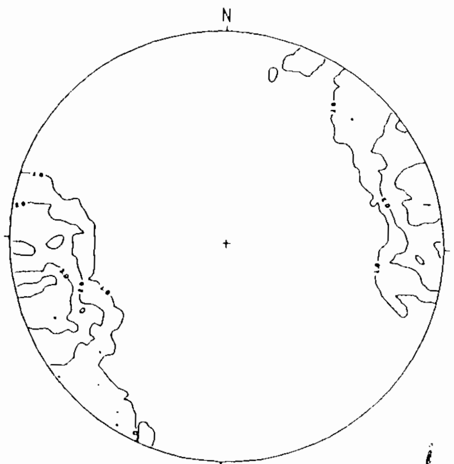
FABRIC 31: VOGELAAR SECTION

Bouldery diamicton



Projection	Schmidt
Number of Sample Points	51
Mean Lineation Azimuth	248 3
Mean Lineation Plunge	1 9
1st Eigenvalue	0 583
2nd Eigenvalue	0 314
3rd Eigenvalue	0 103
LN (E1 / E2)	0 621
LN (E2 / E3)	1 109
(LN(E1/E2)) / (LN(E2/E3))	0 559
Spherical variance	0 6800
Rbar	0 3200

▫ Clast a-axis orientation

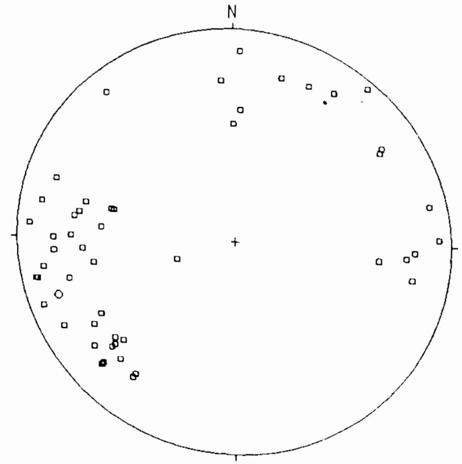


Step Function Grid
Number of Sample Points 51

Contour interval is 1 Sigma

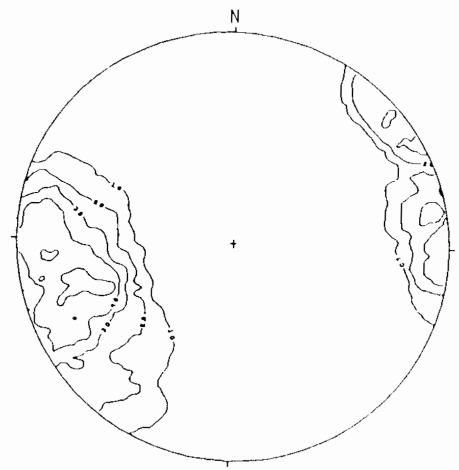
FABRIC 32: VOGELAAR SECTION

Lowest till



Projection	Schmidt
Number of Sample Points	50
Mean Lineation Azimuth	251 5
Mean Lineation Plunge	14 6
1st Eigenvalue	0 676
2nd Eigenvalue	0 221
3rd Eigenvalue	0 103
LN (E1 / E2)	1 120
LN (E2 / E3)	0 757
(LN(E1/E2)) / (LN(E2/E3))	1 478
Spherical variance	0 4942
Rbar	0 5058

▫ Clast a-axis orientation



Step Function Grid
Number of Sample Points 50

Contour interval is 1 Sigma

APPENDIX C

PEBBLE SAMPLE DATA

Px = sample number from variable width diagram.

Sample = # designated when collected in the field ("In field" means sample counted on location).

Shld = continental Shield granitics and metamorphics.

Mqtzt = maroon and banded quartzite of the Purcell Supergroup.

Arg = Red and green argillites of the Purcell Supergroup.

Baslt = Amygdaloidal basalt of the Purcell Supergroup.

Pvolc = Metagabbro and volcanics from the Purcell Supergroup.

Calc = Limestone and dolostone.

Qtzt = White, brown and grey quartzite from the Livingstone Range.

Crow = Crowsnest volcanics.

Chert = Chert and cherty conglomerate.

