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Glacial geology of the Ovando Valley Powell County Montana

Peter A. Dea
The University of Montana

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GLACIAL GEOLOGY OF THE OVANDO VALLEY,
POWELL COUNTY, MONTANA

by

Peter A. Dea

B.A. Western State College, 1976

Presented in partial fulfillment of the requirements for the degree of

Master of Science

UNIVERSITY OF MONTANA

1981

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Chairman, Board of Examiners

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ABSTRACT

Dea, Peter A., M.S., Spring, 1981

Glacial Geology of the Ovando Valley, Northwest Montana

Director: Robert R. Curry

Glacial deposits in the Ovando Valley, northwest Montana, record three major alpine glacial advances, referred to as the Blackfoot, Clearwater and Monture advances. During both the Blackfoot and Clearwater advances the adjacent Clearwater Valley filled up with ice that originated in local mountain ice caps. Upon overflowing through broad passes along its southeast margin, the valley glacier spilled into piedmont lobes in the Ovando Valley. Deposits of the older, more extensive Blackfoot advance consist of isolated patches of striated erratics and moderately to slightly weathered till. These are mainly preserved on the ends of spur ridges, 150 - 400 m upslope from Clearwater advance deposits.

Drumlins, hummocky disintegration moraines, sharp crested lateral moraines and glacial grooves formed by the Clearwater advance reveal its northwesterly ice source from the Clearwater Valley. These southeasterly trending features are abruptly truncated by a southerly trending lateral moraine of the Monture advance. Fed by small valley glaciers from the north, the Monture advance stagnated in a broad piedmont lobe in the central Ovando Valley, as evidenced by its striking knob and kettle disintegration moraine. Several of its prominent lateral moraines occur in sets of 2 or 3 reflecting recessional stades.

Blackfoot deposits and Clearwater-Monture deposits are tentatively correlated to Bull Lake and Pinedale age deposits respectively. Truncation and enclosure of Clearwater deposits by the Monture advance and the fresher appearance of Monture deposits shows that the Monture advance is slightly younger. Varying degrees of till preservation suggest this interval was shorter than the much longer interglacial period separating the Blackfoot and Clearwater advances.

Sandwiched between Blackfoot and Clearwater till, Glacial Lake Missoula silts and a deltaic sequence, outcrop along the Blackfoot River in the southwestern Ovando Valley at elevations between 1333-1400 m (4000 - 4200 ft.). This marks the easternmost extent of Glacial Lake Missoula recognized in the Blackfoot River basin and exposes the Blackfoot River's glacial lake delta. Numerous dropstones reveal the proximity of Clearwater ice which advanced into the lake from the northwest. Ice eventually overrode and deformed the lacustrine and deltaic sediments possibly after a catastrophic lake drainage.
ACKNOWLEDGMENTS

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CHAPTER I
INTRODUCTION

General Statement

Excellent preservation and exposure of glacial deposits and landforms in the Ovando Valley, northwest Montana, offer a unique opportunity to study erosional and depositional features associated with alpine piedmont glaciers. Glacial grooves cut into the bedrock by advancing ice show paleoice flow directions as do well preserved drumlins and lateral moraines. Cross cutting moraines and degree of moraine preservation establish relative ages of different advances. The local chronology based on these relative age dating techniques provides data for the correlation of these deposits to alpine and continental glacial deposits in western Montana.

Location

The Ovando Valley is located in western Montana along the upper reaches of the Blackfoot River 48 kilometers northeast of Missoula, Montana (Fig. 1). Flanked by the Swan Range to the north and Garnet Range to the south, the study area covers approximately 449 square kilometers (175 square miles) of the Ovando Valley and surrounding hillsides and lies between latitudes 46° 58' and 47° 11' north and longitudes 113° 2'3" and 113° 22'30" west (Fig. 2). The town of Ovando lies in the east central part of the study area and supports a small ranching community.
Figure 1. Location map of the Ovando Valley study area in northwestern Montana.
Figure 2 Physiographic map of the Ovando Valley area and local mountain ranges and valleys. Study area lies within the small box. This map was reduced and modified after Alden (1953, Plate 1).

Approximate scale:

0  25  50 km

0  15  30 mi
Despite the extensive alpine and continental glaciation of western Montana, only a few detailed studies exist which were conducted in Glacier National Park and the Mission-Flathead Valley (Richmond, 1960; Nobles, 1952; Whitkind, 1968; and Stoffel, 1979). Consequently much has yet to be learned about the contemporaneity of alpine glaciations throughout western Montana and the entire Rocky Mountain region and their time and spatial relationships to the continental Cordillera and Laurentide ice sheets. Only with a more complete knowledge of these relationships can scientists attain the ultimate goal of reconstructing paleoclimates that existed in the Pleistocene period.

It is the purpose of this study to document the erosional and depositional features of local and regional alpine glaciers in the Ovando Valley and to determine the glaciers' source area, geographic extent, relative chronology and their processes of formation. Application of this data will contribute to a better understanding of the alpine glacial chronology of western Montana and the Rocky Mountain region. This may eventually supplement the foundation for hypotheses on regional climatic patterns associated with glaciation during the Pleistocene period.

**Bedrock Geology**

High mountains of Precambrian Belt Supergroup rocks surround the Ovando Valley. Thousands of feet thick, the sedimentary rocks occur in a variety of colors and lithologies. Red, white and tan colored quartzite and sandstone predominate, yet red, purple and green argillite also outcrop frequently. Quartzite and argillite are commonly interbedded and
often form high resistant cliffs noticeable along the Blackfoot River. Gray limestone and dolomite underlie most of the Little Red Hills in the northeastern part of the study area where it is intruded by a wide diorite sill. The green and white speckled diorite shows moderate to high degrees of alteration where traversed by the St. Mary's Fault.

In general, the rocks strike N40°W and dip 10° to 45° NE except where broken by normal and thrust faults (Clapp, 1936). Clapp mapped several thrust faults and one normal fault in the northeast part of the study area. Pardee (1950) and Mudge (1972) have since mapped the more prominent St. Mary's normal fault northwest and southeast of the study area. The fault trace passes along the southern scarp of the Swan Mountains in the Ovando area and strikes N60°W with the southwest side downthrown. Bedrock along the scarp face is commonly sheared, brecciated and/or mildly hydrothermally altered.

The Ovando area lies within the northern part of the Intermountain Seismic Belt and is frequently shaken by earthquakes of magnitudes less than 2 (Stickney, 1978). Most earthquakes in the region occur along northwest-trending normal faults and northwest oblique-slip faults. A few earthquakes plot along the St. Mary's Fault suggesting its recent activity (Stickney, personal communication). However, I have found no conclusive evidence depicting offset of glacial deposits.

Tertiary mudstone and siltstone outcrop in the central Ovando Valley in small hills and in cliff exposures along Monture Creek and the Blackfoot River. The buff colored tuffaceous sediments contain coniferous and deciduous plant imprints and occasionally contain thin beds of organic
rich tytta. Only one conglomerate bed exists, outcropping on the south-west side of the Little Red Hills. Predominance of clay and fine grained sediments with only minor conglomerate suggests equivalence to the Renova Formation of Oligocene age as described by Kuenzi and Fields (1971). Although flat lying in the valley floor, Tertiary mudstones on top of Monture Hill lie steeply dipping to the southwest, indicating deformation in mid-late Tertiary and/or early Pleistocene time.

Physiographic Setting

The Ovando Valley forms a broad bulge in the otherwise narrow Blackfoot River Valley at a base elevation averaging between 1333 and 1400 m (4000 and 4200 ft.). Diversely quilted with ponds, lakes, hills and meadows the valley offers much scenic and ranching quality. Covering approximately 200 km², the Ovando Valley extends from the southern flanks of the Swan Range south 12 km to the northern edge of the Garnet Range (Fig. 2). Mountains in the southern Swan Range rise steeply from the Ovando Valley to elevations of nearly 2667 m (8000 ft.). Throughout its narrow northwest trend the Swan Range rises to over 3000 m (9000 ft.). Carved by numerous cirques and trough shaped valleys the rugged Swan Range shows the effects of intense sculpturing action by alpine glaciers. In contrast, the Garnet Range rising to elevations between 1800-1950 m (6000-6500 ft.) shows more rounded summits and V-shaped stream valleys characteristic of unglaciated mountains.

From a series of smaller and isolated mountains on its western side, the Ovando Valley stretches 17 km east where it meets Kleindschmidt Flat
and the Nevada Valley. The Blackfoot River enters these lowlands from the mountains to the east before flowing west through the southern Ovando Valley. The Blackfoot River probably flowed through a more central or northern part of the Ovando Valley in pre-glacial times before lobate moraines south of Kleindschmidt Flat deflected the river's westerly course 1 km to the south. Moraines in the Ovando Valley hold the river against the Garnet Range in the south. Several tributaries, Warren, Monture and Cottonwood Creeks, dissect the Ovando Valley to join the river's deflected course. After passing through a narrow bedrock canyon in the southwestern Ovando Valley, the Blackfoot River flows through the narrow Clearwater Valley in route to its confluence with the Clark Fork River 45 km to the southwest.

Two rounded mountains, 1727 m (5180 ft.) and 1875 m (5625 ft.) high, separate the Ovando Valley from the Clearwater Valley to the west. However, broad passes between and north and south of these mountains connect the two valleys. From south to north these are the Blackfoot Canyon (through which the Blackfoot River flows), Boyd Mountain (southeast of Boyd Mountain) and Tote Road passes.

The Clearwater Valley, west of those mountains and the southern Swan Range, is contained to the west by the foothills of the glaciated Rattlesnake mountains. Flowing south through the narrow 45 km long Clearwater Valley, the Clearwater River joins the Blackfoot River. Across a low divide north of the Clearwater Valley the elongate Swan Valley drains the Swan River to the north. The Mission Range on the west and Swan Range to the east contain the glacially scoured Swan Valley.
The excellent exposure of the glacial deposits in the Ovando Valley is partially the result of the relatively dry climate. The mean annual precipitation of 43 cm (U.S. Weather Bureau) allows short grasses and sage to dominate the vegetation of the Valley floor. Scattered groves of lodgepole pine, spruce and aspen inhabit the higher moraines in the northern and eastern part of the valley. Slightly higher precipitation in the surrounding mountains supports thick forests of spruce, Douglas fir and Ponderosa pine.

Previous Work

Pardee (in Alden, 1953) recognized the extensive multiple glaciations of the Ovando Valley in his reconnaissance of the glacial geology of western Montana. Pardee mapped two lobes of a large piedmont glacier that occupied the central Ovando Valley and adjacent Kleindschmidt Flat area to the east in Wisconsin time. He observed that the northerly source for each lobe was alpine glaciers flowing from the adjacent Monture-Dunham Creek Valleys and the North Fork of the Blackfoot River Valley. Both drainage systems extend 7 to 10 km from the Ovando Valley north into the southern Swan Mountains. Pardee also mapped drift south of these deposits and correlated it with till extending to the northwest along the Blackfoot River and up Cottonwood Creek west and north of Ovando. Because this more extensive drift lies outside the margins of the Wisconsin lobe and shows less pronounced topography Pardee considered it pre-Wisconsin in age, possibly Illinoian or Iowan. Pardee also first recognized the southerly deflection of the Blackfoot River around the southern terminus of the glacial deposits which controls the river's present course.
Alden concurred with Pardee's mapping and traced the older drift to the west into the Clearwater Valley and north to the Clearwater-Swan Valley divide. West of Clearwater Junction in the Ninemile Prairie area Alden found drift composed of boulders up to three meters in diameter underlying over three meters of Glacial Lake Missoula silts. He concluded that this represented the westernmost terminus of the pre-Wisconsin glacier which terminated in the glacial lake. Retreat of the glacier allowed the lake to migrate east and deposit lake silts over the drift.

Tweeton (1971) studied the glacial geology of the Ovando Valley using relative age dating techniques and till fabric analyses. He delineated three periods of glaciation yet concluded that each glacier advanced from the Monture Creek Valley, in disagreement with all other studies in the area. Based on relative age data he suggested correlation of the three glaciations to pre-Bull Lake, Bull Lake and Pinedale deposits found elsewhere in the northern Rocky Mountain region.

Witkind and Weber (1979) have recently completed an environmental geologic map of valley bottom and valley hillside deposits within a narrow 4144 km² (1600 m²) area extending from Big Fork south to Avon, which includes the Ovando Valley. Within the Ovando area they mapped glacial and outwash deposits related to two Pinedale and one possible Bull Lake age glaciations. The younger Pinedale deposits cover the central Ovando Valley. They form the striking knob and kettle topography deposited in the piedmont glacier as suggested by Pardee and Alden. The older Pinedale deposits form distinctive, yet less impressive features, south and west of the younger Pinedale deposits.
The possible Bull Lake age drift occurs southeast and southwest of the present thesis area located south of the North Fork's confluence with the Blackfoot River and southwest of the Clearwater Valley respectively. It is these older Pinedale and Bull Lake(?) age deposits that Alden and Pardee considered pre-Wisconsin.
Major glacial advances invaded the Ovando Valley at least three times, referred to here as the Blackfoot, Clearwater and Monture advances. Herein, the term advance refers to a major glacial event, composed of multiple short term (yearly) regionally synchronous advances of ice, evolving during a period of regional glaciation.

Based on the degree of till and moraine preservation two periods of glaciation provided suitable climatic conditions conducive for the three glacial advances in the Ovando Valley. An older glaciation initiated the Blackfoot Advance and a distinctly younger glaciation resulted in the Clearwater and Monture advances. Morphologic relationships also show that the Clearwater advance predated the Monture advance but by a much shorter time than that separating the two periods of glaciation.

Deposits of the Blackfoot advance lie mainly along the southern foothills of the Swan Mountains immediately north of the Ovando Valley and along the Blackfoot River south of Monture Hill. Extensive erosion removed all but a few patches of this deposit making source and flow directions difficult to establish.

