LATE QUATERNARY GEOLOGY OF THE FOOTHILLS: FROM CALGARY TO THE ALBERTA-MONTANA BORDER

A FIELD TRIP PRESENTING HIGHLIGHTS OF FINDINGS BY THE EASTERN CORDILLERAN NATMAP SURFICIAL GEOLOGY MAPPING TEAM:

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Day 1 Calgary to Pincher Creek via Highway 22

We begin our day at the University of Calgary. We will drive south on Alberta Highway 2 along the eastern margin of Calgary, a city of about 800,000 (fig. 1-1). It was founded in 1884 by the Northwest Mounted Police (now the Royal Canadian Mounted Police), at the confluence of the Bow and Elbow rivers, as a frontier fort.

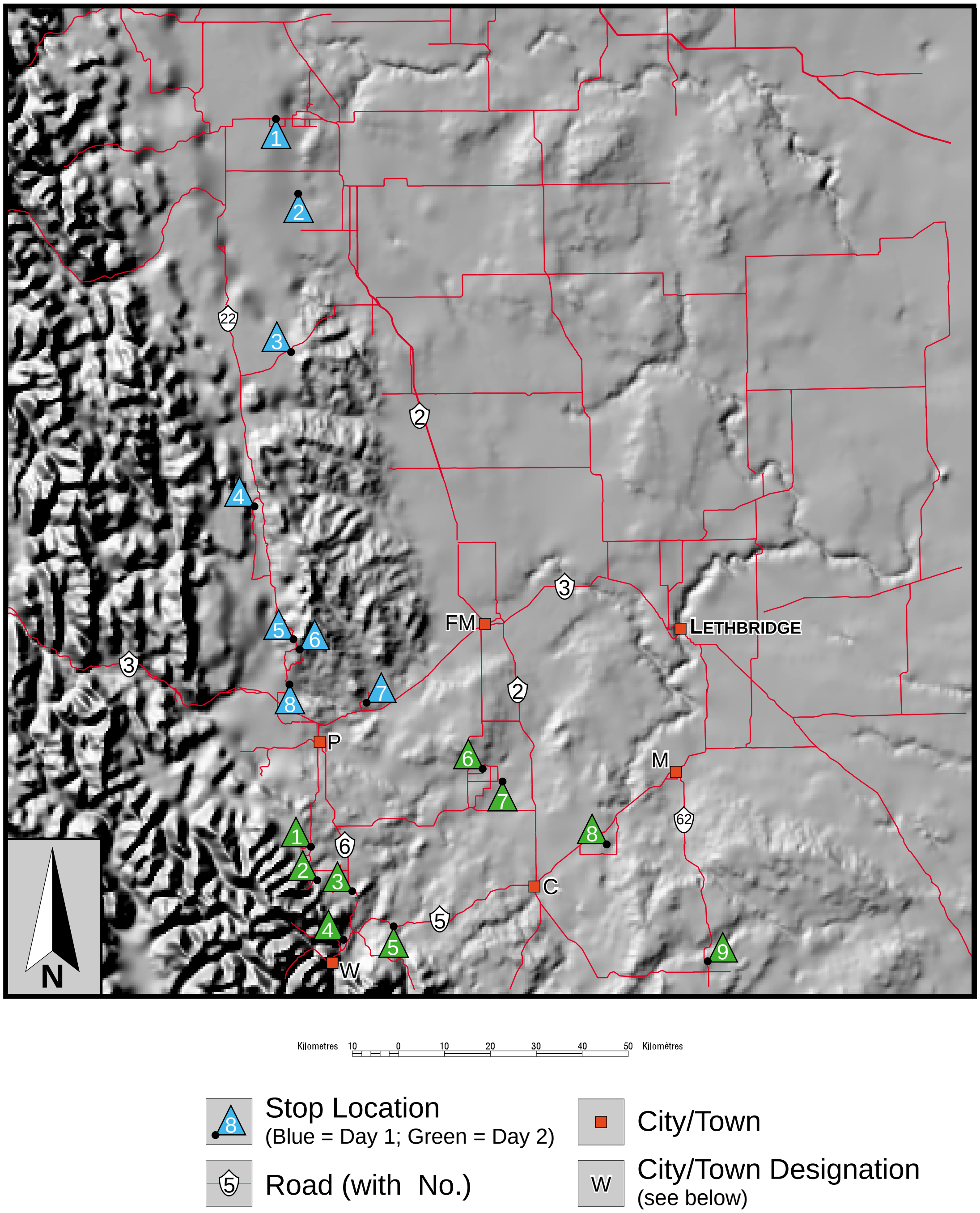
Physical and geologic setting of Calgary

Calgary is situated at the western edge of the Interior Plains and 90 km from the front of the Rocky Mountains. It has an average elevation of about 1040 m. The topography generally reflects underlying topography on the almost flat lying Paleocene Porcupine Hills and Paskapoo formations. These are the youngest of a 6000 m succession of Paleozoic to Cenozoic sedimentary rocks of the Western Canada Sedimentary basin that overlie the craton in this area. Many of these units produce oil and natural gas. Stratigraphic traps, within the flat-lying rocks of the Plains, and the structural traps, within the adjacent Foothills and Rocky Mountains, make Alberta the leading oil and gas producing province in Canada; most oil companies in Canada have their corporate headquarters in Calgary. Immediately to the west of Calgary are the Foothills. Here, the rocks of the Western Canada Sedimentary Basin have been folded and thrust faulted. Faults deep steeply (commonly more that 20°) to the west whereas the undisturbed rocks of the Western Canada Sedimentary Basin dip westward at one or two degrees. Generally, only rocks of Mesozoic age are exposed at the surface within the Foothills and movement along faults are measured in hundreds of metres or a few kilometres. At the Rocky Mountain front, massive cliff-forming Paleozoic Carbonates are brought to the surface along thrust faults with tens or hundreds of kilometres of movement.

Three general levels can be seen within Calgary as one looks west toward the Rocky Mountains. The highest level, at about 1270 m, is underlain by late Wisconsinan glacial till which caps early Pleistocene gravel which in turn caps Paleocene sandstone. The next level is defined by an extensive filling of glaciolacustrine fine sand and silt which was deposited during the retreat of the Laurentide Ice Sheet from the area *ca.* 12-14 k.y. before the present (b.p). Cliffs and slopes created by the incision of the Bow and Elbow rivers into this fill are the loci of most slope stability problems within the city.

The flood plain of the Bow and Elbow Rivers, and alluvial terraces occur at the lowest levels. The latter range from *ca.* 10.5 to less than 6.5 k.y. b.p. The predominantly gravel fill in which the terraces were cut have yielded a rich fauna of ice-age mammals including horse, mammoth, and camel. The oldest human occupation dates to almost 10 ka but controversial sites have been identified that may be thousands of years older (Osborn and Rajewicz, in press; Wilson and Hardy 1987).

During the last (late Wisconsinan) ice age, glaciers originating in the Rocky Mountains merged with the western margin of the Laurentide Ice Sheet in Calgary and elsewhere along the edge of the Rocky Mountain Foothills. Glacier ice was perhaps 1 km thick in the area. This zone of convergence is marked by a remarkable erratics train which will be the focus of our first stop.



City/Town Designations: FM= Fort MacLeod, P=Pincher Creek, C=Cardston, W=Waterton, M=Magrath

Figure 1-1. Stop location map. Hillshade model created from 1:250,000 National Topographic Data Base (NTDB) from Geomatics Canada, with modifications by Terrain Sciences Division. Hillshade and road networks compiled by K. Shimamura, Terrain Sciences Division, Geological Survey of Canada, 1999.

Large building foundation engineering in Calgary

Up until the 1960s, all large commercial buildings in downtown Calgary were constructed on spread and strip footings upon the alluvial sand and gravel that underlies Bow Valley. The skyscrapers of downtown office towers are founded on Paleocene sandstone and shale. Allowable bearing capacity for these gravels is 500-600 kPa. With the construction of progressively taller buildings with underground parking garages extending 16 to 20 m below grade, raft and friction pile foundations, excavation to bedrock with blasting, and excavation of the bedrock itself has become common. Extensive shoring and dewatering systems are required during these deep excavations within the unconsolidated and saturated gravels. Continuous pumping is required to keep the deep basements dry following construction (Oswell *et al.* unpublished; Ledbeater *et al.* unpublished).

Calgary to the Okotoks erratic

About 20 km south of Calgary we leave Highway 2 at the Okotoks exit and drive through the town of Okotoks, one of Calgary's bedroom communities. We turn west on Highway 7 and follow it for three km to our next stop. The route parallels the western edge of the Interior Plains with the first thrust faults of the Foothills a few kilometres to the west. With the exception of small areas of glacial lake sediments, the area is directly underlain by glacial till which in turn blankets bedrock. The route follows the zone of coalescence between glacier ice from the Rocky Mountains and the Laurentide Ice Sheet. This zone is defined by a change in till composition. There are no sources for high grade metamorphic rocks in the Rocky Mountains whereas the Laurentide Ice Sheet was centred on the Canadian Shield an carried vast amount of high grade metamorphic rocks into the area. Over about 10 km from Highway 2 west, plutonic and metamorphic rocks from the Canadian Shield vary from being common to totally absent in the till.

Stop 1-1 The Okotoks Erratic or Big Rock

Okotoks is a local Amerindian word meaning "big rock". The Okotoks Erratic is perhaps the largest glacial erratic in Canada. It was once a single block of pebbly quartzite up to 41 m in length and it is estimated to have a mass of 18 000 tonnes. It is so large that when it was seen by Dr. James Hector, the geologist with the Palliser Expedition (the first geologist to see it) in the mid 1800s, he thought that it was a klippe. It is part of an erratics train composed of thousands of blocks of the same rock which are more that 1 m in size. This erratics train stretches more than 580 km from the Athabasca Valley along the eastern edge of the Foothills to just south of the Montana (U.S.A.) border. Its source is the lower Cambrian Gog Group in the Rocky Mountains of Jasper National Park. The *Geology* paper in appendix A of this guidebook shows the general relationship of the erratics train to glacier flow directions during the climax of the last ice age. The age of the erratics train has been controversial. Alley (1973), Stalker (1977), Stalker and Harrison (1977), and Jackson (1980) placed the late Wisconsinan limit east of the erratics train; others (*i.e.,* Wagner 1966; Bayrock 1969; and Moran 1986) maintained that the erratics rest on late Wisconsinan-age till. No radiocarbon ages from sub-till sediments exist in the vicinity of the erratics train to limit its age in the maximum sense, and radiocarbon ages determined on organic material from sediments overlying the surface till are Holocene or near the Pleistocene-Holocene boundary and significantly post-date deglaciation.

Jackson *et al.* (1997) applied cosmogenic ^{36}Cl dating technique (Zreda and Phillips 1995) to the Foothills erratics train in order to directly determine the age of this feature. Results demonstrate that the last coalescence of continental and montane glaciers occurred during the late Wisconsinan (see Appendix A). This work has also been corroborated by cosmogenic dating of Canadian Shield erratics and montane provenance boulders which were placed along the all-time limit of the continental ice-sheet incursion from the north end of the Porcupine Hills south to Cloudy Ridge and east to Del Bonita. The ^{36}Cl exposure ages of these erratics all fall within the late Wisconsinan. This work is detailed in a preprint of a paper currently in press in the *Canadian Journal of Earth Sciences* (Appendix B).

Stop 1-2 The fifth meridian section

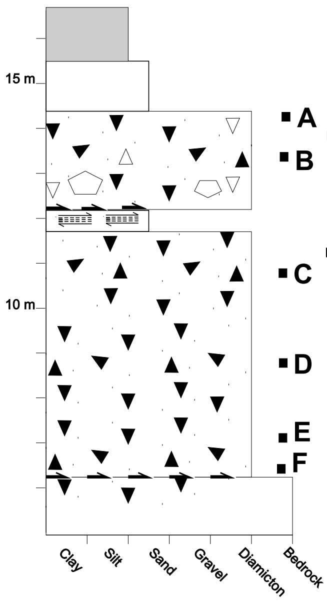
This cliff-bank exposure is situated along the north bank of the Highwood River at the fifth meridian (114° W). This exposure was first described (including a photograph) by Dawson and McConnell (1895). The two tills recognized by them supported their conclusion that the Foothills area had been glaciated several times. However, they failed to notice the presence of Canadian Shield clasts in the upper till. The stratigraphy and sedimentology of the section and its correlation with other cliff-bank exposures upstream along the Highwood River are portrayed in Fig. 1-2a-c. The section shows a characteristic succession of glacial sediments widely repeated along the eastern margin of the Foothills. In many sections, a basal gravel of entirely Rocky Mountain and Foothills provenance, overlies the bedrock underlying valley systems. This unit is typically massive and is devoid of any organic sediments. It is directly overlain by a diamicton also of Rocky Mountain and Foothills provenance, as shown in the correlated cross-section (Fig. 1-2c) that extends several km downstream from our position. At the 5th Meridian section (H1; Fig. 1-2a), lenses of this basal gravel have been ripped up and incorporatred along the base of the lower diamict. Fabrics were measured at several levels within the lower diamict and generally indicate a west to east or southwest to northeast ice-flow. This would be expected because topography would tend to channel glacier-flow down the Highwood River valley in this direction. Similar units in the Oldman River basin indicate that ice from the Rocky Mountains advanced as much as 100 km east to form piedmont lobes over the adjacent Interior Plains. The montane glacial advance responsible for the oldest montane till present in the buried valleys of the Foothills has been called M1 by the NATMAP team.

The lower M1 diamict is succeeded by sheared silty sand with pebbly lenses. This unit indicates the subsequent recession of montane glaciers sufficiently westward into the Foothills to permit the formation of a lake or pond in the area of the 5th Meridian section (H1; Fig. 1-2a). These sediments were then sheared into a deformation till by the incursion of ice from the northeast.

The overlying diamicton bears up to 1% clasts from the Canadian Shield. The strong fabric of this unit, sheared lower contact and Shield provenance clearly indicate this unit to be a till of basal genesis. This unit can be traced widely across the Foothills north of Porcupine Hills. It is the only basal till to be found overlying the montane till in this area, and can be compared to the succession of similar units documented south of the Porcupine Hills. The above observations have led us to the conclusion that the Laurentide Ice Sheet was continuously present north of the Porcupine Hills during much of the late Wisconsinan, whereas numerous fluctuations of its margin took place along its south western margin in the Oldman River basin south of the Porcupine Hills.

Fig. 1-2a (Little and Jackson Stop 1-2)

SECTION H1
82 J/9 (Turner Valley): 712500, 5620700



Silt. Dark brown chernozem soil developed within it. Contains fire-cracked rock from a paleo-Indian campsite.