Sst = Sandstone.

Mst = Mudstone and siltstone.

Other = lithologies that don't fit into categories (incl. quartz, coal and concretions).

Px	SAMPLE	Shld	Mqtzt	Arg	Baslt	Pvolc	Calc	Qtzt	Crow	Chert	Sst	Mst	Other	TOTAL
1	JJE95029	1					15	3		2	32	3		56
1		2%	0%	0%	0%	0%	27%	5%	0%	4%	57%	5%	0%	100%
2	JJE95027						16			1	28	1		46
2		0%	0%	0%	0%	0%	35%	0%	0%	2%	61%	2%	0%	100%
3	JJE95025						10			1	29	1		41
3		0%	0%	0%	0%	0%	24%	0%	0%	2%	71%	2%	0%	100%
4	JJE95017						14	1	1	2	28	4	1	51
4		0%	0%	0%	0%	0%	27%	2%	2%	4%	55%	8%	2%	100%
5	JJE95011	1	1		2	1	10	7		1	25	2		50
5		2%	2%	0%	4%	2%	20%	14%	0%	2%	50%	4%	0%	100%
6	In field		2	3	1		14	5	2	1	13	9	1	51
6		0%	4%	6%	2%	0%	27%	10%	4%	2%	25%	18%	2%	100%
7	JJE95056	1	2				14	8		1	17	3		46
7		2%	4%	0%	0%	0%	30%	17%	0%	2%	37%	7%	0%	100%
8	JJE95060		1				32	8			12	2	1	56
8		0%	2%	0%	0%	0%	57%	14%	0%	0%	21%	4%	2%	100%
9	JJE95054						18	14	1	11	7			51
9		0%	0%	0%	0%	0%	35%	27%	2%	22%	14%	0%	0%	100%
10	JJE95052			1			15	12		2	10	2		42
10		0%	0%	2%	0%	0%	36%	29%	0%	5%	24%	5%	0%	100%
11	JJE95050	2	2	1			21	10		2	10	1		49
11		4%	4%	2%	0%	0%	43%	20%	0%	4%	20%	2%	0%	100%
12	JJE95057	4					20	11		4	19		3	61
12		7%	0%	0%	0%	0%	33%	18%	0%	7%	31%	0%	5%	100%
13	JJE95042	1					9	3		1	28	6	1	49
13		2%	0%	0%	0%	0%	18%	6%	0%	2%	57%	12%	2%	100%
14	JJE95044						11	1		1	33	2		48
14		0%	0%	0%	0%	0%	23%	2%	0%	2%	69%	4%	0%	100%
15	JJE94148	2					15	13			23	6		59
15		3%	0%	0%	0%	0%	25%	22%	0%	0%	39%	10%	0%	100%
16	JJE94177	2	1		2		17	12		1	21	1		57
16		4%	2%	0%	4%	0%	30%	21%	0%	2%	37%	2%	0%	100%
17	JJE94174			1			18	4		1	23	6	1	54
17		0%	0%	2%	0%	0%	33%	7%	0%	2%	43%	11%	2%	100%