Ice of the Clearwater advance spread well into the Ovando Valley. However, the younger Monture advance erased most of its deposits in the study area except along the western and southern parts of the Ovando
Valley. Lateral moraines, glacial grooves, and drumlins defining the southeast ice flow direction indicate that the source area lay to the northwest, possibly in small ice caps in the Rattlesnake Mountains to the northwest and large interfingering ice caps in the Mission and Swan Mountains to the north.

The Monture advance deposited the most striking features in the Ovando Valley as valley glaciers in the Monture and Dunham Valleys flowed 15-20 km through the Swan Mountains and splayed out into a large piedmont lobe upon reaching the Ovando Valley. The lobe grew even larger as the Monture ice coalesced with ice flowing south from the North Fork of the Blackfoot River 15 km to the east. I will refer to this contemporaneous advance from the North Fork as the North Fork advance. Since most of its deposits lie east of the study area I will not discuss them in detail.

A more detailed regional correlation of the three advances in the Ovando Valley follows the description of the glacial deposits.

Blackfoot Advance

The oldest known glaciation of the Ovando Valley resulted in the Blackfoot advance. Lacking knob and kettle topography, the only evidence for this advance resides in thin veneers of erratics, limited patches of till and a few subdued lateral moraines and kame terraces. Most of these elusive deposits rest on the noses of five ridges which protrude from the southern flank of the Swan Mountains between the south flowing Black Canyon and Dunham Creeks (Plate I). They lie 70-240 m
(210-720 ft.) above the lateral moraine marking the upper ice limit of the younger Clearwater advance. On succeeding spur ridges, from west to east, the upper elevation of the till or erratics lie at 1870 m (5610 ft.), 1427 m (5280 ft.), 2000 m (6000 ft.) and 1840 m (5520 ft.). Considering the 2000 m ice limit and estimating the valley floor elevation at 1367 m (1400 ft.) reveals a maximum ice thickness of 633 m (1900 ft).!

Another location of Blackfoot deposits lies 5 km east of the above mentioned deposits in the Little Red Hills. The highest hilltop in the Little Red Hills, at an elevation of 1772.6 m (5318 ft.), is sprinkled with erratics, less than 10 cm in diameter, and lies 35 m vertically above the nearby Monture advance deposits. Two small kame terraces and subdued lateral moraines adorn the west side of the hill, exhibiting the only significant constructional features of the Blackfoot advance seen in the Ovando Valley.

From the limited data seen in the Ovando Valley and exact source of the Blackfoot ice remains speculative. The deeply dissected terrain and lack of high glacial deposits north of the Blackfoot deposits argues against a source to the immediate north. This leaves the only other likely source of a large alpine lobe as flowing from the northwest through the intervalley Cottonwood, Tote Road and Boyd Mountain passes, similar to the Clearwater advance.

**Nature of Deposits.** All five occurrences of Blackfoot deposits between Black Canyon and Dunham Creeks show many similar characteristics. Till and erratics occur only on the southern noses of the spur ridges.
Their presence ends abruptly immediately north of each ridge nose even though the ridge tops flatten and extend north several hundred meters. High concentrations of erratics on the noses gradually decrease downslope to the south and become rare to nonexistent immediately above the younger Clearwater advance deposits.

Usually found only near the ridgetops, the till contains a sandy clay to clay rich matrix supporting highly to slightly weathered clasts of the Belt Supergroup. The well to poorly compacted matrix is light reddish brown to reddish brown in color (Munsell soil colors 5 yr 6/3 to 5 yr 4/3) and contains no calcium carbonate in the exposed upper 1.5 meters.

More abundant and conspicuous than the till are numerous erratics mantling the forested slopes. They consist predominantly of unweathered, subrounded to rounded, white to red quartzite pebbles, cobbles and boulders. Slightly weathered red and green argillite usually comprise less than approximately 20 percent of the erratics. Limestone, dolomite and tertiary mudstone occur rarely.

Striae commonly occur on the otherwise smooth surfaces of the quartzite, and less often argillite, erratics (in contrast erratics of the younger two advances rarely exhibit such striated surfaces). Several of the quartzite cobbles lie in two pieces where frost action has cracked them in half, probably during cold climates associated with the younger glaciation. Erratics deposited by the younger advances are rarely fractured.
The deposits on the five ridge noses lack constructional features except on the two ridges adjoining the east fork of Dry Cottonwood Creek. Here low ramps rise 3 m above the ridge noses and gently slope north for less than 15 m before grading into the flat ridgetop and ending along boulder trains of erratics trending east-west.

The Blackfoot deposits found in the Little Red Hills differ from those found to the west. Erratics are much smaller, rarely exceed pebble size, show few striae, have more sub-angular shapes and are much more scarce. No till was found yet some related constructional features exist on the west side of the hill top. Two small kame terraces, less than 15 m wide, step out below the hilltop at elevations of 1840 m (5520 ft.) and 1737 m (5180 ft.). Small round crested lateral moraines lie downslope and slightly north from each of the en echelon terraces. The northern moraine grades into the small saddle north of the 1733 m (5318 ft.) hilltop.

Till correlated to the Blackfoot advance outcrop on the southern side of Monture Hill where exposed by the Blackfoot River. The four exposures are described in Chapter III, Sections II, III and IV.

Erosion has prevented accumulation and development of soil layering on the ridge crests where Blackfoot till is found at the surface.

A strange phenomena sheds mystique on the Blackfoot deposits. Though clearly visible and preserved on the slopes immediately north of the Ovando Valley at elevations between 1427 and 2000 m, no evidence for Blackfoot till was found on the hills adjacent to Tote Road and Boyd Mountain passes on the western side of the valley despite many thorough
traverses. These hills lie in the only logical path of the advancing Blackfoot advance and should host Blackfoot till and erratics. Lateral moraines marking the upper ice limit of the Clearwater advance lie at least 50 m below the hilltops thereby excluding subsequent glacial erosion as a possible explanation for lack of Blackfoot deposits.

Three possible explanations remain:

1) minimal to negligible deposition of till on the hilltops;
2) mass erosion of surficial material and/or;
3) normal offset of the St. Mary's fault in Quaternary time.

Of the three possibilities, faulting is the least likely due to the magnitude and time required. The St. Mary's fault, traceable immediately south of the Blackfoot deposits found north of the Ovando Valley, is a major structure yet the 227 m offset required within a few 100,000 yrs is extreme even in known tectonically active areas. No evidence of fault offset of the younger glacial deposits was found in the area.

Accelerated local erosion alone is not a likely explanation since many of the hilltops are flat with slopes much less steep than those bearing till less than 2 m to the north. However, significant erosion compounded by minimal deposition may explain the lack of till.

Most debris in a glacier is concentrated along the margins or at the base (Flint, 1971). With the hills located in the middle of the glacier's path, little to no marginal debris would pass over them and much of the debris at the glacier's base would not rise several 100 m to the hilltops. Consequently the hilltops were more likely sites of
glacial erosion rather than deposition. Lack of deposits and their well rounded shapes support this conclusion.

**Clearwater Advance**

The Clearwater advance deposited lateral and disintegration moraines, drumlins and outwash gravels in the Ovando Valley and carved terraces and giant grooves in bedrock to the northwest and west respectively. Most of the deposits lie in the western and southern part of the Ovando Valley and in the passes joining the Ovando Valley with the Clearwater and Swan Valleys to the west and northwest respectively. Lying immediately west and south of the Monture advance deposits, the deposits of each are commonly close to or in contact with each other. However, their different trends and different topography allow differentiation between the two. Older Blackfoot deposits are also easily distinguishable from the Clearwater advance deposits since they lie 30 to 70 m above the younger lateral moraines and bear no resemblance in topographic form. Trends of the lateral moraines, drumlins and glacial grooves all indicate a southeasterly ice flow direction. Ice accumulating high in the Rattlesnake, Mission and Swan Mountains apparently filled up the Clearwater and Swan Valleys before overspilling into the Ovando Valley through the intervening passes.

**Till.** The till contains a reddish brown (4 yr 5/4 m) clay-rich matrix with minor amounts of sand. It is moderately compacted and plastic when wet and crumbly when dry. Till comprising the drumlins contains much more clay, is more compact and bears fewer clasts than
till underlying the moraines. Calcium carbonate when rarely present, has been leached to depths below 100 cm. Sub-angular to sub-rounded clasts consist predominately of Belt Supergroup sandstone and quartzite and substantial amounts of argillite. Limestone, dolomite, diorite and Tertiary mudstone and siltstone occur rarely. Only a few of the diorite and limestone clasts show significant weathering. The presence of fresh limestone and diorite clasts suggests that weathering occurred prior to glacial deposition.

Moraines. Disintegration moraine in isolated fields of hummocky till comprises much of the Clearwater glacial deposits. It is found in several areas including the west central part of the Ovando Valley, the Tote Road and Boyd Mountain passes which lead to the Clearwater Valley, throughout the drumlin field in the northwestern Ovando Valley and on southern Monture Hill.

The hummocks usually have broad rounded forms less than 15 m higher than adjacent depressions or kettles. The well spaced kettles are often, though not always, filled with water. Sediment and vegetation fills in many of the depressions, especially those found in the passes. Streams do not breach the kettles though they frequently flow through the moraines.

Lateral moraines form prominent ridges and clearly define the upper ice limit of the Clearwater advance. They occur above disintegration moraine and drumlins along the northern Ovando Valley wall and along the hillslopes above the Tote Road, Boyd Mountain and Cottonwood passes
(Plate I). Although traceable along their 1 to 8.5 km lengths they always occur in discontinuous sections due to their depositionally undulating profile and more commonly due to wide breaches by local streams. Their sharp to more often rounded or flattened crests usually rise 5 to 15 m locally and frequently impound water. Lying at elevations ranging between 1533 and 1767 m (4600 to 5300 ft.), they generally slope eastward, reflecting the ice surface gradient. Figure 3 shows the approximate ice gradient defined by the lateral moraine along the northern Ovando Valley wall.

Assuming a valley floor elevation ranging from 1333 m (4000 ft.) to 1400 m (4200 ft.), from the southern to northern valley respectively, the ice thickness ranged between approximately 135 to 280 m (405 to 840 ft.). Thicker in the northwestern part of the valley, the ice thinned to the south and southeast as the elevation of lateral moraines show. Ice was thickest northwest of the valley in the Tote Road Pass -- up to 400 m (1255 ft.) thick! Ice entering the Ovando Valley through the Boyd Mountain and Blackfoot Canyon passes was only approximately 113 m (339 ft.) and 126 m (378 ft.) thick respectively.

The few internal cuts through the moraines expose clayey to sandy till. Cobbles and boulders cover the forested crests, and their composition and angularity often reflect erosion from local bedrock.

No terminal moraines of the Clearwater advance are preserved due to erosion by the Monture and North Fork advances.
Figure 3. Graph showing ice surface gradients of Clearwater advance (dashed line) and Monture advance (solid line) as they entered the Ovando Valley. Labels indicate location and elevation of lateral morains (black dots) which define the approximate ice surface gradient. Approximate ice surface gradients for the Monture and Clearwater advances are 22m/km (108 ft/mile) and 7 m/km (29 ft/mile) producing a slope of 1.3° and .4° respectively.
Nature and distribution of lateral moraines. Each of the lateral moraines deposited by the Clearwater advance offer valuable information on the upper ice limit, ice thickness and direction of ice flow. The more detailed description of the moraines provided below supplements the general statements presented earlier and provides a closer look at their location, distribution and character. I will describe the lateral moraines from north to south in order of their initial construction by ice flowing from the northwest (Plate I shows the locations of the moraines for reference).

Southwest of Cottonwood Lakes on the northwestern part of the map area lie three small moraines less than 350 m long forming prominent ridges at elevations of 1800, 1733 and 1600 m (5400, 5200 and 4800 ft.). The upper moraine marks the upper ice limit since no Clearwater till or erosional benches lie above it. The elevation of this moraine corresponds to till covered benches and spurs eroded by glacial ice on the northeast side of the narrow valley, above which no other glacial features exist. These benches continue southward and lead to the northern end of the longest lateral moraine deposited by the Clearwater advance.

Beginning at the North Fork of Cottonwood Creek this most extensive moraine stretches 8.5 km (5.3 m) along the southern flanks of the Swan Mountains until truncated by the southwest trending moraine of the Monture advance. From west to east the crest slopes from an altitude of 1680 to 1600 m (5040 to 4800 ft.). Assuming a valley floor elevation of 1400 m (4200 ft.), the ice thinned from approximately 280 to 200 m
(840 to 600 ft.) along this lateral margin. The moraine usually rises 7 to 13 m in local relief and ranges from 0 to 20 m. Discontinuous deposition and stream dissection have formed an irregular undulating ridge crest with gaps up to 1.2 km long.

From west to east, the North Fork of Cottonwood Creek, Little Shaley Creek, Black Canyon Creek and Dry Cottonwood Creek's east and west tributaries dissect the moraine. The moraine deflects Shaley Creek 0.6 kilometers eastward before the creek finally flows around the moraine to continue flowing southward.

Moraines along the walls of the Tote Road pass, south of the Cottonwood Lake Pass, also slope and lead into the Ovando Valley. On the northern wall just west of the map area, a 500 m long moraine impounds two ponds at an elevation of 1853 m (5560 ft.). Around a bedrock corner and 3.2 km further east two smaller en echelon moraines occur with the easternmost one lying at an elevation of 1666 m (5000 ft.). An approximate 1467 m (4400 ft.) elevation of the pass indicates the ice was nearly 400 m (1200 ft.) thick to the west and thinned to 200 m (600 ft.) to the east. This reflects a steep ice gradient and abrupt decline in the ice surface caused by ice splaying out into the reaches of the Ovando Valley. The surface of the moraines is moderately covered with many angular to subrounded pieces of red and white sandstone derived from the local bedrock.

On the south side of Tote Road pass a narrow lateral moraine extends for nearly 1 km at an elevation of 1732 m (5200 ft.). This 5 to 15 m high and 33 m wide ridge impounds one large and three smaller swampy
ponds. To the west a north-south trending moraine impounds a large pond at an elevation of 1760 m (5280 ft.). Unlike the ponds to the east, a stream drains this pond. A few large blocks, up to 3 m in diameter, of ice rafted argillite litter the surface of the moraine. Subangular to subrounded cobbles and boulders of red and tan sandstone dominate the moderate amount of erratics.