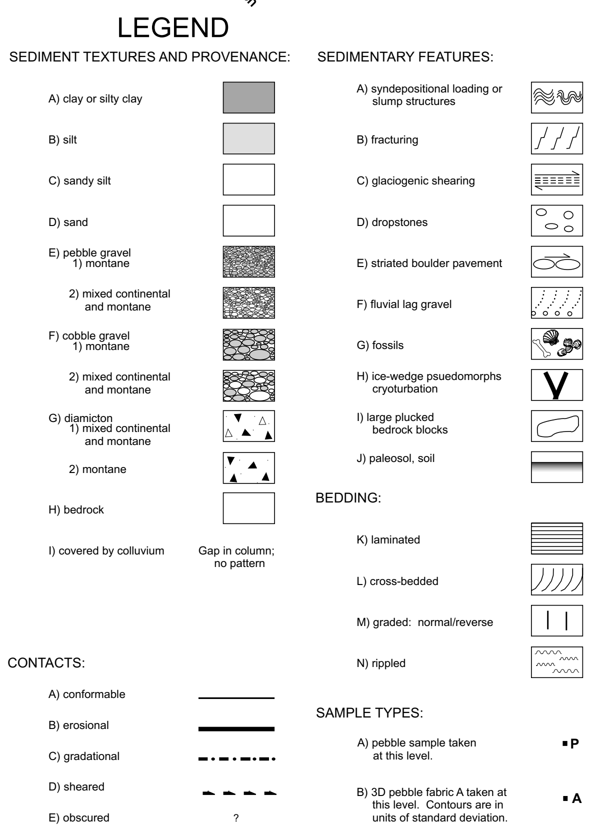
Silty sand. Thinly bedded.

Diamicton. Indurated and moderately stony. Lower 30 cm contains intraclasts from underlying sandy beds. Unit contains scattered Shield pebbles and purple-banded pebbles from the Rocky Mountain Main Ranges.

Sheared, laminated silty sand with pebble gravel lenses. Beds undulate and are locally intruded by the overlying till.

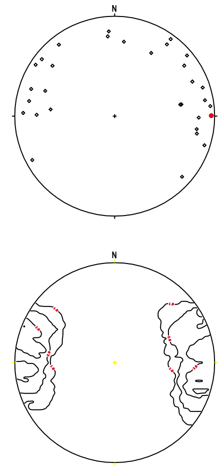
Diamicton. Massive, very stony and indurated. Stones range up to almost 1 m in length. Lenses of disturbed gravel up to 0.5 m thick occur between bedrock and base of the till. Gravel clasts are all Rocky Mountain Front Ranges carbonate and sandstone as are all clasts contained within the till. Most clasts within the till are highly striated, especially along the base. Till becomes less stony and more clay-rich over the upper 30 cm. Basal 30 cm is a deformation till grading from sheared grey shale into overlying diamicton.

Thick bedded and massive sandstone and mudstone.



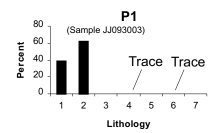
PEBBLE PROVENANCE

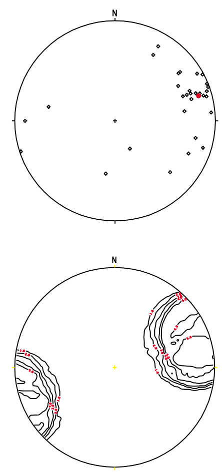
1. Rocky Mountains and Foothills: limestone, dolostone,calcareous shale, coquinoidal limestone.
2. Rocky Mountains and Foothills: grey and white othoquartzite, lithic sandstone, micaceous sandstone, conglomerate and chert.
3. Oldman River headwaters: trachyte and phonolite tuff and tuffaceous sandstone (Crowsnest Volcanics).
4. **Rocky Mountain Main Ranges** (Gog Group) **or Lewis and Clark Ranges** (Purcell Supergroup)**:** purple and maroon quartzite.
5. Lewis and Clark Ranges (Purcell Supergroup)**:** red and green argillite, gabbro, metagabbro.
6. Canadian Shield: granite containing pink plagioclase, schist, gneisss, migmatite, metaquartzite.
7. Other: coal, vein quartz, unidentifiable.



FABRIC A
SECTION H1
Schmidt Projection, Step Function Grid

Number of Sample Points...........30
Mean Lineation Azimuth.............89.7
Mean Lineation Plunge...............2.4
1st Eigenvalue............................0.641
2nd Eigenvalue..........................0.305
3rd Eigenvalue...........................0.054
LN {E1 / E2}...............................0.743
LN {E2 / E3}...............................1.738
[LN {E1 / E2}] / [LN {E2 / E3}]....0.427
Spherical Variance....................0.5811
Rbar...0.4189

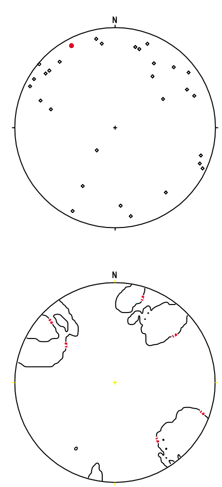




Lithology

FABRIC B
SECTION H1
Schmidt Projection, Step Function Grid

Number of Sample Points...........30
Mean Lineation Azimuth.............73.2
Mean Lineation Plunge...............13.0
1st Eigenvalue............................0.787
2nd Eigenvalue..........................0.130
3rd Eigenvalue...........................0.083
LN {E1 / E2}...............................1.805
LN {E2 / E3}...............................0.445
[LN {E1 / E2}] / [LN {E2 / E3}]....4.057
Spherical Variance....................0.2982
Rbar...0.7018



FABRIC C
SECTION H1
Schmidt Projection, Step Function Grid

Number of Sample Points...........29
Mean Lineation Azimuth............332.0
Mean Lineation Plunge...............6.8
1st Eigenvalue............................0.485
2nd Eigenvalue..........................0.402
3rd Eigenvalue...........................0.112
LN {E1 / E2}...............................0.188
LN {E2 / E3}...............................1.275
[LN {E1 / E2}] / [LN {E2 / E3}]....0.148
Spherical Variance....................0.6193
Rbar...0.3807

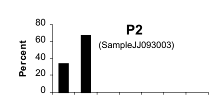
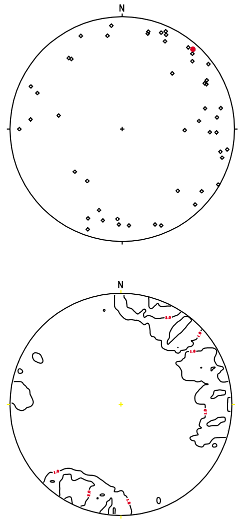
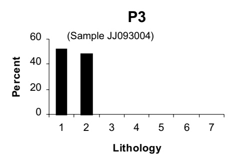


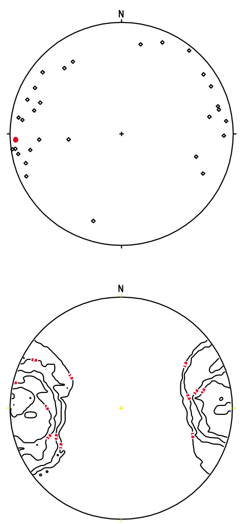
Fig. 1-2b (Little and Jackson Stop 1-2)



FABRIC D
SECTION H1
Schmidt Projection, Step Function Grid

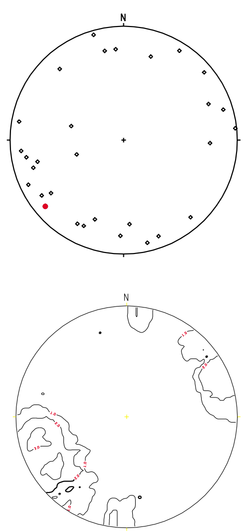
Number of Sample Points...........50
Mean Lineation Azimuth.............41.6
Mean Lineation Plunge...............4.3
1st Eigenvalue............................0.505
2nd Eigenvalue..........................0.403
3rd Eigenvalue...........................0.092
LN {E1 / E2}...............................0.226
LN {E2 / E3}...............................1.483
[LN {E1 / E2}] / [LN {E2 / E3}]....0.153
Spherical Variance....................0.6191
Rbar...0.3809





FABRIC E
SECTION H1
Schmidt Projection, Step Function Grid

Number of Sample Points...........30
Mean Lineation Azimuth............266.8
Mean Lineation Plunge...............4.2
1st Eigenvalue............................0.711
2nd Eigenvalue..........................0.222
3rd Eigenvalue...........................0.067
LN {E1 / E2}...............................1.165
LN {E2 / E3}...............................1.199
[LN {E1 / E2}] / [LN {E2 / E3}]....0.972
Spherical Variance....................0.6528
Rbar...0.3472

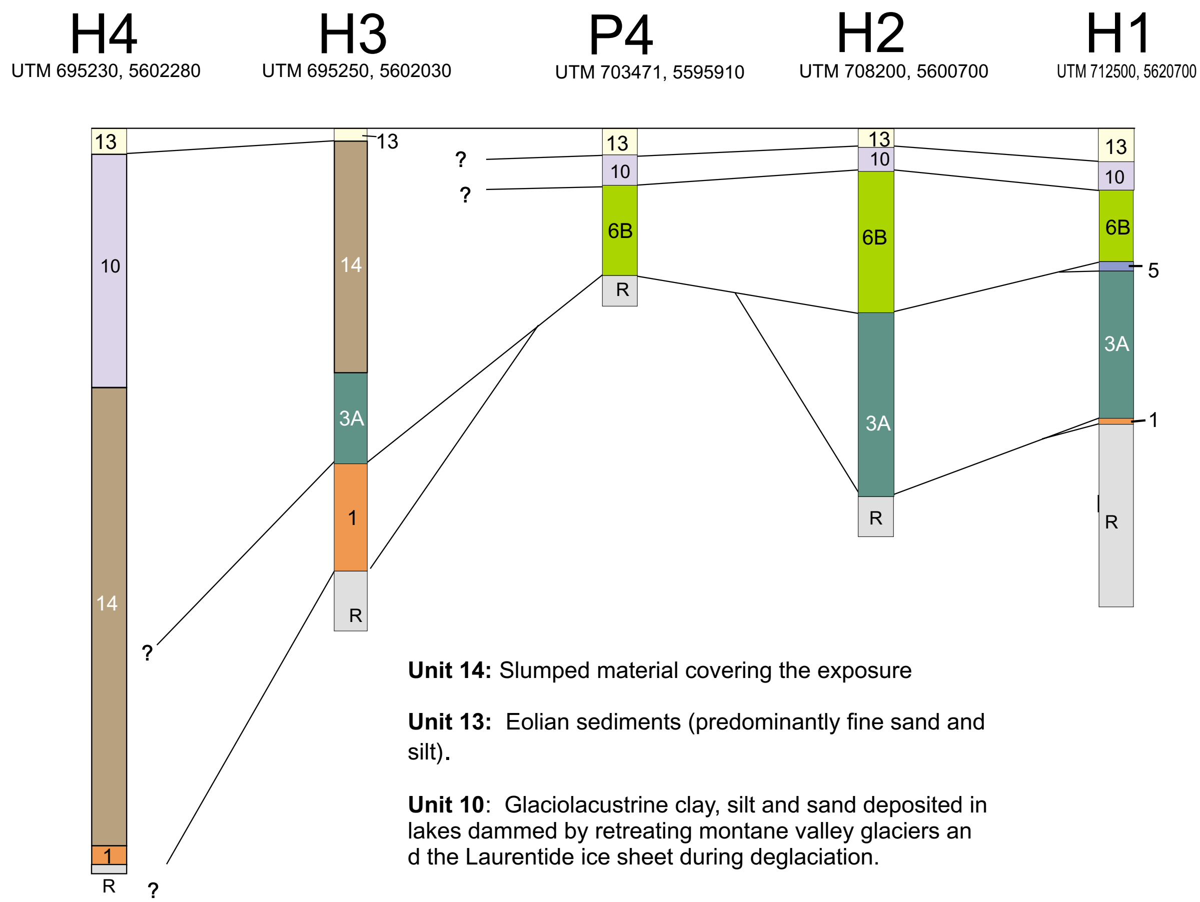


FABRIC F
SECTION H1
Schmidt Projection, Step Function Grid

Number of Sample Points...........30
Mean Lineation Azimuth.............229.8
Mean Lineation Plunge...............9.5
1st Eigenvalue............................0.563
2nd Eigenvalue..........................0.343
3rd Eigenvalue...........................0.094
LN {E1 / E2}...............................0.495
LN {E2 / E3}...............................1.291
[LN {E1 / E2}] / [LN {E2 / E3}]....0.383
Spherical Variance....................0.6602
Rbar...0.3398

Fig. 1-2c (Little and Jackson Stop 1-2)

CORRELATION OF CLIFF-BANK EXPOSURES ALONG HIGHWOOD RIVER, 5TH MERIDIAN TO LONGVIEW



Unit 14: Slumped material covering the exposure

Unit 13: Eolian sediments (predominantly fine sand and silt).

Unit 10: Glaciolacustrine clay, silt and sand deposited in lakes dammed by retreating montane valley glaciers an d the Laurentide ice sheet during deglaciation.

Subunit 6B: Diamicton deposited by the first incursion of the Laurentide Ice Sheet into the Foothills.

Unit 5: Glaciolacustrine clay, silt, and sand overlying montane diamictons deposited during the maximum late Wisconsinan (Pinedale) montane advance (interstratified between montane diamictons beyond the limits of the Laurentide Ice Sheet). Tentatively correlated in part with Unit 4.

Subunit 3A: Stratified or massive montane diamicton

Unit 1: Basal gravel. Clasts are entirely montane provenance.

R: Cretaceous sandstone and mudstone.

R

Black Diamond and Turner Valley oil fields

Leaving stop 1-2, we will pass through Longview which is about 10 km south of the twin towns of Turner Valley and Black Diamond. We will see numerous oil pumps along the way. The coal, oil and gas history of this area deserves a few words.

Oil and gas fields, Turner Valley/ Black Diamond/Longview areas

The town of Black Diamond was named for the coal beds that were exploited during the end of the last century and the early years of this century. Drilling of gas seeps in 1914 along the Sheep River, which separates Black Diamond and Turner Valley, tapped into an anticlinal oil reservoir in lower Cretaceous sandstone. Deeper drilling in 1924 encountered a much more extensive reservoir in Mississippian (lower Carboniferous) carbonates. Since drilling and production were not regulated in those years, the wells were closely spaced. There was virtually no market for natural gas which was produced only for condensate liquids which could be used directly as automobile fuel. Natural gas was simply torched off. The heat of the flares in the area warmed the local climate so much that the area was usually free of snow cover through the severe Alberta winters. Oil was eventually encountered below the gas cap. Unfortunately, the reduction of gas pressure was so severe by that time, only about 12% of the total oil reserves will ever be recovered (Tippet 1987).

Plateau Mountain and the Front of the Rocky Mountains

Approximately 40 km south of Black Diamond, we will pass Plateau Mountain and see the front of the Rocky Mountains close-up. Here, massive and cliff-forming Mississipian carbonate rocks are brought to the surface along a major thrust fault that superposes them upon Mesozoic clastics. The flat, alpine tundra summit of Plateau Mountain ranges between 2440 and 2500 m. Permafrost development, marked by normal and sorted stone polygons, can be observed on the tundra summit of Plateau Mountain. During the last ice age, this mountain was a nunatak which projected above the Rocky Mountain ice cap.