Px	SAMPLE #	Shield	Mgtzt	Arg	Baslt	Pvolc	Calc	Qtzt	Crow	Chert	Sst	Mst	Other	TOTAL
18	JJE94171			1			11	3		4	28	5	2	54
18		0%	0%	2%	0%	0%	20%	6%	0%	7%	52%	9%	4%	100%
19	JJE94165		1				15	3		1	25	2		47
19		0%	2%	0%	0%	0%	32%	6%	0%	2%	53%	4%	0%	100%
20	JJE94168		1		1	2	21	5	1		23	3		57
20		0%	2%	0%	2%	4%	37%	9%	2%	0%	40%	5%	0%	100%
21	JJE94139		1	2	1		24	6		2	19			55
21		0%	2%	4%	2%	0%	44%	11%	0%	4%	35%	0%	0%	100%
22	In field		1				17	2			25	12	1	58
22		0%	2%	0%	0%	0%	29%	3%	0%	0%	43%	21%	2%	100%
23	JJE94136			4	3		20	3	2		22			54
23		0%	0%	7%	6%	0%	37%	6%	4%	0%	41%	0%	0%	100%
24	JJE94180	4					10	3		1	33	8		59
24		7%	0%	0%	0%	0%	17%	5%	0%	2%	56%	14%	0%	100%
25	JJE94183						11	2			32	6		51
25		0%	0%	0%	0%	0%	22%	4%	0%	0%	63%	12%	0%	100%
26	In field		2	7			13	4			23	4		53
26		0%	4%	13%	0%	0%	25%	8%	0%	0%	43%	8%	0%	100%
27	JJE95014		10	3	1		7	4			30	3	1	59
27		0%	17%	5%	2%	0%	12%	7%	0%	0%	51%	5%	2%	100%
28	JJ94061		5	6		3	8	16		3	15	2		58
28		0%	9%	10%	0%	5%	14%	28%	0%	5%	26%	3%	0%	100%
29	JJE95018	3					19	5			34	6		67
29		4%	0%	0%	0%	0%	28%	7%	0%	0%	51%	9%	0%	100%
30	JJE95032			1			18	5	2		27	4		57
30		0%	0%	2%	0%	0%	32%	9%	4%	0%	47%	7%	0%	100%
31	JJE94191		2	1			23	3	2	1	25	4		61
31		0%	3%	2%	0%	0%	38%	5%	3%	2%	41%	7%	0%	100%
32	JJE94186		1				36	4	1		9	2		53
32		0%	2%	0%	0%	0%	68%	8%	2%	0%	17%	4%	0%	100%
33	JJE94187		1				31	4	1	1	13	1		52
33		0%	2%	0%	0%	0%	60%	8%	2%	2%	25%	2%	0%	100%
34	JJE94192	2	1	1	1	1	28	7	1		8		1	51
34		4%	2%	2%	2%	2%	55%	14%	2%	0%	16%	0%	2%	100%
35	JJE94188			1			37	5	1		7		1	52
35		0%	0%	2%	0%	0%	71%	10%	2%	0%	13%	0%	2%	100%
36	JJE95023	1	5	1		1	16	8		1	26	1		60
36		2%	8%	2%	0%	2%	27%	13%	0%	2%	43%	2%	0%	100%
37	JJE95022	1					7	5	1		25	3		42
37		2%	0%	0%	0%	0%	17%	12%	2%	0%	60%	7%	0%	100%
38	JJE95020				1		26		2	1	17			47
38		0%	0%	0%	2%	0%	55%	0%	4%	2%	36%	0%	0%	100%
39	JJE95040						9	8		1	17	1		36
39		0%	0%	0%	0%	0%	25%	22%	0%	3%	47%	3%	0%	100%
40	JJE95038				1	1	17	5		1	14	1	1	41
40		0%	0%	0%	2%	2%	41%	12%	0%	2%	34%	2%	2%	100%
41	JJE95036		2	5			25	3			14	1		50
41		0%	4%	10%	0%	0%	50%	6%	0%	0%	28%	2%	0%	100%
42	JJE95034		5	4	2		13	4		1	22	5	1	57
42		0%	9%	7%	4%	0%	23%	7%	0%	2%	39%	9%	2%	100%

Px	SAMPLE #	Shield	Mqtzt	Arg	Baslt	Pvolc	Calc	Qtzt	Crow	Chert	Sst	Mst	Other	TOTAL
43	JJE94123		2		1		15	12		1	27			58
43		0%	3%	0%	2%	0%	26%	21%	0%	2%	47%	0%	0%	100%
44	JJE94044		2		1		18	10		2	17	3	3	56
44		0%	4%	0%	2%	0%	32%	18%	0%	4%	30%	5%	5%	100%
45	JJE94105	1	1	1	1		5	9		1	41	7	1	68
45		1%	1%	1%	1%	0%	7%	13%	0%	1%	60%	10%	1%	100%
46	JJE94102		1	2			9	7			33	1		53
46		0%	2%	4%	0%	0%	17%	13%	0%	0%	62%	2%	0%	100%
47	JJE94037		1	2			15	5		4	25	2		54
47		0%	2%	4%	0%	0%	28%	9%	0%	7%	46%	4%	0%	100%
48	JJE94153	1	6	1			20	5	3	1	17			54
48		2%	11%	2%	0%	0%	37%	9%	6%	2%	31%	0%	0%	100%
49	JJE94152		2		1		14	2			32	3	1	55
49		0%	4%	0%	2%	0%	25%	4%	0%	0%	58%	5%	2%	100%
50	JJE95004	1	1				21	13			23	6	2	67
50		1%	1%	0%	0%	0%	31%	19%	0%	0%	34%	9%	3%	100%
51	JJE94162	3	3	1			7	3	1	1	36	2		57
51		5%	5%	2%	0%	0%	12%	5%	2%	2%	63%	4%	0%	100%
52	JJE94154		3	3	1		17	1	1		25	2		53
52		0%	6%	6%	2%	0%	32%	2%	2%	0%	47%	4%	0%	100%
53	JJE94159		3	2	3		10	3		1	31	2		55
53		0%	5%	4%	5%	0%	18%	5%	0%	2%	56%	4%	0%	100%

