TOPOGRAPHIC EFFECTS OF GLACIAL LAKE MISSOULA: A PRELIMINARY REPORT

CHESTER B. BEATY
Montana State University

Pleistocene glaciation directly and indirectly affected much of western Montana. Most of the individual ranges in this part of the state supported alpine glaciers and lobes of the Cordilleran glacier of western Canada pushed into northwestern Montana at several places. One huge finger of ice came down the intermountain depression in northern Idaho and British Columbia known as the Purcell Trench (Fig. 1). The point of southernmost advance of the Purcell lobe is problematical, but it was at least as far as the south shore of Lake Pend Oreille. The ice was more than 2,000 feet thick in the vicinity of the lake, and one of its major effects was to block the Clark Fork River drainage where it emerges from the mountains a few miles west of the Idaho-Montana border. This damming of the Clark Fork Valley brought into existence Glacial Lake Missoula, which at its maximum extent covered most of lowland western Montana. At its highest stand the surface of the lake was approximately 4,300 feet above present sea level.

In terms of physiographic evolution, the existence of Lake Missoula has been the most recent significant event in the western part of the state. The "drowned" terrain can be expected to reveal the effects of such a great body of water. The purpose of this study is to examine the morphologic consequences of this impressive inland sea. The present report summarizes results obtained to date.

Occasional suggestions of the presence of a large lake in western Montana are encountered in the literature before the turn of the century, but the earliest comprehensive account of Glacial Lake Missoula, by Pardee, appeared in 1910.[1] This pioneering paper, described in considerable detail the gross features of the lake, its approximate extent, the site of the necessary ice dam, and a number of its physiographic effects.

Following Pardee's initial work, however, few geomorphologists have given attention to Lake Missoula. It is discussed briefly in the *Guidebook of the Western United States*[2] and William Morris Davis[3] mentioned some of the lake's physiographic effects in a paper dealing primarily with direct glacial action in western Montana and northern Idaho. In a series of articles on the channeled scablands of Washington, J. Harlan Bretz[4]

[1] J. T. Pardee, "The Glacial Lake Missoula," *Journal of Geology,* Vol. 18 (1910), pp. 376-385.

[2] Marius R. Campbell and others, *Guidebook of the Western United States:* Part A, The Northern Pacific Route, U. S. G. S., Bull. 611 (1916).

[3] W. M. Davis, "Features of Glacial Origin in Montana and Idaho," *Annals, Assoc. Amer. Geog.,* Vol. 10 (1921), pp. 75-148.

[4] J. H. Bretz, "Channeled Scablands of the Columbia Plateau," *Jour. of Geol.,* Vol. 31 (1923), pp. 617-649; *idem,* "The Spokane Flood Beyond the Channeled Scablands," *Jour. of Geol.,* Vol. 33 (1925), pp. 97-115, 236-259: *idem,* "Channeled Scabland of Eastern Washington," *Geog. Review,* Vol. 18 (1928), pp. 446-447; *idem,* "Valley Deposits East of the Channeled Scabland," *Jour. of Geol.,* Vol. 37 (1929), pp. 393-427, 505-541; *idem,* "Lake Missoula and the Spokane Flood," *Bull., Geol. Soc. Amer.,* Vol. 53 (1942), pp. 1569-1600.