On the south side of this mountain along the northern wall of Boyd Mountain pass, no moraines exist except for one that wraps around the southeast corner of the mountain. It slopes gently to the northeast from 1613 to 1586 m (4840 to 4760 ft.) along its 0.3 km length. A stream drains the small swamp impounded by the moraine through a narrow cut. The till comprising this moraine contains more well compacted clay than the other moraines though the clast lithologies remain similar.

The mountain south of Boyd Mountain pass is framed on three sides by a discontinuous set of moraines. The longest and most continuous moraine faces Boyd Mountain pass, extending 1.6 km along the mountain's northern side. The moraines western section at an elevation of 1613 m (4840 ft.) slopes eastward 133 m until breached by a dry gulch. East of the gulch the moraine resumes at an elevation of 1546 m (4640 ft.) and rises to 1613 m (Plate I). Defining the upper ice limit, this moraine indicates an ice thickness of approximately 113 m (339 ft.) assuming a pass elevation of 1500 m (4500 ft.). The moraine maintains a nearly level elevation eastward except for the swales in the undulating ridge. This relatively sharp crested ridge rises 7 to 13 m above its adjacent periglacial channel and small kame terrace.
Along the west side of the mountain a narrow sharp crested moraine rests precariously on a steep slope at an altitude of 1546 m (4640 ft.). The 1000 m long ridge closes off three adjacent depressions which are separated by 2 bedrock knolls. The grass covered depression shows little evidence of recent sediment filling as seen by the abrupt change in slope from the flat floor to the steep slope. This characteristic and the sharp crested precarious nature of the moraines testify to the youthfulness of the Clearwater advance.

On the east side of this mountain a lateral moraine at the 1600 m (4800 ft.) elevation slopes south and bends slightly with the bedrock ridge until grading into the hillside at the 1546 m (4640 ft.) elevation. To the north an erratic stream moraine passes below and eastward of a higher bedrock ridge. This moraine pinches out shortly but another one begins to the north at the 1600 m elevation. It slopes north in front of a swampy pond. Across the stream which drains the pond the moraine continues for 300 m north. The moraine crest on each side of the stream slopes north suggesting a northerly ice flow direction. However, the upper ice limit is higher to the north demanding a south flowing ice direction which agrees with the overall ice flow direction.

No lateral moraines occur on the south side of this mountain which faces the Blackfoot River. Instead, the upper ice limit is defined at 1466 m (4400 ft.) by hummocks of till resting on broad benches nestled against the steep hillside. Two small drumlin shaped hummocks on the bench have their lee side to the southeast indicating southeast flowing ice.
Steep bedrock cliffs south of the Blackfoot River prevented preservation of lateral moraines. However, a few striated erratics of argillite, quartzite and diorite occur on the narrow bedrock spur protruding from Blacktail Mountain at an elevation of 1466 m (4400 ft.). This upper ice limit concurs with the limit defined across the river to the north. Clearwater till exposed along Highway 20 in the Black Canyon pass at approximately 1340 m (4020 ft.) defines the lower ice limit. These upper and lower ice limits define an ice thickness of approximately 126 m (378 ft.).

Linear bedrock ridges mantled with a veneer of till, 3.5 km east of this bedrock spur, resemble lateral moraines. The linear ridges pass into more rounded bedrock hills a few km to the east yet they all lie on a broad bedrock bench at the northern foot of the Garnet Range which rise abruptly to the south. Glacial ice probably carved this bench and grooved out the linear ridges.

All the east-west trending lateral moraines mentioned above slope eastward which reflects the ice surface gradient as it sloped into the Ovando Valley. From north to south each lateral moraine lies at a slightly lower elevation which further supports a northwesterly ice flow direction with ice thinning toward the southeast.

Drumlins. A small field of drumlins occur between Woodworth and lower Shanley Creek, wedged between the northern lateral moraine and the outwash to the south. Elongated ridges extend 330 to 660 m long and less than 100 m wide rising 7 to 13 m above adjacent troughs and disintegration moraine. Flat-floored troughs 15 to 100 m wide separate
the rounded to flat-topped drumlin crests. The drumlins trend south­
easterly as shown in the rose diagram in Figure 4 indicating a
southeast ice flow direction. Till comprising the drumlins consists of
well compacted dark brown clay supporting fewer and smaller clasts than
the sandier more loosely compacted till found in nearby moraines.

Drumlins usually occur in vast numbers where large continental ice
sheets flow into more open and level areas (Embleton and King, 1974).
Under suitable conditions drumlins may form during alpine glaciation as
demonstrated by the Clearwater drumlin field. Smalley and Unwin (1968)
have suggested that drumlins form in response to a change in stress levels
exerted by the ice on basal till. Relatively high stress levels cause
expansion (which they term 'dilatancy') and mobility of the till. A
decrease in stress to a critical range causes the till to collapse and
become compacted preventing further movement allowing drumlin nucleation.
Such a decrease in stress may occur where a glacier decreases its velocity
and thickness. As the Clearwater ice flowed from the narrow Cottonwood
and Tote Road passes into the broader Ovando Valley, its velocity and
thickness decreased providing suitable conditions for drumlins to form.
Elevation of lateral moraines show the ice thickness at the drumlin field
as 100-140 m less than ice lying 3 km to the west in the passes.

From an initial nucleation site drumlins may grow by accretion of
basal material derived from the lower layers of ice as concluded by
Wright (1957). Thornbury (1954) showed that basal ice gathers this
accretionary material by local erosion which the Clearwater drumlins also
illustrate. X-ray diffraction analysis of the clay fraction comprising
Figure 4. Rose diagram showing trend of 12 drumlins reflecting the southeasterly ice flow direction of the Clearwater advance.
the drumlins shows smectite as the predominant clay mineral whereas clay in other tills throughout the study area rarely contain smectite (Appendix I). Of possible bedrock sources for the smectite, only Tertiary mudstone contain appreciable amounts. Fresh and weathered outcrops of the smectitic Tertiary mudstone occur on the western up-glacial side of the drumlin field. The weathered mudstone in this outcrop appears identical to the clay-rich till matrix of drumlins in contact with it.

This indicates that as ice flowed into the Ovando Valley from the west and northwest, it eroded the soft Tertiary mudstone and rapidly redeposited it in drumlins.

Flowage of basal ice and water-soaked till around drumlins streamline them into elongate shapes parallel to ice flow in order to offer the least resistance to erosion. Smectite may have aided the streamlining process since Smalley and Unwin (1968) have suggested that thixotropic clay, such as smectite, aid in streamlining due to their fluid consistency when wet and under stress.

**Outwash.** Outwash gravels deposited by melting Clearwater ice carpet the western side of the Ovando Valley. A kilometer wide corridor of till separates the outwash into two distinct fields. Cottonwood Creek dissects the northern and larger outwash plain which occupies 8 square km². The unterraced surface slopes gently to the southeast, having drained ice melting in the Tote Road and Cottonwood passes and the drumlin field area during its last stages of activity. At its southeast end the pear-shaped outwash plain narrows to a 250 m wide neck before truncation by Monture outwash.
The southern outwash plain lies between lower Cottonwood Creek and Boyd Mountain pass to the west. Only 2 km² remain of this outwash since outwash from the Monture advance truncates and covers its southern and eastern extent. Similar to the northern outwash surface, the soil cover contains a veneer of subrounded to rounded cobbles predominantly of Belt rock types. South-flowing streams carried outwash sediments across this area from Boyd Mountain pass and areas immediately north towards the Blackfoot River.

Lack of multiple terraces contrasts Clearwater outwash surfaces to the multi-terraced Monture advance outwash plains. Clearwater ice apparently melted at a continuous rate in contrast to several pulses of Monture ice melting which produced multiple terraces.

**Erosional features.** The Clearwater ice eroded bedrock terraces along its upper ice limit in the upper Cottonwood Creek valley and gouged large grooves in bedrock across the northern Clearwater Valley towards the Ovando Valley.

Numerous bedrock terraces step out from the steep valley wall east of Cottonwood Lakes and Cottonwood Creek. Lack of till or similar terraces above them indicate they define the upper ice limit. Confined to this narrow V-shaped valley, ice apparently scoured bedrock walls laterally as well as vertically to carve the terraces. In contrast to most glaciated valleys, the Cottonwood Valley retained its V-shape instead of scouring to a more classic trough or U-shape.

The northernmost terraces protrude from the valley wall as narrow spurs 1 km northeast of Cottonwood Lakes. The largest and highest spur
protrudes at an elevation of 1880 m (5649 ft.) with two lower spurs nested closely below. Two of the spurs trend southeast, compatible with the ice flow direction yet one oddly trends northwest, possibly controlled by the northwest structural trend. Till bearing angular to subangular clasts of local bedrock mantle the spurs.

Within a kilometer to the southeast a more benchlike and till covered terrace protrudes from the steep hillside at an elevation of 1760 m (5280 ft.). The extreme 120 m drop in the ice elevation over a kilometer suggests the presence of an ice fall. The passage of ice from the narrow Cottonwood pass near the lakes into the wider Cottonwood Creek valley to the southeast explains the abrupt drop in the ice surface gradient.

One kilometer further to the southeast a much larger till covered terrace lies at an elevation of 1693 m (5080 ft.). This is the southern most bedrock terrace along this valley side. To the southeast, across the north Fork of Cottonwood Creek, lies the lateral moraine which continues along the southern flank of the Swan Mountains. Southwest of this terrace, across Cottonwood Creek, lies the largest of the high bedrock terraces. Its upper surface north of Spring Creek slopes gradually to the southeast from an elevation of 1770 to 1620 m (5160 to 4860 ft.) within 1.5 km. The surface consists of subdued rolling hummocks of till yet lacks closed depressions.

The expression of these erosional terraces and paucity of lateral moraines resulted from a deep ice gradient. From the northern spurs to the northwest corner of the Ovando Valley the upper ice elevation dropped nearly 200 meters within 2.4 km.
Long glacial grooves carved into bedrock extend west and northwest of the study area. Although most lie out of the map area, this illustrates the directions of ice flowing into the Ovando Valley and point towards the glacier's source area. They are most noticeable west of Boyd Mountain pass in Blanchard Flats (Plate I) and northwest of Tote Road pass. Trending east-west in the passes, the grooves and adjacent ridges shift to a more northwesterly trend in the Clearwater Valley. To the north, en echelon sets of discontinuous grooves parallel the Clearwater Valley towards the divide with the Swan Valley.

Individual grooves extend from 100 m to 1 km in length and usually lie less than 70 m below the adjacent bedrock ridges. Rounded bedrock ridges consist predominantly of Belt Supergroup quartzite, argillite, and limestone, except in Blanchard Flats where the grooves incise Tertiary mudstone. Although the grooves follow the general northwest structural grain of the bedrock, their trough shaped bottoms, rounded ridges, striated surface, and mantling of Clearwater till mark them as glacially carved. Their trend also shifts in response to the trend of east-west ice passes which traverse the bedrock structure.

Smith (1948) has recorded giant glacial grooves up to 1.6 km long in northwest Canada which were uninfluenced by bedrock of structure or topography. He concluded they originated from glacial gouging. Such large grooves result from glacial erosion parallel to ice flow (Gravenor and Menley, 1958). Boulders lodged in basal ice may gouge smaller flutes, but the origin of larger grooves remains obscure (Embleton and King, 1971, p. 183). Embleton and King propose two possible origins. Groups
of boulders packed and frozen together may explain the smaller grooves. Larger grooves may form by parallel bands of varying pressure zones in the ice which erode rock from high pressure zones more than in the low pressure zones.

Regardless of the exact origin, the glacial grooves carved by the Clearwater advance point towards a northwesterly source from the Swan Valley area for the ice.

Soil. A detailed soil survey of the Ovando Valley was initially planned to aid in relative age dating of glacial deposits on the basis that degree of soil development reflects the length of time exposed to weathering. However, I found no complete soil exposures on the Blackfoot till and those on the Clearwater and Monture tills and gravel appeared highly variable as also noted by Tweeton (1971, unpublished M.S. thesis). This variability requires a detailed systematic soil survey which my time commitments prevented. The U.S. Department of Agriculture Soil Conservation Service based in Deer Lodge, Montana plans to conduct a detailed soil survey of the Ovando Valley within the next couple of years.

Tweeton noted the following general variabilities in soil development in the area near and north of Monture Hill:

1) lateral moraines formed less developed soils than on hummocks due to abundance of boulders; 2) northern exposures had significantly greater soil depth than eastern, western or southern exposures because of greater water retention; 3) soil depth under forest cover exceeded that for grasslands; and 4) soil depth on the base of moraines or hummocks was greater than at the top.
Tweeton's measured soil depth on Clearwater till underlying grass
lands and on the upper 50 percent of morainal slopes. The "A" and "B"
horizons ranged between 31-51 cm and 21-54 cm with mean depths of 44
and 41 cm respectively. Depth of leaching ranged between 77 to greater
than 185 cm.

My reconnaissance soil survey revealed comparable depths of mollisol
on Clearwater till. The dark brown (10 YR 3/3 m) "A" horizon ranged
between 15-50 cm. It contained weathered pebbles and a sandy matrix
giving the granular structure and gravelly loam texture. The brown
(10 YR 4/3 m) "B" horizon varied from 30-50 cm thick and contained less
weathered pebbles than the "B" horizon. Depth of leaching exceeded
100 cm and was often indeterminable due to thickness of exposure, where
it exceeded at least 150 cm.

Monture Advance

Alpine glaciers flowing down the Monture and Dunham valleys from
the Swan Mountains coalesced upon reaching the broader Ovando Valley and
fanned southward into a large piedmont glacier—the Monture advance.
Stagnation of the ice deposited till in a striking knob and kettle dis-
tegration moraine, high lateral moraines and a partially preserved
terminal moraine. Meltwater streams deposited gravel in kame terraces,
periglacial channels and broad outwash plains which dissect and envelope
the till. Deposits of the Monture advance, occupy the central part of
the Ovando Valley covering 80 km$^2$. Ice thickness varied from approxi-
mately 367 m (1000 ft.) in the northern Ovando Valley to 167 m (500 ft.)
near the Monture Hill. South trending lateral moraines truncate east trending moraines deposited by the Clearwater advance and lie vertically below Blackfoot advance deposits.

