Glacial and fluvial land forms adjacent to the Big Arm embayment Flathead Lake western Montana

D. G. Smith

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GLACIAL AND FLUVIAL LAND FORMS ADJACENT TO THE BIG ARM EMBAYMENT, FLATHEAD LAKE, WESTERN MONTANA

By

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B.A. University of Montana, 1965

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1966

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CHAPTER I

INTRODUCTION

Location

The Big Arm embayment occupies the westernmost part of the Flathead Lake basin in western Montana (Figure 1). The study area, about 110 square miles in size, lies approximately nine miles northwest of Polson, Montana, in the northwest corner of Lake County. The area is covered by the following 7½ minute U. S. Geological Survey topographic quadrangles: Proctor, Lake Mary Ronan, Irving Lookout Tower, and Elmo. The last of these is situated at the focal point of the study area (Plate 1). The location point common to all four quadrangles is at 47° 52' 30" N. Latitude and 111° 22' 30" W. Longitude.

The Big Arm embayment of Flathead Lake is one of the many side valleys which make up the western margin of the "Rocky Mountain Trench" (Daly, 1912, p. 596). The Flathead Valley, which contains the lake, is either the southern part of or a large offshoot valley from the Rocky Mountain Trench. Flathead Lake is flanked by the Mission Range on the east and low mountains on the west, with the "Polson Moraine" damming the southern end of the lake.

The study area includes three small valleys branching to the northwest, west, and southwest from the Big Arm embayment (Figure 2). Dayton Valley trends to the northwest from the small lakeside settlement of Dayton. The Big Draw has an east-west axis and begins at the lakeshore...
Figure 1. Index map of study area adjacent to the westernmost bay of Flathead Lake in western Montana.
Figure 2. Orientation of Dayton, Big Draw, and Big Arm Valleys in relation to Big Arm Bay.
village of Elmo. The Big Arm Valley extends to the southwest from Big Arm, a third lakeshore settlement. All three valleys seem to radiate from a common focus, the Big Arm embayment.

The study area is easily reached by U. S. Highway 93 along the west shoreline of Flathead Lake. From Elmo, State Route 28 extends westward through the Big Draw. Secondary gravel roads occupy the centers of both Dayton and Big Arm Valleys, with a network of farm and logging roads affording ready access to much of the area.

Purpose of the Study

As is true of much of western Montana, the landscape of the Big Arm embayment has until recently received only limited attention from the geomorphologist. Although there is considerable evidence of glaciation in the study area, no detailed investigation has previously been attempted. Reports by Alden and others indicate that an impressive array of glacial features has been preserved. In an attempt to add to the limited geomorphological knowledge about the numerous land forms, an investigation of the surface features was undertaken. The principal purpose of the study has been to examine the land forms of the Big Arm embayment, interpret their morphology, and piece together the glacial history of the area.

Previous Work in the Area

During the past half-century, the land forms of the study area have received an occasional glance. Elrod (1903, p. 202) described a possible outlet, Pleistocene in age, of Flathead Lake through the Big Draw and into the Little Bitterroot Valley. In his 1917 study, Meinzer
(1917, p. 16) concluded that the Big Draw was a former outlet of Flathead Lake and that the artesian gravel formation in the Little Bitterroot Valley was laid down by the waters from that outlet. Shenon and Taylor (1936, p. 7) also did field work in the area, noting that the beach lines above the Elmo Moraine were further evidence of Pardee’s Glacial Lake Missoula (1910, pp. 376-86).

The most extensive study was undertaken by Alden (1953, p. 94, pp. 121-23); he attempted to define the glacial limits and piece together some of the late Pleistocene events. Beaty (1962, p. 117) noted the existence of silts on top of the Elmo Moraine, which may suggest a recession of the Big Arm ice lobe before the draining of Glacial Lake Missoula. That same year, 1962, the Flathead Indian Reservation Agency had aerial photographs taken of the area, the use of which has contributed greatly to the field work of the present study. Johns (1964, pp. 12-16) described some of the glacial features along the north side of the Dayton Valley. Also in 1964, the U. S. Geological Survey published advanced 7 1/2 minute topographic maps covering the entire study area. The maps have a scale of 1:24,000, with 40-foot contour intervals, and were invaluable for determining locations and elevations.

**Present Study**

Between June and September of 1965 and 1966, 40 days were spent in the field examining the various land forms. Before inspecting the surface features, a careful study was made of both aerial photographs and topographic maps, with special attention directed toward shapes of land forms and their elevations. Next, the land forms were observed in the field; there, study was focused on the sediments so that the processes
which led to the development of the land forms could be determined. The features were then classified according to their origin, and plotted on topographic maps. The land forms were categorized into two groups, the ones which formed while the ice front lay stationary during its farthest advance, and those formed while the ice front was retreating. All elevations used in this study are taken from topographic maps by the U. S. Geological Survey.

Acknowledgments

The writer is very grateful to Dr. C. B. Beaty, who during the course of this investigation offered many valuable suggestions and comments and spent considerable time in the field. Thanks are extended to Dr. Paul Alexander and Dr. Arnold Silverman who have reviewed the manuscript and made helpful comments and criticism. Dr. R. L. Konizeski of the U. S. Geological Survey is also thanked for his field criticism. The assistance and cooperation of the faculty of the Geography and Geology Departments of the University of Montana are gratefully acknowledged.
CHAPTER II

PHYSICAL GEOGRAPHY

General Statement on Glaciation

During the last great glacial advance, the Flathead Glacier moved down the Rocky Mountain Trench, depositing the "Polson Moraine" at the south end of Flathead Lake (Nobles, 1952, p. 9), and various moraines in the Big Arm embayment. Near the middle of the lake, the southward-moving Flathead ice split into two parts. One lobe continued south into Poolson Bay. The other turned to the west and moved into the Big Arm embayment. The Big Arm ice split again into three sublobes; these, in turn, pushed into the Dayton, Big Draw, and Big Arm Valleys. The three sublobes deposited terminal moraines in each valley, moraines which are believed to be of the same age as the Polson Moraine (dated as late Wisconsin by Nobles).

Throughout the glacial period, glacial till accumulated in large volumes and buried much of the pre-glacial topography. These accumulations have resulted in many unusual land forms. As the ice released its load of till, great amounts of meltwater carved many features of unique shape into the local landscape. During the ice retreat several small proglacial lakes evolved, existed for a short time, and then drained as their ice dams melted. The present topography has had little modification since the glacial period. Many of the land forms found today still exhibit large volumes of glacial till and show the scars of fluvial erosion that resulted from the Ice Age.
General Topography

As is shown in Figure 3, the three valleys adjoining the Big Arm embayment all have similar characteristics: size, location, physiography, and glacial moraines. The valleys average from two to three miles in width and five to ten miles in length, and are separated by low mountains that rise from 1000 to 1500 feet above their floors. Crests of the terminal moraines in each valley lie at elevations approximately 600 feet above the surface of Flathead Lake (2893 ft. elev.). Each valley slopes gently toward the lake; inclination of the floors varies from 50 to 200 feet per mile. The valleys contribute very little water to Flathead Lake, only the Dayton Valley supporting perennial streams. However, spring runoff and flash-flood waters do occasionally discharge down the dry stream channels of the Big Draw and Big Arm Valleys.

Dayton Valley, the largest of the three valleys, possesses the most varied topography. Ten miles in length by three miles in width, the valley contains Lake Mary Ronan, dammed by the Ronan Moraine at its upper end. Dayton Valley contains the small towns of Dayton at the lower end, Proctor in the middle, and summer resorts along the east shore of Lake Mary Ronan. Gentle, low, rolling hills characterize the lower terrain, with upper slopes, which partially surround the valley, attaining elevations between 5000 and 6000 feet. A high kame terrace* lying along the north side of the valley, dams both Bow and Skags Lakes.