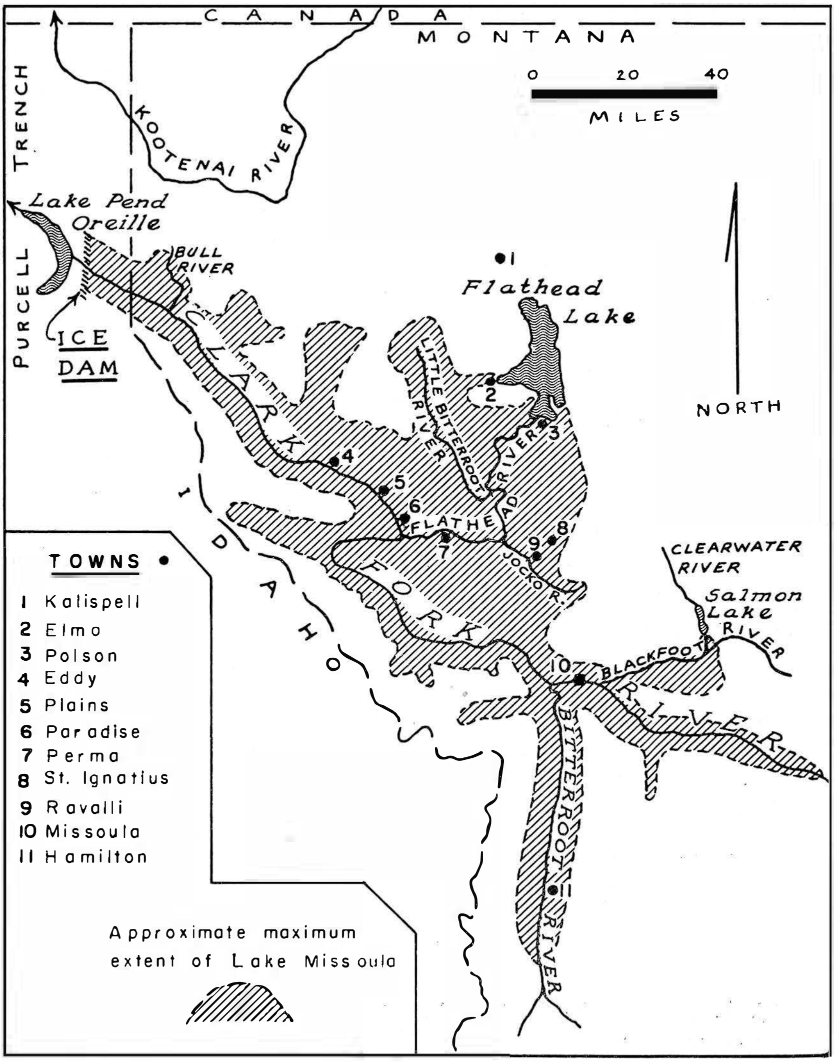

Figure 1. Index map of area of Glacial Lake Missoula, western Montana.

noted the necessity for a glacially dammed body of water to provide the runoff responsible for the extreme dissection of that part of the Columbia Plateau.

Pardee made another major contribution with his classic study of the effects of a rapid draining of the lake,[5] in which a rough calculation showed that most of the 500 cubic miles of impounded water could have been released in less than two days. The "unusual currents" thus produced—to use Pardee's term—brought about notable topographic effects within the basin of Lake Missoula.

W. C. Alden[6] discussed the lake in some detail in a report concerned chiefly with glaciation in western Montana, in which alternative explanations for some of the land forms described by Pardee were offered.

Finally, Bretz *et al.*[7] published what appears to be the definitive study of the Washington scablands. The morphology of the scablands tract demands flood waters of enormous volume but short duration and Bretz and associates demonstrated convincingly that only a sudden draining of Lake Missoula could have provided the necessary inundation. They postulated a series of major floods, rather than only one great rush of water as implied by Pardee in 1952.

Against this background of former studies the present investigation is set. The object is a recognition and understanding of all the morphologic effects of the lake.

Glacial Lake Missoula produced a wide range of physiographic features. Discussed below are land forms mentioned in former studies or identified in the field in the course of this writer's investigation. In no way are the descriptions to be considered complete. They give only some idea of the different topographic forms related directly or indirectly to the existence of the lake.

Beach Lines. The most widespread of the topographic effects was the cutting of beach line terraces on slopes within the lake basin. Beach lines are seen in the following localities: Missoula Valley; Bitterroot Valley; Big Draw west of Flathead Lake; Jocko Valley; Nine Mile Prairie; Flathead Valley; Little Bitterroot Valley; Clark Fork Valley around Plains; and in many other isolated places.

