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UNUSUAL CURRENTS IN GLACIAL LAKE MISSOULA, MONTANA

BY J. T. PARDEE

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ABSTRACT

The area submerged by Glacial Lake Missoula includes several intermontane basins and constricted interconnecting valleys or "narrows" that drain to a single outlet, the Clark Fork River. A sudden failure of the ice dam that blocked this valley, near the Idaho-Montana State line, caused unusually large and rapid currents through the narrows and wind gaps in the partly submerged rim of Camas Prairie basin. Evidences of such currents include commensurate, but otherwise ordinary, effects of streams confined to rocky channels and the unique giant ripple marks. At its high stage the lake is roughly estimated to have held more than 500 cubic miles of water of which nearly three-fourths was stored above a constricted part of the Clark Fork Valley called the Eddy Narrows. Calculations based on available incomplete data indicate a flow through the Eddy Narrows that reached a maximum of 9.46 cubic miles per hour. Whether the lake was completely drained at that time has not been determined, but a later set of beaches testifies that the basin held a lake soon after the rapid outflow. Apparently the final draining was gradual.

INTRODUCTION

In the Pleistocene much of the Clark Fork drainage basin in northwestern Montana (Fig. 1) was briefly submerged by "Glacial Lake Missoula" (Pardee, 1910). A lobe of the Cordilleran glacier advanced southward along the Purcell Trench into northern Idaho where it occupied the basin of Pend Oreille Lake and crowded up the valley of the Clark Fork River to a position near the Montana State line. The water thus impounded in the Clark Fork Valley rose to a maximum altitude of 4150 feet or about 2000 feet higher than the floor of the valley just above the dam. On the east, south, and west it was held in by mountains, and on the north possible outflow channels were blocked by other lobes of Cordilleran ice.

The ice dam is thought to have failed, permitting a sudden large outflow. The consequent depression of the water surface in the arm

of the lake above the dam caused huge and rapid currents in the narrow valleys and passes connecting this arm with the wider depressions in the lake basin farther east. The records of these currents are described. The interpretation of certain gravel deposits and denuded

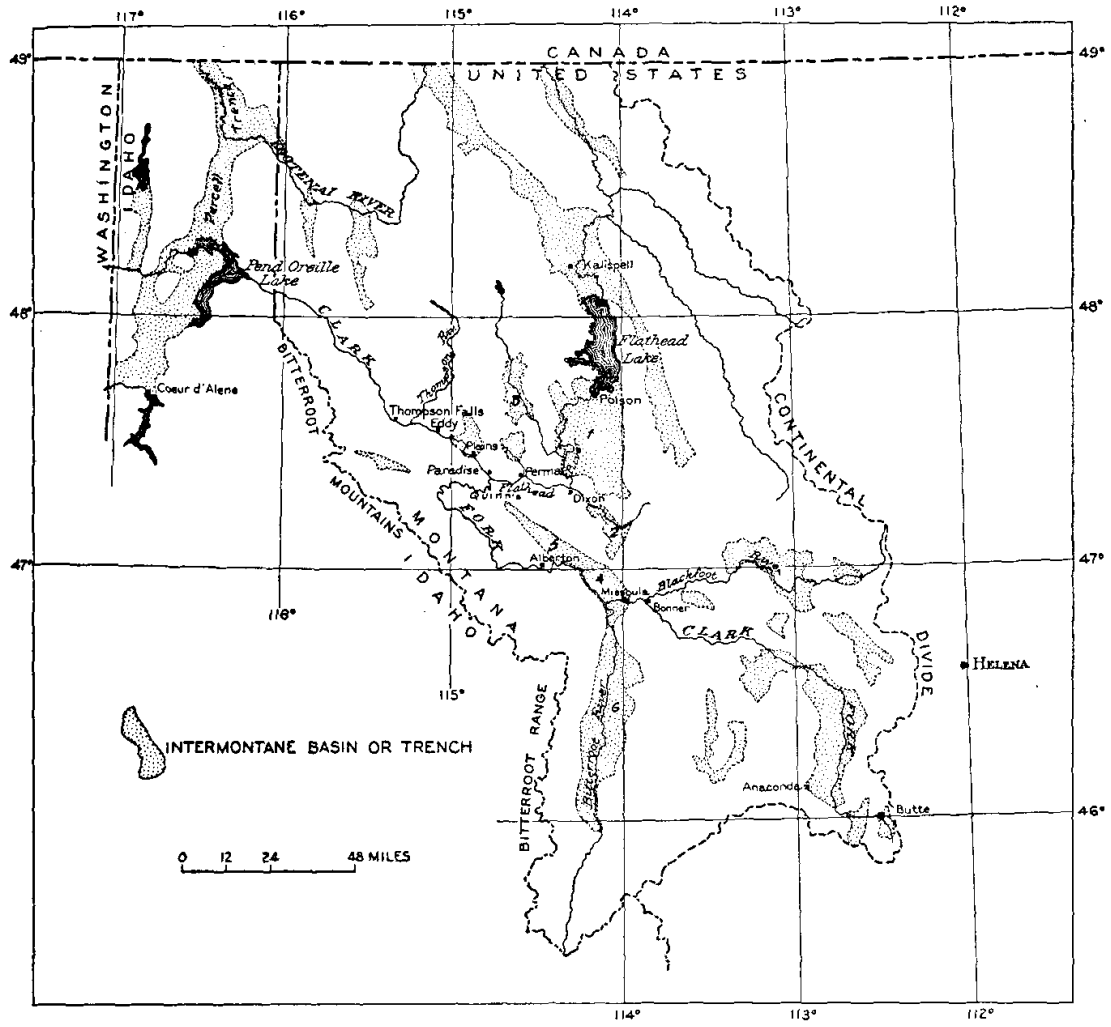


FIGURE 1.—*Index Map*

1. Mission Valley.
2. Jocko Valley.
3. Little Bitterroot Valley.
4. Missoula Valley.
5. Ninemile Valley.
6. Bitterroot Valley.

surfaces in the Perma and Paradise narrows as the effects of such currents differs from that of Davis (1921) who regarded them, respectively, as "moraines" and "ice scoured slopes." Field work by W. C. Alden and the writer has failed to uncover any evidence of glacial origin.

Not long after the rapid outflowing ceased the basin again held a lake. So far it is not clear whether this body was part of the original ponded water whose escape had been halted or a new filling. In contrast to the earlier outrush, final draining seems to have been very slow.