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*Kame terrace—stratified sediments laid down by streams flowing between a glacier and an adjacent valley wall (Flint, 1957, p. 147).
Figure 3. Sketch map showing physiographic and cultural features of the study area.
Terminal and lateral moraines* restrict drainage in the upper part of the valley. Two miles west of Dayton, a zone of peculiar cliffs and benches has been cut horizontally around a portion of the mountain slope (Figure 3). Dayton and Ronan Creeks, flowing the year around, have cut deep channels through the lateral moraines. Near the head of its channel, Ronan Creek waters have cut down to bedrock and carved Smith Falls, a 40-foot-high feature, into a portion of the exposed bedrock. Because much of the water sinks into the permeable glacial fill, the valley is naturally sub-irrigated, allowing much of the land to support a lush vegetation cover.

The Big Draw, about ten miles long and a mile or more in width, is open at both ends and has steep rocky sides sloping precipitously to a nearly flat, gravelly floor. Two and one-half miles west of Elmo, the Elmo Moraine lies across the valley, completely blocking it. This terminal moraine forms a part of the drainage divide between the Flathead basin and the Little Bitterroot drainage; the latter drainage is a continuation of the Big Draw. The lowest pass through the moraine, where the highway crosses, lies at 3345 feet, or 450 feet above Flathead Lake. To the west of the Elmo Moraine, a smooth, gravelly outwash surface slopes gently westward at about 65 feet per mile (Figure 3). To the east of the moraine, a till- and silt-covered extension of the Big Draw, the "Elmo basin" (Figure 3), slopes gently eastward. The moraines which surround the basin are marked by hummocky-shaped mounds of till. Strand

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*Terminal moraine—moraine deposited at the toe of a glacier.

Lateral moraine—moraine deposited along the sides of an ice lobe.
lines of Glacial Lake Missoula traverse the grassy hillsides south of the Elmo Moraine. North of Elmo, between Dayton Valley and the Elmo basin, there is a cliff zone which reaches its greatest height at a very distinct landmark known as Chief Cliff (Figure 4). Eastward from the cliff is a low, grass-covered bedrock ridge which was once overridden by ice. Since waters can discharge from both ends of the Big Draw, the valley floor is very dry, having only a scanty vegetation cover consisting mainly of grass.

The Big Arm Valley, about four miles in length by two miles in width, is the smallest of the three valleys. Like the others, it is till-covered, bowl-shaped, and slopes gently to the shore of Flathead Lake. A kame terrace, which formed on top of lateral moraine, has filled the gulches along the east side of the valley. The highest remnant of this lateral moraine lies at an elevation of 4,340 feet. Across the valley, two and one-fourth miles west of Big Arm, the highest accumulations of lateral moraine occur at 4,200 feet. A terminal moraine (the Big Arm Moraine) has dammed a small basin in the southeast corner of the valley, forming Loon Lake. This moraine has also diverted the drainage in the upper part of the valley, causing it to flow toward the southwest into Irving Flats (Figure 3). About one mile west of the morainal drainage divide, Alden (1953, p. 94) found an "outer" moraine. This moraine obviously marks the outermost recognizable limit of glacial advance. Much of it was eroded by meltwaters during the recession of ice. Beyond the outer moraine lies the upper Big Arm basin, from which glacial meltwaters once escaped by way of Black Gulch (Figure 3), a narrow rock gorge cut into the low hills to the south. The meltwaters then flowed
Figure 4. View looking north. Big Arm Bay in foreground. In the background, Chief Cliff at eastern end of Hog Heaven Range. Glacial ice from the northeast overrode the mountain ending at the arrow.
onto Irving Flats, a large, level, clay-covered basin south of the study area. As is the case in the Big Draw, drainage flows from both ends of the Big Arm Valley.

**Bedrock Geology**

Precambrian meta-sedimentary rocks of the Belt Series underlie the entire study area. The general rock type, according to Johns (1964, p. 18), is the undifferentiated Ravalli. These rocks are thin-bedded, medium and light-gray sericitic and noncalcareous mud-cracked argillites, and quartzose argillites containing occasional thin layers of light-gray or white quartzite (ibid.).

In the Chief Cliff area and other nearby outcrops, the beds are jointed and dip gently to the south. However, the beds in the entire area consistently tend to dip at low angles. The bedrock exposures between the Dayton Valley and the Big Draw have numerous quartz veins, which have been intensively prospected, as evidenced by many shafts and test pits. The vertical quartz veins trend in an east-west direction and average from four to seven inches thick. At the base of the Chief Cliffs, impressive talus accumulations are found. Bedrock of the cliffs is highly jointed and breaks into roughly rectangular blocks; talus material is brick-sized or larger. Because of the thick cover of ground moraine, other bedrock exposures in the area are scarce. During the investigation it was noted that the dip of the beds continually varies, but is never more than 25 or 30 degrees, suggesting only gentle folding in the area.
Climate

Climatic records are not available for the study area proper; however, temperature and precipitation data have been obtained from the U. S. Weather Bureau for the nearby stations of Polson and Lonepine. Polson, situated on the south shore of Flathead Lake, lies nine miles southeast of the study area. Lonepine, located in the Little Bitterroot Valley, lies 13 miles southwest of the area. Data from both stations are presented in Figures 5 and 6.

The climate of the study area is semi-arid. Summers are warm and dry, with occasional moisture from thunderstorms, while winters are cool, damp, and cloudy with irregular periods of cold. All seasons except summer and early fall are marked by general cloudiness. This pattern is constantly affected by incoming moist Pacific air, giving all of western Montana a relatively mild and moist climate. The long-term annual mean precipitation values at Polson and Lonepine for the period 1931-55 were 14.66" and 11.27", respectively. The average annual mean temperatures at Polson and Lonepine for the same period were 45.6°F., and 45.4°F., respectively. The highest and lowest temperatures recorded at Lonepine were 104°F. and -40°F. The coldest and warmest monthly means (January and July) at Polson are 25.2°F. and 67.4°F.; Lonepine recorded means of 23.3°F. and 68.3°F. It is believed that these figures give a reasonably good representation of the climate in the study area.

Vegetation

Dayton Valley, with greater subsurface moisture supply, supports a moderately lush vegetation cover which contrasts with the drier prairie
Figure 5. Graphs showing climatological data for Lonepine.
(From records of the U.S. Weather Bureau.)

Figure 6. Graphs showing climatological data for Dolson.
(From records of the U.S. Weather Bureau.)
grasslands of the Big Draw and Big Arm Valleys. Irrigation water from Dayton Creek and Ronan Creek, the two main streams flowing through the valley bottom, enables hay and grain crops to be grown. Dense stands of Douglas-fir interspersed with ponderosa pine and western larch cover the upper slopes. Near Dayton, the lower end of the valley is characterized by dry, grass-covered slopes, perhaps due to groundwater shortages.

To the south, the Big Draw and Big Arm Valleys both experience near drought-like conditions throughout the summer and fall. In addition to comparatively low seasonal precipitation, the dryness is attributed to the fact that terminal moraines act as drainage divides across the valleys, allowing ground and surface waters to drain from both ends of each valley. Their upper slopes are timbered with ponderosa pine and Douglas-fir. The prairie grasslands of the two valleys are green only in the spring; during the remainder of the year the bunch grass turns brown. Most of the dry rangeland is utilized for cattle grazing.
Evidence of Two Glaciations

Field evidence suggests that perhaps two glacial episodes may have been responsible for the formation of the landscape of the Big Arm embayment. Evidence supporting this possibility consists of upper and lower levels of lateral moraine, and two terminal moraines, inner and outer. The lower lateral and inner terminal moraines are of the most recent advance as evidenced by their location in relation to the upper lateral and outer terminal moraines; the latter must logically be older. The more recent of the two sets of moraines has a much greater volume of material, is fresher in appearance, and is more consistent in its morainal form than is the older.