Stop 1-3 readvance or still stand moraine, Magnetic Hill

This stop is located at the northern end of the Porcupine Hills at the 5th meridian at an elevation of about 1370 m (4500 ft.) at the upper elevation limit of a belt of hummocky moraine. This moraine can be traced discontinuously along the east and south margins of the Porcupine Hills (PH). The belt represents a still-stand in the retreat of the Laurentide Ice Sheet or a readvance during deglaciation. Canadian Shield erratics have been found to elevations of approximately 1760 m (5770 ft.) at the northern summit of Porcupine Hills a few km to the south of our position (Day 1971). Our NATMAP team has dubbed this all time maximum extent of the Laurentide Ice Sheet in this region "C1" and the major readvance position "C2". The C1 erratics at the northern end of PH have yielded late Wisconsinan cosmogenic ^{36}Cl exposure ages (see Appendix B). The summit of the southern end of PH, which rises slightly above 1550 m, escaped glaciation. From this difference in elevation, a surface gradient for the Laurentide Ice Sheet of about 1 m/km can be calculated in a southernly direction along the 30 km eastern margin or the Porcupine Hills during the LGM (Jackson *et al.* 1996).

At the time that the C2 belt of moraine seen at this stop was deposited, ice also pressed up Willow Creek which crosses PH immediately to the south. It also pressed up Callum Creek (locally called Martha

Creek) along the west side of PC. This created a vast Foothills lake called Glacial Lake Westrup (Alley and Harris 1974) which had a high stand of about 1400 m. We will follow the former long axis of this lake to our next stop. The clay-rich lacustrine sediments deposited in this lake creep on slopes of a few degrees.

If time permits, we will try out the optical illusion from which magnetic hill gets its name!

Porcupine Hills

The high point on our way south to Pincher Creek is along the west side of Porcupine Hills. This upland represents the western limit of unfaulted rocks of the Western Canada Sedimentary basin. The Porcupine Hills are underlain by early Tertiary sandstone, siltstone and bentonitic mudstone. These rocks are the eroded remnants of a vast molasse deposited during the thrusting and folding of the Rocky Mountains and Foothills during the late Cretaceous and early Tertiary Laramide Orogeny. The weight of the stacks of imbricate thrusts depressed the crust to the east. The rocks of the Porcupine Hills accumulated within this basin.

Stop 1-4 Mammoth tooth road cut (Section 015)

A mammoth molar apparently eroded out of the glaciolacustrine sediments which cap this road cut (Fig. 1-3a). This tooth was found on the surface by Ted Little in 1995. It yielded a radiocarbon age of 11 220±60 a b.p. (Beta 79915); the oldest finite radiocarbon age determined on surficial sediments during the 1993-1997 Geological Survey of Canada NATMAP study of this area. The age probably postdates the recession of the Laurentide Ice Sheet from this area by several thousand years. The underlying till contains up to 1% stones from the Canadian Shield as well as clasts from the Purcell Supergroup and the Crowsnest Volcanics which indicate that ice-flow was from south to north in this area.

As we travel south to our next stop, we will descend through several levels of glacial lake plains deposited as the Laurentide Ice Sheet retreated south. The lake plain at this stop is the highest of the succession. Each successively lower level has hanging deltas that are graded to it. Figure 1-3b correlates cliff bank sections described between stop 1-4 and Oldman Reservoir. Only one till (the highest in the section) bearing Shield and Purcell Supergroup lithologies is present in these sections. It is not clear if this represents a single late Wisconsinan advance of the Laurentide Ice Sheet or more than one which has reworked the surface till, hence the uncertainty of the relative age of the unit shown in Fig. 1-3b.

Stop 1-5 Overlook, southwestern Porcupine Hills

We leave Highway 22 at the crossing of the Oldman River and drive south on Snake Trail along the west side of PH. Snake Trail winds through the upper limits of laciolacustrine sediments, thin till, colluvium and bedrock. At the south end of PH we climb to approximately 1520 m. Our stop is a gravel deposit laid down in an ice marginal channel within a few tens of metres of the all time limit of glaciation in this area. Lithologies from the Canadian Shield are plentiful in this deposit. From this vantage point (two provinces and one state are visible), the thickness of montane and Laurentide ice sheets can be visually reconstructed. The problem of the westward rising of the limits of the Laurentide Ice Sheet will be discussed

.

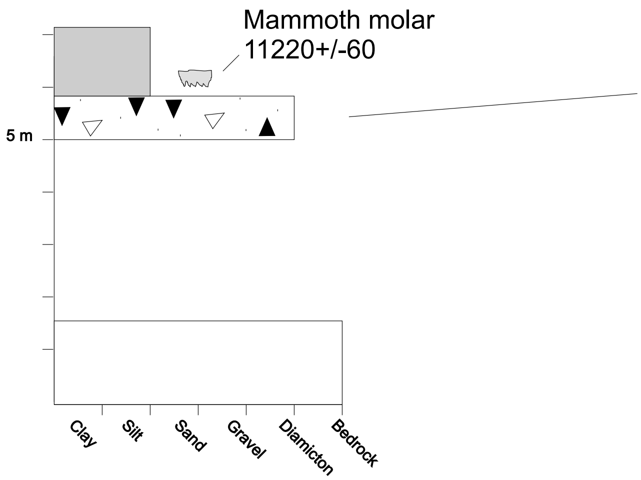
Stop 1-6 Second crossing of C2 Moraine

As we descend from the previous stop, toward the Oldman Valley, we cross the hummocky terraine of the C2 moraine at about 1370m.

Figure 1-3a (Little and Jackson stop 1-4)

SECTION O15

82 G/16 (Maycroft): 704869, 5536379



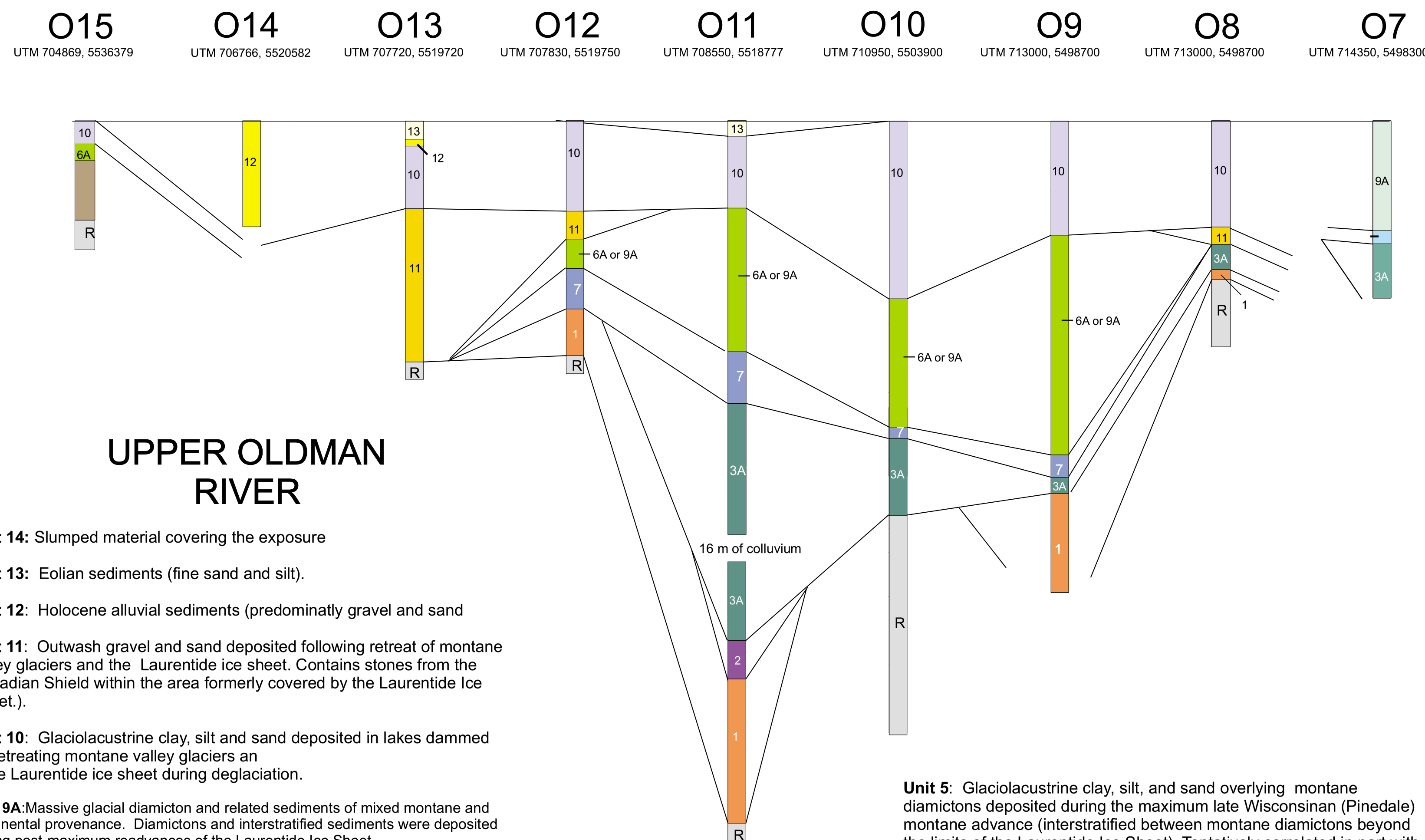
Sandy, clayey silt. No apparent stratification.

Diamicton. Sandy, clayey silt matrix. Clasts dominated by disaggregated sandstone and shale. Scattered carbonate clasts and clasts from the Canadian Shield.

Obscured by grading due to highway construction.

Bedrock, mudstone.

Fig. 1-3b (Little and Jackson Stop 1-4)



UPPER OLDMAN RIVER

Unit 14: Slumped material covering the exposure

Unit 13: Eolian sediments (fine sand and silt).

Unit 12: Holocene alluvial sediments (predominatly gravel and sand

Unit 11: Outwash gravel and sand deposited following retreat of montane valley glaciers and the Laurentide ice sheet. Contains stones from the Canadian Shield within the area formerly covered by the Laurentide Ice Sheet.).

Unit 10: Glaciolacustrine clay, silt and sand deposited in lakes dammed by retreating montane valley glaciers an
d the Laurentide ice sheet during deglaciation.

Unit 9A:Massive glacial diamicton and related sediments of mixed montane and continental provenance. Diamictons and interstratified sediments were deposited during post-maximum readvances of the Laurentide Ice Sheet.

Unit 7 Glaciolacustrine fine sand, silt, and clay separating diamictons deposited by readvances of montane valley glaciers and the Laurentide Ice Sheet.

Unit 6B: Diamicton deposited by the first incursion of the Laurentide Ice Sheet into the Foothills.

Unit 5: Glaciolacustrine clay, silt, and sand overlying montane diamictons deposited during the maximum late Wisconsinan (Pinedale) montane advance (interstratified between montane diamictons beyond the limits of the Laurentide Ice Sheet). Tentatively correlated in part with Unit 4.

Unit 3A: Stratified or massive montane diamicton

Unit 2: Lacustrine or glaciolacustrine fine sand, silt and clay predating the initial late Wisconsinan (Pinedale) advance of Montane glaciers. Partly or pervasively sheared by glacial overriding..

Unit 1: Basal gravel. Clasts are entirely montane provenance.

R: Cretaceous sandstone and mudstone.

Stop 1-7 View of Bitango section

From Stop 1-6 we drive across Oldman Dam to Highway 3. We will stop along the north side of the Highway at the western edge of the Peigan Reserve to view an impressive cliff-bank exposure which Elizabeth Leboe called the Bitango section after the owner of the property (Leboe 1996). The most revealing cliff-bank exposures in the Oldman River basin are nearly vertical. Dual rope rappel/safety line and re-bar anchor systems were used to study and sample this and other exposures during the NATMAP study.

The Bitango section is composed of four major diamicton units all bearing stones from the Canadian Shield (Fig. 1-4a). The strong fabrics of the units alternate between northeast and southwest mean directions. These and internal shearing and sheared or abrupt erosional basal contacts indicate a basal ice environment of deposition (Fig. 1-4a and b summarize the stratigraphy and sedimentology of the Bitango section. Gravel units separating these units suggest that ice advanced and retreated several times in the area of the Bitango Section. The change in ice flow direction from one unit to the next likely reflects deflection of ice-flow by local topography during advance pulses which alternated in strength along the advancing ice margin. This is in contrast to the stratigraphy seen in the Highwood River valley (Stop 1-2) earlier today. There, evidence exists for a single advance of continental provenance ice.

Several km down stream from the Bitango Section is the Brocket Section which is not available to us (the Peigan Council has consistently refused access although individuals have taken us there as friends). At the Brocket section, a similar stratigraphy is seen along with the following underlying units: montane till (Albertan Till), montane gravel (interpreted as outwash) and Cretaceous bedrock. These additional units are exposed because the Oldman River cuts further through the section as it decends in elevation. There is no evidence of anything more than a brief hiatus between the deposition of the lowest continental (Shield-stone bearing till) and the underlying Albertan Till. There is unanimity among all who have seen this succession that the Laurentide Ice Sheet arrived in the area shortly after the montane glaciers retreated to the west. Local glaciolacustrine beds separate the two tills indicating that subaerial conditions did exist, at least locally in the area, between the retreat of montane piedmont glaciers and the advance of the Laurentide Ice Sheet (see Appendix C).

Stop 1-8 Island Section

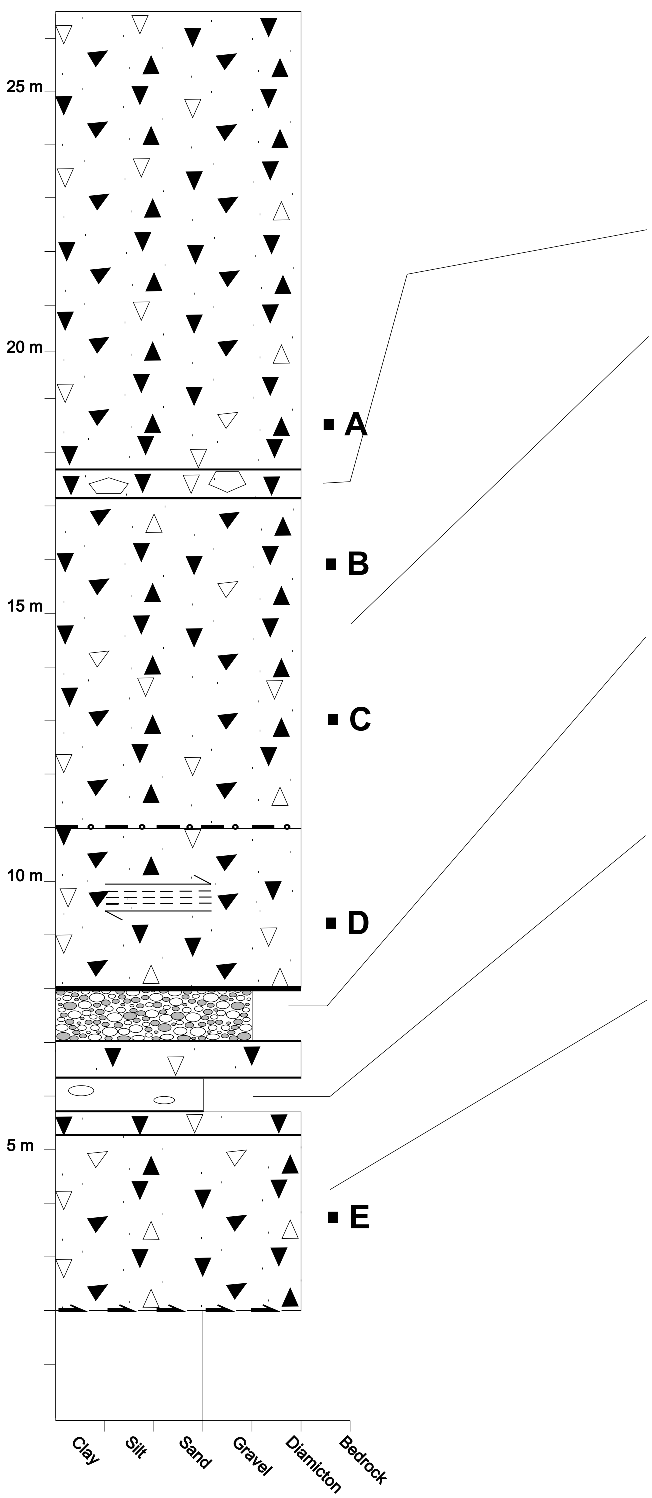
This is an optional stop and dependent upon whether we can line up a boat to take us to a small island on the Oldman Reservoir. Here, two diamictons are separated by highly sheared lacustine beds (Fig. 1-5). The upper unit contains abundant Shield pebbles. It has a strong fabric suggesting movement from the east. The underlying tectonized, laminated clay-silt strata document an ice overriding event. The underlying diamict contains rare Shield stones. Nailhead striations on the bullet boulders indicate a west to east ice-flow during the deposition of this unit. The presence of Shield lithologies within the lower unit indicates that the montane advance which deposited it postdated C1. This major montane readvance is called M2. Here it clearly predates the C2 till.