**Till.** The Monture advance deposited tills of variable matrix from clay, clayey sand to sand with the sandier tills associated with the lateral moraines. Lateral moraines also contain less compacted till than the moderately compacted till in the disintegration moraine. Color of the till matrix ranged from reddish brown (5 yr 5/4 m) to light brown (7.5. yr 6/4 m). Depth of calcium carbonate leaching varies from 25 to 105 cm with lime absent in many exposures.

Subangular to subrounded clasts include predominantly red, white, tan and green quartzite and sandstone, green and red argillite and minor limestone all derived from the Precambrian Belt Supergroup. Friable diorite, Tertiary mudstone, siltstone and organic rich gyttja occurs less frequently. Most clasts and erratics lack striae and show no significant weathering.

**Moraines.** Disintegration moraine occupies nearly half of the area blanketed by the Monture advance. The most striking of all features in the Ovando Valley, it consists of very bumpy knob and kettle topography (Fig. 5). knobs, or hummocks, commonly rise 15 to 35 m above the adjacent kettles and range from subtle mounds to hills nearly 55 m high.

Hummocky disintegration moraine results from the downwasting of a stagnant glacier littered with rock debris. Material within and on the
Figure 5. View looking northwest from Monture Hill showing hummocky disintegration moraine and outwash plain of the Monture advance in center; and two lateral moraines of the Monture advance on northwestern Monture Hill in the foreground. In the background from right to left are Tote Road, Boyd Mountain and Blackfoot Canyon passes.

Surface of the ice originates from glacial plucking below and along the glacier's margins and rockfalls from valley walls above the ice. Up-thrusting along shear planes may further concentrate debris on the surface at a stagnated terminal zone as shown schematically by Bishop (1951) in Figure 6. As the ice melts debris fills in cracks and depressions which eventually become hummocky leaving kettles between as shown in Figure 7 (Flint, 1971).

The round, elongate and irregular hummocks in the Ovando Valley commonly slope steeply to up to $35^\circ$. Unweathered cobbles and boulders cover the grass and sage inhabited slopes. The unbreached kettles are
Figure 6. Schematic cross section of an ice sheet in northwest Greenland at three successive times. A narrow terminal zone stagnates due to thinness, impeding the flowing ice upstream which shears over it. Rock particles move to surface along the shear planes. This supra-glacial debris slides or is let down to the ground as deglaciation proceeds. Not to scale. (After B.C. Bishop, 1957, in Flint, 1971, figure 5-14.)
Figure 7. Four schematic stages in the formation of hummocky knob and kettle topography characteristic of disintegration moraines. Supraglacial debris fills in cracks and depressions through mass-wasting processes. Processes similar to these probably formed the hummocky moraines in the Ovando Valley. (After Flint, 1971, figure 8-10.)
usually small yet some form large lakes and ponds ranging up to 1600 m long and 300 m wide. No perennial streams drain the lakes or dissect the disintegration moraine. Instead, the moraine deflects Monture, Warren and Dick Creeks toward the adjacent outwash plains.

The only vestage of a terminal moraine lies in the southeastern part of the Monture advance about 1 km southeast of Monture Hill. Less than 3 km wide, it arcs into a prominent hummocky ridge rising 13-25 m above the surrounding outwash plain. Deflection of ice around Monture Hill prevented growth of the terminal moraine immediately to the west. West of Monture Hill the Blackfoot River and/or glacial outwash streams have eroded the southwestern extent of the terminal moraine.

Lateral moraines enclose most of the disintegration moraine and outwash deposits of the Monture advance and extend north of the Ovando Valley. From north to south they lie perched along the western wall of the Dunham Valley, along the southwest and southeast trending limbs of the advance and wrap around Monture Hill. Except for the moraine on the southwest limb, each location contains a nest of 2 or 3 lateral moraines. The upper moraine is usually larger and defines the upper and lateral extent of the glacier during its maximum stade. Shorter recessional stades deposited the lower and smaller moraines which usually decrease in size downslope.

The sharp to rounded moraines rise 15 to 40 m above their outer
periglacial channels. Despite their prominent form, perennial tributaries have often breached the moraines, incising deep narrow channels.

Processes depositing the moraines varied from ice to meltwater dominated as evidenced by the variable composition of sandy clay till to well sorted gravels. Their origin along different parts of the glacier such as along the margin of the narrow Dunham tributary glacier, along the unconfined margins of the piedmont lobe in the central Ovando Valley and around the large bedrock obstacle of Monture Hill, also suggest a variety of depositional mechanisms. Documentation of processes forming lateral moraines remains minimal in the literature except for a study by Osburn (1979) on lateral moraines formed by multiple advances.

**Nature and distribution of lateral moraines.** Sets of lateral moraines deposited by the Monture advance differ in size, form and continuity and formed in different types of physiographic terrain. In general, the moraines formed in response to different glacial processes as controlled by different local physiography.

The northern most set of lateral moraines lie at the edge of the hanging valley of upper Cave Creek which indents the western wall of the Dunham Valley. In contrast to other lateral moraine sets in the study area, the two moraines at Cave Creek do not lie parallel to each other. United at their northern ends they immediately bifurcate. The outer moraine diverges to the southwest away from the Dunham Valley and ends abruptly against the southwest valley wall of Cave Creek. The inner moraine extends south remaining parallel to the Dunham Valley and to the
paleo-ice flow direction. It ends on the south side of the hanging valley where the deflected Cave Creek finally breached the moraine.

Similar in height and width each moraine rises to an elevation of 1760 m (5280 ft.) with 15 to 27 m of local relief and measures approximately 65 m wide. The moraines contain loosely compacted, poorly sorted till bearing many rounded clasts. Although ice deposited the till, the rounding of the clasts may indicate periglacial or supra-glacial stream abrasion prior to ice deposition. The rounded shape of the clasts differs completely from the very angular clasts comprising lateral moraines along alpine glaciers seen at Athabasca and Mt. Edith Cavel glaciers in British Columbia. Here rock falling on the ice from the valley walls and plucked from the valley walls by the ice has traveled less than 10 km resulting in little to no rounding. Perhaps rocks comprising the Cave Creek moraines traveled farther distances, in combination with glaciofluvial abrasion, to account for the rounded clasts.

The glacier deposited the outer moraine first as ice spilled into the hanging valley during its maximum stade. During a recessional stade with ice at a slightly lower elevation at the base of or slightly below the floor of the hanging valley (1133 m/5200 ft.) the glacier constructed the inner moraine.

Preservation of the Cave Creek moraines is directly related to their construction on the flat floor of upper Cave Creek. The steep walls of Dunham valley north and south of Cave Creek prevented preservation of lateral moraines. Large lateral moraines do exist south of
the narrow Dunham Valley where the ice flowed into the broad Ovando Valley forming the piedmont glacier.

The southwest limb of the piedmont lobe deposited a large lateral moraine surfaced with hummocks and closed depressions (Plate I). It extends from 1 kilometer south of the Dunham Valley 6 kilometers southwest to Bandy Reservoir. The irregular crest slopes southwesterly from 1547 to 1473 m (4640 to 4420 ft.) above sea level. It averages 500 m wide, and stands 40 m above Shanley Creek which occupies an old periglacial channel to the west. The knob and kettle surface grades into disintegration moraine to the east with no recessional moraines evident.

The moraine's irregular surface and poorly sorted till composition suggests formation dominated by downwasting of stagnant ice with minimal fluvial deposition. The reason for its grander size and unity in contrast to the other morainal sets remains unclear. During the initial and maximum stade much ice and debris may have flowed into this area since no bedrock hills or walls confined it. This could explain the large size of the moraine. Its lack of gradient and distance from the central and fastest moving part of the glacier may have stagnated the ice during the recessional stades while ice in other morainal areas remained active. Lateral moraines require stable levels yet active ice movement to form the other moraines in the area lie closer to the glacier's center including those due east of the southwest lateral moraine which define the southeast limb of the piedmont lobe.
Along this southeastern margin three lateral moraines extend from the Little Red Hills southward. The highest and largest moraine extends 8.3 km southeastward until truncated by a moraine deposited by the southwestward flowing North Fork advance which coalesced with the Monture ice. From north to south the knobby crest of the upper moraine slopes from an elevation of 1533 to 1493 m (4600 to 4450 ft.). The middle and lower moraines stretch only 3.2 and 1.6 km respectively in a more southerly direction. The middle moraine slopes from an elevation of 1487 m to 1473 m (4460 to 4420 ft.) and the lower moraine slopes from 1447 to 1413 m (4340 to 4240 ft.). From the upper to lower moraines widths of the moraines range from a maximum of 600 m on the upper moraine to 160 m on the lower moraine. Local relief varies between 40 m on the upper moraine to 7 m on the lower moraine.

McCabe Creek now dissects the three moraines although the deep channels behind the upper two moraines suggest the moraines once deflected McCabe around them. Upon dissecting the moraines, McCabe Creek built a large alluvial fan into the Ovando Valley which now deflects Monture Creek (Plate I).

Dominance of moderate to well sorted gravels interbedded with lesser amounts of till reflect a fluvial-meltwater reworking and deposition of the morainal material.

In the south central part of the piedmont lobe the glacier built a spectacular complex of lateral moraines on Monture Hill. Although only one prominent moraine stretches across the northern side of Monture Hill, three tightly nestled moraines wrap around the southwestern side
and two distinctive moraines and one questionable moraine wraps around the southeastern side of the hill (Plate I). The discontinuous nature of the moraines probably reflects erosion off the steep northern side of Monture Hill.

Based on their arcuate trend and relative elevations and sizes, the upper moraines on the east and west side of Monture Hill correlate with the one moraine on the northern side. Similarly the middle and lower moraines on the eastern and western sides correlate.

The arcuate moraine on northern Monture Hill rises 10 m locally and reaches a maximum elevation of 1500 m (4500 ft.). This marks an ice thickness of 167 m (500 ft.) above the valley floor which lies at 1333 m (4000 ft.).

Figure 8 is a cross section view of Monture Hill showing the large lateral moraines on the east compared with those on the west side. Moraines on the western side of Monture Hill (Fig. 5) have a maximum local relief of 18, 7 and 3 m from the upper to lower moraines respectively. They all slope to the southwest with the upper moraine sloping from 1473 to 1347 m (4420 to 4040 ft.). The ridges are less than 60 m wide with all three moraines tapering and becoming sharper crested to the north where they grade into the hillside.

The two prominent upper and lower moraines on the east side of Monture Hill are separated by knob and kettle disintegration moraine which masks the questionable middle moraine. Discontinuous linear ridges through the hummock field poorly define the possible middle moraine.
Figure 8. Cross section view of Monture Hill showing larger lateral moraines on east compared with those on west side.
All three moraines slope to the south. The upper moraine slopes from 1473 to 1400 m (4420 to 4200 ft.) and the lower moraine slopes from 1440 to 1367 m (4320 ft.). Maximum local relief is 30 m. Each of the sharp crested ridges is less than 60 m wide and littered with abundant rounded erratics.

The much greater deposition of till on the eastern margins of Monture Hill in contrast to the much smaller moraines on the western side seems significant. It suggests that the mainstream of ice flowed more towards the northeast side of Monture Hill after deflected by this large bedrock obstacle with lesser ice and debris shed to the west. This would require an ice flow direction trending approximately S20°W from the Dunham-Monture Valley confluence to the northeast side of Monture Hill. Fluted bedrock north of Monture Hill reflects a similar ice flow direction as mentioned above.

Ice contact features. Features formed in contact with the Monture advance include the Mollet Park and related kame terraces and the McCabe Creek kame terrace, all of which lie near McCabe Creek. Of questionable origin are two possible kames formed in moulins south of Ovando.

The Mollet Park kame terrace forms a broad tear shared plain ranging up to 5.6 km long and 1333 m wide. It lies between the upper McCabe Creek lateral moraine and the foothills to the east. A nest of much smaller kame terraces lie between the middle and upper lateral moraine. An organic rich dark brown soil, bearing much gravel, covers these gently undulating surfaces engraved with ancient channels. Each
of the terraces is incised by a deep periglacial channel which arcs toward McCabe Creek at its upstream end where it now "hangs" 70 m above McCabe Creek. Apparently each of the moraines deflected McCabe Creek behind their respective ridges which aided in the building of the expansive kame terraces.

Northeast of these kame terraces lies another kame terrace which McCabe Creek now dissects. It fills in a bulge in the otherwise V-shaped canyon where the creek had previously eroded laterally into a diorite dike altered and weathered by the St. Mary's fault. The 1500 m long 1000 m wide terrace consists of interbedded gravelly till, well bedded and well sorted gravels and local lenses of sand and mud. Repeated fining upward sequences of sand, silt and mud may reflect small deltas filling up ice dammed ponds or local floodplain deposits. The diversity of sediments reflects a complex glacio-fluvial depositional environment. Along the southeast facing hillslope above the terrace clay-rich till overlies more gravelly till composed predominantly of angular limestone clasts. Crude bedding planes dip southeast away from the Little Red Hills. This attitude, predominance of local limestone bedrock throughout the deposit and lack of other possible source area indicates that till was derived from ice flowing over the Little Red Hills.

Well preserved knob and kettle topography, on the broad saddle within the Little Red Hills confirms the deposition by Pinedale glaciation. Although this saddle lies 1 km southeast of where the converging
Dunham and Monture Valley glaciers entered the Ovando Valley, the ice elevation at 1733-1743 m (5200 - 5320 ft.), remained the same at both locations if not a little higher in the saddle. This indicates a minimum ice thickness of 367 m (1100 ft.) considering the valley floor elevation of 1367 m (4100 ft.). Due west 3 km, where a bedrock spur such as the Little Red Hills did not confine the ice, its surface had dropped nearly 200 m lower to 1533 m (4600 ft.). This illustrates that the glacier flowing southeasterly from the canyons, retained its elevation along its western margin for at least 2 km into the Ovando Valley and pushed ice up and over the northern Little Red Hills. Upon bypassing the Little Red Hills the ice surface sloped down to an elevation more level with its western margin as defined by the upper McCabe Creek lateral moraine.