The highest recognizable terrace is about 4,200 feet above present sea level. No single beach line has been traced horizontally for more than a few hundred yards because the topographic expression of terrace remnants is generally poor. No single terrace is conspicuously better developed than any of the others. The relatively slight slope indentations suggest that the level of the lake must have fluctuated more or less continuously.

The most impressive development of terraces was on slopes adjacent to long arms of the lake on which prevailing winds could generate large

---

[5] J. T. Pardee, "Unusual Currents in Glacial Lake Missoula, Montana," *Bull., Geol. Soc. Amer.*, Vol. 53 (1942), pp. 1569-1600.

[6] W. C. Alden, *Physiography and Glacial Geology of Western Montana and Adjacent Areas,* U. S. G. S. Prof. Paper 231 (1953), pp. 154-165.

[7] J. H. Bretz, H. T. U. Smith, and G. E. Neff, "Channeled Scabland of Washington: New Data and Interpretations," *Bull., Geol. Soc. Amer.*, Vol. 67 (1956), pp. 957-1050.

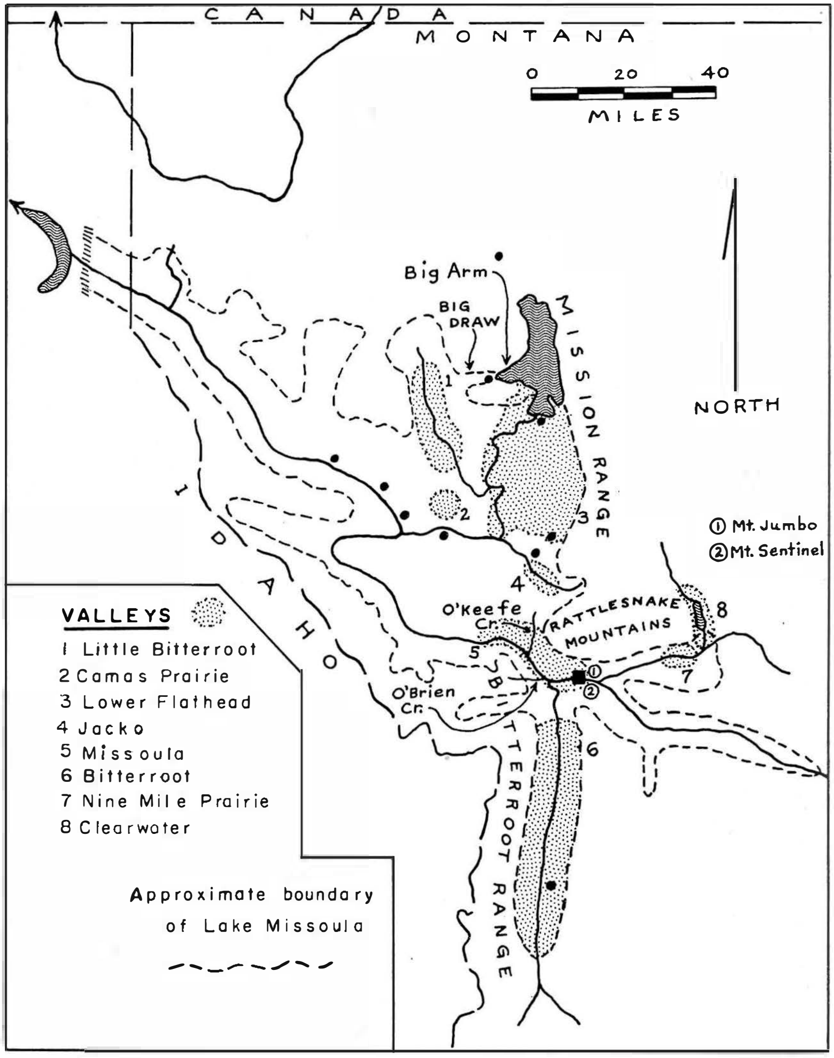

Figure 2. Location of specified features within basin of Glacial Lake Missoula. western Montana.

waves. The most spectacular terraces seen during the present investigation are along the south side of the Clark Fork River west of Missoula, where railroad embankment-like treads have been cut in bedrock.