Fig. 1-4a (Jackson and Little Stop 1-7)

SECTION O4

82 H/5 (Brocket): 297500, 5493700

Bitango Section



Diamicton. Sandy silt matrix. Fabric indicates ice flow from SE. Depositional lower contact.

Angular and irregular intraclasts of fine light grey sand within diamicton. Intraclasts range up to 10 cm. Depositional lower contact.

Diamicton. Cohesive matrix. 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.

Diamictons containing Shield stones interstratified with thin sheared and contorted sand layers. Lower contact is abrupt and erosional. Fabric at base indicates ice flow from NE.

Pebble gravel. Poorly sorted. Contorted. Varies in thickness from 0.1 to 1.2 m. Depositional lower contact.

Diamicton with sandy silt matrix and clasts up to 5 cm with some silt beds. Depositional lower contact.

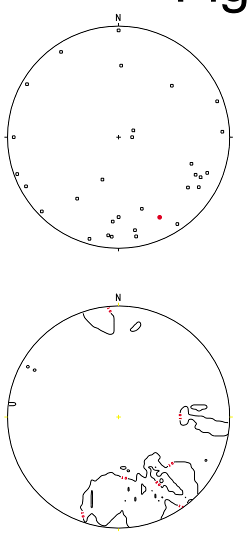
Alternating layers of fine sand and silt with pebbles. Depositional lower contact.

Stony silt or silty diamicton. Depositional lower contact.

Diamicton. Light grey (dry), dark greyish brown (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.

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

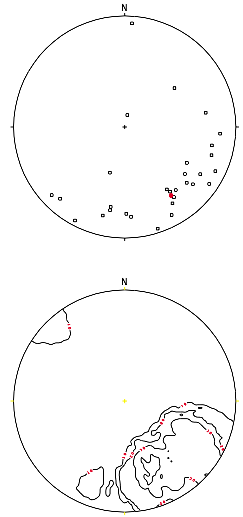
Fig. 1-4b (Little and Jackson Stop 1-7)



Fabric A
Section O4
Schmidt Projection, Step Function Grid

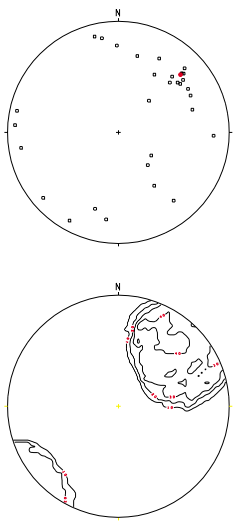
Number of Sample Points	30
Mean Lineation Azimuth	152.9
Mean Lineation Plunge	19.0
1st Eigenvalue	0.500
2nd Eigenvalue	0.367
3rd Eigenvalue	0.133
LN (E1 / E2)	0.309
LN (E2 / E3)	1.014
[LN(E1/E2)] / [LN(E2/E/3]	0.304

Spherical variance
0.5441
Rbar
0.4559



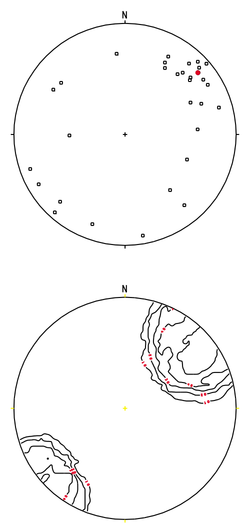
Fabric C
Section O4
Schmidt Projection, Step Function Grid

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/E/3]	0.615
Spherical variance	0.2780
Rbar	0.7220



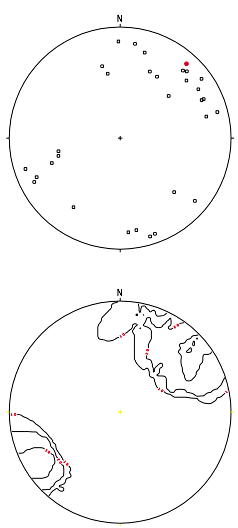
Fabric B
Section O4
Schmidt Projection, Step Function Grid

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/E/3]	1.182
Spherical variance	0.4787
Rbar	0.5213



Fabric D
Section O4
Schmidt Projection, Step Function Grid

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/E/3]	1.913
Spherical variance	0.5216
Rbar	0.4784



Fabric E
Section O4
Schmidt Projection, Step Function Grid

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/E/3]	1.224
Spherical variance	0.5844
Rbar	0.4156

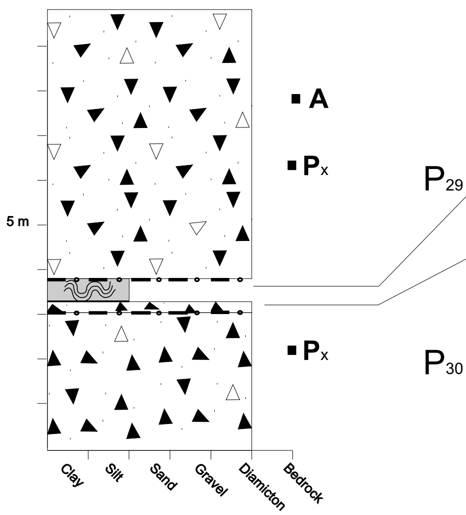
ISLAND SECTION

SECTION O7

82 G/9 (Blairmore): 714350, 5498300

Fig. 1-5

Little and Jackson Stop 1-8

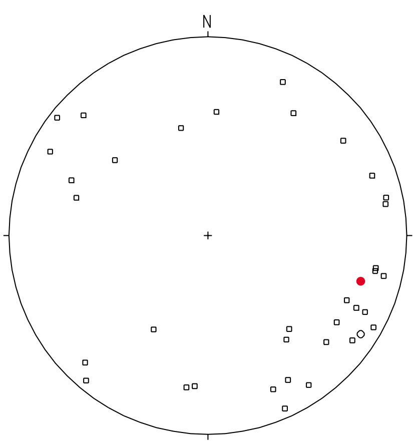


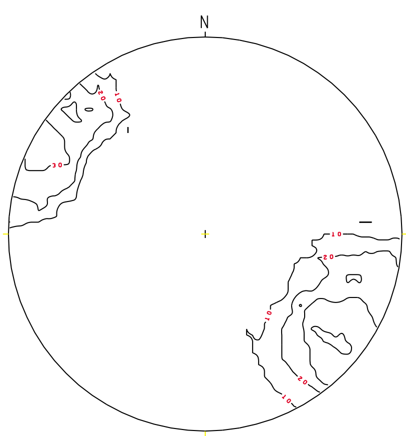
Diamicton, massive. Dark brown. Clayey matrix with 10% stone content. Contains Shield stones. Lower contact is gradational. Fabric indicates ice flow from SE.

Silt and clay laminae interbedded with dark grey clayey diamicton. At top, beds and laminae have been convoluted, vertical, or folded over by glacial overriding. Depositional lower contact.

Diamicton, grey, interbedded with thin, near-horizontal silt beds with dropstones. Lower contact is abrupt in some places, and slightly gradational in others.

Diamicton. Stones are montane with rare Shield stones. Silty sand matrix with 15-20% stone content. Upper contact is abrupt in some places, and sightly gradational in others. Nailhead striations on lodged boulders indicate west to east ice flow.





Fabric A
Section O7
Schmidt Projection, Step Function Grid

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/E/3]	0.789
Spherical variance	0.5593

Day 2 Pincher Creek to Del Bonita

Part I Pincher to Waterton

We will continue our trek from Pincher Creek, heading south on Hwy 6 towards Waterton National Park. Just north of Twin Butte, we will make our 1st stop at a section of elevated lacustrine sediments. Following this, we will be stopping at Cloudy Ridge and the Waterton Buffalo Paddock before heading east towards the Raley map sheet area. As we head out of the Waterton map sheet area, we will be approximating the C2 limit.

Stop 2-1 Drywood Creek

Overlapping till sheets and associated glaciolacustrine sediments

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.

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. 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. 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 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 (Fig. 2-1a-d). 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, which correlates with Horberg's (1954) Outer Continental Drift.

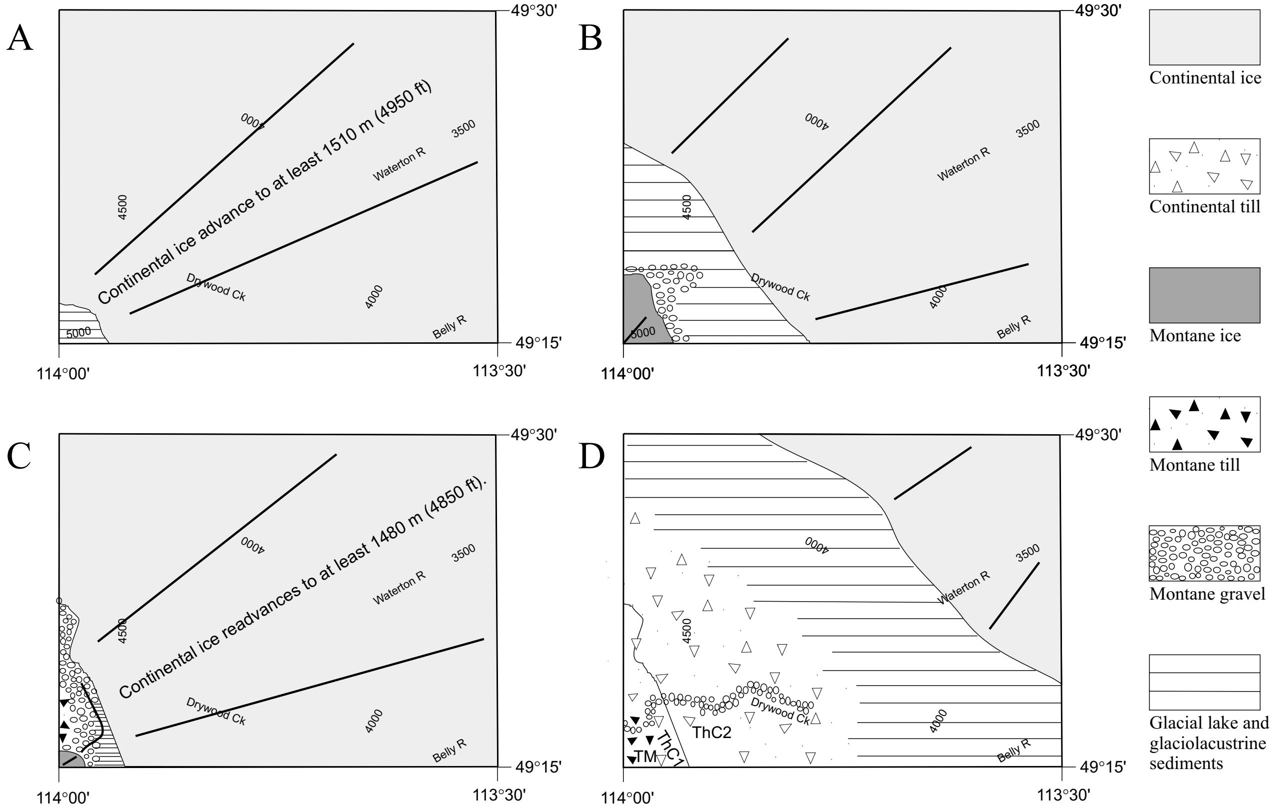


Figure 2-1a-d. Events responsible for the formation of overlapping till sheets and associated lacustrine sediments in the southwest corner of the Pincher Creek map area: A (maximum advance of ice into area); B (retreat of ice from maximum position); C (readvance of ice to 1480 m); and D (final retreat of ice from area)

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 .

Continental ice underwent 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 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.