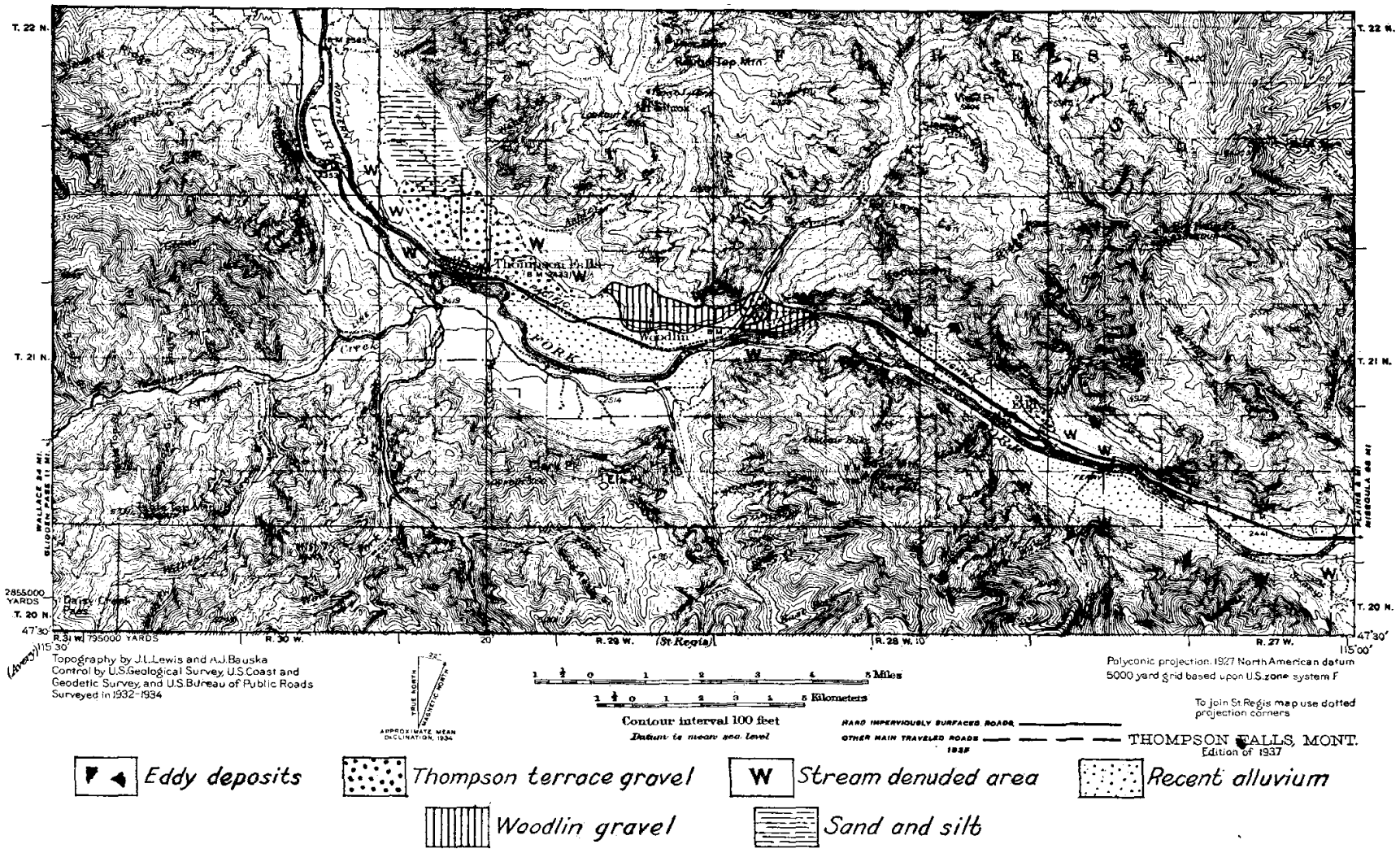


FIGURE 2.—*Eddy Narrows and Thompson Falls Valley*

Reproduced from Thompson Falls, Montana, topographic sheet of the U. S. Geol. Survey. (The term "eddy deposits" in the legend is equivalent to "high eddy deposits" in the text.)

ACKNOWLEDGMENTS

The field work for this paper was facilitated by the use of aerial photographs of the United States Forest Service without which much of the evidence presented could not have been obtained. To W. C. Alden of the United States Geological Survey the writer is indebted for collaboration in the field work and to W. W. Rubey and W. B. Langbein of the same bureau for calculations of stream flow.

TOPOGRAPHY

BASINS

Although the region of Glacial Lake Missoula is occupied chiefly by mountains, the topography is diversified by a number of wide valleys (Fig. 1) or intermontane basins.

The basins are enclosed by generally rough and steep mountains standing from 2000 to 4000 feet higher. Exceptionally high rugged ranges west of the Bitterroot Valley (Bitterroot Range) and east of Mission Valley (Mission Range) rise abruptly to serrate crests 5000 to 6000 feet above the adjacent lowlands. Some of the basins are isolated except for narrow outlet valleys that join them in a common drainage system. Others are more closely connected in irregular groups and in certain linear series known as trenches. Most of the individual basins are one-fifth to half as wide as they are long. Their floor areas range from about 50 square miles in Camas Prairie to 400 square miles or more in Mission Valley and consist mainly of gently sloping plains that merge with a medial flat or flood plain or end as terraces above it. Several of these basins were submerged by the central and eastern parts of the glacial lake. Among them the Mission, Jocko, and Little Bitterroot valleys (Figs. 1, 3) form a closely spaced group drained by the Flathead River. Another group that drains into the Clark Fork River above the mouth of the Flathead includes the Missoula, Ninemile, and Bitterroot valleys. Two other relatively small basins submerged in the central part of the lake are of particular interest in its history: Plains Valley (Fig. 9; Pl. 1, fig. 1) along the Clark Fork River a few miles below the mouth of the Flathead, and Camas Prairie, east of Plains Valley and a short distance north of Perma.

NARROWS

Clark Fork River and its tributaries drain the basins through comparatively narrow valleys which in certain places become severely constricted and gorgelike narrows. The 70-mile stretch of the Clark Fork Valley between the Missoula-Ninemile-Bitterroot group of basins and the Plains Basin generally is not more than 1 or 1½ miles wide

and is enclosed by steep, rugged mountains 2000 to 4000 feet high. Parts narrowed to half a mile or less occur near Alberton (Alberton Narrows), above Quinn's Springs (Quinn's Narrows), and below the