The two suspected moulin related kames lie 1 km southwest of Ovando in an isolated hummock field. These features stand 7-13 m high forming prominent conical shapes distinctive of kames deposited in moulins -- their shape possibly resulting from meltwater depositing glacial debris into vertical ice holes or moulins. Vegetation prevented exposure of their composition to determine if they contained gravelsindicative of such kames.

Erosional features. Passing beneath the hummocky till between Mud, James and Shoup Lake, in the central part of the Monture lobe, lie a series of parallel flutes and adjacent ridges (Plate I). Despite their surficial resemblance to drumlins, they contain a core of Tertiary bedrock overlain by soil, or a thin veneer of till, as exposed in a bluff cut by Monture Creek.
Flutes show v-shaped troughs and narrower widths than the ridges. The rounded ridges are broadest to the north spanning up to 160 m wide and narrow to the south as they pinch out or pass beneath the hummocky disintegration moraine. They extend 400 to 800 m long yet rise less than 5 m above the adjacent flutes.

In explaining the origin of smaller grooves Hoppe and Schytt (1953) have proposed abrasion by boulders imbedded in basal ice. Similarly, abrasion may have initiated the Monture advance flutes which set a track for subsequent ice and basal debris to more deeply increase. Gravenor and Menley (1958) have explained flutes in Alberta as resulting from slightly higher pressure zones in the ice, parallel to lower pressure zones, which groove the underlying bedrock.

Despite the question of their origin, most glaciologists consider flutes the result of glacial erosion parallel to ice flow. The location of the Monture advance favors an erosional hypothesis since it underlaid the central part of the glacier where maximum ice velocity and erosion occur.

The flutes in the Ovando Valley trend S 20°W to S 40°W (Fig. 7). The trend of the flutes gradually fans out southwesterly from the east reflecting the radiating flow of ice as it fanned outwards into the piedmont lobe.

**Outwash.** Extensive outwash plains dissect the distintegration moraines throughout the central Ovando Valley. Their relatively smooth surfaces slope transitionally from adjacent moraines to the south, southwest or west. In many areas threads of anastomizing channels
Figure 9. Rose diagram showing the trend of 28 glacial grooves cut in Tertiary bedrock by ice of the Monture advance reflecting the south-southwesterly ice flow direction.
weave through the gravel blanket reflecting the pre-existence of braided streams. Roadcuts along Highway 200 expose a minimum thickness of 7 m for the gravel deposits which may range up to 10 m thick. These gravels appear well sorted, poorly bedded, containing sub-angular to sub-rounded pebbles, cobbles and boulders of lithologies similar to those found in the till.

The three main areas covered by outwash plains occur along the western margin of the Monture advance, surrounding the Ovando townsite and 1-9.7 km north of Monture Hill. The western outwash plain forms a long fan gently sloping west from the disintegration moraine. A few boulder trains and channel furrows finger across the surface from larger intramorainal channels. As in the Clearwater outwash the surface is pitted with depressions up to 10 m deep indicating burial of glacial ice by outwash gravels. This suggests rapid surface ablation which deposited outwash on top of the thinning glacier margin. Price (1969) revealed that the sandur in front of Briedamerkurjokull in Iceland built up over a relatively short period of time and that melting of buried ice modified large areas of outwash plain. Price (1971) also noticed outwash kettles 2 to 7 m deep developing in only 3 years between 1962 and 1965 as other parts of the outwash plain dropped 2-4 m.

In the area surrounding Ovando, erosional scarps 5 to 10 m high separate the outwash plain into four distinct terraces. The three terraces north of Ovando slope to the south and decrease in elevation from east to west, similar to the three lateral moraines to the northwest. The upper two terraces slope away from the kame terraces and periglacial
channels located behind the upper two lateral moraines. These relationships suggest that the outwash terraces may have formed during interstadial recessions.

Due to its slightly lower elevation and westerly slope the fourth terrace truncates the three terraces lying to the north. Passing south of Ovando it extends 7 km to the northwest separating moraines of the Monture and North Fork advance. It therefore carried outwash gravels from both glaciers to the west, and southwest towards the Blackfoot River. The most westerly transported gravels coalesced with those swept from the central part of the glacier, in the confluence of outwash plains northeast of Monture Hill.

**Soil.** Soil overlying the Monture till and gravels resembles the Clearwater till except for showing less development. Tweeton measured the "A" horizon as ranging between 8-21 cm with a mean depth of 13.6 cm. It commonly graded into the parent material with no "B" horizon present.

My study found the "A" horizon ranging between 15-30 cm. The "B" horizon varied from 20-40 cm. on north facing forested slopes yet was sometimes absent in the forest and more commonly absent in the grasslands. The dark brown mollisolic "A" horizon commonly appeared in sharp and less often gradational contact with fresh underlying till. Depth of leaching was 25-105 cm, often extending into the till.

**Discussion of Clearwater and Monture Advances**

Although the Blackfoot advance clearly defines the oldest recognizable glacial advance in the study area, the time relationships between the
younger Clearwater and Monture advances remain less clear. Several features suggest the Monture advance is slightly younger: southerly trending moraines of the Monture advance truncate easterly trending moraines and drumlins of the Clearwater advance; lateral moraines deposited by the Monture advance wrap around Monture Hill and enclose Clearwater till on the south side; Monture advance moraines are more well preserved with more water filled kettles; and soils on Monture till appear less developed than on Clearwater till.

Suggesting a distinctly younger advance of such magnitude as the Monture advance implies a rejuvenation of the Swan Range ice cap. This rejuvenation was of less magnitude than during the Clearwater advance.

During the Clearwater advance ice occupied the Clearwater Valley to high elevations forcing ice to overflow into the Ovando Valley. At the same time ice probably filled the Swan Valley and flowed north. Witkind (1978) showed that the last major glacier that occupied the Swan Valley merged with the Flathead Lobe of the Cordilleran ice sheet which penetrated the Flathead Valley from the Canadian Rockies. As ice thickness grew in the Swan Valley it was deflected west across the northern Mission Range. This deflection rounded off and carved giant glacial grooves seen from miles away on the northern Mission Range. Witkind suggested the Cordilleran ice carved the southwest trending grooves on the far northern end of the range but the Swan Valley ice carved ones to the south as Johns (1970) had also suggested.

During the Monture advance the Clearwater Valley did not completely fill with ice and no ice flowed into the Ovando Valley from the Clearwater
Valley. Instead only smaller alpine glaciers readvanced into the Swan and Clearwater Valleys from adjacent mountain ice caps. They terminated in piedmont lobes a few kilometers from the canyon mouths.

One of these valley glaciers terminated near Holland Lake in the southern Swan Valley. Here multiple lateral moraines fan out from the narrow Holland Creek canyon mouth and ends in a hummocky terminal moraine which dams Holland Lake. These moraines lie vertically below the moraines formed by the ice related to the Clearwater advance (Curry, 1979, personal communication).

Another moraine possibly deposited to the same time as the Monture advance deposits lies at Seeley Lake in the central Clearwater Valley (Curry, 1979, personal communication). Witkind (1979, personal communication) has recognized a small moraine at the northern end of Swan Lake located in the northern Swan Valley. He postulates its correlation to small advances postdating ice advances contemporaneous with the Clearwater advance.

The North Fork advance deposits in the Nevada Valley also appears contemporaneous with the Monture advance deposits. Alden (1953) also noted deposits of several other small piedmont lobes east of Nevada Valley near Lincoln, Montana. He suggested their contemporaneity with deposits of the Monture and North Fork advances.

More detailed work is needed to define deposits of the last advances in the Swan, Clearwater and Nevada Valleys before definitively correlating them to each other and the Monture advance deposits. However, their tentative correlation seems likely.
Significant glacial advances from numerous canyons without a major ice filling of the Clearwater and Swan Valleys may have resulted from a relatively short interval of conditions favorable for glacial advance. Smaller glaciers have a much quicker response time to climatic changes than larger piedmont lobes or long valley glaciers -- possibly on order of magnitude greater. Local climatic factors may have influenced glaciers in different drainage basins even for glaciers of initially the same size. Terminal fluctuations may occur in an area but not in adjacent areas. This may explain variations in size and extent of advance of the smaller piedmont lobes in the Swan, Clearwater, Ovando and Nevada Valleys.

Presumably the ice cap in the Swan Range did not melt completely during the Clearwater - Monture advances interval. Instead, the large valley glaciers shrank to unknown sizes possibly melting completely. Smaller tributary glaciers extending from the mountain ice cap may have still occupied canyons and merely readvanced into the larger valleys (i.e. Ovando Valley) during a short interval of renewed glaciation. Richmond (1965) believes the mountain ice caps in the Rocky Mountains did not completely melt until after approximately 6,000 - 7,500 yr B.P. which presumably postdates the Monture and related advances.
CHAPTER III

GLACIAL-FLUVIAL-LACUSTRINE SEDIMENTS EXPOSED ALONG THE
BLACKFOOT RIVER -- EVIDENCE FOR A GLACIAL LAKE DELTA

Glacial-Fluvial-Lacustrine Sediments

In the southern Ovando Valley four exposures along the Blackfoot River reveal complex sequences of interstratified till, sand, silt, clay, and gravel. Three of the exposures outcrop on southern Monture Hill (Sections II, III, and IV) and one outcrops 10 km west in the canyon of the Blackfoot River (Section I). Measurement of stratigraphic sections and examination of sedimentary structures and textures has allowed delineation of six lithofacies: glacial, lacustrine, deltaic, fluvial, paleosol, and eolian (Fig. 10). The two tills of the glacial lithofacies sandwich the stream and lake deposited sediments and are locally overlain by paleosol and loess (Section II, Fig. 11).

Glacial lithofacies. A lower and upper till, deposited by the Blackfoot and Clearwater advances respectively, define the glacial lithofacies. Correlation of the lower till to the Blackfoot advance is based on its moderate degree of weathering and stratigraphic position below stream and lake sediments separating it from the Clearwater till above. In Section IV slopewash partly buries the lower till making it difficult to discern from lenses of till interfingering with sand and mud above. Its greater thickness 3-4 m, and stratigraphic position indicate it is a distinct unit correlative with the other lower till outcrops.
Figure 10. Correlation diagram of glacial-fluvial-lacustrine sediments exposed along the Blackfoot River. See figure 11 for the explanation of geologic symbols.
Figure 11. Correlation diagram of three measured sections exposed along the Blackfoot River on the southwest side of Monture Hill at Section II. Looking N55W.
The upper till is characterized by calcium carbonate which coats the clasts as caliche and more sand and gravel lenses, many of which were deformed as surrounding ice melted. Contact of the upper till with lower beds is irregular and erosional at Sections II, III and IV yet appears conformable where it overlies a 6 cm layer of sand and mud lying between it and gravel at Section I.

1.2 km southeast of Section II lies a small yet significant outcrop of till and interbedded sand, silt and mud. This 11 meter thick sequence lies below an arcuate river terrace cut into southern Monture Hill, 40 m vertically above where the present Blackfoot River bends sharply to the south. Although covered by vegetation and slopewash, digging into the steep hillside revealed over 4 m of till overlain by over 7 m of sand, silt and mud. The well compacted till rests directly on bedrock and consists of brown (7.5 yr 5/2) sandy clay containing pebble and small cobble size clasts. Many clasts are very weathered which may be more related to water impounding above the bedrock surface and saturating the till rather than age of deposition.

Five-hundred m east of Section III till overlies the deltaic lithofacies at the upper part of a steep river cut of Section IV and rises to a high rounded hill shown at 1445 m (4335 ft.) elevation on the geologic map (Plate I). The hill is part of the knob and kettle disintegration moraine deposited by the Clearwater advance on southern Monture Hill.

Immediately northeast of all four sections the upper till forms hummocky Clearwater advance moraines.
Lacustrine lithofacies. Three beds of thinly laminated silt and clay record the presence of proglacial lakes in the Ovando Valley (Sections I and II, Fig. 10). In Section I, two beds of varved-like laminae are separated by a thick bed of cobble gravel. The salmon to buff-colored lake beds are 10 m (lower) and 3 m (upper) thick, the latter capped with 70 cm of mollisol. The lower bed extends 40 m laterally and lies in contact with gravel to the west. The upper bed, extending less than 20 m laterally, interfingers with the upper (Clearwater) till to the east, revealing its deposition in a proglacial lake.

The lake bed in Section II overlies Blackfoot till and contains thin laminae of muddy sand (1-10 cm thick) and small pebble and sand lenses, the latter showing festoon crossbeds. Dropstones less than 2 cm wide occur randomly distributed throughout the unit in Section II and IV and commonly warp the silt laminae.

Deltaic lithofacies. Three outcrops of interbedded sand, silt, and clay containing lenses of gravel and till reflect deltaic deposition in a proglacial lake (Sections II, III, IV; Fig. 10). Colluvium and vegetation limit the exposure at Sections III and IV in contrast to the well exposed river bluff at Section II.

Seven meters of alternating silty sand (less than 20 cm thick) and muddy clay beds overlie 4 m of Blackfoot till at Section III. Similar sediments in a much thicker sequence outcrop 500 m to the east in Section IV. Sand beds are less than a meter thick and usually are 10-30 cm thick with clay beds usually less than 15 cm thick. Sand to clay size
grains, sand lenses and horizontal lamination suggest deposition in both moving and standing water.

Streams flowing into a lake may have deposited the sand followed by silt and clay deposition from suspension as velocity decreased. Dropstones in the muddy laminae reflect the presence of a glacier in contact with the lake. Irregular shaped lenses of till-like material occasionally occur in Section IV which may have resulted from till slumping into the lake from the shore on southern Monture Hill.