Stop 2-2 Cloudy Ridge

Cloudy Ridge (CR) is a planar-topped, unforested spur that descends from the wall-like Rocky Mountain front from about 1770 m to 1550 m elevation over a linear distance of about 2500 m. It contains diamicts and paleosols (Little 1995). Both these deposits are of montane provenance. Canadian Shield erratics

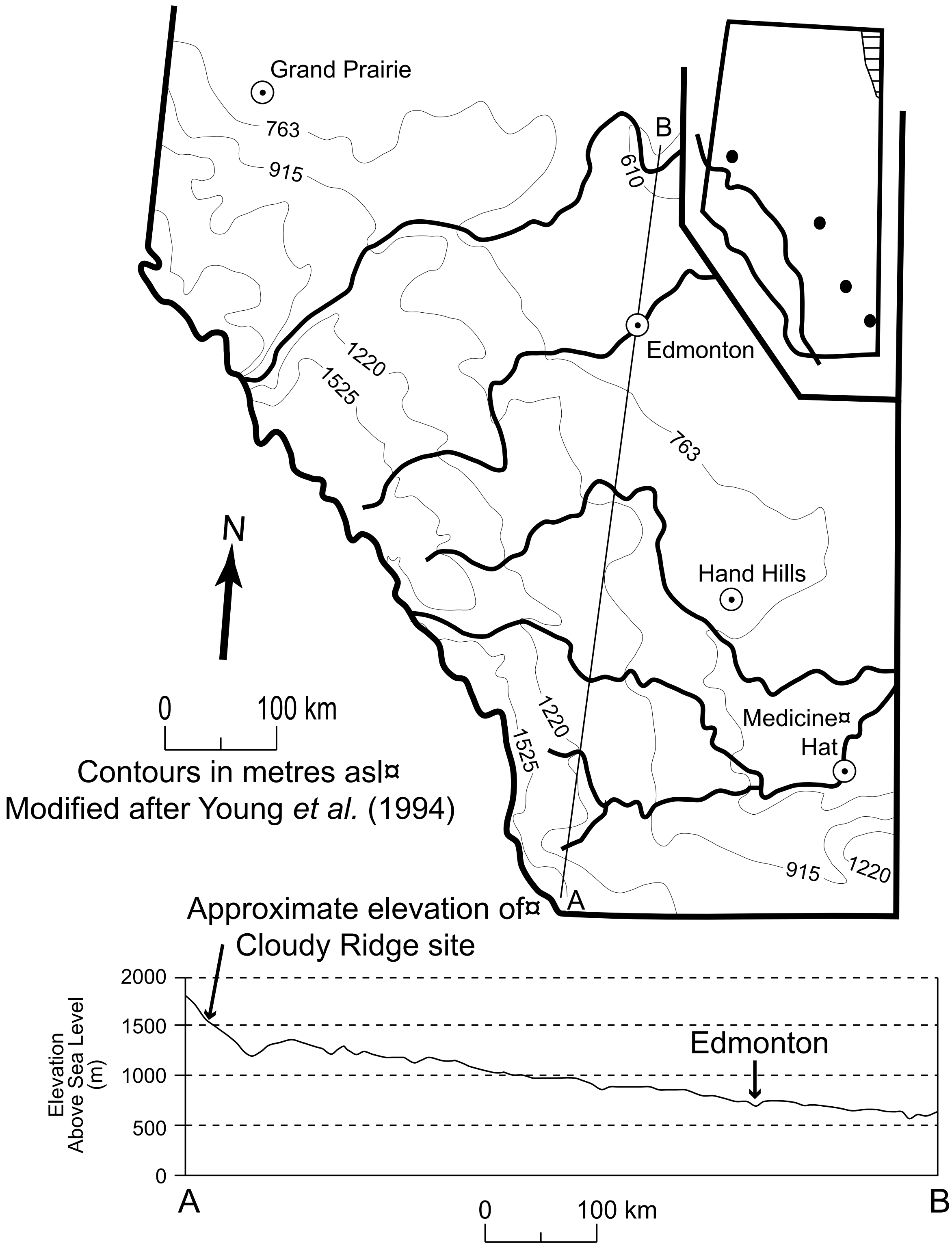


Fig. 2-2. Contour map of southern Alberta. Contours trending northwest to southeast illustrate natural drainage to northeast. The attitude of the slope is one reason why proglacial lakes ponded in front of continental ice retreating to the northeast. Insert map of Alberta shows maximum limits of montane and continental ice according to Young *et al.* (1994). X-section illustrates the difference in elevation between Edmonton and the Cloudy Ridge (C1) site, thus demonstrating hypotheses put forth by Young *et al*(1994) and supported by evidence from Wagner (1966) and Liverman (1989).

are common only on the surface of CR up to about 1585 m elevation. These represent the all time limit of continental glaciation (Fig. 2-2). They were deposited when the terminus of a Continental ice sheet partly overrode the pre-existing montane drift (or montane ice) on CR, leaving behind Canadian Shield erratics in the process. Three erratics sampled for ^{36}Cl exposure dating yielded ages of approximately 15-16k cal. years (Jackson *et al.* in press). These erratics were firmly in placed and there was no evidence to indicate that they were ever overturned.

The presence of Shield erratics on the surface suggests one of three possibilities: 1) that continental ice had pushed past CR to a higher elevation followed by redeposition to their present location by montane ice and/or gravity; 2) that continental ice had deposited the clasts directly on top of the ridge; or, 3) Canadian Shield erratics were transported from the continental ice to the montane ice across the convergence zone, then subsequently deposited *via* meltout (Wagner 1966).

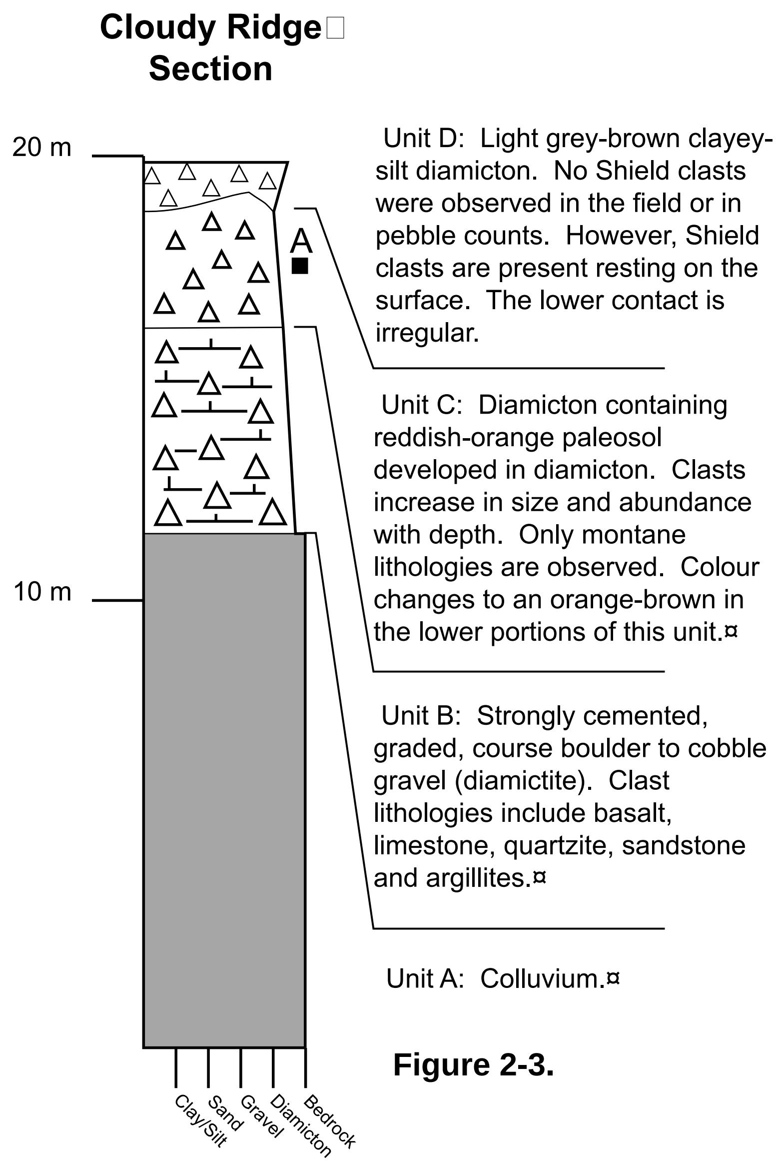


Figure 2-3.

Presently, no Shield erratic evidence for a continental ice limit higher than CR (1585 m asl.) has been observed within the Waterton map sheet study area. This agrees with the work of others who also reported no Shield material higher than 1 585 m asl (*e.g.*, Stalker 1959, 1962; Wagner 1966; Stalker and Harrison 1977) within the study area; and no Shield clasts were observed above 1 590 m asl in the southern Porcupine Hills, located north of the study area (Leboe 1996). Also, it is interesting to note that no Shield material is present within the upper most unit (D: Fig. 2-3) on CR (Shield erratics are only observed on the surface). This suggests that third hypothesis is the most acceptable and agrees with that put forth by Wagner (1966, pg. 40).

Deposits underlying the uppermost unit (D) at CR have been a source of controversy for many years (see Taylor 1987 and references therein). Some researchers interpret the diamicts in the section to be fan-related deposits while others believe them to be glaciogenic deposits.

A clast fabric obtained from CR, unit C exhibits two bipolar modes (Fig. 2-4). The primary mode

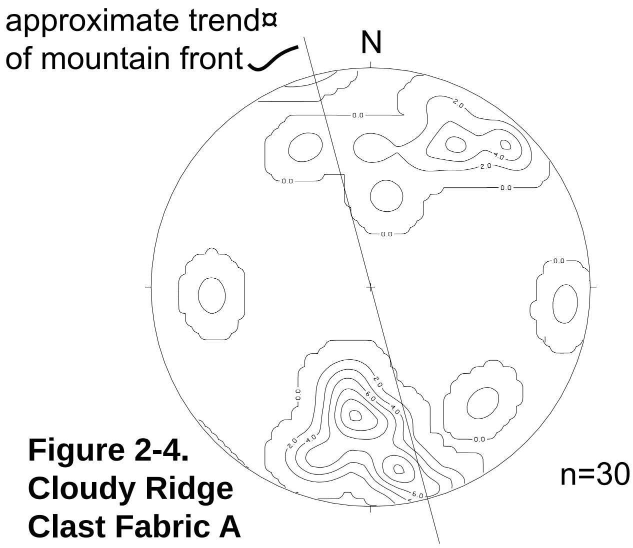


Figure 2-4. Cloudy Ridge Clast Fabric A

trends north-south, peaking in the south. The trend of the second, weaker mode is orthogonal to the primary mode. The primary mode is sub-parallel to the trend of the local mountain ridges.

The CR section, Unit C is characterized by an abundance of amygdaloidal basalt relative to other sections. There are three sources for this lithology: approximately 6 km southwest of Cloudy Ridge (Grid Ref.: 281600 5450500), 7 km south-southwest of Cloudy Ridge (in the vicinity of Mt. Dungarvan; Grid Ref.: 283200 5448800) and southwest of the Waterton townsite (Grid Ref.: 282800 5433800; Lebel *et al.* 1994).

One hypothesis explaining the origin of this unit is the deposition of till in a subglacial environment. Ice advancing out of the Waterton Valley would have been moving almost due north, suggesting that this deposit may be a till trending towards a lodgement end member. However, this location is sheltered behind Lakeview Ridge and no other evidence supporting glacial genesis was obtained from the section. Contrary to the above hypothesis, this unit can also be explained by fan deposition (Taylor 1987). This conclusion is supported by the relatively close proximity of two of the amygdaloidal basalt sources, clast a-axes orientation (approximately parallel to the trend of mountain front), the graded nature of the unit, and the occurrence of similar deposits of this age observed elsewhere in the Cordillera (Clague 1974).

A third possibility also exists; there are similarities between the Cloudy Ridge, Unit C fabric (Fig 2-4) and ice colluvium fabrics obtained from the Matanuska glacier margin in Alaska (Lawson 1979). Clasts with a-axes sub-parallel to the trend of a ridge (be it an ice ridge or a mountain front) suggest clasts rolling down the slope.This raises the question:

> Could this deposit be an ice slope colluvium deposit (flow till) from a mountain glacier moving out of the Yarrow Creek Valley during the same glacial episode that deposited the Mokowan Butte Unit 5 - the soil forming in both diamicts during the subsequent interglacial period (see Cioppa *et al.* 1995 for details)?

In any case, there is presently insufficient evidence from this site to make a positive identification. Evidence for sub-aerial deposition in the form of alluvial fan, slope colluvium or ice slope colluvium processes is only marginally stronger than evidence for the lodgement till hypothesis. Therefore, more data are required to interpret confidently the origins of the sediment comprising this unit.

Stop 2-3 Pine Ridge

The prominent WSW-ENE trending bedrock-cored ridge know as “Pine Ridge” roughly marks the southernwestern most extents of the late Wisconsinan continental maximum. Approximately 200m south of this local topographic high, Shield-stone-bearing deposits are no longer observed; Shield-stone-bearing tills disappear beneath montane glaciogenic deposits in that vicinity. At the culmination of the continental advance, montane ice from the Waterton and subsidiary valleys prevented the continental ice from entering this area. The "protective orientation" of Pine and Palmer ridges with respect to the inferred northeast-southwest continental ice movement aided the mountain ice in limiting the advance of the continental ice (Fig. 2-5a). However, continental ice east of Palmer Ridge did manage to advance sufficiently farther south. Between Pine and Palmer Ridges, continental ice may have advanced slightly farther south, but evidence of such an advance has been covered/destroyed by subsequent montane advance (Harrison 1976). Jackson *et al.* (in press) have dated a train of montane lithology boulders south of Pine Ridge marking the limit of late (post-C2) montane ice advance. This train of amygdaloidal basalt and limestone boulders is interpreted as being deposited by the last montane ice advance out of the Waterton Valley region; ^{36}Cl ages between 11.3-14.4k cal. years suggest deposition during the continental deglaciation phase of marine oxygen isotope stage (MIS) 2.

North of Lakeview Ridge/Indian Springs Ridge, south of Spread Eagle Road and west of Hwy #6, a proglacial lake, named " Glacial Lake Dungarvan" (Grid Ref.: 289000 5455000; Horberg 1954), was formed during the final retreat of both ice masses. This lake was dammed by the mountains and Lakeview Ridge to the west and south respectively, and by retreating continental ice to the north and east. The primary source feeding the lake would have been meltwater flowing from a retreating montane Waterton lobe through a large (presumably re-utilized) north-south trending meltwater channel. Other sources include meltwater from a small cirque glacier northwest of Mount Dungarvan (Harrison 1976), meltwater from the continental ice, and fluvial run-off from the surrounding terrain.

Stop 2-4 Esker Complex and Buffalo Paddock

During the retreat of montane ice from this area, but prior to the Waterton meltwater diversion to the present-day Waterton River (Fig. 2-5b,c), a large esker complex (Fig. 2-6a) and meltwater channels were developed (Harrison 1976). On the south side of Pine

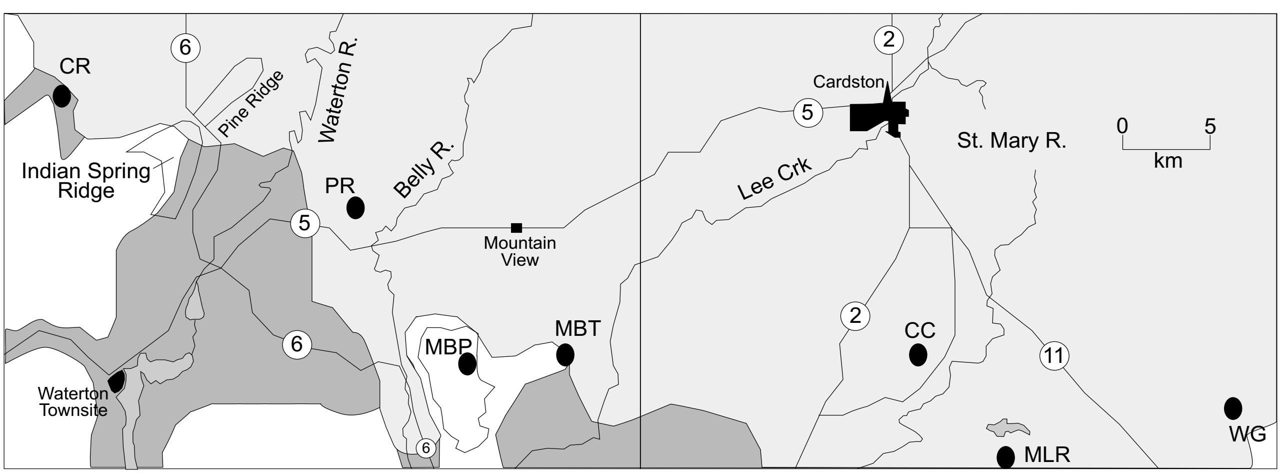


Figure 2-5a. Diagram illustrating the approximate location of continental ice as it pushes to its all time maximum extent (C1). Waterton lobe ice prevents continental ice from entering the area protected by Pine Ridge and Palmer Ridge (west of "PR" site); this coalescence increases the surface slope of the ice masses involved. St. Mary lobe ice prevents continental ice from advancing up the St. Mary River Valley. Continental Ice = Light Grey; Montane Ice = Dark Grey; Lakes = Intermediate Grey. (CR=Cloudy Ridge, PR=Palmer Ridge, MBP=Mokowan Butte Paleosols, MBT=Mokowan Butte Terrace,CC=Coal Canyon Site, MLR=Mary Lake Ridge Site, WG=Whiskey Gap Site)

Ridge, the large montane meltwater channel (Grid Ref.: 292500 5449000) flowed north into an ice dammed lake north of Indian Springs Ridge; it is possible that this channel's size is due to re-use by meltwater (Hicock, personal com. 1995). Also at this time, meltwaters rushing out from beneath the Waterton glacier eroded a cresentic scour (Fig. 2-6b) and formed drumlins south of the esker complex. Water that formed these features, would have flowed out through the large meltwater channel south of Pine Ridge.