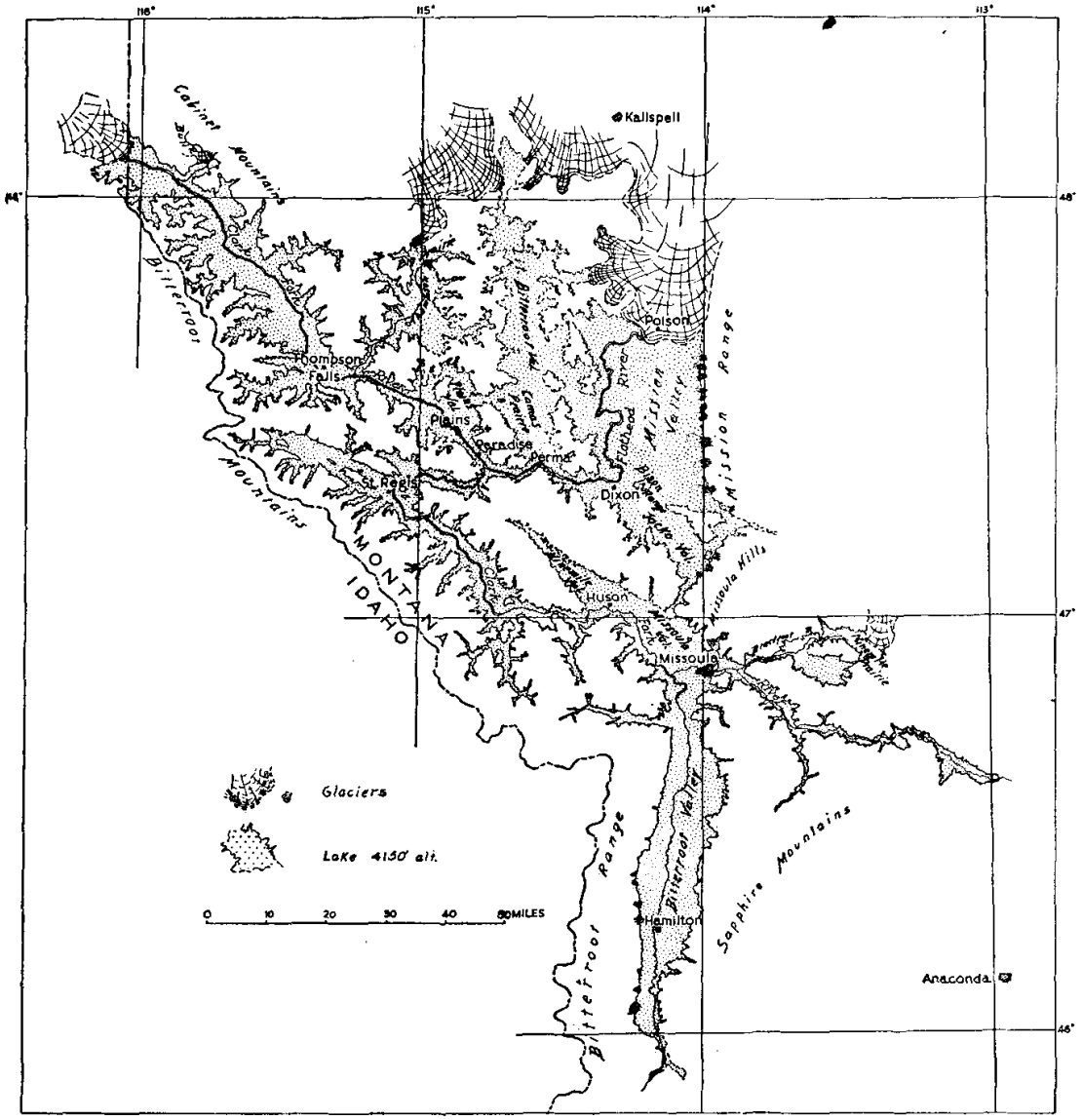


FIGURE 3.—*Glacial Lake Missoula*
High Stage

mouth of the Flathead River from Paradise to Plains (Paradise Narrows). The Clark Fork Valley throughout 10 miles below Plains Basin is again less than a mile wide (Eddy Narrows) between steep, rugged slopes 4000 feet high (Fig. 2). The valley widens abruptly at the lower end of this stretch and from there for about 70 miles to the northwest to the Idaho State line is generally straight and averages 2 and 4 miles in width. The Cabinet Mountains northeast of this

FIGURE 1. PLAINS VALLEY
One of smaller intermontane basins. Looking west into Eddy Narrows, the outlet. Timbered terrace in background is part of coarse gravel deposit. Cultivated area of Recent alluvium.

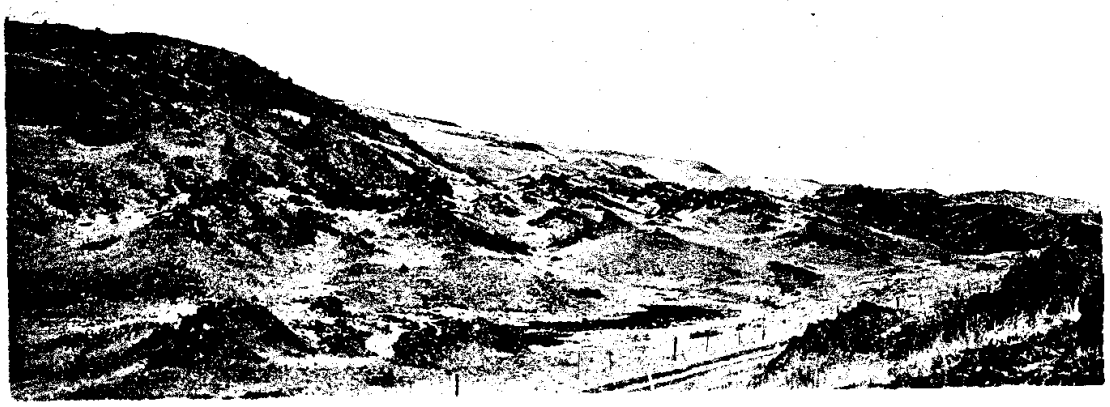


FIGURE 2. WILLS CREEK PASS
Looking north (upstream). Ponded channel depression in foreground. Projecting rock ledges with appended gravel deposits.

FIGURE 3. SOUTH SIDE OF EDDY NARROWS
Near Outlaw Gulch. Severely denuded spur at left. Normal waste mantle begins above 1000 feet.

FIGURE 1. LOOKING WESTWARD (downstream)
About 1 mile above Perma. Denuded rock bench at left separated from cliff by trench partly filled with Recent talus.

FIGURE 2. ENTRANCE TO NARROWS
Stream-denuded surfaces and channel excavations with ponds (B) and gravel deposits. From aerial photos by U. S. Forest Service.

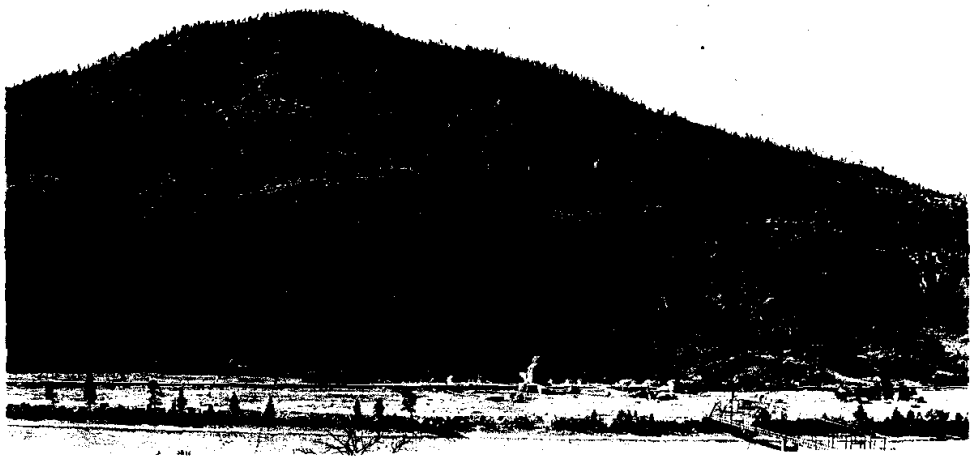


FIGURE 3. DENUDED ROCK BENCH AT PERMA.