Numerous problems are encountered in a consideration of the terraces, particularly problems of time relationships between glacial advances and the existence of Lake Missoula. For example, beach lines are found on numerous glacial moraines within the basin. Well-preserved shore lines on the moraines suggest a comparatively late stand of the lake. It seems probable, therefore, that advances and retreats of the larger lobes of ice occurred at different times and at different rates. The Flathead and Purcell Trench lobes must have operated more or less independently, and the glacier that invaded Nine Mile Prairie (Fig. 2) from the Clearwater Valley very probably was out of synchronization with those farther west. Similarly, the development and recession of alpine glaciers probably did not parallel the advance and retreat of the larger Cordilleran lobes; this viewpoint, however, has been challenged.[8]

The apparently intricate time relationships between glacial advances and stands of the lake at various levels remain to be worked out. The widespread distribution of shore lines should be of assistance in piecing together an acceptable chronology.

Silt Deposits. Silts were deposited on the floor of Lake Missoula in much of its basin. They are found in the following localities: Missoula Valley, Jocko Valley, Flathead Valley, Little Bitterroot Valley, Nine Mile Prairie, Camas Prairie, and in scattered situations throughout the general area.

Silts are thickest and cover the largest areas in basins immediately adjacent to margins of the larger ice masses or on valley floors directly downstream from the most massive glaciers. Those in the Little Bitterroot Valley and in western Missoula Valley are thickest and areally most extensive. There is also a large body of silts in the lower Flathead Valley near the junction of the Jocko and Flathead rivers. The Bitterroot Valley and the Clark Fork Valley east of Missoula all but lack deposits of silt. In part this may be the result of post-Lake Missoula removal by stream action and slope wash, but it must primarily be the case because lobes of the Cordilleran glacier did not deliver their silt-laden meltwaters into these arms of the lake.

Silts are found on top of the moraine west of Elmo at the head of the Big Draw. Since beach lines in the Big Draw itself are well above the upper surface of this moraine, it is obvious that the lake once extended east of the moraine. The Flathead lobe of ice must have receded before the Purcell Trench lobe, as has been suggested above. A complication is added in this part of the Lake Missoula basin by the fact that there are no silts in the Big Draw proper.[9] This former outlet of Flathead Lake is floored entirely with much coarser glacial outwash; the coarse outwash disappears beneath silts in the northern Little Bitterroot Valley several miles to the west.

---

[8] L. H. Nobles, "Glacial Sequence in the Mission Valley, Western Montana," *Bull., Geol. Soc. Amer.*, Vol. 63 (1952), p. 1286.

[9] O. E. Meinzer, "Artesian Water for Irrigation in Little Bitterroot Valley, Montana," *U. S. G. S., Water Supply Paper 400-B* (1917), pp. 9-37, ref. p. 16.

Other somewhat peculiar, isolated silt deposits are found in diverse parts of the basin, and a careful consideration of all of the evidence will be necessary before an acceptable timetable for the final extinction of the lake and the recession of the various larger ice masses can be formulated.

"Ripple Marks" in Camas Prairie. One of the most remarkable topographic features related to the existence of Lake Missoula is a series of ridge-like masses of gravel in Camas Prairies termed "giant ripple marks" by Pardee.[10] Briefly, he believed the forms were created by powerful currents sweeping through Camas Prairie as Lake Missoula was rapidly drained. He postulated that the lake surface over Camas Prairie fell suddenly with respect to that in the adjacent Little Bitterroot Valley, and that a great rush of water through Camas formed the "ripple marks." Alden[11] has offered an alternative explanation for their origin. Bretz *et al.*[12] sustain Pardee's thesis and describe similar features of larger size in the channeled scablands of Washington. This writer has made only a brief reconnaissance of the Camas Prairie area and is not at present in a position to support or deny Pardee's ideas.