Piecing together the remnants and patches of the assumed older upper lateral and outer terminal moraines is nearly impossible, since erosion has almost completely removed their remains. However, their presence and particular locations give one reason to speculate that they were deposited by an earlier glacial advance.

The best-preserved deposits of upper lateral moraine are found along the north side of Dayton Valley. These deposits lie between 360 and 440 feet above the Dayton kame terrace (see p. 8). Located on the ridge crest two and one-third miles northeast of Dayton, upper lateral moraine is found at an elevation of 4700 feet, about 440 feet above the
kame terrace (see Figure 11). One mile north of Proctor, deposits lie at 1280 feet, 360 feet above the terrace. Both remnants of upper lateral moraine have the same terrace-like shape as the Dayton kame terrace.

A second site of presumably older upper lateral moraine is located at an elevation of 1340 feet on a ridge crest one and one-half miles east of Big Arm. This moraine is several hundred feet above the lower lateral moraine. It is possible, even probable, that deposits of upper moraine exist in other parts of the study area; however, if they are present, they are indistinguishable from deposits of lower moraine, and glacial drift from "Glacial Lake Missoula" (Pardee, 1910, pp. 376-86). Glacial drift has been deposited up to an elevation of 1150 feet (Pardee, 1912, p. 1570).

Accumulations of glacial till which lie at the head of Dayton Creek are found at an elevation of 5200 feet. These are located where the high voltage power line crosses the drainage divide between Lakeside and Dayton Creeks (see Plate 1). Since these deposits are found at such a high elevation, it is thought that they may be of the same age as the remnants of upper lateral moraine located north of Dayton.

Three-fourths of a mile southeast of the power line site a low mountain pass is located at an elevation of 1540 feet. The presence of glacial till in this gap and at the power line site suggests that an ice lobe of an early glaciation may have pushed through the gap and deposited much of the glacial debris that now covers the floor of the upper Dayton Creek drainage basin.

Several problematic remnants of outer moraine lie to the west, beyond the younger and more massive inner terminal moraines. One well
preserved outer morainal remnant lies nearly a mile west of the Big Arm Moraine (Figures 7, 8). This feature, now partially destroyed by outwash erosion, is still easily identified by the presence of deeply weathered mounds of moraine situated in an arcuate pattern. This moraine can be traced for nearly two miles. One mile northwest of the Elmo Moraine lies a second outer fragment (Figure 22), which is also believed to have been left behind by an early ice advance. The surface of this remnant is also weathered and covered with a deep thickness of soil.

In the Dayton Valley, thin accumulations of glacial debris cover a number of the slopes along the northwest and southwest shores of Lake Mary Ronan. The thinness of these deposits suggests, however, that they may possibly be glacial drift.*

From the above evidence the writer feels that there is reason to believe that deposits from at least two glacial advances are present in the study area. The glacial deposits of the presumed recent glaciation are so abundant that they will be discussed in greater detail in Chapter IV.

**Probable Age and Correlation of Glacial Deposits**

As noted above, extension of an earlier ice lobe into the Big Arm embayment is quite probable. Alden (1953, Plate 1) indicated that the Polson Moraine (Figure 9) and the major moraines of the Big Arm embayment were both Wisconsin in age. To the south of the Polson Moraine, both Nobles (1952, pp. 79-85) and Alden (1953, pp. 92-94) have identified morainal deposits of an earlier glacial advance. These they

*Glacial drift—material rafted by icebergs.*
Figure 7. Looking south down onto Big Arm Moraine. Outer moraine extends across the hill in center of photo as indicated by the arrows. Irving Flats in far background.

Figure 8. East-west cross section of Big Arm Moraine.
Figure 9. Sketch map showing locations of towns and moraines.
have termed the "Mission Moraine," which is located about 18 miles south of Polson. Nobles (1952, Table 8) implied that the Mission Moraine and Polson Moraine were deposited by middle and late Wisconsin glacial advances, respectively.

Richmond et al. (1965, pp. 234-35) have suggested that the Polson Moraine consists of glacial till which has accumulated from two separate glacial advances. These they have termed as early and middle Pinedale in age (see Table 1); the Mission Moraine has been dated late Bull Lake.

Measurements of projected ice surface slopes of selected sites between moraine in the Big Arm area and Mission Valley indicate that morainal deposits of the study area correlate with the Mission and Polson Moraines. Alden (1953, p. 119) estimated that the slope of the surface of the Flathead ice lobe from Whitefish and Columbia Falls to the Polson Moraine would have averaged about 50 feet per mile. When this same type of estimate was computed from the elevation of the upper lateral moraine (4700 ft. elev.) north of Dayton to the Mission Moraine (3000 ft. elev.) south of Charlo, a distance of 33 miles, the projected slope of the ice surface would average about 51 feet per mile. This calculation is almost identical with that made by Alden. If this same calculation is figured from elevations between the upper lateral moraine north of Dayton and the upper lateral moraine (4340 ft. elev.) southeast of Big Arm, the projected slope of an ice surface would average 48 feet per mile. Between the lower lateral moraine (4260 ft. elev.) north of Dayton and the Polson Moraine (3400 ft. elev.) near Kerr Dam, the projected slope of the ice surface would average 50 feet per mile. These calculations seem to indicate that the ice surface near the lower end of the Flathead
ice lobe had a slope of approximately 50 feet per mile.

Few definite conclusions can be drawn from the background presented. It may be argued that not enough evidence has been found to warrant any kind of conclusion; however, it is the opinion of the writer that an attempt should be made to give relative dates and correlate the glacial deposits of the study area with those of the Mission Valley.

On the basis of the evidence presented and of the projected slopes of ice surfaces, the following ages and correlations are offered: Upper lateral and outer terminal moraines in the study area were deposited before lower lateral and inner terminal moraines, and are therefore older in age. It seems logical to correlate the older deposits with the Mission Moraine, which is believed to be either middle Wisconsin or late Bull Lake in age (Table 1). Deposits of lower lateral and inner terminal moraine, being younger in age, would correlate with the Polson Moraine, which is presumed to be late Wisconsin (Nobles and Alden) or early and middle Pinedale (Richmond et al.) in age. A correlation of glacial deposits of the Big Arm embayment is summarized in Table 1.

In conclusion, there is only one absolute date that can be applied indirectly to the glacial deposits of the Big Arm area. In the Flathead Valley, north of Flathead Lake, a layer of Glacier Peak ash, dated at 12,000 years B.P., overlies glacial deposits of the most recent recessional moraine (oral communication, R. L. Konizeski, U.S.G.S.). This moraine must be younger than the most recent glacial deposits of the Big Arm embayment. Therefore, the latter must be over 12,000 years old.

In the following chapters the two glaciations will be referred to as "early" and "late" glacial advances.
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Table 1. Relative ages and correlation of glacial deposits in Big Arm embayment.
CHAPTER IV

GLACIAL AND FLUVIAL LAND FORMS OF THE TERMINAL STAGE OF GLACIATION

Glacial Background

Many of the most interesting land forms in the Big Arm embayment evolved during the late glacial advance and were a result of two episodes of glacial activity, here called the terminal and recessional stages. The term "terminal stage" denotes the period of transition from the halt of the advancing ice to the recession of the ice front. The second stage of land form development, the "recessional stage," occurred when back-melting of stagnant ice exceeded the accumulation of incoming ice. Each stage of land form development was accompanied by different processes of erosion and deposition. Land forms that were created during the recessional stage will be discussed in Chapter V.