The most striking and telltale delta deposits outcrop in Section II (Fig. 11). This 10-20 m thick sequence consists predominately of silt and clay laminae which protrude like shelves from the more recessed and thicker sand laminae interbedded with numerous gravel lenses (Fig. 12).

Thickness of the sand and silt layers varies, yet two general sizes dominate. Thicker layers, consisting of very fine to medium grained sand ranges from 2-15 cm thick and interlayer with silt-clay layers 0.5 to 7 mm thick. They usually are more continuous than the thinner layers, extending 10's of meters across the cliff. The well sorted and equigranular texture of the sands usually masks internal structures although some beds show faint horizontal to cross laminae. Asymmetrical ripple cross-laminae often pass upwards into more symmetrical cross-laminae.

The thinner layers contain sand laminae 0.3 to 4 cm thick and silt laminae 1 to 10 mm thick occurring in sequences 20 to 50 cm thick and less than 2 m wide. They often grade laterally and/or vertically into
Figure 12. Glacial-fluvial-lacustrine sequence exposed along the Blackfoot River at Section II.

Figure 13. Sequence of asymmetrical ripple cross-laminae grading upward to more symmetrical ripple cross-laminae from the deltaic lithofacies at Section II. Note the dropstone in the right central part of the photograph.
the thicker sand and silt beds or festoon crossbeds of coarse grained sand, or lie in abrupt contact with gravel lenses. They differ internally from the thicker sand beds in showing well preserved horizontal laminae and climbing ripple cross-laminae.

Several localities show thin horizontal laminae or festoon and foreset cross-beds of coarse to very coarse grained sand grading laterally and vertically to climbing ripple sequences. Transition from horizontal laminae to climbing ripple crossbeds indicates a shift from upper to lower flow regime as current velocity decreased and sediment load increases. Transition from festoon and foreset crossbeds to climbing ripple crossbeds reflects a decrease in current velocity within the lower flow regime (Reineck and Singh, 1973).

Transitional structures also occur within the climbing ripple sequences (Fig. 13). At the base of the sequence, asymmetrical ripple cross-laminae, showing only lee side preservation, grade up to more symmetrical ripple cross-laminae where stoss and lee sides are preserved yet the lee side thicker. These grade up to more sinusoidal ripple laminae where stoss and lee sides show more equal thicknesses. Silt-clay layers, 1-5 cm thick, commonly drape over the ripple sequence and conform to the ripple bedform below. Overall, the grain size becomes finer upwards as the ripples become more symmetrical.

Jopling and Walker (1968) have described similar cross-laminae sequences from a kame delta complex in Concord, Massachusetts. They have attributed the progression of cross-laminae types to the suspended...
load/bedload ratio (Fig. 14). With a low ratio, bedload predominates deposition preserving only the ripples' lee side. The current and constant migration of the ripples erodes the stoss sides before suspended load can fall and bury them. This forms the type A cross laminae defined by Jopling and Walker. As the ratio increases more suspended sediment falls on the ripples which buries and preserves the stoss as well as lee sides (type B of Jopling and Walker). Since bedload and lee side deposition still dominate, each ripple crest migrates slightly ahead of the underlying crest resulting in a climbing appearance shown in Figure 14. When suspended load predominates, the stoss and lee side build up in equal thicknesses forming sinusoidal ripples. Gustavson, Ashley and Boothroyd (1975) have termed laminae similar to sinusoidal ripples as draped laminae. They imply deposition of suspended load in quiet water which allows the falling sediment to inherit the often rippled bedform below. The fining upwards and increase in suspended load/bedload ratio reflects a decrease in velocity with the final result of sediment falling completely out of suspension in standing water.

A favorable environment for these sequences requires pulses of sediment discharge into a standing body of water. As concluded by Jopling and Walker and Gustavson, Ashley and Boothroyd (1975) a proglacial lake delta provides such an environment. Based on similar sedimentary structures and proximity to glacial deposits, the sand, silt and clay sequence along the Blackfoot River in the Ovando Valley also formed in a proglacial lake delta.
Figure 14. Diagrammatic representation of sedimentary structures and related depositional environments in a kame delta deposit in Massachusetts. Topset, foreset and bottomset refer to regional parts of the delta complex. Lower part of the sketch shows the types of ripples formed as the delta progrades into the lake. As suspended/traction bedload ratio increases more symmetrical climbing ripples form due to suspended load deposition on the ripples' stoss side. Particle size in sinusoidal ripples is smaller resulting in more cohesive bed (modified after Jopling and Walker, 1968, figures 2 and 16.)

Pulses of sediment discharge flowing into the lake from meltwater streams and/or the Blackfoot River could rapidly deposit climbing ripple sets as the lake gradually slowed down the current. Pulsations of sediment inflow may be related to diurnal temperature changes melting nearby ice and releasing sediment rich water. Short term climate fluctuations or rapid migration of braided channels across the delta plain would produce similar results. Short intervening periods of low to no discharge would allow the finest grained sediment to fall out of suspension and bury the ripples.
The continuity of sequences within the unit suggest rapid deposition, which may be expected. In a flume, Southward (1972) has produced a 15 cm sequence of ripple drift cross-laminae, changing from type A to type B ripples and ending with draped laminae, all in only two hours.

Other features in this unit provide more insight to the complexity of the delta. Cutting through the finer sediments are numerous lenses and tabular beds of gravel, indicating higher energy streams flowing through the delta plain possibly during wetter and warmer climatic events. Many of the tabular gravel beds show foreset crossbeds dipping in opposite directions from nearby cross-laminae implying different source directions.

Dropstones found throughout the sand and silt beds indicate the presence of a glacier in contact with the lake which continually calved off icebergs into the lake. Dropping of these pebbles and cobbles from the melting icebergs commonly warped the silt laminae.

The predominance of gravels toward the top of the unit and increased concentration of dropstones suggests ice advancing closer to the delta. Ice eventually overrode the delta, depositing the Clearwater till. The advancing Clearwater ice scoured the soft deltaic sediments and deformed the bedding and laminae. Many tight and open overturned folds and minor fault offsets characterize the upper part of the delta sediments. Many smaller folds resemble climbing ripples but are much more irregular and often show minor vertical offsets.
Fluvial lithofacies. In addition to numerous small channel lenses, two thick gravel beds overlie the lower till and lake silts in Sections I and II. The moderate to well sorted gravel contains angular to sub-angular pebbles, cobbles and boulders of lithologies similar to the till set loosely in a sandy matrix. Gravel thickness at Section II is 15 m and interbedded with two layers of muddy sand. Less than 15 cm thick and over 100 m long these sand beds may reflect overbank deposits laid on top of abandoned channel gravels deposited by the late Pleistocene Blackfoot River.

The 20 m thick gravel bed in Section I contains foreset crossbeds nearly 5 m high, dipping approximately 25° west. West of these unusually large crossbeds rest two immense blocks of bedrock up to 2 m wide supported by the cobble gravel matrix. Such large foresets and clasts require high energy transport possibly related to a sudden flood discharge associated with the breaching of an ice dammed lake. The narrow constriction of the Blackfoot canyon where these gravels occur could have forced large volumes of water through the canyon at an accelerated rate during a catastrophic draining of a lake filling the Ovando Valley. Baker (1973) has noticed similar high angle crossbeds in a pendant bar in the channeled scablands of eastern Washington deposited during the catastrophic draining of Glacial Lake Missoula.

Paleosol lithofacies. Paleosol and loess cap the Clearwater till in Section II. The paleosol varies from 1 to 1.5 m thick with the lighter brown colored "B" horizon comprising the lower 40-50 cm grading up to a drak brown "A" horizon. It commonly contains dense well
compacted clay bearing few stones. The soil formed after deposition of the Clearwater till until silt and sand, swept off outwash plains related to the Monture advance, buried it.

Eolian lithofacies. Eolian deposited loess capping the soil contains silt, very fine to medium grained sand a few randomly distributed granules less than 2 mm in diameter. The structureless loess is 1 to 1.5 m thick and grades from a "dirty" brown color at the base to a lighter brown toward the top. Streaks of dark brown soil mottle the loess in some locales. No significant soil has developed on the loess.

Loess deposits usually form from the erosion and redistribution of silt and sand derived from nearby glacial outwash plains (Smalley, 1978). Since the loess postdates the retreat of the Clearwater advance by a significant time period, as indicated by the thick soil, the loess probably originated from sediment blown off the nearby outwash plains associated with the retreating Monture ice.

Discussion

The lithofacies described above provide evidence for a large pro-glacial lake which occupied at least the southwest part of the Ovando Valley during Pinedale time. Its areal coverage remains unknown. However, if the highest lake related deposits, found in Section IV at 4200 ft. above sea level, indicate the minimum surface elevation of the lakes at its maximum, it may have flooded most of the Ovando Valley.

Sediment distribution in the lake deposits of mostly sand and silt at Monture Hill fining to varved silt and clay to the west at the highway cut show that the lake filled from the east. The varved lake
sediments in Section I reveal deposition in water that was quieter and farther from the sediment source in relation to the coarser sediment deposited near Monture Hill. As mentioned above the coarser sediments and related sedimentary structures near Monture Hill label them as deltaic deposits. Presumably the Blackfoot River flowed south of Monture Hill in Pinedale time, as it does today, where it would have emptied into the lake and deposited much of its load on the delta.

The source of the abundant sediment load is also unclear. The river may have incorporated sediment from soft Tertiary bedrock or older till exposed along its present banks to the east. Glaciers extending south from the Monture and Dunham Valleys and the North Fork Valley during the Clearwater advance, if present, could also have supplied much sediment to the Blackfoot River and proglacial lake. Although no evidence for an advance from the Monture and Dunham Valleys during the Clearwater advance exist (possibly due to overriding by the younger Monture advance) a moraine suspected to be correlative to the Clearwater advance exists south of the North Fork Valley. Here three nested terminal moraines arc south of Kleindschmidt Flats. The northern moraine clearly appears correlative to the Monture advance which I have termed the North Fork advance. The southernmost moraine has deflected the Blackfoot River to the south side of the valley as seen on the Browns Lake Quadrangle map. Its subdued and nearly dissected topography appears much older than deposits associated with the Clearwater advance. It, therefore, represents a Bull Lake (Blackfoot advance?) or pre-Bull Lake glacier.
The intermediate terminal moraine resembles the Clearwater deposits in topographic form. It may therefore represent an advance separate yet contemporaneous with the Clearwater advance.

Meltwater streams from this smaller glacier, lying east of Monture Hill, could have carried abundant sediment to the Blackfoot River and/or directly to the delta.

Origin of Lake

Two different locations with a similar ice damming mechanism for impounding the Blackfoot River into a large lake seem plausible. The more distal location of the ice dam and one favored by the author, is near the northern Idaho-Montana state line where the Pend Orielle lobe of the continental Cordilleran ice sheet dammed the Clark Fork River and formed Glacial Lake Missoula. First recognized by Pardee (1910), Glacial Lake Missoula flooded most of the Clark Fork Valley and its immediate tributaries in western Montana. Covering approximately 1000 square kilometers it rose to a maximum altitude of 1400 m (4200 ft.). The lake filled and drained several times although the actual number remains controversial. Richmond et al (1965) proposed five separate fillings based on depositional-erosional relationships described by Pardee (1910, 1942). Three of these lake fillings emptied catastrophically and two more gradually. The youngest catastrophic flood emptied in Pinedale time evidenced by its scourings of early Pinedale moraines and subsequent burial of its lake silts by middle Pinedale till (Bretz, 1923).

Thinly laminated varved sediments deposited by Glacial Lake
Missoula outcrop throughout the Clark Fork Valley and in several places along the Blackfoot River Valley. Alden (1953, p. 156) mapped Glacial Lake Missoula silts along the Blackfoot River where it incises Ninemile Prairie 17 km west of the Ovando Valley. Lying at an altitude of 1213 to 1260 m (3640 to 3780 ft.) the silts overlie till which Alden considered pre-Wisconsin age. Alden concluded that a glacier advanced into Glacial Lake Missoula and upon retreating the lake prograded over the till and deposited the varved silts. However, Harris (1967, unpublished M.S. thesis) and Witkind and Weber (1979) have mapped this till as Bull Lake in age. This till appears to correlate to the Blackfoot till in the Ovando Valley.

Alden (1953, p. 167) also noted possible Glacial Lake Missoula silts near Salmon Lake (13 km north of Clearwater Junction) underlying glacial outwash at an altitude of 1333 m (4000 ft.). Glacial deposits in this area can be traced to the Ovando Valley and correlate to the Clearwater advance.

More recently Harris has recognized Glacial Lake Missoula shorelines and silt deposits throughout the Ninemile Prairie and Clearwater Valley area. Shorelines faintly etch hillsides at the east end of Ninemile Prairie and 1 km west of Harper’s Lake at altitudes between 1300-1380 m (3900 - 4100 ft.).

Varved lake silts outcrop along Highway 20 (east of Ninemile Prairie) at elevations between 1252 and 1328 m (3755-3985 ft.). Similar to silts described by Alden, the silts commonly overlie till of Bull Lake age, as seen north of Roundup Bar. The Bull Lake till underlying lake silts
in the Ninemile Prairie area is believed to correlate to the Blackfoot till in the Ovando Valley which also underlies lake related deposits as seen in Sections II and III.