PERMA NARROWS AND ROCK BENCH

part of the valley are steep and regular and are 3000 to 5000 feet higher than the valley. The Bitterroot Mountains opposite are lower and less regular. Beyond the State line the Clark Fork Valley opens into the Purcell Trench which in turn joins the Spokane Valley.

The outlet of the Mission group of basins, the valley of the Flathead River, narrows from 2 miles near Dixon to less than a mile at McDonald Station 7 miles downstream (McDonald Narrows). At Perma, 6 miles farther down, the valley becomes still narrower. From Perma to the mouth of the Flathead River, where it merges with the Paradise Narrows, it averages less than half a mile in width (Perma Narrows). As the width of the valley decreases, the enclosing slopes become higher and more rugged. Below Perma they rise 3000 feet or more with slopes characterized by cliffs and bare rock ledges (Pl. 2, fig. 1).

The river bed generally occupies half or more of the valley floor within the different narrows. The remainder of the floor is formed chiefly of low alluvial terraces and an occasional projecting rock knob or ridge. In the adjoining wider stretches of the Clark Fork Valley the terraces are larger and commonly stand 100 to 200 feet above the river. Other pertinent topographic features described in the section on evidences of the unusual currents are wind gaps in the rim of Camas Prairie Basin.

GEOLOGY

BEDROCK FORMATIONS

The region of Glacial Lake Missoula is largely underlain by pre-Cambrian Belt sedimentary formations which, with some intrusive granitic bodies, compose the mountains and extend beneath the Tertiary and later sediments in the lowlands. In the Camas Prairie and Plains basins and the different narrows, the older rocks consist mainly of dark-gray argillites and sandstones of the Prichard formation and Ravalli group, and of a number of diorite dikes and sills. The rocks are deformed by large north to northwestward trending folds and faults and are closely jointed as a rule. Most of the finer-grained beds separate into thin slabs along cleavage planes generally parallel to the bedding. In addition the rocks are traversed by shear zones represented at the surface by notches and trenches, conspicuous on the sides of Perma and Paradise narrows.

These rocks weather to a rubble and finally to a fine-grained sand-clay soil. Above or beyond the area flooded by the lake rubble and soil mantle most of the level and moderate slopes to a depth of several feet, with only particularly resistant beds or dikes projecting through it. Close spacing of joint and cleavage planes produces a rather fine shingle talus with comparatively few large slabs or blocks.

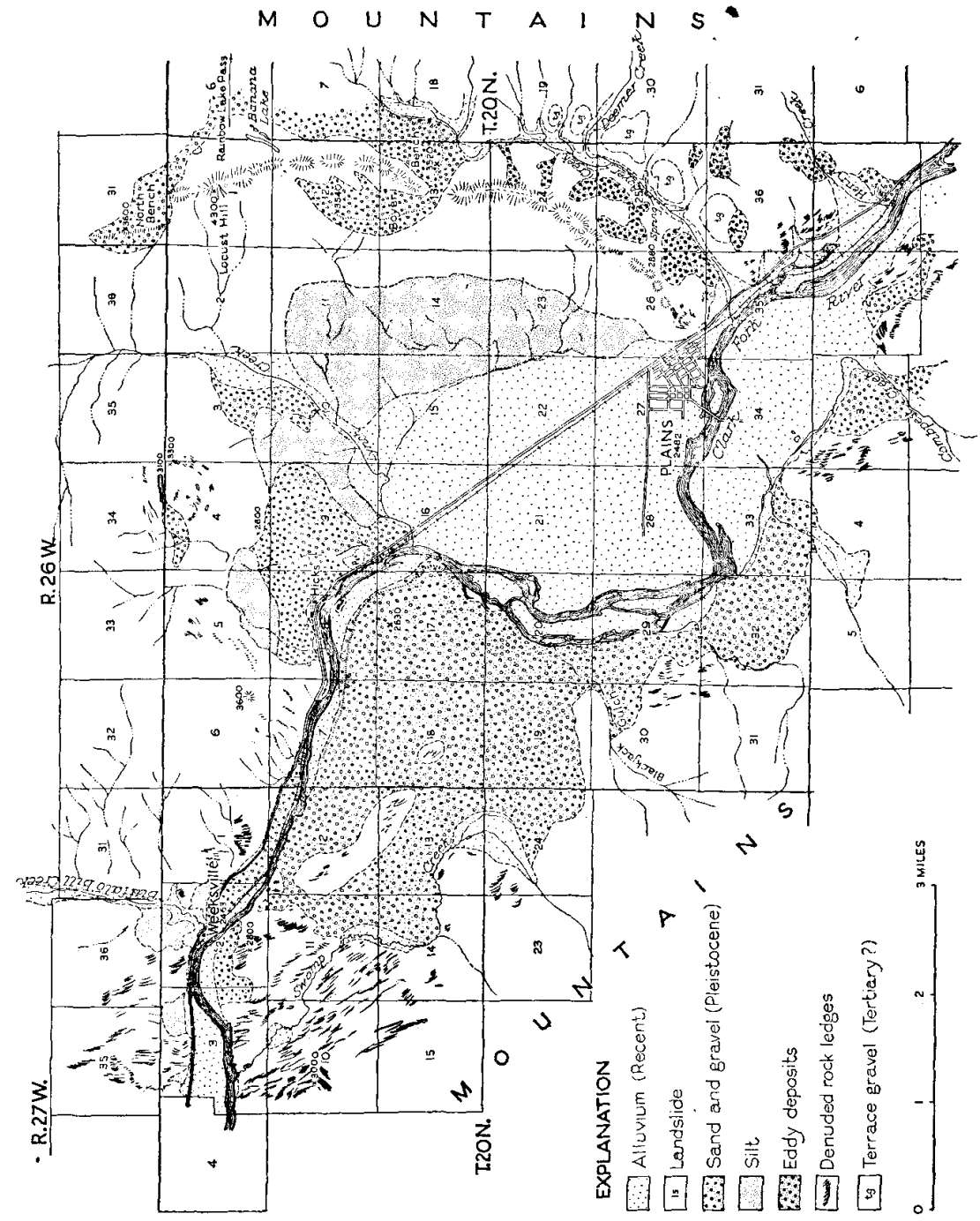


FIGURE 4.—*Southern Part of Plains Basin*

Denuded rock ledges indicated by lines parallel to their trends. The landslide indicated in the legend is on the bank of the river in Sec. 8, T. 20 N., R. 26 W.

On slopes that faced the wider reaches of water the mantle was more or less modified by wave action as described under the section on Beaches. In the narrows the mantle was largely removed by currents during the outflow.