High Eddy Deposits. Another consequence of a rapid draining of Lake Missoula and the development of powerful currents was apparently the deposition of masses of debris in certain valleys tributary to the lower Flathead River and Clark Fork River trunk canyons. Several such debris masses are found between Perma and Plains (Fig. 1). They were called "high eddy deposits" by Pardee.[13] He thought they were swept into the mouths of tributaries by the turbulent currents which rushed through constricted reaches of the trunk canyons. Pardee's ideas have recently been supported by Bretz *et al.*[14]. Alden[15] called the deposits "gulch fillings" and thought they might represent bars or deltas. The U. S. Geological Survey's *Guidebook of the Western United States*[16] termed them deltas. W. M. Davis[17] erroneously indentified them as glacial moraines.

These features have not been examined carefully during the present investigation, and their origin remains in question. Certainly they are not moraines, nor do they resemble deltas in external form. The writer tends to accept Pardee's expanlation, although more intensive field study remains to be done.

Degraded Slopes. In many of the narrows of the lower Flathead and Clark Fork canyons the valley walls as far as 1,000 feet above present river level are virtually devoid of regolith. The Perma, Paradise and Eddy narrows are conspicuous in this respect. In some places, especially upstream from Perma, the terrain at first glance appears to have been created by massive rock falls and bedrock landsliding on a large scale.

Pardee[18] believed these slopes were degraded by the "unusual currents" generated by the catastrophic draining of Lake Missoula. Presumably

[10] Pardee, *op. cit.* (1942), pp. 1587-1588.

[11] Alden, *op. cit.*, p. 96.

[12] Bretz *et al.*, *op. cit.*, pp. 980, 986, 1006, 1007, 1045.

[13] Pardee, *op. cit.*, pp. 1589-1593.

[12] Bretz *et al.*, *op. cit.*, pp. 980, 986, 1006, 1007, 1045.

[15] Alden, *op. cit.*, pp. 158-160.

[16] Campbell *et al.*, *op. cit.*, p. 142.

[17] Davis, *op. cit.*, pp. 126-127.

[18] Pardee, *op. cit.*, pp. 1588-1589.

some of the debris in the "high eddy" deposits is upstream regolith concentrated and re-deposited by the currents. Davis,[19] appealing to glaciation, professed to see in the denuded rock masses evidence of the abrasive action of ice. However, there is no supporting field evidence that glaciers occupied any of the trunk canyons east of the Idaho-Montana boundary, nor have satisfactory source areas for the postulated glaciers been discovered.

This writer reserves judgment on the degraded slopes. Granting a rapid draining of Lake Missoula, violent currents undoubtedly were present in the narrows, and it is accepted that at least some of the apparent removel of regolith was accomplished by these. However, other possibilities exist. For example, there is a conspicuous break in slope inclination at the upper limit of the denuded canyon walls, and it may well be that lower, steeper segments were partially degraded by immediately post-Lake Missoula mass movements. Regolith on the submerged slope facets would have been thoroughly saturated and would have lacked a protective vegetation cover. Gravity-induced movements could have stripped off impressive volumes of regolith in a relatively brief time.

Bedrock Channels and Depressions in Rim of Camas Prairie. The north, east, and northwest rims of Camas Prairie (Fig. 2) are notched by several passes, or windgaps, marked by high-elevation bedrock channels and depressions. Pardee[20] thought these features were cut by rapid, concentrated currents formed when the lake surface over Camas Prairie dropped suddenly. Without a doubt the features are water-cut, but this investigator is skeptical of a short-time origin. Bedrock is a tough, clinkery quartzite, and it is difficult to believe that such impressive forms could have been eroded by only brief spasms of current action.