Eventually, the meltwater channel-path emptying into Glacial Lake Dungarvan could have been abandoned in favour of a more direct route into what is now the present Waterton River. A narrow, but deep channel cut through a bedrock ridge north east of the esker complex (Grid Ref.: 292100 5445900) may have been the meltwater channel used once the larger meltwater channel flowing to Glacial Lake Dungarvan was abandoned. Sediment supply to Glacial Lake Dungarvan continued from fluvial and glaciofluvial (small cirque glacier) sources. This buried the mouth of the large north-south trending channel northeast of Indian Springs Ridge.

Farther south, ice moving out of the Waterton Valley passed over top of Bosporus, the name given to a resistant bedrock riegel separating the Upper and Middle Waterton Lakes opposite the townsite at the Waterton Narrows. During retreat, the thinning ice would have reached a critical thickness, below which no ice would have passed over the bedrock barrier. The ice on the north side of Bosporus would then have stagnated, producing a large ice block. Harrison (1976) suggested the melting of this large block of stagnant glacial ice had produced an ice block depression encompassing the present basins of the Middle and Lower Waterton Lakes as well as that of Maskinonge Lake. The subsequent infilling of water and the development of alluvial fans into this depression from Blakiston Creek and Sofa Creek led to the division of Middle and Lower Waterton Lakes.

Stop 2-5 Example of C2 Ice Stagnation Limit

From Waterton National Park, we follow the new Hwy 5 east towards Cardston. The position of the C2 stagnation (Fig. 2-7a) is marked by meltwater channel separating kettle lake topography (C2 deposit)

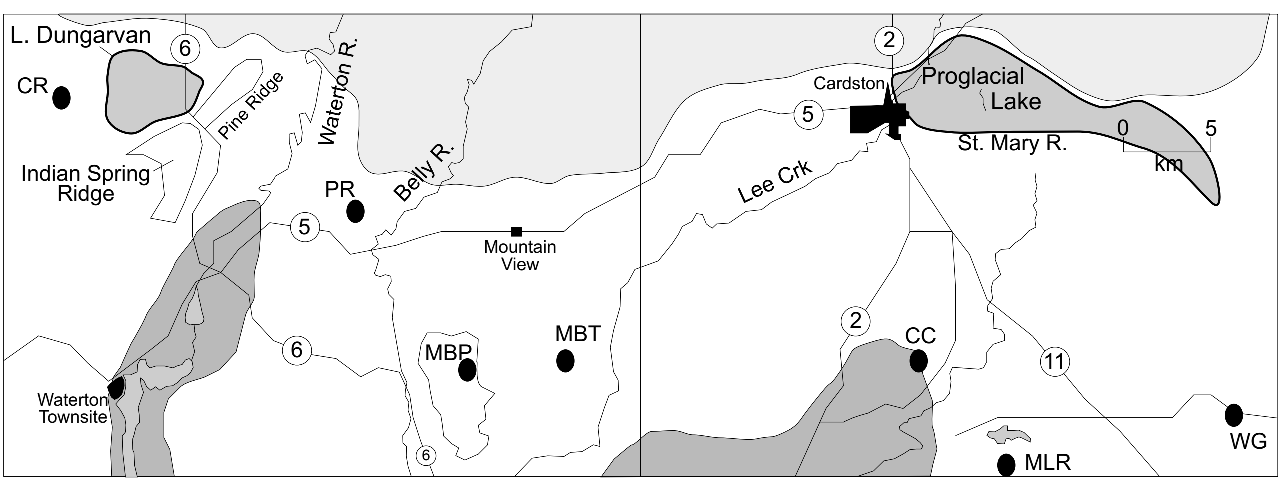


Figure 2-5b. Diagrammatic time slice showing continued retreat of continental ice from its maximum position. Montane ice begins to retreat as well; forms the montane moraine at the Coal Canyon site (CC @ 1 460 m). Meltwater from the retreating of the Waterton lobe forms large meltwater channel feeding Lake Dungarvan.

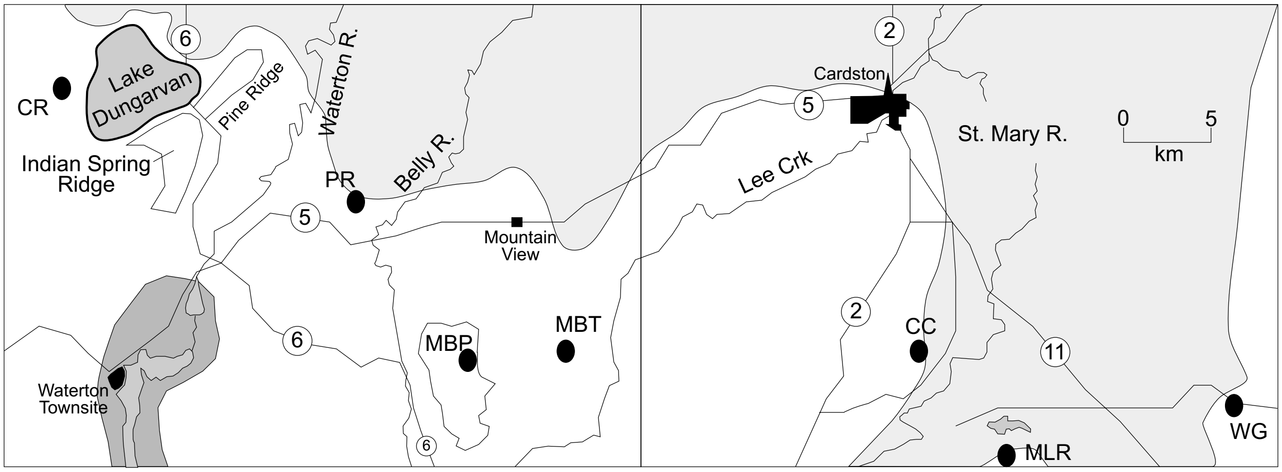


Figure 2-5c. Diagram illustrating a minor readvance of the continental ice. Due to different surface slopes and the conservation of volume for glacial advance, the continental ice in the eastern portion of the study area advance farther south than the western ice. Formation of esker complex west of Highway #6 (Map A). Lake Dungarvan is shown at its maximum level north of Lakeview Ridge. Continental drift pushes up to 1 420 m at Coal Canyon site (C2).

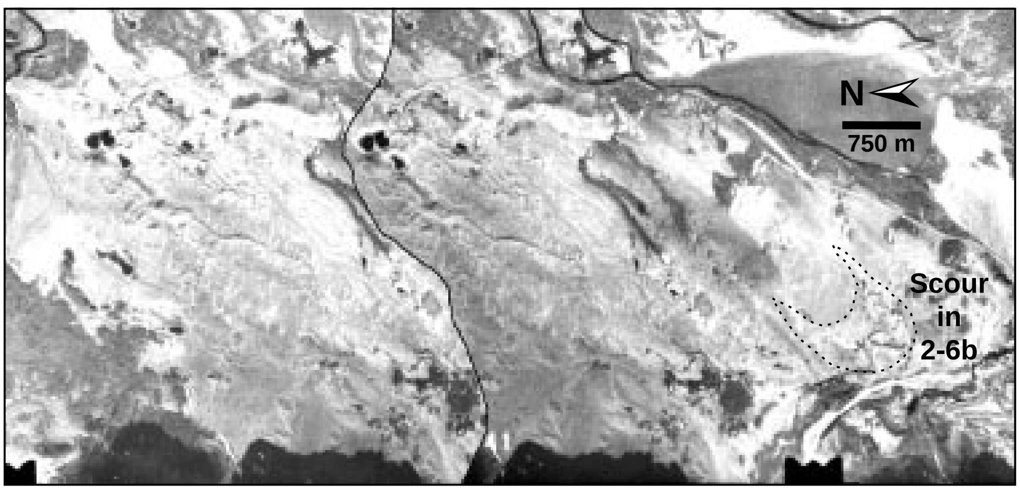
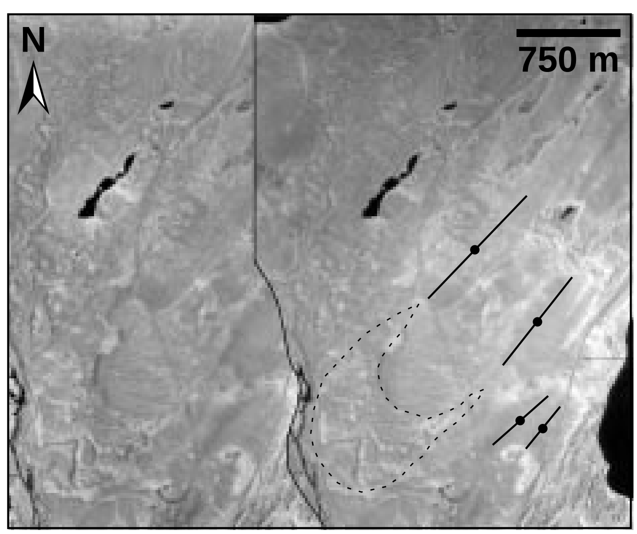


Figure 2-6a (above). Stereo-pair of Esker complex (right of centre). Some eskers can be traced for more than 2 km. In lower left corner, crescentic scour. Tails lead into drumlinoid features (see figure 2-6b).

Figure 2-6b (right). Originally this feature was described as a crevasse-fill structure (Harrison 1976). However, we re-interpreted the feature as a cresentic scour. The tails of the crescent lead into drumlinoid features to the NE.



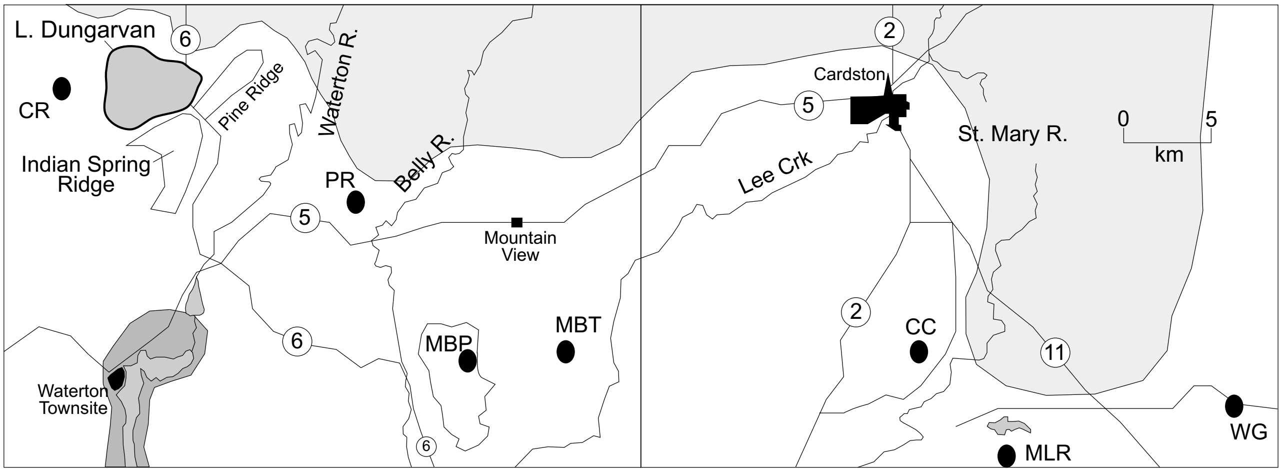


Figure 2-7a. Diagram showing the continental ice position during the formation of the Kimball moraine, recessional ridges at Coal Canyon site, and descending parallel ridges at Whiskey Gap site. Esker complex is no longer covered by ice.

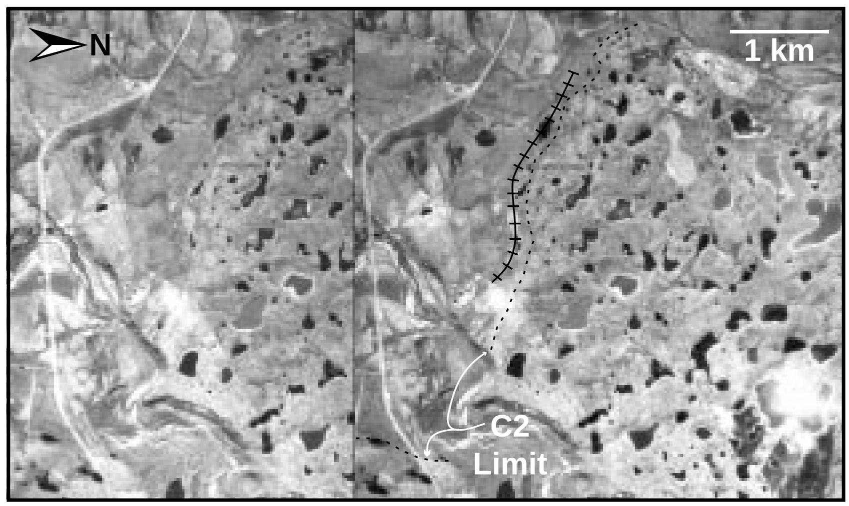


Figure 2-7b. Stereo-pair showing C2 till (Kimball Moraine) to the north (right) of a small meltwater channel, and C1 till south (left) of the meltwater channel.

of the Kimball Moraine (Little 1998a; Horberg 1954), from continental till blanket (C1 deposit) south of the meltwater channel (Fig. 2-7b).

Part II Waterton to St. Mary Reservoir Area

We continue to head east on Hwy 5 passing a region of southwest dipping, northeast verging, bedrock thrust sheets (Lebel and Williams 1994); the highest elevation within this "hogback" region is 1460 m (see Cardston Map Sheet, 82H/3). Canadian Shield erratics located on the top of the highest hogback ridge suggests that continental ice did cover the hogbacks during the C1 (maximum) advance phase (depicted in Fig. 2-5a). However, based on the elevations of the C2 limit farther west, we concluded that the C2 ice was confined to the lower elevations (below 1425 m) on the east and west sides of the Hogback region (Fig. 2-5c).