TERTIARY (?) DEPOSITS

Tertiary sediments, extensive in the Missoula-Ninemile and Bitterroot basins, have not been positively identified within the submerged basins to the north and west. In those areas deposits unconformably on the bedrock which may be Tertiary include: (1) water-laid volcanic tuff at the north of Little Bitterroot Basin; (2) "rusty" gravel and sandstone exposed in road cuts and ditches along the foot of the Bison Range; (3) partly decomposed gravel exposed by a road cut in a bench east of Boyer Creek in Plains Basin; and (4) a small patch of gravel with smooth quartzite cobbles on the ridge west of Camas Creek about 2 miles north of Perma.

DEPOSITS ASSOCIATED WITH THE GLACIAL LAKE

Moraines and erratics.—The Pleistocene formations are comprehensively described by W. C. Alden (manuscript in preparation). Among those most closely related to the glacial lake are moraines of contemporaneous mountain glaciers and Cordilleran ice lobes. Several small moraines within the margin of the lake (Fig. 3) were deposited in the Mission and Jocko valleys by glaciers from the Mission Range and Missoula Hills on the east, and in the Bitterroot Valley by glaciers from the Bitterroot Range on the west. Larger moraines were formed at the fronts of the Cordilleran ice lobes that held back the lake on the north. The largest, the Polson moraine at the foot of Flathead Lake, marks the southern limit of the ice which held the arm of the glacial lake in the Mission Valley. Other moraines were deposited by Cordilleran ice lobes in Ninemile Prairie on the Blackfoot River, north of Big Prairie on the Thompson River, and in the valley of Bull River a few miles above its junction with the Clark Fork. Somewhat modified morainal material deposited by the lobe that blocked the Clark Fork Valley is exposed locally near the Idaho State line. Presumably it underlies and thus forms a peculiar sand-covered pitted terrace south of the river at Cabinet Gorge.

Erratics, evidently transported by icebergs from the different glaciers that entered or touched the lake, were distributed irregularly through the submerged areas.

A large body of fine-textured well-washed gravel (Fig. 2) apparently outwash from the retreating ice lobe in Thompson River Valley, forms 50-foot terraces in Clark Fork Valley above and below the entrance of Thompson River.

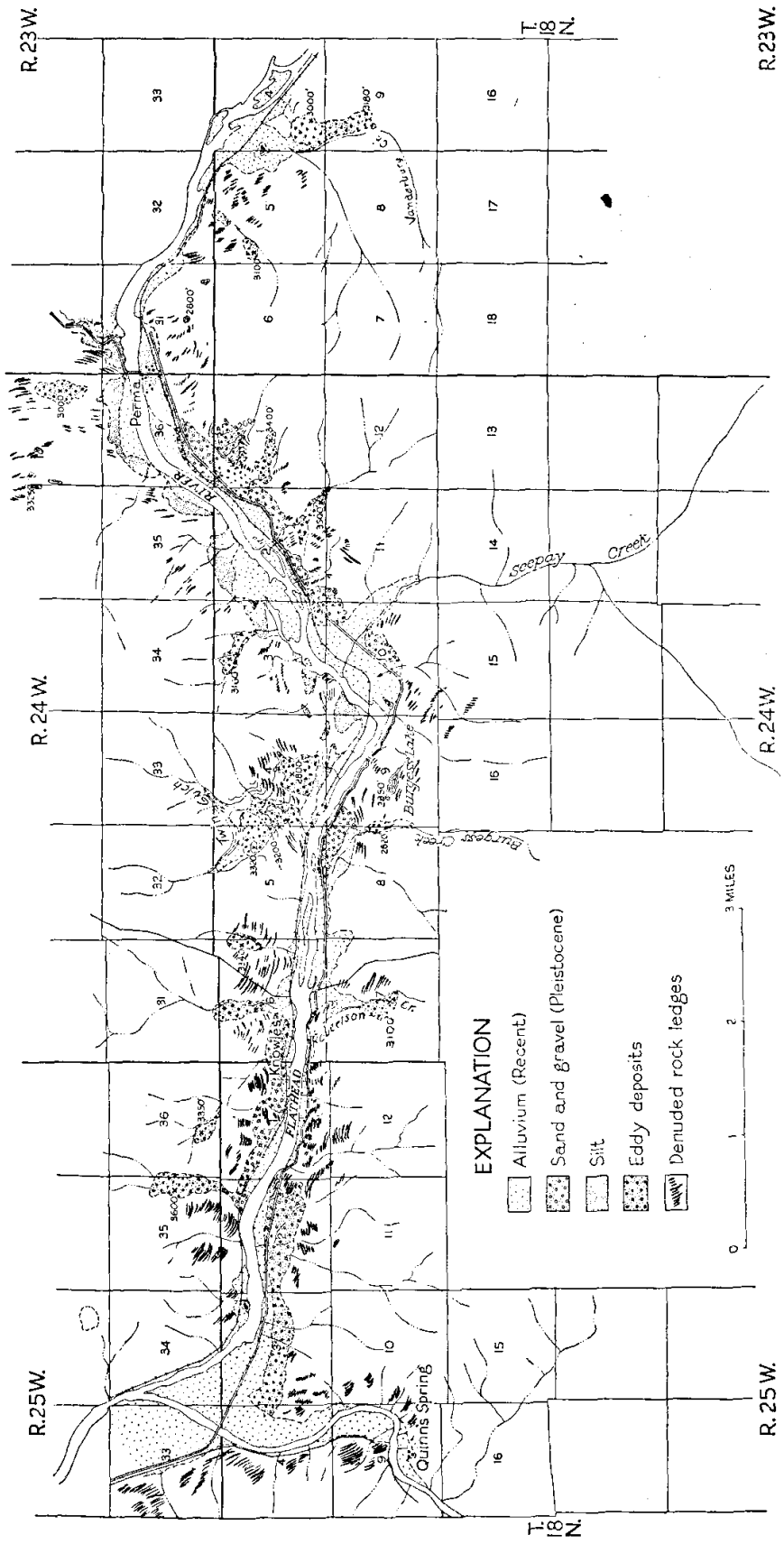


FIGURE 5.—*Perma Narrows*

Denuded rock ledges indicated by lines parallel to their trends.