According to Alden (1953, 190 pp.), a tongue of ice moved southward from Canada down the Rocky Mountain Trench during late Pleistocene time. As this tongue moved southward, it increased in size by additions of ice from adjacent mountain glaciers. The ice tongue grew until it became the large Cordilleran ice complex that covered much of northwestern Montana. It continued south and moved into the Flathead Lake basin. Near the middle of Flathead Lake, a lobe of ice split off and moved westward from the main glacier. The western lobe divided again and pushed into the Dayton, Big Draw, and Big Arm Valleys in a distributary pattern (Figure 10). While the ice front remained stationary, great volumes of meltwater deposited outwash gravels and eroded numerous
Figure 10. Terminal stage showing Dayton, Elmo, and Big Arm ice lobes. Arrows indicate directions of ice movement. Irregular dark areas represent proglacial lakes and channels. Source of glacial meltwater from Lakeside drainage in upper right corner.
drainage channels. At the same time that proglacial lakes were developing along the ice front, escaping waters cut deep channels into moraine and bedrock slopes.

During the terminal stage, the glacier unloaded debris which formed terminal and lateral moraines along ice margins in the Dayton, Big Draw, and Big Arm Valleys. Backmelting of the ice front, keeping pace with incoming ice, brought glacial expansion to a standstill. Great heaps of glacial moraine or till (mixture of boulders, gravel, and clay) piled up along the margins of the Dayton, Elmo and Big Arm ice lobes. Terminal moraine accumulated along the toes of the lobes. Next to the ice-flanks, lateral moraines were deposited. The uppermost surfaces of some lateral moraines contained meltwater streams which formed kame terraces. By identifying locations and shapes of glacial till, ice-limits can be defined and episodes of glacio-fluvial activity can be interpreted.

Previous Work

The first definitive account of glacial activity in the Dayton, Big Draw, and Big Arm Valleys was published by Alden in 1953. Although a moraine across the Big Draw has been referred to in the literature by Elrod (1903), Meinzer (1917), Shannon and Taylor (1936), Beaty (1962), and Johns (1964), only Alden has dealt with the terminal moraines of all three valleys. He located and described the following end-glacial features: Two and one-half miles west of Elmo a terminal moraine (Elmo Moraine) lies athwart the Big Draw (p. 49); three miles southwest from the Big Arm community an inner and an outer terminal moraine (Big Arm Moraine) lie across the valley (p. 94); in the upper Dayton Valley a
terminal moraine (Ronan Moraine) has dammed Lake Mary Ronan (p. 117). Throughout Alden's publication such features as bedrock striations, accumulations of till, outwash, and channels in bedrock are cited as evidence of glacial action in the study area.

Terminal and Lateral Moraines

Hummocky deposits of terminal and lateral moraine mark the margins of the glaciers that once occupied the Dayton, Big Draw, and Big Arm Valleys. Both types of moraines, late Wisconsin in age, were deposited at the same time in each of the valleys. Terminal moraines are crescent-shaped features deposited along the ice fronts.

The Dayton Valley terminal moraine or "Ronan Moraine" (Johns, 1964, p. 16), which forms the east shore of Lake Mary Ronan, defines the farthest extension of the most recent Dayton ice lobe. The thickness of the moraine is unknown. Since the greatest depth of Lake Mary Ronan is only 17 feet (published hydrographic map, Montana State Fish and Game Department), it might be supposed that the moraine consists of a relatively thin cover; however, two wells drilled into the moraine end 320 feet below the surface without reaching bedrock (well log files, Montana Bureau of Mines and Geology). These wells are located one and three-fourths miles to the southeast of Lake Mary Ronan. The top of one of the wells, located near the center of Sec. 30, T25N, R21W, lies 400 feet lower in elevation than the crest of the Ronan Moraine. This fact suggests that parts of the moraine may be at least 700 feet thick.

Lateral moraines deposited along the ice flanks grade transitionally into the Ronan terminal moraine. These moraines have dammed the mouths of several gulches as well as Lake Mary Ronan and, also, at
one time, the upper Dayton Creek drainage and Big Meadow basin.

The "Elmo Moraine" (Beaty, 1962, p. 121), lying two and one-half miles west of Elmo, marks the drainage divide between the Flathead Lake basin and the Little Bitterroot Valley. Meinzer (1917, p. 16) stated that a well drilled into the moraine penetrated 560 feet of unconsolidated deposits and ended, at a level considerably below Flathead Lake, without reaching bedrock. Lateral moraine along the north side of the Big Draw was greatly modified by stream action of late Pleistocene age. Moraine or till is also found on top of the eastern part of the Hog Heaven Range, suggesting that the elevation of the ice surface near Chief Cliff must have been approximately 4300 feet.

Located two miles west of Big Arm on the ridge crest or drainage divide between the Elmo basin and Big Arm Valley is a series of ice-scoured ledges cut into bedrock. There are seven of these ledges in a stairstep-like pattern, with cliffs averaging 60 feet in height between them. The direction of the striations found on some of the ledges indicates that they were formed as the ridge crest, acting as a wedge, split the oncoming ice into the Elmo and Big Arm sublobes.

The Big Arm Moraine, two and one-half miles southwest of Big Arm, is a drainage boundary between Irving Creek and the Big Arm Valley. This terminal moraine causes the upper Big Arm basin to drain toward the south through Black Gulch (Figure 3) into Irving Creek. The ripply surface of part of the moraine is believed to have been caused by small ice front retreats, followed by periods of temporary stability (Figures 7, 8). Depth of the terminal moraine here is unknown. Lateral moraine amounts to a thin veneer of glacial debris along the hillsides.
Kame Terraces

Kame terraces were formed at high elevations on mountain slopes north of Dayton and southeast of Big Arm. After the glaciers melted, these terraces remained, sloping gently downward as they extend upvalley. Two terraces have been identified in the study area, each having been formed on top of accumulations of lateral moraine presumably from the late glacial advance.

One of the terraces, lying along the north side of Dayton Valley, consists of a narrow bench gently sloping to the northwest (Figures 11, 12). The terrace extends for three and one-half miles, ending one mile north of Proctor. Both Alden and Johns thought that meltwater may have flowed along the bench into a glacial lake near the vicinity of Lake Mary Ronan. After forming the terrace, the stream eroded two channels through lateral moraine before ending in a small deltaic flat on the north side of the moraine (Figure 13).

The other kame terrace is located along the southeast side of the Big Arm Valley (Figure 14). Formed mainly on high deposits of lateral moraine, it extends for three miles. This semi-continuous feature has filled several gulches along the slope. The Big Arm terrace grades into a broad deltaic flat, three-fourths of a mile in length, which extends into the Loon Lake basin (Figure 15). Holes dug at several locations on both Dayton and Big Arm kame terraces have exposed several feet of stratified gravels and sands overlying till.

Fluvial Land Forms of the Upper Big Arm Valley

Although the terrain near Chief Cliff is the major area of fluvial action, there is one feature resulting from fluvial erosion in the upper
Figure 11. View of Dayton kame terrace. Arrow points to location of upper, older lateral moraine 440 feet above the terrace. Picture taken facing north from Dayton.

Figure 12. Sketch of cross section of Dayton kame terrace.
Figure 13. Sketch of Dayton kame terrace ending in a deltaic flat north of lateral moraine, one mile north of Proctor. Upper delta believed to have formed during early glacial advance.
Figure 14. Kame terrace along southeast side of Big Arm Valley. Arrow points to a possible deposit of upper lateral moraine at an elevation of 4340 feet.

Figure 15. Big Arm kame terrace ending on a deltaic flat built into Loon Lake basin.
Big Arm Valley. The presence of a deep, narrow gorge notched into the southwest rim of the upper valley (Figure 3) suggests that it was once the outlet for sizable volumes of water. Alden (1953, p. 94) thought that this gorge was cut by escaping glacial meltwaters. Two basins at the head of the Big Arm Valley are encircled by low hills and are believed to have once been the site of a small lake fed by water from the Big Arm ice lobe (Figures 10, 16). While the front of the Big Arm ice lobe lay stationary, meltwaters in the upper Big Arm basin rose, and found an outlet over a low pass and presumably carved Black Gulch, a narrow rock gorge some 400 feet deep. Holmes (1965, p. 668) has termed such features "overflow channels." For water to cut such a deep gorge, it is thought that the proglacial lake must have existed for a long period of time. Beach lines along the grassy slope north of Black Gulch provide probable further evidence that a lake once occupied the upper Big Arm Valley; it is possible, however, that the beach lines may have been formed by Glacial Lake Missoula.