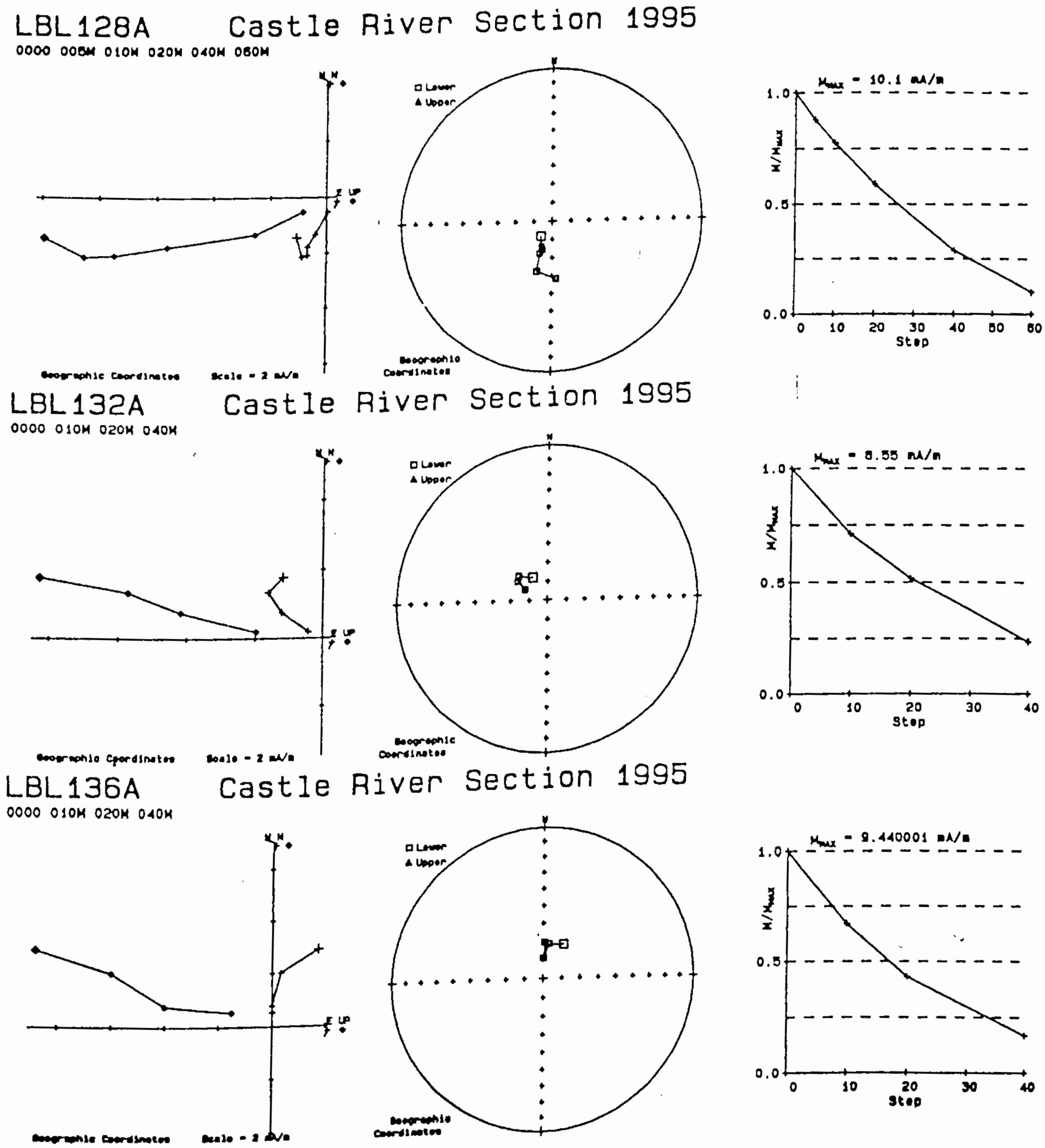
APPENDIX D

TILL MATRIX TEXTURAL DATA

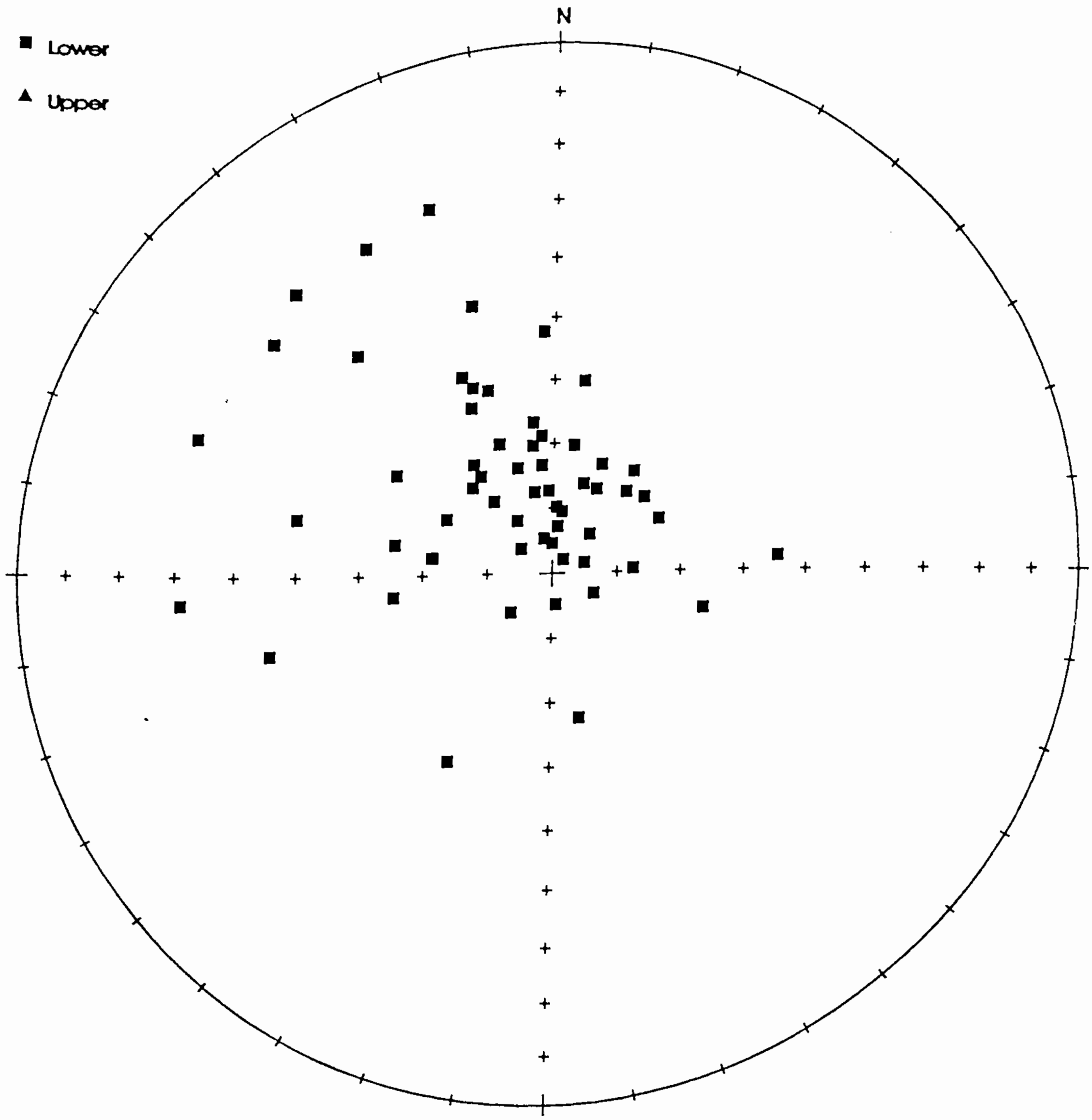
Tx	SAMPLE	SAND %	SILT %	CLAY %	Unit
1	JJE95028	32.01	44.54	23.45	4A
2	JJE95026	20.30	59.18	20.52	2B
3	JJE95024	20.45	45.66	33.89	2B
4	JJE95015	31.02	52.07	16.91	2B
5	JJE95009	27.41	42.69	29.90	4A
6	JJE95007	34.90	49.36	15.74	2B
7	JJE95055	24.84	56.86	18.31	4A
8	JJE95059	23.98	54.85	21.17	4A
9	JJE95051	25.17	51.12	23.70	4B
10	JJE95049	25.82	55.73	18.46	4A
11	JJE95041	29.72	44.38	25.90	4A
12	JJE95043	29.27	50.23	20.50	2B
13	JJE94146	20.97	44.50	34.53	4A
14	JJE94175	21.63	48.61	29.76	4A
15	JJE94172	35.70	45.18	19.12	2D
16	JJE94169	20.97	59.36	19.67	2B
17	JJE94163	23.91	49.44	26.66	2B
18	JJE94137	16.72	48.37	34.92	4A
19	JJE94134	38.24	51.01	10.74	2B
20	JJE94178	24.12	41.95	33.94	4A
21	JJE94181	42.02	47.93	10.05	2B
22	JJE95012	29.92	47.18	22.90	2B
23	JJE94189	25.90	57.47	16.64	2D
24	JJE94184	24.26	57.56	18.19	2B
25	JJE95021	24.17	50.73	25.10	4A