Another possible explanation would involve a blocking of the Little Bitterroot River near its junction with the Flathead River by the the Flathead lobe of ice. That such a blocking took place was suggested by Alden[21] and the writer has found questionable field evidence to support the contention. An independent lake would thus have been created in the Little Bitterroot Valley. It could have overflowed into Camas Prairie, and the water-cut features in the various gaps could have been eroded by current action over an extended period.

Deposits on West Slope of Mount Sentinel. The western slope of Mount Sentinel above the Montana State University campus appears to have been covered to varying depths by materials deposited during at least one of the high stands of Glacial Lake Missoula. An impression is gained that steep, V-shaped bedrock valleys on the slope had been filled almost to the brim, converting what must have been a highly irregular front into a comparatively smooth surface. Post-Lake Missoula gullying has scoured parts of the slope. The supposed process of deposition is not understood. Possibly there was slack water or eddying immediately downstream from the constricted Hell Gate channel just east of Missoula. The deposits on Mount Sentinel are thus perhaps akin to the "high eddy" deposits farther west in the trunk canyons of the Clark Fork and Flathead rivers.

---

[19] Davis, *op. cit.*, pp. 126-127.

[20] Pardee, *op. cit.*, pp. 1582-1584.

[21] Alden, *op. cit.*, p. 158.

Terraced Glacial Outwash. A series of alluvial terraces in glacial outwash is found in the lower Clearwater River drainage basin south of Salmon Lake (Fig. 1). In places as many as seven or eight matched terrace treads are seen along the river, which is flowing in a trench 100-150 feet below the highest outwash surface. The physiographic evidence suggests strongly that the terraces were cut by the Clearwater River as its level declined with the falling surface of Lake Missoula. It seems probable that a shallow arm of the lake once extended north at least as far as Salmon Lake. As Lake Missoula drained, its level dropped progressively and the newly established Clearwater River followed suit, trenching the poorly consolidated outwash south of Salmon Lake.

Erratic Boulders and Smaller Debris. Throughout the basin of Lake Missoula, erratic boulders and smaller materials are widely distributed. Most must have been rafted by icebergs as such widespread occurrence admits of no other mode transportation.

Source areas for the icebergs which transported the erratics were numerous. The largest masses of ice washed by the lake were in Flathead Valley and Nine Mile Prairie (Fig. 2). However, alpine glaciers entered Lake Missoula in the southern Bitterroot Valley and along the western flank of the Missoula Range, and lobes of ice from north of the international boundary were probably in contact with arms of the lake in a broad zone between Flathead Lake on the east and the Bull River farther west (Fig. 1).

The wide distribution of erratics, some of which are faceted and striated, confuses the matter of deciding where limits of glaciation may lie. Glacial limits are easily recognized along much of the perimeter of the lake, but in some places the outer boundaries of direct action are obscure. Striated and faceted boulders may reveal direct glacial deposition, or they may simply indicate stranding and wasting of debris-laden bergs. Any erratics below the 4,200-foot level may have been iceberg rafted.

Anomolous Depressions on Flanks of Missoula Valley. An unusual depression is found on the ridge between O'Brien Creek and the Clark Fork River six miles west of Missoula (Fig. 2). Its origin is not clearly understood. It resembles a typical sink hole in karst terrain, but the underlying bedrock is not limestone, nor is there other evidence of solution in the immediate area. In all probability it has come into existence as a result of deposition of an underwater bar across a small, tranverse tributary of O'Brien Creek.

A similar feature is found northwest of Missoula, one and one-half miles west of lower O'Keefe Creek. As seen from the air, this depression appears to be a topographic pocket formed when a shallow valley, draining toward the Clark Fork River, was blocked by subsurface deposition.

Both of these depressions are well below the level of the highest stand of Lake Missoula, and their somewhat curious shapes and positions seem to indicate an origin directly related to subsurface currents and deposition within the body of the lake.

Landslides. Glacial Lake Missoula may have contributed indirectly to the formation of landslides in the Clark Fork Valley immediately east of Missoula. There are two major landslide zones here, one on the south wall of Hell Gate Canyon, one on the northeast side of Mount Jumbo.