Silt.—Light-colored varved silt, composed of glacial rock flour derived mostly from the lobes of Cordilleran ice, forms discontinuous terraces 50 to 100 feet high in most of the submerged basins. The silt is confined

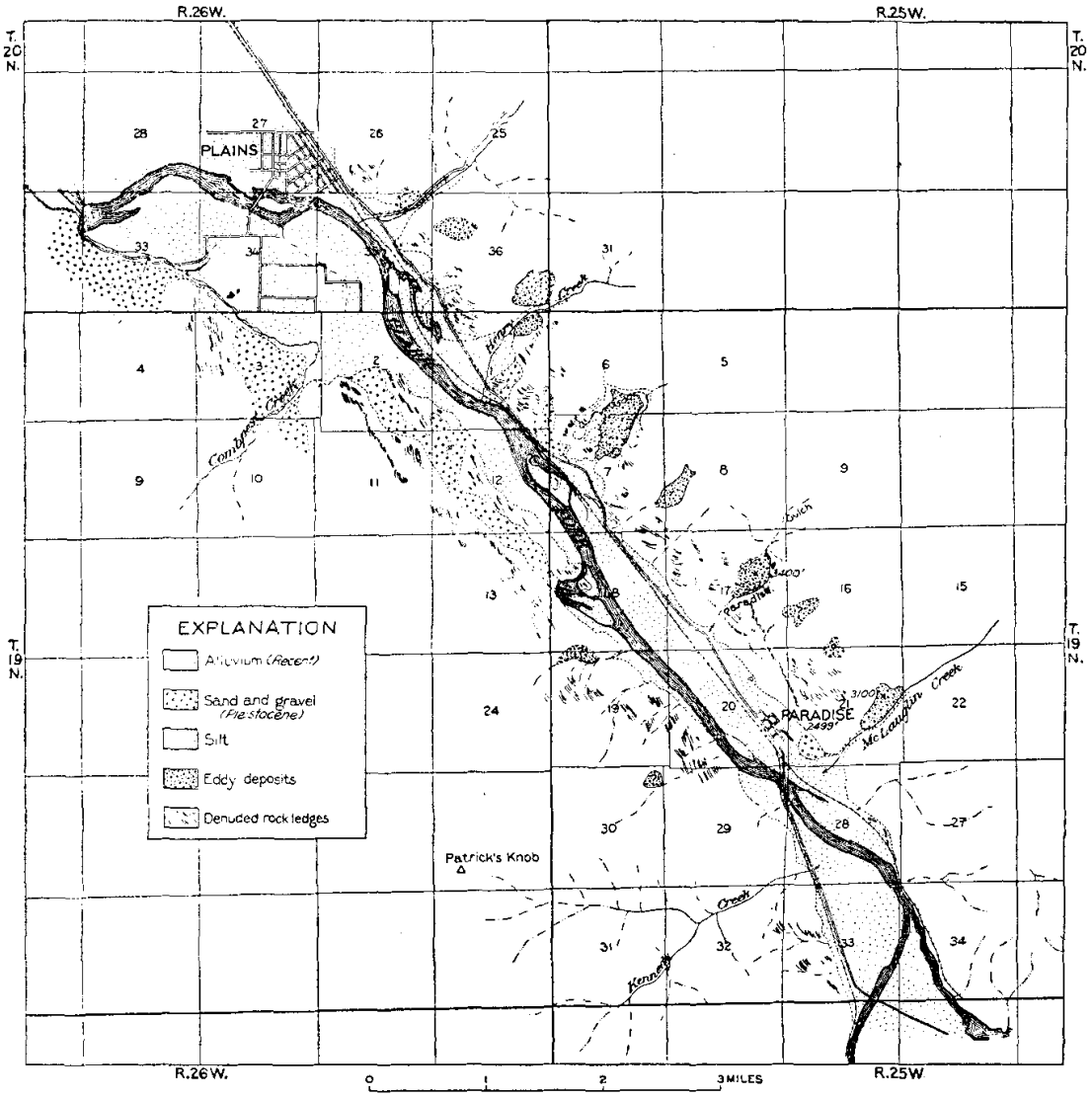


FIGURE 6.—*Paradise Narrows*

Denuded rock ledges indicated by lines parallel to their trends.

to the lower parts of the basins and thins out upslope at the height of the terraces which evidently mark its original upper limit. The Bitterroot Basin and, above the mouth of the Blackfoot River, the valley of the Clark Fork received meltwater from local mountain glaciers only, and in both areas little silt was deposited. In the Missoula-Ninemile Basin, however, silt derived apparently from large glaciers in the Blackfoot Valley forms extensive terraces 50 feet or more high between Missoula and Huson. In the Jocko Basin comparatively small discontinuous

terraces are composed of silt that came chiefly from glaciers washed by the arm of the lake in upper Jocko Valley. Silt discharged by the lobe of Cordilleran ice that filled the basin of Flathead Lake occupies large areas in the lower parts of the Mission and Little Bitterroot basins and forms discontinuous terraces up to 50 feet in height in the valley of the Flathead River (Pl. 7, fig. 3) to the Perma Narrows.

The silt in Little Bitterroot Basin is exposed by stream trenching to a depth of about 100 feet and is found to 200 feet in the middle of the basin in wells (Meinzer, 1916). In the Plains Basin, silt carried from either or both the Mission and the Missoula-Ninemile basins forms terraces about 100 feet high in a large area north of the river (Fig. 4).

In the Perma and Paradise narrows limited exposures of the silt occur (Figs. 5, 6) in protected places, and in the other narrows none has been observed. The somewhat wider stretches of the Clark Fork Valley between the Alberton Narrows and Quinn's Narrows and from the Eddy Narrows to the Idaho State line appear to contain silt in places, but its extent and relations have not been determined.

Deposition of the silt apparently was limited to the lower parts of the basins by conditions similar to those observed at Lake Mead above Boulder Dam on the Colorado River and in other reservoirs; owing to its higher specific gravity, slowly moving turbid water sinks and flows along the bottom without mixing with the overlying clarified water (Grover, *et al.*, 1938). In Lake Missoula the silt, in order to reach Plains Basin, must have been thus carried 50 to 75 miles from its sources in glaciers discharging their meltwater in the Mission and Missoula-Ninemile basins. No silt was deposited in Camas Prairie because none of the entrances to that basin were low enough to divert the layers of turbid water passing down the adjacent Little Bitterroot Basin and the Perma Narrows.

In Little Bitterroot Basin upper and lower silt formations separated by sand layers, and, at one place by gravel, are indicated by well records (Meinzer, 1916, p. 15). The partings occur at depths of 80 to 150 feet, and the underlying silt is 100 feet or more thick.

Deltas.—At all the different still stands of the lake, deltalike deposits of alluvium were doubtless formed at the upper limits of the arms extending into the many tributary valleys. The level of the water surface shifted rapidly so that individual deposits generally must have been rather small. Also, as they were exposed to later stream attack, few would remain sufficiently unmodified to be recognized. Gravel deposits in the Vermilion River Valley that may be the remnants of exceptionally large deltas begin at Cataract Creek about 5 miles from the mouth of

the valley and at Sims Creek about 3 miles farther up. The deposit at Cataract Creek forms a terrace 500 feet high along the south side of Vermilion River. From an altitude of 3200 feet at the lower end the surface ascends gradually upstream. The deposit consists of gravel overlying glacial till, which was observed at one place by W. C. Alden (personal communication). On the opposite side of Vermilion River and about a mile above Cataract Creek is a similar terrace in Lyons Gulch. A small undrained area at the back of this terrace indicates that the deposit was formed by currents turning out of the valley of Vermilion River. The terrace at Sims Creek is about 300 feet high, and the surface rises gradually upstream from an altitude of about 3550 feet at the terrace front.