Glacial Lake Ronan

Several lines of evidence suggest that the Dayton ice lobe impounded a glacial lake in the upper Dayton Valley. This lake, termed here "Glacial Lake Ronan," was centered approximately over the site of contemporary Lake Mary Ronan (Figures 3, 10). Alden (1953, p. 123) suggested the possibility of an ice-dammed lake in the upper Dayton Valley. Johns (1964, p. 16) verified Alden's idea by identifying lakebed silts deposited west of Lake Mary Ronan. The writer believes that the glacial lake attained the following dimensions during its high stand: surface elevation 3880 feet, greatest depth (near Big Meadow) 322 feet, surface
Figure 16. Sketch of upper Big Arm Valley as it would have appeared during glaciation.
extent approximately 22 square miles. The physiographic evidence used
to define this level of the lake is reasonably reliable. A feature
identifiable in photographs and on topographic maps appears to be a
deltaic flat. This deposit is located at an elevation of 3880 feet,
lying above the Dayton kame terrace outlet one mile north of Proctor.
A field check of this land form showed that it contains stratified grav­
els similar to those found in textbook deltas. Furthermore, because of
its location above the Dayton kame terrace, it is believed to have been
deposited by an ice-margin stream of the early glacial advance (Figure
13). On the mountain slope two miles west of Dayton, a small, high
level bedrock cliff and bench are cut into the slope at the 3880-foot
level. These are believed to have been cut by water from Glacial Lake
Ronan. The deltaic flat and the bedrock bench, both at 3880 feet,
suggest strongly that the surface of the lake stood at a 3880-foot
level, and it is concluded that this was indeed the case.

Outside the perimeter of the Dayton terminal and lateral mor­
aines, silts and erratic boulders overlie the slopes and country rock.
This glacial debris is believed to have been both rafted by icebergs
and also to be silts deposited on the lakebed. The deposits can be
found in the following three locations: the upper Dayton Creek drainage,
the area of Lake Mary Ronan, and the south side of the Big Meadow. How­
ever, since erratics have been found at elevations of up to 4200 feet,
Glacial Lake Ronan must have at times risen to a considerable height
before an outlet was established. Varved lakebed clays, overlain by
ten feet of morainal material, imply that occasional masses of glacial
debris spilled out onto the bottom of the glacial lake. These varves
are exposed in a road-cut near the present canyon cut through lateral moraine northeast of Big Meadow.

Field evidence suggests that the waters which filled Glacial Lake Ronan were derived from two main sources. The first source would obviously have been meltwater from the Dayton ice lobe. The second source is believed to have been represented by glacial meltwaters coming from the Lakeside drainage north of the upper Dayton Creek basin (Figure 10). Waters are thought to have flowed southward from the Lakeside drainage into upper Dayton Creek through two low mountain passes. Topographic maps and aerial photographs show two wind gaps notched into the mountain range at the head of Dayton Creek; elevations of the gaps are 4540 and 4780 feet (Plate 1). A field check of the higher pass, located five and one-half miles north of Proctor, revealed the following characteristics: (1) walls of the gap are steep, rocky, and triangular in shape (Figure 17); (2) the bottom of the pass is a narrow channel (approximately ten feet wide) with scattered, large, angular blocks of rock, which have recently rolled down from the steep walls of the gap; (3) the channel originates on the north side of the divide, then slopes at approximately 12 degrees toward Dayton Creek (Figures 17, 18); and (4) the gap is nearly 300 feet deep.

The lower wind gap (4540 ft. elev.), briefly discussed in Chapter III, is thought once to have been a channel for glacial meltwater and possibly for a small ice lobe. Because of its U-shaped profile, size and lower elevation, the writer believes that perhaps a small finger-like lobe of ice, approximately 450 ft. wide and 100 ft. thick as estimated from the gap profile and topographic map, pushed through the wind
Figure 17. Sketch of higher wind gap cut into mountain range five and one-half miles north of Proctor. Viewed from upper Dayton Creek.

Figure 18. Side view of higher wind gap. Floor of the gap begins on north side of mountain.
gap during the period of late glaciation. This belief is partially speculative because no striations were found. However, the low elevation of the pass, the presence of till on the sides of the gap, and its shape seem to suggest the possibility of a late glacial ice lobe, melting of which would have certainly supplied extra quantities of water to Dayton Creek. The evidence presented indicates the probability that glacial meltwaters from north of Dayton Creek drained through the gaps and contributed large volumes of water of Glacial Lake Ronan.

Chief Cliff Terrain

In the study area, the later part of the Ice Age was also a time of impressive erosion by meltwater flooding. As the waters of Glacial Lake Ronan drained away, a conspicuous two-mile zone of rugged cliff and bench topography was cut into the eastern slopes of the Hog Heaven Range two miles northeast of Elmo. This steep terrain culminates at 500-foot high Chief Cliff, a prominent local landmark (Figure 19). The cliff topography originates near the Big Meadow in Dayton Valley and continues around the eastward-facing slopes of the Hog Heaven Range. From Chief Cliff, this terrain extends westward to the Elmo Moraine. Alden (1953, p. 123) believed that the waters impounded behind the Dayton ice lobe escaped between the glacier and the mountain slope; thus, a temporary spillway was eroded at the base of Chief Cliff and produced what Flint (1957, pp. 166-68) terms "glacier-margin channels." Field evidence supports Alden's ideas.

Drainage from Glacial Lake Ronan ripped loose and swept away thousands of cubic yards of solid rock while cutting a channel between the ice and the bedrock slope. This feature, situated two and one-half
Figure 19. Looking north at Chief Cliff, 500 feet high. Dayton Valley in background. Photo taken from airplane over Big Arm Bay.
miles west of Dayton and half-way up the eastern slope of the Hog Heaven Range, trends in a southeast direction for almost two miles between Red Lake and Chief Cliff. Water draining from Lake Ronan cut back into the mountain slope and stripped away rock up to heights of 500 feet (Plate 1). The floor of the bench lacks ground moraine and is scarred by a complex of interconnecting trenches and benches, which are similar to the "channeled scablands" of Washington (Bretz, 1959, 57 pp.). Erosion by ice scour is a second possibility for the creation of the cliff terrain; however, most of the evidence implies that the features were formed by severe fluvial erosion.

While the "outlet" waters of Glacial Lake Ronan were held against the east end of the Hog Heaven Range by glacial ice, the water eroded many channels into the bedrock bench. One outstanding channel, located one-fourth mile northwest of Black Lake, is the best developed water-cut gorge in the entire study area. Briefly discussed earlier, this channel is thought to be an outlet for Glacial Lake Ronan at the 3680-foot level. Cut through a small high-level bench, the gorge now lies high and dry, 400 feet above the floor of Dayton Valley (Figure 20). Carved into the nearly horizontal Precambrian beds, the gorge averages 60 feet deep by 40 feet wide, is aligned in a north-south direction, and extends for one-fourth of a mile. At the north entrance of the gorge the chipped and undercut vertical walls imply rigorous fluvial erosion. A pile of sand and gravel dug up from the bottom of the gorge by early prospectors suggests that the gorge was carved by moving water. The presence of glacial striations trending N. 73° W. on the bench surface, almost perpendicular to the gorge alignment, precludes the possibility of gorge origin by glacial scour.
Figure 20. Showing deep gorge cut into bedrock bench, two and one-half miles west of Dayton.
Elmo Spillway

The same discharging waters which eroded the Chief Cliff terrain carved a spillway into bedrock along the north side of the Elmo basin, between Hog Heaven Range and the Elmo lateral moraine (Figure 21). This spillway consists of a network of deep interconnecting channels having a gently westward inclination. Its width varies from 200 to 2600 feet and it extends for four and one-half miles from Chief Cliff to the north end of the Elmo Moraine. The spillway is a continuation of the bedrock terrace west of Black Lake. As it extends westward it broadens into meandering and braided channels before finally widening out onto the Big Draw outwash (Figures 10, 22) north of the Elmo Moraine. The spillway cannot be seen from Elmo because it lies behind high accumulations of lateral moraine. However, a cliff zone marking the north wall of the channel is visible from Elmo. The orientation, size, shape, depth, and "scabland" appearance imply that the spillway was carved by fluvial erosion. Channel bed material consists of stratified sand, gravel and boulders. The presence of scattered automobile-sized blocks of rock, still very angular and unworn, suggests a short distance of transportation by either ice or water. The writer believes that possibly the large blocks could have been quarried and transported during periodic flooding by discharge from Glacial Lake Ronan; movement of ice, however, is more likely.