In Hell Gate Canyon a single, large slide or slump has occurred in which a piece of the Mount Sentinel massif has slipped down and toward the river. The slide is apparently situated on a fault zone.[22] The immediate cause of movement was probably undercutting by the river. A contributary cause may have been saturation under the waters of Lake Missoula by which the structurally weak block would have suffered a further loss of cohesion.

The slide area northeast of Mount Jumbo is also located on a fault zone.[23] The hummocky, subdued character of the topography is possibly the result of submergence in Lake Missoula. Saturation of an already unstable zone of regolith, gouge, and shattered bedrock may have materially promoted the movements which created the present distinctive land forms.

Landslides are also found along the north side of the Missoula Valley on the grassy slopes flanking the Rattlesnake Mountains. This writer has seen only a limited portion of this region and cannot judge the extent of the slide area or its possible relation to Lake Missoula.

The major effect of Lake Missoula on slope stability would have been in the saturation of all regolith below the 4,200-foot level. A consequent loss of cohesion in the loosened debris above bedrock could be expected, and landsliding might thereby be favored. However, a proved connection between the existence of the lake and specific slides has not yet been demonstrated.

Deltas. It is reasonable to assume that many deltas would have been built in Lake Missoula. Known deltas are few, however, probably because the level of the lake fluctuated so frequently that large masses of debris simply never were deposited at one particular elevation.

It has been suggested that the accumulation of gravels in the mouth of Marshall Canyon a few miles east of Missoula is a delta.[24] Also, the unusual gravel deposits in tributary valleys along the lower Clark Fork and Flathead rivers have been identified as deltas.[25] These are the features called glacial moraines by Davis,[26] "high eddy deposits" by Pardee,[27] and "gulch fillings" by Alden.[28]

It seems likely, however, that only very small true deltas were built in the constantly fluctuating Lake Missoula, and that most, if not all, have been destroyed or greatly modified by post-Pleistocene stream action and slope washings.

Moraines Deposited in Standing Water. The existence of Lake Missoula beach lines on glacial moraines in parts of its basin suggests that at least some may have been deposited in standing water. The rounded and smoothed appearance of the Polson Moraine, the Elmo Moraine, and the

---

[22] John P. Wehrenberg, Ed., *Guide Book to Field Trips,* Geol. Soc. Amer., Rocky Mountain Section, 12th Annual Meeting, Missoula, Mont., p. 8.

[23] *ibid.,* p. 8.

[24] *ibid.,* p. 8.

[25] Campbell *et al., op. cit.,* p. 142.

[26] Davis, *op. cit.,* pp. 125-126.

[27] Pardee, *op. cit.,* pp. 1589-1593.

[28] Alden, *op. cit.,* pp. 158-160.

terminal moraine in Nine Mile Prairie gives the impression of a subduing of a more rugged topography by water action. The large number of rounded cobbles and boulders, especially in the Polson Moraine, implies abrasive action by waves and currents, either contemporaneously with deposition or thereafter. In the upper Bitterroot Valley, lateral and terminal moraines of alpine glaciers of the Bitterroot Range have undoubtedly been smoothed and lowered by water action.[29] A rather careful discrimination will have to be made, however, between moraines modified after formation by wave and current action and those laterally deposited in the standing waters of the lake. Such a distinction has not yet been made in most parts of its basin.

A fair idea of the topographic effects of Glacial Lake Missoula has been attained during the course of this investigation, but a great deal of knowledge about the lake and its effects remains to be gained. Accurate time relationships—perhaps only relative rather than absolute—must be established. The degree of preservation of various topographic features within the basin must be correlated with such factors as slope orientation, bedrock type, depth of regolith, distance from active ice fronts, and geologic structure. The extent to which post-Lake Missoula gradational action has altered original forms is little known. A single field season, in short, has served only to outline the problems in a general way and to whet the intellectual appetite of the investigator.

---

[29] R. L. Konizeski, personal communication, 1961.