Once in Cardston, we turn north and find we are traversing some of the most subdued topography in the entire region; in a stretch of Hwy 2 (north of Cardston) the elevation change is only 30 cm in 5 km. This area was the site of a large ice proximal lake that

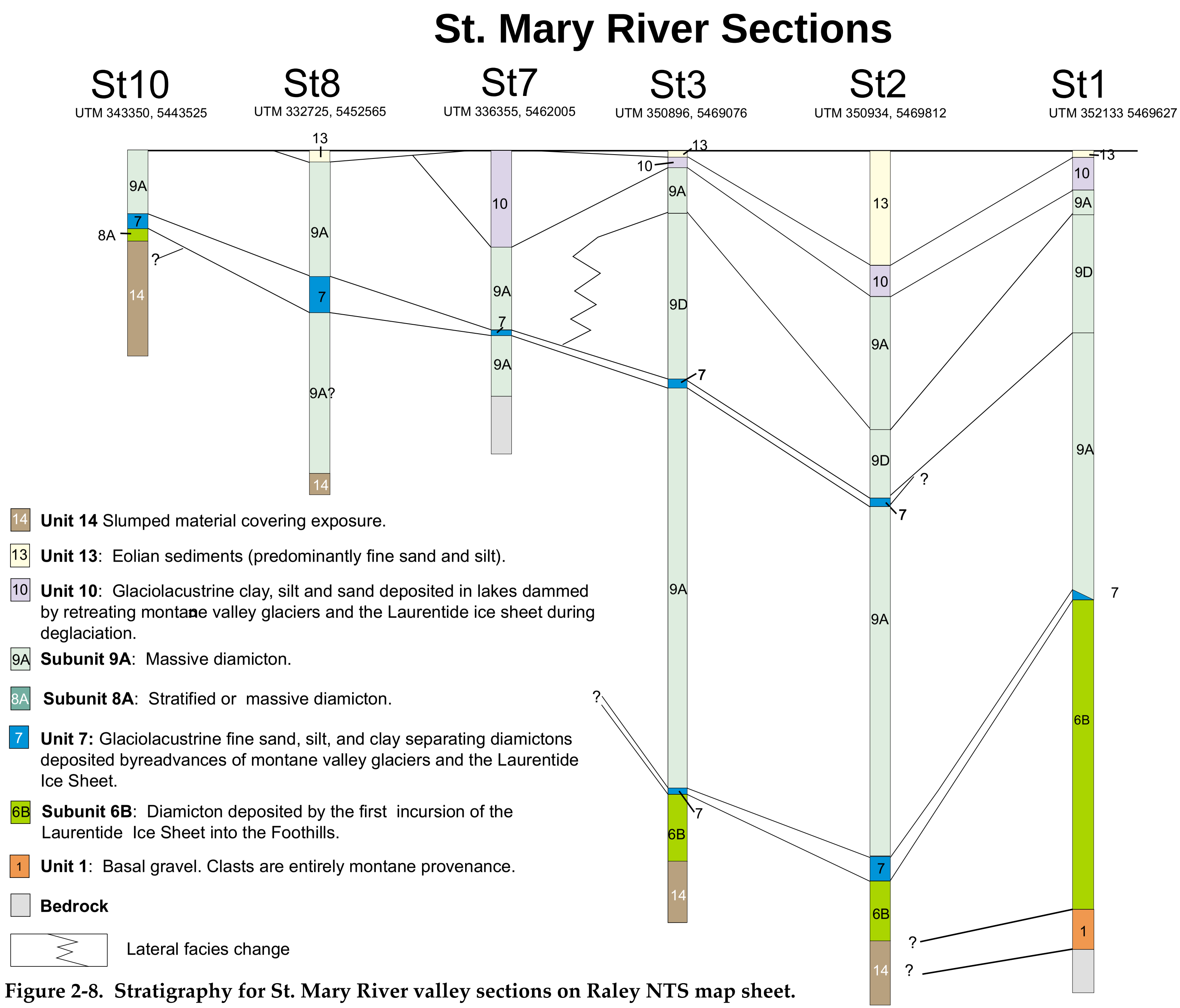


Figure 2-8. Stratigraphy for St. Mary River valley sections on Raley NTS map sheet.

occupied an area of more than 225 square km. Laminated silts and clays found within sections surrounding the St. Mary Reservoir suggest that predicessors of this lake occupied the this area several (at least 3) times since the first continental ice advance through this region (Fig. 2-8, units 7 and 10).

Stop 2-6 The "New Gully" Section

A Cardston Municipality gravel pit is the location of this stop. During the Pincher Creek Flood of 1995, erosion of the Waterton River bank at this site formed a new exposure. The upper gravel of this section forms a terrace of the Waterton River (Fig. 2-9a). Below, laminated lacustrine sediments are observed overlying continental till. This continental till exhibits a clast fabric (Fig. 2-9b) that shows an a-axis orientation that is aligned to the general ice flow direction for this region (Little *et al.* in review). Only one continental till is observed at this location. This may be due to the site being located far enough from the fluctuating margin (see Stop 2-5) to pevent the development of significant intra-till variablity.

Below the continental till, a glaciofluvial gravel is observed. This gravel is interpreted as glaciofluvial in origin for two reasons: 1) the character of the gravel is much different that other pre-glacial gravel in the region (*i.e.,* Saskatchewan Gravels); and, 2) there are montane tills observed in section within 7.5km of this site (see Stop 2-7). In addition,

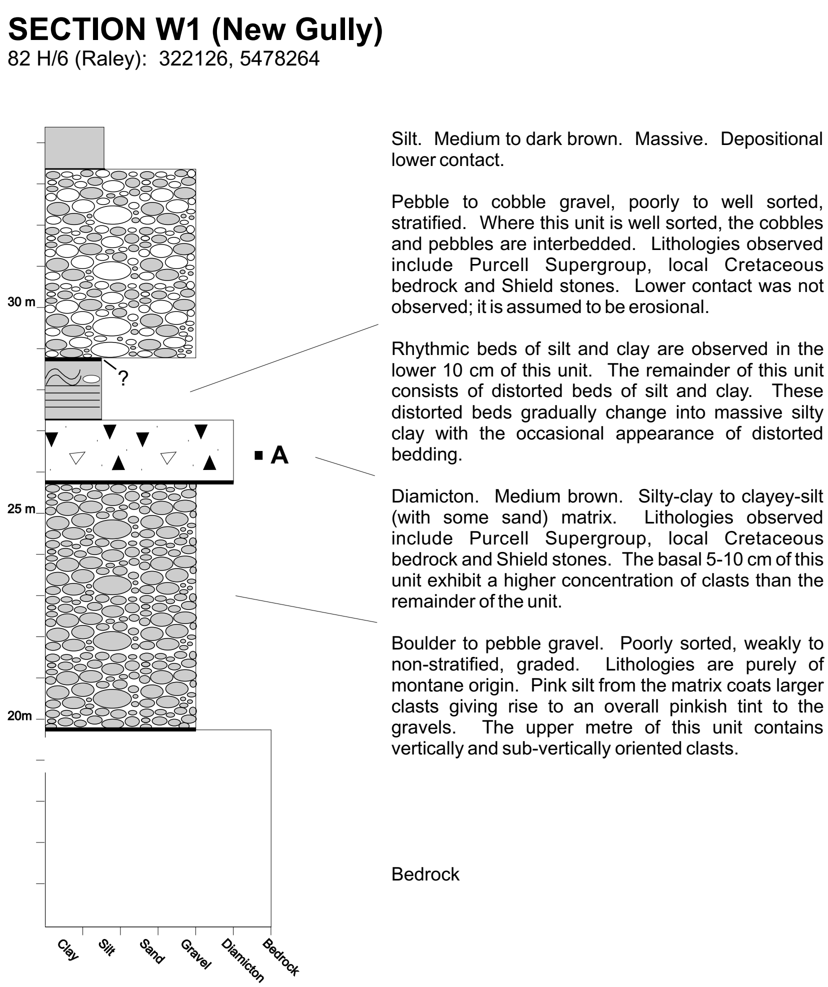
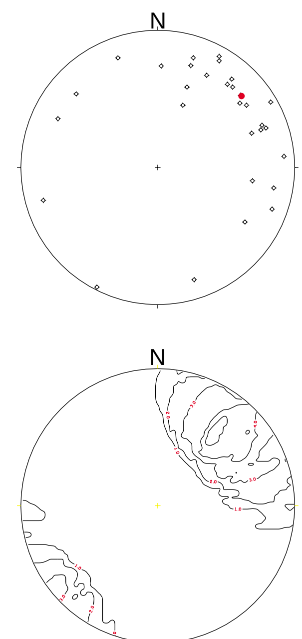


Figure 2-9a.



Fabric A
Section W1 (New Gully)

Schmidt Projection, Step Function Grid	
Number of Sample Points	30
Mean Lineation Azimuth	49.6
Mean Lineation Plunge	19.7
1st Eigenvalue	0.667
2nd Eigenvalue	0.281
3rd Eigenvalue	0.052
LN (E1 / E2)	0.865
LN (E2 / E3)	1.677
[LN(E1/E2)] / [LN(E2/E/3]	0.516
Spherical variance	0.3585
Rbar	0.6415

Figure 2-9b.

the upper-most portion (1m) of this unit exhibits a weak vertical orientation of clast a-axes interpreted as periglacial involutions formed as conditions grew colder at the onset of the last glacial maximum, when montane ice was in close proximity (<7.5km).

Stop 2-7 The "Buffalo Jump" Section

This section was (so we were told) used by natives as a buffalo jump. Ranchers in the area have found numerous Bison skulls in the vicinity, but to date, no NATMAP members have found any - and we've tried!

This section is unique, in that it contains a montane gravel at its base (Fig. 2-10a), and a montane till overlying the gravel at a distance of approximately 50 km from the mountain front. This is the most distal montane till observed during the course of this NATMAP project; montane till and ice contact gravel are, however, observed in the Lethbridge area (*e.g.,* Stalker 1963; Wagner 1966).

Overlying the montane till at the Buffalo Jump section is a continental till composed of three units, each of which contains Shield material (Fig. 2-10a). The differences between these units is interpreted as intra-till variability during late Wisconsinan deposition from the continental ice sheet. The uppermost till exhibits pervasive deformation and shearing suggesting a water saturated sediment. Overlying this till are laminated and rhythmically bedded silts and clays deposited as ice withdrew from this area.

Interpretations of clast fabrics from this section (Fig. 2-10b) will be discussed during the stop.

Stop 2-8 (optional - time dependant) Pine Pound Creek Hummocks

The moraine surrounding Pine Pound Creek in the Raley map sheet area, was first interpreted from air photos as "classic" ice stagnation moraine. However, when ground truthing was initiated, a different interpretation started to develop.

Three sections were examined in 1995 while ground truthing the air photo interpretations. The original interpretation was hummocky topography produced from stagnant continental ice. Upon logging the sections and examining what we had found, however, the field data did not agree with our initial interpretations.

The sections that were examined are all located in close proximity (all within 2 km) to one another (see Little 1998b: sections 1, 2, and 3). One of the sections (St4; Fig 2-11a) contained 7.5 m of continental till; the second

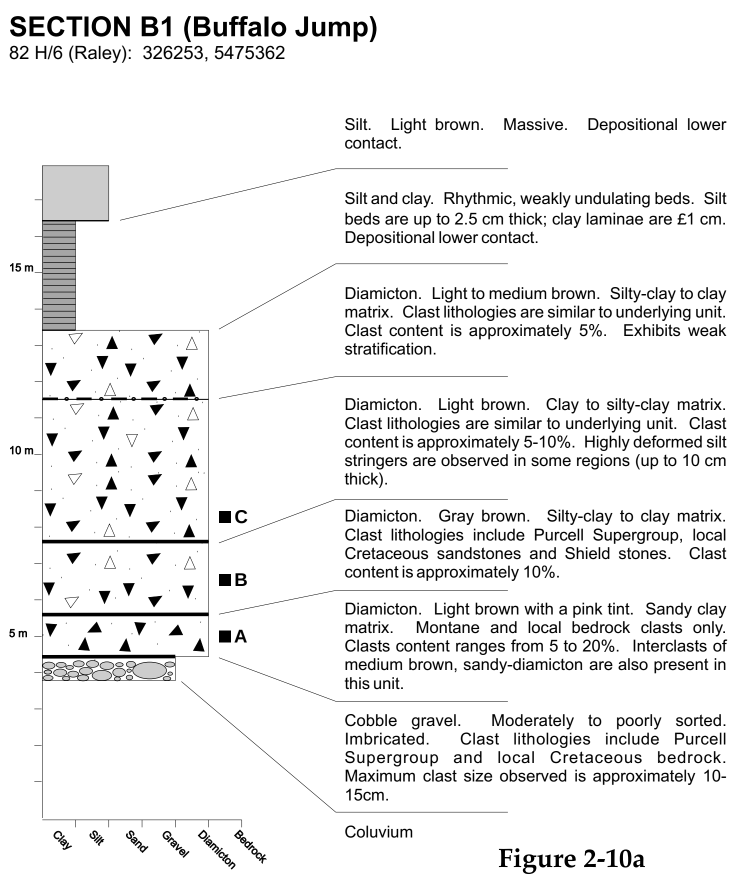


Figure 2-10a

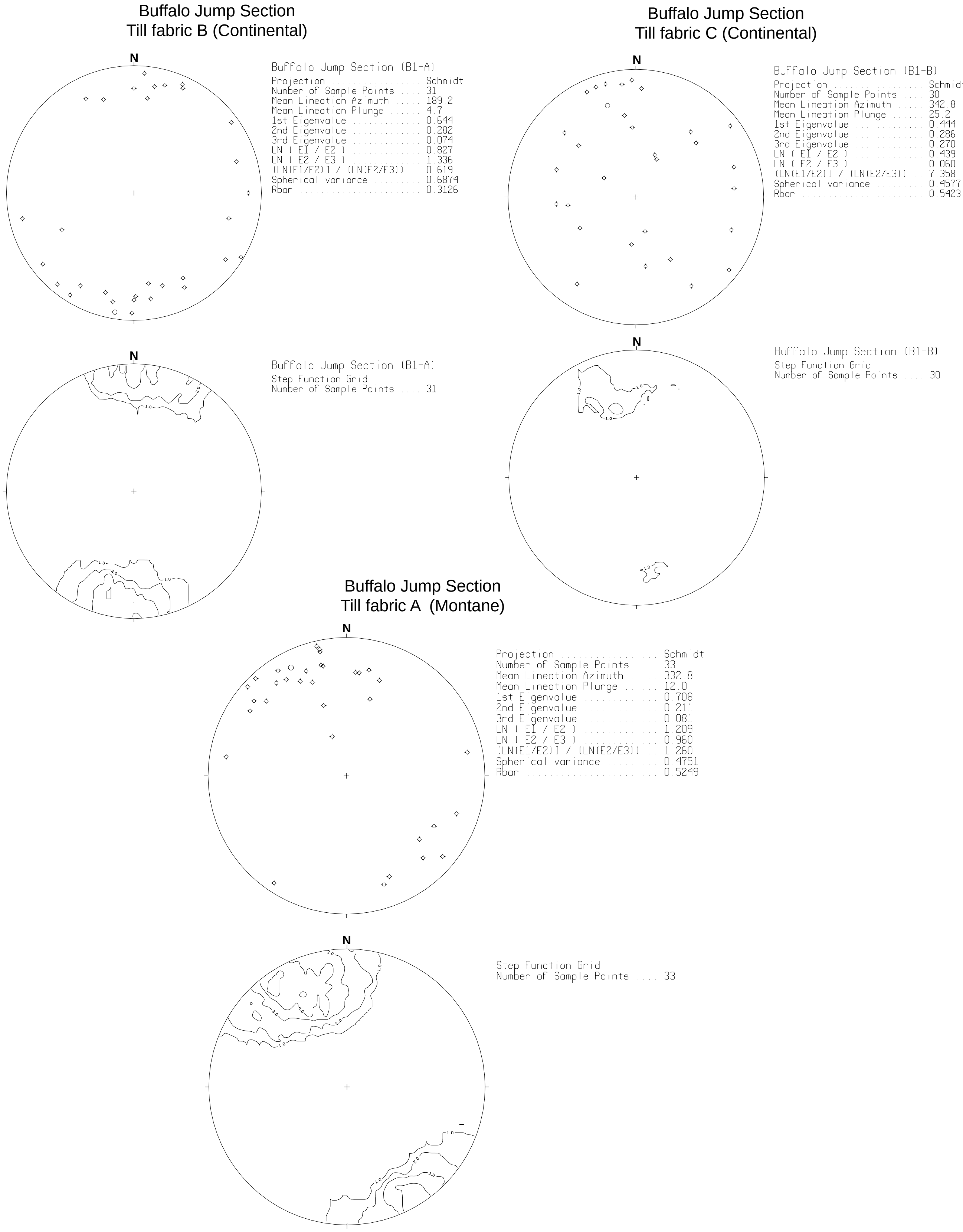
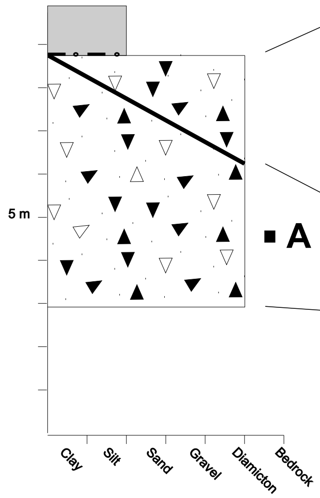


Figure 2-10b. To be discussed during our stop.