Big Draw Outwash

Deep accumulations of gravel outwash on the floor of the Big Draw indicate that an immense volume of sediment-choked meltwater once
Figure 21. Elmo spillway along north side of Big Draw. Aerial view looking east with Flathead Lake in background.
Figure 22. Looking down onto floor of Big Draw. Elmo spillway joins Big Draw outwash on north side of Elmo Moraine. Arrows point to deltaic deposits. Outer moraine remnant encircled by broken line.
discharged down the Big Draw (Figure 23). The Big Draw outwash, varying from one-half to one mile across, extends westward for eight miles from the Elmo Moraine. The gravel outwash surface slopes to the west at approximately 65 feet per mile. In cross section, the Draw has the shape of a V-shaped valley partially filled with gravel. Elrod (1903, p. 202) thought that the flat valley floor of the Big Draw formed when outlet waters of Flathead Lake temporarily overflowed the Elmo Moraine and discharged down the Big Draw. Meinzer (1917, p. 14) suggested that during Pre-Wisconsin glaciation the Flathead River outlet occupied the Big Draw. Aerial photographs show the surface to be engraved with a braided net- work of dry channels (Figure 23); such channel patterns on a valley outwash are characteristic of periglacial areas according to Flint (1957, p. 139); these features are formed as a result of rapid deposition from overloaded streams. Deposits in the Big Draw are believed to have been laid down by sediment-choked waters from the Elmo ice lobe and Glacial Lake Ronan. Surface materials consist of stratified sand and gravel-sized particles with some scattered boulders and angular blocks. The absence of varved clays from Glacial Lake Missoula implies that late glacial stream waters eroded and transported the clays downvalley, presumably after the withdrawal of the last stand of Lake Missoula. Depth of the valley fill is unknown; however, in the E\text{2} S\text{W}\text{2}, Sec. 20, T24N, R22W, a well only 400 feet from the north wall of the valley penetrated 191 feet of unconsolidated material before encountering bedrock (Osborne, Liberty Drilling).
Figure 23. Looking east up the Big Draw. Meltwater outwash flowed westward leaving braided stream patterns engraved in the floor.
Deltas of Lake Missoula

Just west of the Elmo Moraine, two deltaic remnants suggest stream deposition in standing water. The first feature lies a short distance northwest of the moraine (Figure 22); it is located at the foot of the mountain slope and has two levels of stratified sediments, at elevations of 3400 and 3400 feet. The second remnant is found on the west side of the Elmo Moraine just south of State Route 28 (Figure 24). Its surface is also at 3400 feet, but its area is much larger than that of the deposit on the other side of the valley. Since both partially eroded fragments contain stratified gravels 100 feet thick, have surface elevations of 3400 feet, and extend west of the Elmo Moraine, it can be postulated that their origin was the result of the deposition of sediments by meltwater discharging into Glacial Lake Missoula.
Figure 24. On the left side of photo the flat-surfaced, bench-like, deltaic feature is believed to have been built into a stand of Glacial Lake Missoula (3440 ft. elev.). State Route 28 (center of photo) extends westward through Elmo Moraine and down the Big Draw outwash.
CHAPTER V

GLACIAL LAKES AND RELATED FEATURES OF THE RECESSONAL STAGE

General Statement

Land forms of the recessional stage of late Pleistocene glacia-
tion are represented by numerous drainage channels and various types of
lacustrine deposits. In each of the three valleys glacial lakes evolved
along the ice fronts, "lived" for a short time, then drained as their
ice dams melted (Figure 25).

During early stages of ice withdrawal, lake surfaces were lowered
by continuous downcutting of the outlets. Later, the surface levels of
all three lakes were controlled by the elevation of the outlet of the
lake occupying the Elmo basin (Glacial Lake Elmo). This outlet was cut
into the Elmo Moraine to an elevation of 3345 feet. Throughout the dis-
cussion of glacial lakes this level is frequently referred to as being
the elevation at which many of the outlets, inlets, and deltas occur.
It is believed that all three glacial lakes merged into one large body
of water covering much of the Big Arm embayment. Persistent ice shrink-
age eventually opened an outlet channel of lower elevation to the east,
and the glacial lakes of the Big Arm Bay drained into Polson Bay. This
event marks the end of land form development directly or indirectly
caused by glaciers in the study area.
Figure 25. Recessional stage showing Glacial Lakes Dayton, Elmo, and Big Arm. Arrows show probable direction of retreat of glacial margins.
Valley Floor Ground Moraine

Deep thicknesses of ground moraine* melted free from the ice and accumulated on the valley floor as the ice front withdrew. For the most part, the surfaces of ground moraine are smooth and slope gently toward Flathead Lake. Some parts of the valley floors are characterized by fluted, pocked, and hummocky patterns. Ground moraine varies in thickness as is shown by the following well log data.

In the middle of Dayton Valley, a well drilled at the Proctor school house penetrated 540 feet of unconsolidated material without reaching bedrock. However, another well just east of the Dayton post office encountered bedrock at 156 feet (Roy Williams Drilling, well log files). The depth of unconsolidated material at Dayton indicates that the valley is filled with glacial till to a depth considerably below the surface of Flathead Lake.

Logs of wells drilled into the ground moraine that covers the Elmo basin suggest that bedrock here is overlain by unconsolidated material to a great unknown depth. At the Elmo school house, one well ended in sand and gravel 300 feet below the surface (Glenn Camp Drilling, well log files), indicating that the Big Draw is filled to a great depth with unconsolidated material.

The bedrock floor of the Big Arm Valley is also deeply buried beneath ground moraine. Near the Big Arm post office bedrock was encountered 316 feet below the surface (Liberty Drilling, well log files).

* Ground moraine as defined in this thesis—moraine deposited beneath a glacier, and/or moraine deposited at the toe of retreating ice.
The depth of ground moraine in all three valleys suggests several different explanations. Till could have been deposited beneath the bases of the ice lobes. Another possibility is that large amounts of glacial debris may have been deposited during ice recession. To deposit such thick masses of material, recession must have been slow, enabling considerable volumes of incoming ice to deposit additional amounts of ground moraine. A third explanation of the deep thickness of till would involve several successive episodes of glaciation, each overriding "earlier" deposits of ground moraine, and each contributing additional moraine during recession. Probably a combination of all three processes accounts for the deep accumulations of material indicated by the well log data.