A gravel filling in McLaughlin Gulch east of Paradise apparently was formed when the lake surface was at 3200 feet. About 1½ miles from the mouth of the gulch this deposit begins as a terrace about 30 feet high. Upstream it narrows and ends within half a mile because of the more steeply ascending bedrock channel of the gulch. The deposit is partly trenched by the stream and shows rather vague top-set bedding. Remnants of other gravel fillings apparently related to still stands of the lake extend up the valley of the St. Regis River from points above Taft at 3800 feet altitude and near Borax at 4100 feet. Both deposits rise gradually upstream from low terrace fronts.

Beaches.—At many places on the untimbered sides of the basins up to an altitude of 4150 feet the horizontal markings of closely spaced lake beaches are plainly visible from moderate distances. Within 1000 feet of the limiting altitude as many as 40 may be counted in favorable exposures (Pl. 5, fig. 1). Thus different still stands were so closely spaced that practically all of a given slope below 4150 feet was exposed to the waves which were most effective, of course, on the higher parts of a slope because they faced the wider stretches of water.

Scattered observations indicate that the beaches consist of a generally slight terracelike indentation thinly covered by cleanly washed and sorted gravel. On slopes that faced the wider arms of the lake the terrace or bench, as it rounds projecting spurs, may be several yards wide, and its related bars in adjacent re-entrants may be measured in cubic yards. Other conditions being equal, the beaches are not only more extensive around the larger basins but appear to be more deeply indented around their southern and eastern sides as if the prevailing winds were from the north and west. In many places rows of loose stones are ridged along the backs of the beaches where, presumably, they were shoved by expanding lake ice.

The beaches are less prominent in the smaller basins and become inconspicuous or absent in the valleys that held the narrower arms of the lake. In the relatively narrow valley of the Clark Fork River above Missoula they may be detected on hills west of Harvey Creek and west of Tyler Creek at altitudes between 3900 and 4150 feet. In the somewhat wider valley below Thompson Falls beaches may be observed between 2700 feet and 3500 feet altitude on partly bare slopes south of Tuscor and northeast of Noxon. Within the narrows beaches have not been identified.

RECENT ALLUVIUM

Within the basins recent alluvium forms flood plains and low terraces along the streams. In the narrows and the relatively narrow stretches of Clark Fork Valley, particularly below Thompson Falls, such features are absent or negligible because the river generally occupies a steep-sided inner trench.

EVIDENCES OF THE UNUSUAL CURRENTS

CHANNELED WIND GAPS IN RIM OF CAMAS PRAIRIE BASIN

General statement.—Camas Prairie Basin north of Perma is almost 12 miles long from north to south and 5 or 6 miles wide in the middle. Its floor descends gradually from an altitude of about 3100 feet at the north to about 2900 feet at the south and includes a flat from which the surface rises gradually to the moderately steep slopes of the surrounding mountains. At the high stage of the glacial lake (Fig. 3), the mountains on the east and west sides of the basins stood well above the water, but those on the north and south were almost entirely submerged. The arm of the lake in this basin was confluent, therefore, with the arms in Little Bitterroot Basin on the north and Perma Narrows on the south. In addition a strait in Rainbow Lake Pass connected it with the arm in Plains Basin on the west. When the water surface fell 500 feet or to about 3650 feet this pass became dry, and the northern rim partly emerged, thus dividing the water connection to the Little Bitterroot arm among four gaps. As the lake shrank further these gaps became dry, Duck Pond and Big Creek passes at about 3500 feet altitude, Markle Pass at 3400 feet, and finally Wills Creek Pass at 3300 feet. A wide gap at the south emerged when the lake fell about 300 feet more, and, except for the narrow outlet trench east of this gap, the water connection between the basin and Perma Narrows ceased.

Gaps in north rim.—Although they begin and end as it were "up in the air", the four gaps in the northern rim of Camas Prairie Basin carried large and vigorous streams. In Duck Pond Pass a marshy pond

with coarse gravel beyond it, and a bare rock hump, resemble a basin and succeeding bar formed by a south-flowing current plunging over the obstructing hump. Markle Pass and Wills Creek Pass have channel