SECTION St4

82 H/6 (Raley): 349090, 5461500



Silt to clayey-silt. Light brown. Massive.

Diamicton. Light brown. Sandy-silt matrix containing clasts up to 20 cm. Clast content is approximately 2-3%, but there are clast-rich zones where the content is approximately 15-20%. Areas containing abundant clasts are lensoid and concentrated in the lower portion of the unit. Lithologies are similar to the underlying unit.

Diamicton. Light brown. Silty-clay to clayey-silt matrix. Lithologies include Purcell Supergroup, local Cretaceous bedrock and Shield stones. Clast content is approximately 5-10%.

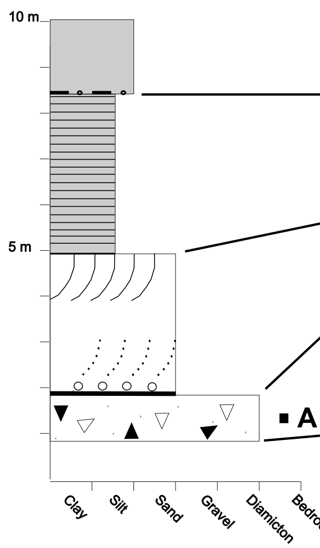
Colluvium.

Figure 2-11a (left).

SECTION St5

82 H/6 (Raley): 348959, 5460782

Figure 2-11b (right).



Silt. Massive. Medium to dark brown.

Silt and clay. Rhythmically bedded. Conjugate sets of normal faults displace bedding.

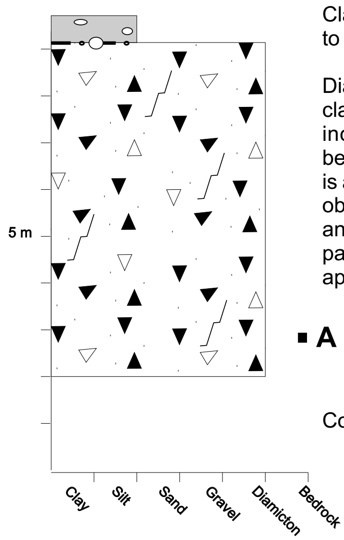
Sand and pebbly sand. Cross-bedded. Medium to light brown. Occasional pebble lags are observed.

Diamicton. Medium to light brown. Silty-clay to clayey-silt matrix. Clast lithologies observed include Purcell Supergroup, local Cretaceous bedrock and Shield stones. Clast content is approximately 5-10%.

Colluvium.

SECTION St6

82 H/6 (Raley): 348826, 5459664

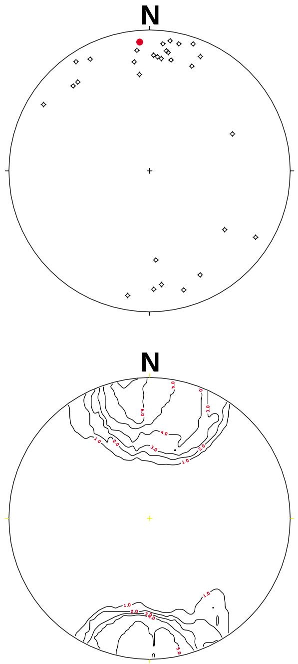


Clayey-silt to silt with rare clasts. Massive. Medium to light gray-brown.

Diamicton. Medium brown or medium grey. Silty-clay to clayey-silt matrix. Clast lithologies observed include Purcell Supergroup, local Cretaceous bedrock and abundant Shield stones. Clast content is approximately 5-10%. Conjugate sets of faults are observed within this unit; planes are oriented 180/34 and 005/35. Superimposed on the planes are sets of parallel to sub-parallel ridges and furrows trending approximately north-south.

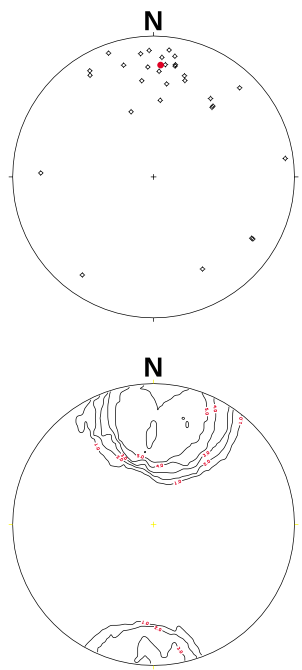
Colluvium.

Figure 2-11c (left).



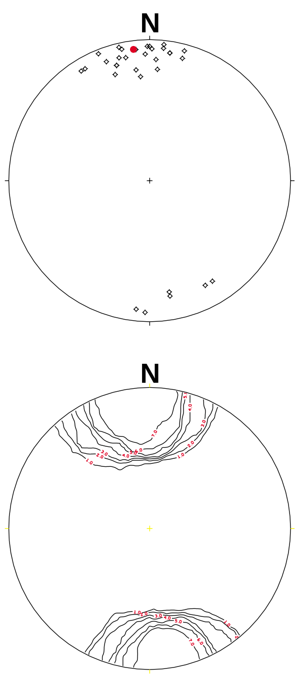
Fabric A
Section St4
Schmidt Projection, Step Function Grid

Number of Sample Points	30
Mean Lineation Azimuth	355.6
Mean Lineation Plunge	7.9
1st Eigenvalue	0.767
2nd Eigenvalue	0.164
3rd Eigenvalue	0.069
LN (E1 / E2)	1.543
LN (E2 / E3)	0.861
[LN(E1/E2)] / [LN(E2/E/3]	1.792
Spherical variance	0.4929
Rbar	0.5071



Fabric A
Section St5
Schmidt Projection, Step Function Grid

Number of Sample Points	30
Mean Lineation Azimuth	3.7
Mean Lineation Plunge	20.6
1st Eigenvalue	0.729
2nd Eigenvalue	0.207
3rd Eigenvalue	0.065
LN (E1 / E2)	1.261
LN (E2 / E3)	1.163
[LN(E1/E2)] / [LN(E2/E/3]	1.084
Spherical variance	0.2955
Rbar	0.7045



Fabric A
Section St6
Schmidt Projection, Step Function Grid

Number of Sample Points	32
Mean Lineation Azimuth	353.1
Mean Lineation Plunge	5.8
1st Eigenvalue	0.915
2nd Eigenvalue	0.051
3rd Eigenvalue	0.034
LN (E1 / E2)	2.883
LN (E2 / E3)	0.424
[LN(E1/E2)] / [LN(E2/E/3]	6.801
Spherical variance	0.3716
Rbar	0.6284

Figure 2-11d. Clast frabrics obtained from sections St4, St5 and St6 along Pine Pound Creek. Each fabric was measured from clasts in a correlative continental till. All sections are located with 2 km of one another. These till fabrics suggest either a basal lodgement or meltout till deposited beneath active ice.

(St5; Fig.2-11b) exhibited a similar till which was only 0.8-3.5 m thick and was overlain by a channel cut and fill sequence which in turn was overlain by stratified silts and clays; the third section (St6; Fig. 2-11c) exhibited a till in the lower portion of the section, and a gravelly diamicton (flow till or debris flow) in the upper portion, both of which contained Canadian Shield material.

Clast fabrics measured in the continental tills in all three sections (Fig. 2-11d) produced bull's-eye patterns that are typically associated with base lodgement or basal meltout tills (from active ice). If topography is interpreted as being formed from ice stagnation, then one would expect different fabric distributions at each site, poorly oriented (near random) clast fabrics, or both. However, the fact that all three fabrics are similar, have bull's-eye fabrics distributed in the same region of the net, leads to the interpretation that the continental till was deposited as a basal lodgement till/meltout till during a time of active ice, and not during ice stagnation. This then forces us to ask the question: "How did the hummocks form?" Recently, Monro and Shaw (1997) have proposed that some hummocky topography is produced by meltwater scouring/erosion, and not by ice stagnation.

Given the interpretation of lodgement/ meltout tills and channel cut and fill sequences in the Pine Pound Creek sections, the meltwater scouring hypothesis appears to be more applicable than the classical "ice stagnation" hypothesis in this particular case.

Stop 2-9 Del Bonita Periglacial Involutions and Ground Wedges

Through Whiskey Gap

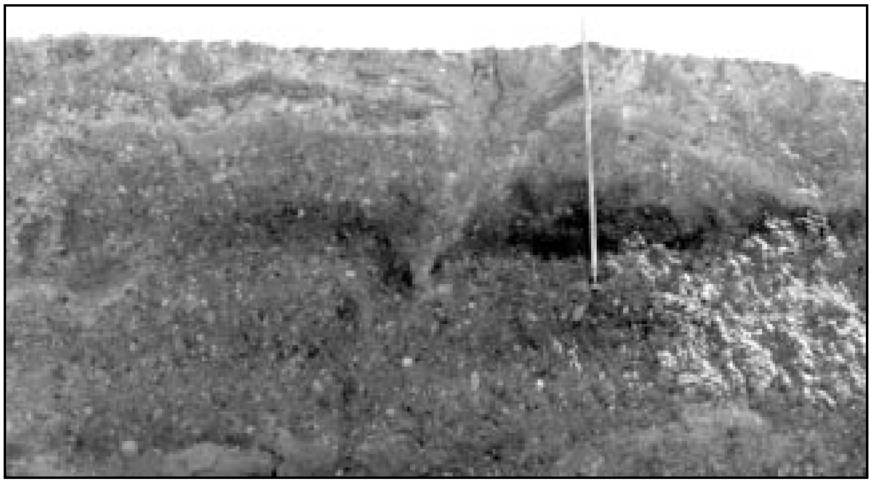
Continuing on to our last stop of the day, we head southeast towards Whiskey Gap. This large meltwater channel cuts down through the Milk River Ridge which was a major topographic obstacle to the continental ice. This barrier to both mountain and continental ice resulted in the unglaciated region southeast of its position (Brierley, 1988). The Whiskey Gap meltswater channel was probably the outlet for most of the meltwater produced in the Waterton, Cardston and Raley map sheet areas. Meltwater that drained through this outlet, would have ended up in a paleo-Milk River drainage system that eventually entered the Mississippi and flowed south to the Gulf of Mexico.

Once we have passed through Whiskey Gap, we arrive on the southeast side of the Milk River Ridge. The geomorphology we observe here is essentially a remnant of Tertiary topography. As we continue east, we will rise up onto the Del Bonita Plateau, which is correlated to other plateaus in southwestern Alberta and Northern Montana such as Mokowan Butte, Two Kennedy Ridge (USA), St. Mary Ridge (USA). Together, these elevated plateaus form the Flaxville surface which has been interpreted as an earlier prairie surface.

Del Bonita

Approximately 1-2 km north of the Del Bonita cross-roads, a Cardston Municipality gravel pit displays some of the best periglacial features in southwestern Canada. The gravel is composed entirely of montane lithologies as it has never been overridden by continental ice. Developed within the gravel, are periglacial features including: ice wedge pseudomorphs, polygonally patterned ground, involutions, and vertically oriented clasts (Fig. 2-12a-c).

Approximately 5 km North of Del Bonita, the C1 limit is roughly estimated at an elevation of 1 295 m asl (the surficial geology of this area has not been mapped in detail). In this vicinity, Shield clasts become evident at the ground surface suggesting the presence of continental ice influence in close proximity.



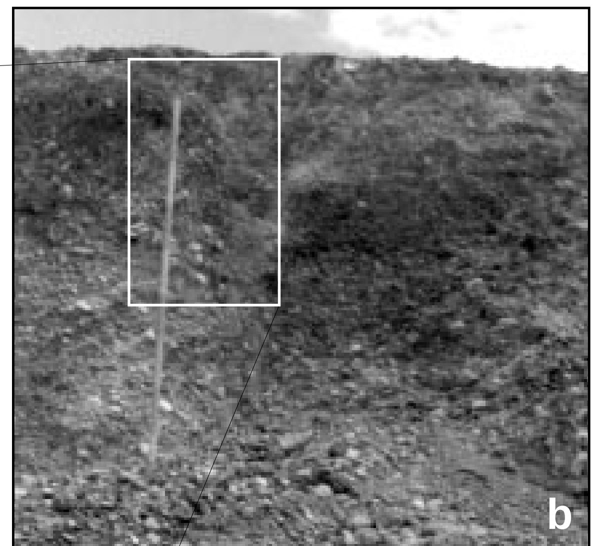


Figure 2-12a-c. Ground wedges formed from periglacial processes acting on the unglaciated gravels of the Del Bonita Plateau (bands on measuring stick are 20 cm). Figures 2-12c is a close up of the infilling material of 2-12b. Smaller, weaker ground wedges are also superimposed on the larger frame work (Velichko, pers. com. 1997). Evidence of these smaller wedges can be observed in plan view (see Little 1995).

Homeward Bound

From our final "official" stop of the day, we head north to Ft. Macleod, then onward to Calgary. We hope that you have enjoyed the last couple of days in the field with us! Both Lionel and myself would like to thank everyone for their participation - it was a real pleasure showing you some of the highlites of our work here in southwestern Alberta.

Thank-you

Merci

Спасибо Большое

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