**Glacial Lake Dayton**

As the Dayton ice lobe melted back from the Ronan Moraine, melt-waters collected, forming a glacial lake between the moraine and the ice front. This lake, termed here "Glacial Lake Dayton," evolved, enlarged, and drained as the ice withdrew from the valley (Figure 25). At its maximum extent, Glacial Lake Dayton "drowned" nearly seven square miles of the valley floor. This short-lived lake was not part of Glacial Lake Ronan. Glacial Lake Ronan was located at a higher level, outside of the Ronan Moraine, while Glacial Lake Dayton occupied the area within the morainal crescent. Lake water accumulated from three sources—Dayton Creek, Ronan Creek, and glacial-melt runoff. Such features as deltas, clay varves, and outlet channels provide evidence supporting the theory of the existence of Glacial Lake Dayton.
Dayton Deltas

While Glacial Lake Dayton was forming in front of the retreating ice lobe, Dayton and Ronan Creeks deposited two deltas (Figure 26). The deltaic flats lie at an elevation of 3360 feet, 470 feet above present Flathead Lake. The material for both deltas was eroded from deep stream channels cut into the lateral moraines.

Dayton Creek delta, the largest and best developed delta in the study area, covers 250 acres and is located two miles northwest of Proctor, just below the road to Lake Mary Ronan. The delta extends 3500 feet from apex to periphery; in that distance the surface drops 50 vertical feet. A network of small dry channels on the delta surface fans out from the source canyon (Figure 27). In a gravel pit located on the delta periphery in the SW¼, Sec. 20, T24N, R21W, excellent examples of deltaic foreset beds are observed to consist of interfingered layers of sand and gravel (Figure 28). Because of the slow settling velocity of fine material, these beds contain no silt or clay. Just outside the periphery of the delta are deep thicknesses of sand which are believed to be bottomset beds.

On the slope 25 and 45 feet above the delta apex are found two small remnants of deltaic deposits consisting of fine gravel-sized particles. These deltas were formed in early high stands of Glacial Lake Dayton. The large Dayton Creek delta probably represents deposition during the final stand of the lake.

Across the Dayton Valley from the Dayton Creek delta lies Ronan Creek delta. Now densely forested and partially eroded away, it also consists of stratified gravels. Ronan delta has two levels (Figure 26),
Figure 26. Sketch of deltas found in Dayton Valley.
Figure 27. Aerial photograph showing Dayton Creek delta. Area is 250 acres; radial extent is approx. 3500 ft. from apex to periphery. Dry channels on surface fan out from apex.
Figure 28. Photo showing front view of foreset beds in Dayton Creek delta. Beds consist of interfingered layers of sand and gravel.
separated by about 25 vertical feet. These different levels are thought to have resulted from a lowering of Glacial Lake Dayton during formation. The delta covers only a few acres. Its size, compared to the Dayton Creek delta, suggests that Ronan Creek carried much less sediment than did Dayton Creek. It is therefore believed that Dayton Creek, having a much smaller drainage basin than that of Ronan Creek, received most of its water from glacial lakes to the north by way of two water gaps located at the head of Dayton Creek; these have been discussed in an earlier section of this report (pp. 37-39).

**Varved Clays of Glacial Lake Dayton**

Varved* clay deposits near Proctor verify the existence of Glacial Lake Dayton. The varves, varying in thickness, overlie much of the ground moraine in the Dayton Valley. On the steeper slopes, clay either did not accumulate or has completely eroded away, while on the flats some layers still remain intact. The clay varves are overlain by soil and underlain by glacial till. Varves average one and one-half inches thick. Lenses of gravel found within the clay layers probably represent droppings from melting icebergs. In a road-cut just south of the Dayton Creek school near Proctor, a vertical profile of varves contains 14 varve layers in 22 inches of clay. A second column, located one-half mile southeast and downvalley from the school house, includes 11 varves within 17 inches of clay. Although varves at various sites can be counted, an attempt to estimate the rate of ice retreat and age of the

* Varve—a layer of clay or silt on a lake bottom believed to represent a year's deposition.
lake would be a risky calculation at best, since post-Wisconsin erosion had presumably destroyed some of the varves.

**Outlets of Glacial Lake Dayton**

As the ice continued to retreat, the outlet of Glacial Lake Dayton near the base of Chief Cliff was relocated at successively lower elevations. This, in turn, caused the surface of the lake to lower at the same rate. In addition to the deltaic remnants previously described, this hypothesis is supported by a number of benches eroded into bedrock near the base of Chief Cliff. These benches, shown in Figure 29, are thought to represent outlet channels cut between the hillslope and the retreating ice front.

The highest bench at the base of Chief Cliff is thought to have been the outlet of Glacial Lake Dayton at its maximum stand. This channel is believed also to have been used by waters escaping from Glacial Lake Ronan. The bench, first in a series of outlets, lies at an elevation of 3540 feet and is now partially buried by talus slopes at the foot of the cliff. From this bench it is thought that waters turned westward and swept down the Elmo spillway.

A second bench was eroded at 3410 feet. However, the absence of a continuous channel in the Elmo basin suggests that this outlet was used for only a short time.

The third outlet, a channel cut to an elevation of 3390 feet, has an average width of 40 feet and extends for nearly one-third mile. In that distance the surface drops 30 vertical feet, ending on a deltaic flat in the Elmo basin. At present the channel is used as a pass for a
Figure 29. Cross sectional sketch of postulated successive outlets of Glacial Lake Dayton. Looking north at Chief Cliff, benches, and channels cut into bedrock.
Glacial Lake Elmo

"Glacial Lake Elmo," as it is termed here, formed in front of the receding Elmo ice lobe, "drowning" the lower land surface of the Elmo basin (Figures 25, 30). Outlet waters from this lake sluiced a channel 100 feet deep through the Elmo Moraine. Since the inlet deltas and outlet channel were both cut at/or near an elevation of 33.45 feet, it is believed that the lake surface stood close to this level. Considerable evidence confirms the existence of Glacial Lake Elmo: (1) located along the north side of the Elmo basin are seven channels eroded through lateral moraine, ending on seven flat-to-hummocky surfaced deltaic features; (2) lacustrine silt deposits cover much of the lower surface of the basin; (3) a large outlet channel has been cut through the Elmo Moraine ending on the floor of the Big Draw. A discussion of each of these features follows.

Elmo Deltas and Inlet Channels

As the Elmo ice lobe retreated to the east, seven channels ending on deltas formed along the north shore of Glacial Lake Elmo. The deltas, all occurring at about the same elevation (Plate 1), are represented by a row of hummocky mounds situated along the relatively smooth south-facing slope of the lateral moraine (Figures 30, 31). It is believed that their peculiar shape was caused by the inwash of gravel over the top of stagnant ice; distortion was caused by slumping where the buried ice eventually melted. Size of the deltaic features varies from two to
Figure 30. Sketch of Glacial Lake Elmo and adjacent land forms during recessional stage.
Figure 31. Looking east with Elmo spillway in center of photo. On right side of photo are hummocky deltaic deposits that were built into Glacial Lake Elmo. Inlet channels connect the spillway to the deltas.
ten acres. The deltas consist of stratified gravels and boulders. The
seventh one, located at the south end of the pass at the foot of Chief
Cliff, has the most easily examined bedding. Here, profiles of well-
sorted and stratified gravels have been exposed by excavation.

Inlet channels from the Elmo spillway have been eroded through
lateral moraine and terminate on the Elmo deltaic features (Figure 31).
As the Elmo lobe retreated, low divides on top of the lateral moraine
allowed discharging water, flowing westward down the Elmo spillway, to
change course, turning southward and flowing into Glacial Lake Elmo. A
network of many abandoned channels implies that the water changed course
seven times. It is believed that each "new" delta and channel formed
as the retreating ice front exposed succeededly lower gaps in the mor-
aine. Since all seven features end at an elevation near 3345 feet, it
can be assumed that they were built into a glacial lake that stood at
about that level.