Most of the Glacial Lake Missoula silt beds noted by Alden and Harris lie within the elevation range of lake silts (found at Section I) in the Ovando study area. Silts in Section I lie between elevations 1307 to 1330 m (3970 - 4000 ft.). This further supports their correlation and agrees with known Glacial Lake Missoula elevations in western Montana. During early Pinedale glaciation Glacial Lake Missoula stood at an elevation of 1280 m (4200 ft.). During later Pinedale time it stood probably at the same elevation but at least to an elevation of 1090 m (3580 ft.) (Pardee, 1910, 1942). It is not known which of the Pinedale lake fillings deposited the silts in the Blackfoot River Valley. If the youngest lake only filled to 1090 m (3580 ft.) then only the earlier lake could have inundated the upper Blackfoot Valley as dictated by elevations of the silt beds. Correlation with the younger lake would imply a catastrophic or at least rapid draining of the lake in this area. Pardee (1942 in Richmond) has correlated the withdrawal of the earlier Pinedale lake with a catastrophic flood evidenced by flood scoured channels, giant current ripples 5 to 9 m in height and 75 m in wavelength (seen at Camas Prairie) and deposition of large boulders and coarse gravels on the wider parts of the Clark Fork Valley floor. In contrast the younger Pinedale rise of the lake drained gradually (Pardee, 1942).
Possible evidence for catastrophic draining of Glacial Lake Missoula exists in the Blackfoot Valley. Harris has mapped a large alluvial fan north of the Roundup Bar which Highway 20 crosses. Littered with boulders 1-1.5 m in diameter it fans into Ninemile Prairie from Woodchuck Canyon (old west branch) covering nearly 2 square km. Harris postulates that rapid draining of Glacial Lake Missoula increased the slope gradient of the canyon stream which, aided by excessive discharge, transported abundant coarse material from the bedrock canyon to Ninemile Prairie. In the Ovando study area, Section I shows coarse gravels with high angle foreset crossbeds and large boulders. They obviously reflect transport in high water energy. Since they overlie varved lake silts, rapid draining of the glacial lake is a possible and probable source for the flood scale currents needed to move the large clasts.

The other possible location for the ice dam lies in the Clearwater Valley where the Clearwater advance may have dammed the Blackfoot River. Harris and Witkind and Weber have mapped till contemporaneous to the Clearwater advance south of the Blackfoot River and to the north above the 1400 m (4200 ft.) upper limit of the lake. However, several of the lake silt deposits outcrop southeast of this Pinedale till indicating a dam further west.

North of the Blackfoot Canyon near Section I of the Ovando study area, Clearwater till lies at an altitude of 1467 m (4400 ft.). Erratics suspected to correlate to the Clearwater till lie at a similar elevation immediately southeast of Section I on top of the bedrock ridge protruding
from Blacktail Mountain. Lying on both sides of the Blackfoot River, these deposits also provide evidence for an ice dam. However, Clearwater till overlying the lake or delta deposits in Sections I, II, and IV indicate maximum advance of the ice occurred during or after establishment of the lake. Ice either flowed into the already dammed lake or after it had drained. The preexistence of the lake at least before the southernmost advance of Clearwater ice indicates a more distal and westerly location for the lake's impoundment. Maximum advance of the Clearwater ice may have dammed the Blackfoot River as it overrode the previously deposited lake deposits. No lake deposits related to this local ice dam have been recognized.

If the Clearwater advance did span the Blackfoot River two possibilities exist for the lack of lake deposits: 1) a lake existed for only a short time period preventing accumulation of significant deposits; or 2) the Blackfoot River flowed under or through the glacier preventing formation of a lake.

Interpretation and Conclusion

As the Blackfoot River passed south of Monture Hill during early Pinedale time, as it does today, it deposited channel gravels (fluvial lithofacies in Section II) while Glacial Lake Missoula was either low or nonexistent in the area. As the lake level rose and backed up to the east, the river deposited its sediment load in a large delta complex, which is now partially exposed on southern Monture Hill. Clearwater ice advanced into the lake from the northwest in Pinedale time and calved
off icebergs which shed dropstones in the lake and delta deposits (Fig. 15). Draining of the lake may have been sudden resulting in powerful currents through the Blackfoot canyon southwest of the Ovando Valley as suggested by high angle foresets and large clasts in the channel gravels. As the advancing Clearwater ice spread eastward and filled up the Ovando Valley (Fig. 16), it scoured and deformed the deltaic sediments. After an interglacial period recognized by the paleosol on Clearwater till, the later Pinedale age Monture advance (Fig. 17) deposited till and outwash. Winds eroding the outwash plain carried silt and fine grained sand to southern Monture Hill where it now forms a loess cap overlying the paleosol.

The Blackfoot River delta represents one of the few exposed deltas deposited in Glacial Lake Missoula. It marks the easternmost extent of Glacial Lake Missoula in the Blackfoot River Valley so far recognized and defines the upper lake level during earlier Pinedale time at 1367-1400 m (4100 - 4200 ft.). Recognition of similar delta deposits may aid in further defining the age(s) and outer limits of the numerous fillings of Glacial Lake Missoula.
Figure 15. Block diagram showing Glacial Lake Missoula and the early stages of the Clearwater advance in the Ovando Valley. The Blackfoot River delta is prograding into the lake as shown in the lower central part of the diagram.
Figure 16. Block diagram of the Clearwater ice advancing into the Ovando Valley from the Clearwater Valley through Cottonwood, Tote Road, Boyd Mountain and Blackfoot Canyon Passes. Monture Hill protrudes in the lower right hand corner.
Figure 17. Block diagram showing the Monture ice advancing from the Dunham and Monture canyons into the Ovando Valley.
CHAPTER IV

REGIONAL GLACIAL CHRONOLOGY AND CORRELATION

During Pleistocene time numerous glacial advances of various magnitudes and origins inundated northern Montana. Lobes of Cordilleran ice flowing from massive ice sheets capping the Canadian Rockies penetrated, and terminated in, Montana several times. Smaller ice caps in the high mountains of Montana and the Rocky Mountain region fed local alpine valley glaciers. Upon spilling into larger valleys, alpine ice either merged with the Cordilleran ice or formed separate piedmont lobes. East of the Rocky Mountains the Laurentide ice sheet, originating in Arctic Canada, merged with Cordilleran ice to form a nearly continuous mass that extended east from north central Montana across the remaining northern United States.

As noted by Stoffel (1979) the chronology of mid-continent Laurentide glaciations appears somewhat out of phase with Cordilleran glacial events. This resulted from different regions of climate control--the Laurentide ice controlled by Arctic climates and the Cordillera glaciations responded to climate patterns dominated by the Pacific Ocean.

Synchroneity of Cordilleran and local alpine glacial advances also remain unclear, yet appears more related than with Laurentide glaciations. Alpine glaciers merged with Cordilleran ice in the Flathead Valley (Whitkind, 1978) and in Glacier (Richmond, 1960) and Waterton National Parks (Harker, 1954). The Cordilleran, or continental, ice also overrode
the alpine deposits (Harberg, 1954) indicating the two may have been slightly out of phase, possibly due to different response times to climate changes. Larger ice sheets may take longer time to accumulate enough ice to rejuvenate valley glaciers than would smaller mountain ice caps or cirque basins. However, the Rocky Mountain ranges often form rain shadows to the eastern side causing less precipitation eastward as distance from the Pacific Ocean increases (Flint, 1971). Local mountain ice caps and cirques were therefore more susceptible to local orographic conditions than the larger Cordilleran ice sheets that could accumulate snow over a broader area.

The variations in mass, source areas, and response times of the many kinds of glaciers existing in Montana has particularly created conditions of non-synchronous, crosscutting glacial evidences. These are well demonstrated in the Ovando Valley area.

Despite uncertainties about exact synchronities, general periods of alpine Cordilleran and Laurentide glaciation and related advances have been recognized and correlated. After a review of the glacial chronology of the Rocky Mountain Region, I will present regional correlations of the Ovando Valley glacial advances.

Glacial Chronology of the Rocky Mountains

Blackwelder (1915) established the criteria for the chronology of alpine glacial deposits in the Wind River Ranges, Wyoming upon which Holmes and Moss (1955) elaborated. Richmond (1965) has since expanded this chronology throughout the Rocky Mountain region, although recent
age dating techniques recommend modifications of this "standard"
chronology (Pierce et al., 1976). Scarcity of organics or volcanics
in or near most glacial deposits limit precise radiometric age dating.
This has led to widespread use of much less precise relative age dating
techniques which measure the relative amounts of time a deposit is ex-
posed to weathering. Relative age dating criteria include preservation
of moraines, height and steepness of hummocks, degree of sediment fill
in kettles, weathering of till, clasts and erratics, depth of calcium
carbonate leaching and soil development as well as stratigraphic and
geographic position of the deposits. Variable climate conditions weaken
the regional application of some of these criteria.

In the Rocky Mountain region, inclusive of Western Montana, five
major and one minor periods of glaciation have been reported, separated
by interglacial perios (Richmond, 1965). During the oldest glacial
period, pre-Bull Lake, three major glaciations are recognized by three
tills separated by strongly developed soils, the latter forming inter-
glacially. Richmond has named these the Washakie Point, Cedar Ridge and
Sacawagea Ridge glaciations from oldest to youngest. Pre-Bull Lake
tills show variable degrees of weathering and underlies flat to low
rolling hummocks. Only insoluble lithologies remain as erratics on
the surface with limestones usually absent due to complete dissolution.
Rock striations are rarely preserved. These deposits exceed the
120,000 - 130,000 year B.P. date placed on the earliest Bull Lake
 glaciation (Birkeland, et al., 1970), and may exceed 150,000 year B.P.
(Pierce, et al., 1976). In northwest Montana three pre-Bull Lake tills

Bull Lake glaciation followed a long interglacial period separating it from pre-Bull Lake glaciation. It consists of two major stades and possibly three according to Richmond (1965). Smooth rounded moraines vary with highly subdued to moderately high ridges. Streams commonly breach the moraines preventing retention of lakes. Sediment often fills the kettle holes with water often absent. Although striations are rare, soluble rock types such as carbonates may occur. Mature zonal soils on each till reflect significant interglacial periods.

Richmond and Obradovich (1972) originally dated late and early Bull Lake stades in Yellowstone National Park at 80,000 - 105,000 and 105,000 - 125,000 yr. B.P. respectively. However, recent mapping and obsidian hydration dating techniques (which measures the rate at which non-hydrated obsidian clasts hydrate along fractures sustained during glacial transport) has shown only one Bull Lake stade dating between 130,000 - 140,000 yr. B.P. (Pierce, et al., 1976).

The last major glaciation of the Rocky Mountains, Pinedale glaciation, has been subdivided into three stades, early, middle and late, by Richmond (1965), yet Knoll (1977) has recognized nine Pinedale stades in the Lemhi Range, Idaho. Glaciers of the older stades commonly advanced out of the canyon mouths yet the glaciers of the younger stade(s) ended much farther up valley. Moraines form prominent steep sided ridges which erosion has only slightly modified. Numerous water filled kettles enhance their fresh appearance. Unweathered soluble and insoluble rock types cover the ground. Immature zonal soils overlying the
till appears thinner and less developed than Bull Lake age soils, indicating shorter interstadial or interglacial periods.

Dates for early Pinedale glaciation range between 20,000 and 35,000 yr. B.P. (Pierce, et al., 1976 and Richmond, 1972). Mid-Pinedale glaciation began 21,000 yr. B.P. (Richmond, 1972) and retreated no later than 13,000 yr. B.P. (Madole, 1978). Benedict (1973) has dated the youngest Pinedale advance between 9,000 - 10,000 yr. B.P.

A long interglacial period known as the Altithermal Interval spanned the years 5,000 - 9,000 B.P. reaching its maximum between 6,000 and 7,500 yr. B.P. (Benedict).

In cirque basins throughout the Rocky Mountains rough bouldery moraines define three stades of the Neoglacial period commonly called the "little ice age". The three stades, Temple Lake, Gannet Peak and Audubon stades occurred between 3,000 - 5,000, 1,000 - 2,000 and 100 - 300 yr. B.P. respectively (Benedict, 1973).

**Correlation of Ovando Valley Glaciations**

Lack of radiometric age dates limits the basis for correlation of Ovando Valley glacial events to relative age dating techniques. The Blackfoot advance displays similar features to both Bull Lake and pre-Bull Lake deposits and the Clearwater and Monture advance deposits compare favorably with those of Pinedale age.

Poor exposure of the Blackfoot glacial deposits hampers a specific age classification. Criteria favoring a pre-Bull Lake age correlation include:
1) scarcity of deposits occurring mostly on the noses of spur ridges high above younger deposits;
2) absence of deposits along the northern extension of the spur ridges even at elevations lower than Blackfoot erratics on adjacent ridges -- possibly indicating extensive erosion, non-deposition or fault offset;
3) relatively few and small constructional features;
4) predominant preservation of quartzite erratics with less argillite and carbonates.

Criteria favoring Bull Lake age correlation include:
1) till varies between moderately weathered and unweathered;
2) preservation of slightly to unweathered carbonate and argillite clasts on the surface;
3) presence of distinct constructional features as seen in the Little Red Hills

Possibly the Blackfoot deposits may include both Bull Lake and pre-Bull Lake glacial events on the Little Red Hills and spur ridges respectively.

Based on these criteria alone, correlation to the standard Rocky Mountain chronology is difficult. However, along the Blackfoot River till correlated to the Blackfoot glaciation lies stratigraphically below the Clearwater till; and along the northern Ovando Valley the Blackfoot till lies immediately outside and upslope from the Clearwater moraines (due to more extensive glaciation). The Clearwater advance's correlation to Pinedale age deposits implies the Blackfoot deposits
reflect the next oldest glaciation which is Bull Lake. For these stratigraphic and physiographic reasons I favor a Bull Lake age correlation for the Blackfoot deposits.

Standard Bull Lake age deposits correlated with the early Wisconsin stage of mid-continent glaciation (Richmond, 1965). However, application of the modified alpine glacial chronology proposed by Pierce, et al. (1976) shows Bull Lake glaciation correlative to the early Illinoian glaciation of the mid-continent. As the authors show, their new data corresponds remarkably well with the generalized mid-continent glacial chronology as well as with the marine paleo-climatic record determined by oxygen-isotope analysis, foraminiferal studies and changes in sedimentation. In preferring this new chronology, I consider the glaciation responsible for the Blackfoot advance equivalent to early (yet possibly later) Illinoian glaciation.

Features of the Clearwater and Monture deposits clearly indicate their correlation to established Pinedale age deposits. These criteria include:

1) prominent steep sided and sharp crested moraines;
2) narrow breaching of lateral moraines by streams;
3) impoundment of standing water behind lateral moraines and numerous water filled kettles;
4) unweathered till, clasts and erratics.