26	JJE95019	51.18	38.63	10.19	2B
27	JJE95039	27.44	42.63	29.93	4A
28	JJE95037	43.91	47.01	9.08	2B
29	JJE95035	36.51	55.17	8.32	2B
30	JJE95033	33.76	55.75	10.50	2B
31	JJE94124	26.74	43.67	29.59	4A
32	JJE94045	30.88	46.66	22.46	4A
33	JJE94103	31.10	44.85	24.05	4A
34	JJE94100	32.97	45.34	21.69	4A
35	JJE94038	31.35	51.86	16.80	4A
36	JJE94150	24.66	51.72	23.62	2B
37	JJE95006	20.09	57.42	22.49	4A
38	JJE94160	25.83	42.82	31.35	4A
39	JJE94155	26.64	57.85	15.51	2D
40	JJE94157	43.93	56.07	0.00	2B

APPENDIX E

PALEOMAGNETIC DATA



Representative demagnetization plots of samples from the Castle River section (#1a). Oriented samples were stepwise demagnetized in alternating fields with peak fields given in milli-Tesla (mT) and then measured in a spinner magnetometer. At each step, the least stable magnetic particles were "cleaned", leaving the more stable magnetized carriers. Orthogonal plots (left column) show horizontal and vertical projections. The linear segments roughly directed towards the origin indicate that these samples contain only one component, other than a very soft (<10 mT) laboratory induced component. Stereographic projections (centre column) show that this direction is steep down and usualy north with no great evolution towards any other direction. The intensity plots (right column) show median destructive fields of about 20 mT, suggesting that multi-domain magnetite is the dominant magnetic carrier (R. Enkin, Pacific Geoscience Centre, pers. comm.).



Stereograph of remanence directions from the Castle River section (#1a). The steep down northward direction (declination = 330.70, inclination = 74.20, Fisher precision parameter = 11.2, 95% confidence interval a95 = 5.80, n = 59 specimens) is typical of the normal polarity geomagnetic field. The relatively large scatter is typical of unconsolidated sediments (R. Enkin, Pacific Geoscience Centre, pers. comm.).

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