Silts of Lake Elmo

The floor of the Elmo basin contains silt overlying ground mor-
aine. This silt is believed to have settled from the water of Glacial
Lake Elmo. Exposures are relatively common, for they occur in every
major road-cut of State Route 28 west of Elmo. The silt deposits con-
sist of thin horizontal to wavy layers. Gravel lenses are occasionally
interbeded with the silts; these are attributed to iceberg rafting. The
lack of clay-sized particles in the deposits suggests continual discharg-
ing and replenishment of the water in the lake. Lake current would sweep
the suspended clay-sized particles toward the outlet, while particles of
larger grain-size would settle on the bottom. Although the surface of
Glacial Lake Elmo stood at 33¼ feet during its late existence, silts were found on the Elmo Moraine near the 3400-foot level, across the highway from a sand storage building. These deposits indicate that the lake, once higher, was lowered by downcutting of the outlet.

**Lake Elmo Outlet**

A pass through the Elmo Moraine, now used by State Route 28, is thought to be the outlet for Glacial Lake Elmo. Located two miles west of Elmo, this deep channel extends for a mile through the moraine before ending on the Big Draw outwash (Figure 24). The east end of the channel has an elevation of 33¼ feet. The channel averages 300 feet wide by 100 feet deep. Stratified and imbricated gravels laid down by outlet waters are found next to the sanding house, contrasting with glacial moraine across the highway. This difference in material indicates that the highway was cut through the contact zone between the outlet channel and the Elmo Moraine.

**Glacial Lake Big Arm**

Recession of the Big Arm ice lobe resulted in the ponding of a small body of water, termed here "Glacial Lake Big Arm" (Figure 25). The lake covered roughly three square miles of the lower Big Arm Valley and later merged with Glacial Lake Elmo. During the investigation, the only evidence found that points toward the existence of Glacial Lake Big Arm was a deltaic feature located two miles southwest of Big Arm (Figure 25). The deltaic flat is situated at the 33¼-foot level. The eastern portion of the delta has been swept away by water which once presumably flowed from the Loon Lake basin (see below). The gravels of the deltaic
flat cover 15 acres and can best be observed in a gravel pit along the delta's northwest periphery. Lakebed silts and outlet features of the lake were not found; however, a more intensive investigation might reveal their presence. As ice continued to retreat, Glacial Lakes Dayton, Elmo, and Big Arm all joined, submerging approximately 25 square miles of land.

**Loon Lake Fluvial Features**

While retreating ice occupied much of the Big Arm Valley, escaping waters from the Loon Lake basin carved three different outlet channels (Figure 32). Most of the water, which flowed into Loon Lake basin by way of the Big Arm kame terrace, inwashed a 120 acre-sized deltaic flat. The periphery of the delta, at the 3580-foot elevation, served as part of the north shoreline of the earlier, high-standing Loon Lake. A distinct beach line along the west shore also marks this stand. Along the south periphery of the delta, excavation of a gravel pit has exposed the foreset beds of the delta (Figure 32). Contemporary Loon Lake, at an elevation of 3450 feet, is presently only a foot or two deep and usually completely evaporates in the summer; the clay-covered lake bed is then exposed. The course of each outlet, shown in Figure 32 is numbered, indicating its relative chronological position in the time sequence. During the terminal stage of glaciation, waters from Loon Lake first flowed westward between the terminus of the Big Arm ice lobe and the mountain slope, then into the upper Big Arm basin forming the first outlet (No. 1 on Figure 32). As the ice retreated, waters changed course and drained towards the northwest, eroding a second channel between a low mountain and the terminal moraine before flowing into the upper Big
Figure 32. Sketch map of Loon Lake fluvial features. Numbers indicate sequence of use of outlets.
Arm basin (No. 2 on Figure 32). The third outlet was cut through the terminal moraine and extends northward toward Big Arm Bay (No. 3 on Figure 32).

The Draining of the Glacial Lakes

The concluding event of the period of glacial activity in the study area was the draining of the glacial lakes. There is no physical evidence to support the following theory; however, this seems to be what must logically have happened:

Before they emptied, the combined glacial lakes in the Big Arm embayment stood at an elevation of about 33\45 feet and drained westward down the Big Draw. At this time the retreating Flathead ice lobe acted as both a dam and drainage divide between Big Arm and Polson Bays. The Flathead ice continued to melt, opening a channel connecting the two bays. If the water level in Polson Bay had been higher than that in Big Arm Bay, the entire Flathead drainage would have flowed westward down the Big Draw. However, if the water level in Big Arm Bay was higher, water would have drained eastward into Polson Bay and then south by way of its outlet through the Polson Moraine. At present the entire area drains through Polson Bay. It is, therefore, obvious that the drainage of the Big Arm area must have reversed direction and flowed eastward. The writer believes that this must have happened when the Flathead ice lobe thinned and opened up a "new" outlet, thereby allowing the combined lakes to drain eastward. No attempt has been made to locate the hypothetical channel; finding it might be impossible since the channel may have formed on the surface of stagnant ice.
When the lakes joined, the area once covered by Glacial Lakes Dayton, Elmo, and Big Arm became a western extension of Flathead Lake. This event marks the end of direct and indirect glacial land form development in the Big Arm embayment.
CHAPTER VI
SUMMARY AND CONCLUSIONS

An investigation was undertaken in the area adjacent to the Big Arm embayment of Flathead Lake in western Montana, to study and interpret the morphology of the land forms and piece together a glacial history of the area. The study has indicated that many of the existing surface features evolved during terminal and recessional stages of the middle and late Wisconsin glaciation. The shapes of some of the land forms suggest strongly that enormous volumes of ice and running water played major roles in the formation of much of the area's landscape.

During the terminal stage, the margins of the various sublobes of ice in the Big Arm area became stabilized. The highest deposits of glacial till north of Dayton suggest that the ice surface over the Big Arm embayment attained elevations of nearly 4700 feet. Large amounts of meltwater collected along the ice margins and, while draining, carved many ice-contact features. While the ice front was stationary, a sequence of morainal land forms developed simultaneously in the Dayton, Big Draw, and Big Arm Valleys. Glacier-margin streams deposited kame terraces along several of the mountain slopes. Deposits of terminal and lateral moraine, left behind by melting ice, mark the farthest extent of ice. Between the Dayton Valley and the Elmo basin, swollen outlet waters from Glacial Lake Ronan shaped a conspicuous zone of high cliffs and deep channels. West of the Elmo Moraine, sediment-choked waters filled
the Big Draw to a great depth with gravel outwash. A small lake at the head of the Big Arm Valley provided the water for cutting a 400-foot-deep outlet to the southwest. The terminal stage can be considered to have been a time of thick morainal deposition during which vast quantities of meltwater also carved many cliff and channel features.

When backmelting caused the three ice lobes to recede, three separate glacial lakes formed along the ice fronts. In time the individual lakes coalesced to form a single body of water. Toward the end of its existence the surfaces of this lake stabilized at the 3345-foot level, 450 feet above the present surface of Flathead Lake. The presence of Glacial Lake Dayton, submerging nearly seven square miles of land at its maximum extent, is verified by the presence of two deltas, varved clays, and various outlet features. Seven deltaic deposits and lakebed silts provide evidence of the existence of Glacial Lake Elmo. The lake drained through an outlet channel cut into the Elmo Moraine. This outlet, during the recessional stage, held the level of the three connected glacial lake at 3345 feet. The existence of Glacial Lake Big Arm is confirmed by a deltaic flat at an elevation of 3345 feet. Glacial Lakes Elmo and Big Arm joined, thereby "drowning" 15 square miles of land during their maximum extent. Further ice melting allowed all three lakes to connect. The enlarged lake was short-lived; continued recession of ice opened a channel between Big Arm Bay and Polson Bay, allowing the drainage to reverse direction and flow eastward. When the surface of the glacial lakes was lowered to that of Polson Bay of Flathead Lake, the effects of land form evolution caused directly and indirectly by glaciers ceased as the Ice Age in the Big Arm embayment came to a close.
REFERENCES CITED