Slightly poorer preservation in the Clearwater advance deposits suggests they are slightly older than the fresher looking Monture advance.
deposits. These older-looking features of the Clearwater deposits include:

1) wider breaching lateral moraines by streams of approximate size;
2) more rounded and subdued hummocks;
3) greater sediment filling of kettles and moraine dammed ponds;
4) greater degree of calcium carbonate leaching.

Pinedale age equivalence of these deposits implies correlation to the Wisconsin stage of the mid-continent glacial chronology (Richmond, 1965; Frye, et al., 1968). Relationships between the Clearwater and Monture advances suggest correlation to earlier and later subdivisions of the Wisconsin stage respectively.

Tentative correlation with the Cordilleran glacial chronology of Washington and Oregon is possible by comparing Ovando Valley glacial deposits with till deposited by several major advances of the Cordilleran's Flathead lobe in the Flathead Valley. Stoffel's (1979) study of the southern Flathead Valley delineated three distinct tills. In decreasing age to the north these include the Jocko, St. Ignatius and Mission till. Strong oxidation and moderate weathering of the Jocko till provided only a pre-Wisconsin correlation with criteria lacking for further classification. Stoffel correlated the St. Ignatius till with the Cordilleran Salmon Springs glaciation as defined by Fulton (1971), Clague (1978) and Alley (1979) and correlated the Mission till with the Vashon stade of the Fraser glaciation (Esterbrook, 1969).
In comparison to the Ovando Valley no till found appears as altered and weathered and therefore as old as the Jocko till. The subdued rolling topography and integrated drainage pattern of the St. Ignatius deposits implies a significant period of erosion as does the subdued and patchy distribution of the Blackfoot till. Both tills are partially weathered yet contain fresh clasts including carbonates and a predominance of quartzite boulders on the surface. Both deposits also represent a glaciation considerably older and more extensive than its apparent successor. In the Flathead Valley the St. Ignatius till lies downvalley from the much more pronounced Mission moraine.

Although their synchronicity is unknown, the Blackfoot and St. Ignatius deposits appear similar enough to tentatively correlate to the same general period of glaciation. This implies a Salmon springs equivalent for the Blackfoot glaciation. Stoffel noted similarities of the St. Ignatius till to the established pre-Bull Lake and Bull Lake deposits yet suggested correlation to Richmond's (1976) early stade of the Bull Lake glaciation.

The Mission moraine forms on immense arcuate ridge spanning the southern Flathead Valley south of Ronan. Covered with numerous hummocks and water filled kettles, and underlain by unweathered till it resembles deposits of the Clearwater advance. This tentative correlation is further supported by the Mission moraine's position south and downvalley from the younger and more fresh looking Polson moraine. This relationship is similar to the Clearwater deposit's slightly older appearance compared to the Monture advance deposits.
Correlation of the Clearwater Advance to the Cordilleran

Glaciation that deposited the Mission moraine implies the Clearwater advance is equivalent in age to the Vashon stade of the Fraser glaciation by extrapolation from Stoffel's work. Stoffel correlated the Mission moraine with Richmond's (1965) early Pinedale stade and suggested its possible correlation to Pierce's (1976) early Pinedale advance (i.e. ca 35,000 yrs. B.P.).

North of the Mission moraine, and damming the southern end of Flathead Lake, the Polson moraine marks the last major advance of the Flathead lobe into the Flathead Valley. Its striking knob and kettle topography with numerous water filled kettles displays much similarity to the distintegration moraines of the Monture advance.

Only one major readvance of the Cordilleran ice after the Vashon stade is recognized in Washington. This readvance, known as the Sumas stade, lasted for 11,000 to 10,000 yr. B.P. (Crandel, 1965 and Fulton, 1971). Assuming Stoffel's correlation of the Mission moraine to the Vashon stade is correct, the Polson moraine is probably correlative to the Sumas stade of Cordilleran glaciation. Correlation of the Polson and Monture deposits would therefore imply Sumas stade equivalence for the Monture advance deposits.

Since the Cordilleran chronology is based primarily on glacial deposits in Washington and Oregon, the ice sources lay in the Coast Ranges whereas the Canadian Rockies along the Alberta-British Columbia boundary provided the accumulation zone for Cordilleran ice that flowed into Montana. With the climate more severe near the coast, there may
have been a lag time in the accumulation and advances of Cordilleran lobes from west to east. Therefore, the correlation to Cordilleran chronologies to the Flathead Valley represents only an approximation as does the correlation of alpine and Cordilleran glaciations.
Northwestern Montana's prime location in the heart of alpine, Cordilleran and Laurentide glacial deposits offers the potential for many intriguing glacial studies. A few such areas worthy of future study lie adjacent to the Ovando Valley. In the Nevada Valley, east of Ovando, two broad morainal loops arc across the valley. Each reflects a local ice source to the north from the North Fork of the Blackfoot River. In the southern Nevada Valley north of the Blackfoot River the older and much larger terminal moraine appears highly dissected by small dry channels and contains few kettles with only the larger ones retaining water. It is this moraine that deflects the Blackfoot River nearly a kilometer south of its original path.

Excellent exposure along the easily canoeable Blackfoot River provides examination of the till. Weathered till overlies Tertiary lake silts, mud flow deposits, and volcanic ash beds. A mature zonal soil overlies the till. Multiple soil layers separated by sand and silt (loess?) also occur.

This deposit's old appearance and downvalley position from a much younger moraine suggests it may be related to the Blackfoot deposits. If so, the two related ice masses may have coalesced to form a large piedmont glacier; or possibly the advance in the Nevada Valley post-dated Blackfoot advance which may more easily explain its nearly
complete morainal loop. Weber and Witkind (1979) have mapped an older
till south of the Blackfoot River which also requires examination.

In the northern Nevada Valley south of Kleinschmidt Flat lies the
terminal moraine(s) related to the North Fork advance. Its fresh
degree of preservation suggests deposition contemporaneous with the
Monture advance. Their synchronicity has not been worked out in detail,
although the apparent truncation of Monture lateral moraines by the
southwestern North Fork laterally moraines suggests that either the
latter is slightly younger or was more dominant.

The most outstanding feature in this area is Kleinschmidt Flat,
extending from the North Fork moraine north to the southern Swan
Mountains. The pod shaped flat is engraved with numerous channel scars
evident of a braided stream system which drained from the north of the
North Fork Canyon. It obviously reflects an outwash plain but whether
it represents normal glacial outwash or a surface formed by raging flood-
waters of a glacial lake outburst flood as suggested by Curry (1978,
personal communication) has not been proven.

Possibly related to Kleinschmidt flat's origin are several large
river terraces sitting well above the present North Fork and Blackfoot
River's floodplains. I have postulated their origin as related to a
glacial lake outburst in the Kleinschmidt Flat area but this theory re-
mains untested. They may be incoincidental and reflect more normal
river terrains.
West of the Ovando Valley, till, glacial lake silts and outwash gravels mantle the southern Clearwater Valley and Ninemile Prairie area. Although reconnaissanced by Alden (1953), and Weber and Witkind (1979), it lacks a detailed geologic study. Harris' geomorphologic study provides a general scenario of glacial events yet offers no detailed correlation to adjacent glacial deposits. Interfingering of lake silts and till provide examination of the effects of ice contact features related to Glacial Lake Missoula.

Possibly of more regional interest and the least studied are glacial deposits and erosional features of the northern Clearwater and southern Swan Valley. Although thickly forested, numerous dirt roads provide excellent access. Particularly of interest would be to define the upper ice limits of the large valley glaciers which supplied ice for the Blackfoot and Clearwater advances and to establish the relative lower limits of the ice caps lying in the adjacent mountains. Witkind (1978) has defined the upper limit of ice flowing from the Swan Valley around the northern edge of the Mission Range. Deposits equivalent to the Monture advance deposits also need examination to determine their source areas and regional extent.

Detailed chronology and a more thorough understanding of local and regional glacial events await the result of these and similar studies.
REFERENCES CITED


Alley, N.F., 1979, Middle Wisconsin stratigraphy and climatic reconstruction, southern Vancouver Island, British Columbia: Quaternary Research, v. 11, p. 213-237.


APPENDIX A

CLAY MINERALOGY ANALYSIS OF TILLS
Morphologic trends of Clearwater and Monture advance moraines in the northern Ovando Valley allow easy differentiation of the two deposits. In contrast, moraine morphologies in the southern Ovando Valley are less distinct, making till differentiation difficult. To determine if clay mineralogy differences in the tills would aid in mapping the two deposits, x-ray diffraction analyses of the clay fraction of the tills was conducted.

Analyses showed the presence of illite, chlorite, kaolinite, and smectite in both the Clearwater and Monture tills. No clay minerals appeared unique to either till negating the possibility of distinguishing tills based on clay mineralogy. In benefit to the understanding of glacial processes, the analyses showed that smectite is restricted to till contaminated by Tertiary valley fill. Localization of Tertiary bedrock and proximity to smectite bearing drumlins illustrates a short distance of transport.

**Sample Preparation**

The less than 2 micron fraction of sixteen till samples and two mudstone samples and the less than .5 and less than 10 micron fraction of the two till samples were prepared on glass slides and analyzed by x-ray diffraction. All samples were ethylene glycol treated. Twelve samples were heated to 550-600°C for one hour and two samples were treated with 1 n Hcl acid. The acid treated samples were also analyzed after reglycolation.
Results

Illite, smectite, chlorite and kaolinite occur in various combinations in till samples collected throughout the study area (see Table 1). Illite prevails in all till samples as seen by tall sharp 10 Å peaks. However, samples of altered and fresh Tertiary mudstone, W.W.-2 and W.W.-3 respectively, show extremely low rounded 10 Å humps indicating little to no illite.

Smectite occurs in Clearwater advance till samples S.W.-2, S.W.-3 and W.W.-1 all of which contain the red clay matrix. Smectite also predominates in the red Tertiary mudstone, samples W.W.-2 and W.W.-3. The mudstone lies in contact with sample W.W.-1 and closely resembles it and samples S.W.-2 and S.W.-3 in outcrop. Smectite also occurs in samples MC-1, MC-14 and F-1 of the Monture advance till. All of the above samples show approximately 17 Å peaks after glycolation.

Chlorite occurs in all the Monture till samples yet only in three Clearwater till samples. Glycolated samples containing chlorite showed a peak ranging between 14.029 - 14.371 Å except where smectite co-existed. The 17 Å smectite peak obscured the chlorite peak in the glycolated samples but heating to 550-660°C for one hour destroyed the 17 Å peak and preserved the 14 Å peak confirming the pressure of chlorite. Chlorite's 002 and 003 peaks commonly occurred as 7.13 - 7.1957 Å peaks respectively. However, the 002 peak is often confused with the 001 kaolinite peak.

Kaolinite occurs in samples S.W.-2, S.W.-3 and W.W.-1 indicated by the 7.1954 Å peak. Acid treatment reduced these peaks to 12.998 Å
and 7.1668 Å respectively. Reglycolation expanded the former to a 17.673 Å smectite peak indicating the 7.1668 Å peak reflected kaolinite. Acid treatment and reglycolation also confirmed the presence of kaolinite in sample MC-1 of the Monture advance. Similar treatment is necessary to confirm kaolinite's presence in all the samples of this advance due to the prevalence of 14 Å chlorite peaks. However, kaolinite exists in both till units and is not a valid correlation mineral, therefore, I did not analyze for it in the other samples.

Till samples B.F. I-E and B.F. I-A, which were collected from the Clearwater and Blackfoot tills along the Blackfoot River bluff in the southern part of the valley (Section II), contain illite, smectite, chlorite, and possibly kaolinite. Till deposited by the Blackfoot advance, found high on the southern flanks of the Swan mountains, contains illite, chlorite, and possibly kaolinite (sample B.C.-6).

No differences exist in the less than .5 micron and less than 10 micron fraction in comparison to the less than 2 micron fraction of the two samples analyzed, W.W.-1 and D.W.-1.

Discussion and Interpretation

The presence of illite, chlorite and kaolinite in tills found north and west of the Ovando Valley implies a Belt bedrock origin (Maxwell and Hower, 1967). Prevalence of smectite in till found within the Ovando Valley implies a valley origin for the smectite, since:

(1) Tertiary mudstone outcropping the valley contains smectite;
(2) till in contact with and resembling the Tertiary clay contain smectite; and (3) till sampled from outside the valley (samples C.L.-1, C.N.-1, D-6, and D-5) contained little to no smectite.

Apparently, ice flowing into the Ovando Valley initially contained clays indigenous to the Belt such as illite, chlorite and kaolinite. Upon entering the valley, the glaciers engulfed smectite rich Tertiary mudstone and clay and later deposited it as part of the till.

A roadcut 25 km east of Woodworth exposes red smectitic till in contact with (on the eastern and "downglacier" side) fresh and weathered Tertiary mudstone. The tills' matrix closely resembles the weathered mudstone in field observation and in clay mineralogy. Drumlins within a few kilometers to the northeast also contain abundant red smectitic clay in the matrix. The proximity of the smectitic till to its source area indicates rapid erosion and deposition. This may have resulted from the ice losing its momentum and carrying capacity as it splayed out into the relatively flat Ovando Valley.

Smectite found in samples MC-1 and MC-14 on the eastern moraines of the Monture advance probably originated from buff colored Tertiary mudstone lying below the till and/or from red clay rich Tertiary conglomerate exposed within a mile to the north of the sample sites.
Fig. 18. Location map of till samples used for x-ray diffraction. Base map is copied from Chouteau 2°x4° sheet. Highway 200 shown in heavy solid line with dirt roads shown by dashed lines.
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APPENDIX B

MAP AND AERIAL PHOTOGRAPHS USED
Map and Aerial Photographs Used

Four 7 1/2 minute topographic maps published by the U.S. Geological Survey were used as a base map for all geologic mapping and compilation. These include:

- Chamberlain Mountain Quadrangle
- Ovando Quadrangle
- Ovando Mountain Quadrangle
- Woodworth Quadrangle.

Seventeen aerial photographs from three flight lines aided in geologic interpretation. Prepared by the U.S. Department of Agriculture and Forest Service at a scale of 1" = 1 mile, they include:

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