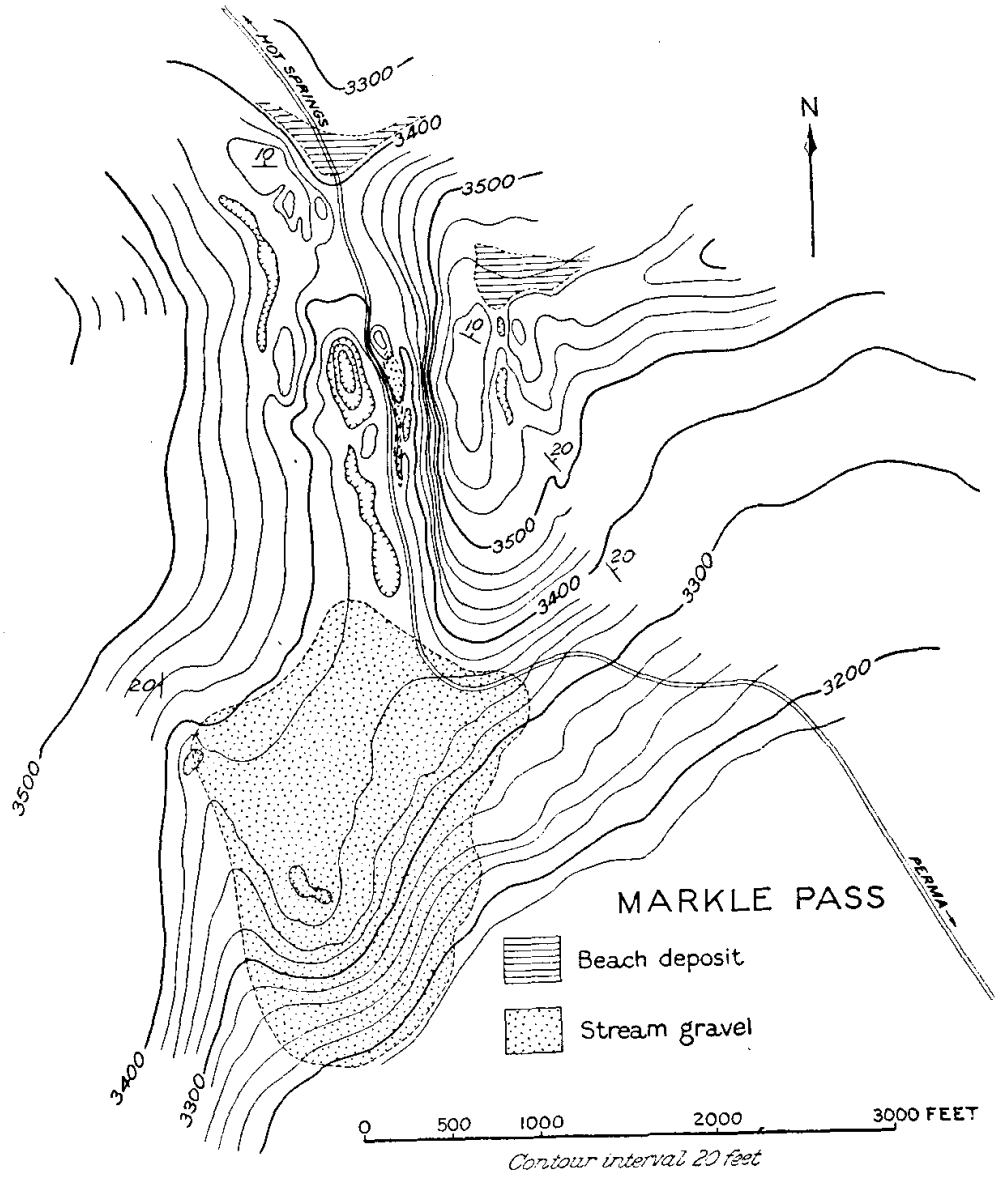


FIGURE 7.—*Topography and geology of Markle Pass*
Areas not patterned represent tilted Belt rocks.

excavations and discontinuous gravel deposits associated with projecting knobs and ridges. In Markle Pass (Fig. 7) an undrained depression 50 feet deep adjoins a prominent knob to which a gravel train is attached on the downstream side. East of the knob Recent talus partly fills another channel, and beyond that, to a height of 100 feet or more, the surface is denuded and channeled. South of the pass

coarse gravel with scattered large angular fragments plucked from ledges within has the form of a bar about 50 acres in extent built out to a height of 150 feet over the slope descending to the basin.

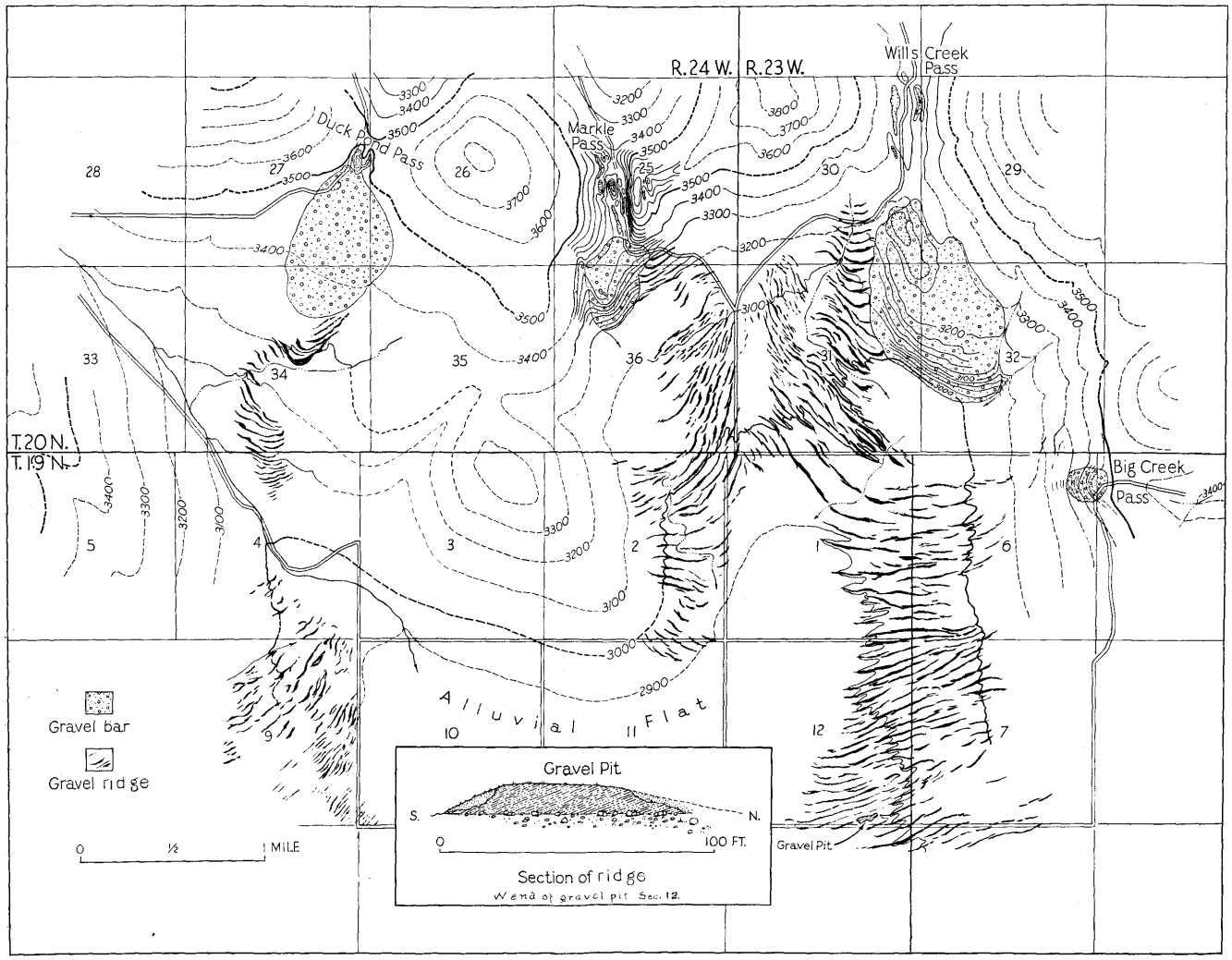
In Wills Creek Pass, channel features are developed on a still larger scale. Along the base of a steep slope at the east side is a pond 1000 feet long. On the west side (Pl. 1, fig. 2) are channels with undrained hollows and bare angular knobs and ridges projecting above discontinuous deposits of gravel. South of the pass a deltaic bar is built out for 1 mile on the slope descending to the basin (Pl. 3). The bar is 200 feet high at the southern end and like the deposit in front of Markle Pass is composed of coarse gravel with large angular fragments plucked from ledges within the channel. In front of Big Creek Pass a relatively small, almost circular barlike gravel deposit is built over a steep slope.

Apparently the inflowing currents were caused by a lowering of the water surface in the arm held by Camas Prairie Basin relative to the surface in Little Bitterroot Basin. Since the channels show no after effects of dwindling currents the flows must have ceased rather abruptly. The evidences described indicate actively eroding currents at least 30 or 40 feet deep in Duck Pond and Big Creek passes, 150 feet deep in Markle Pass, and 250 feet deep in Wills Creek Pass.

Gap at south.—The south rim of Camas Prairie Basin is lowered by a wide gap to within a few hundred feet of the adjacent basin floor and is penetrated east of the gap by a narrow steep-sided outlet trench. Evidences within the gap of a huge outflowing stream include denuded rock surfaces, discontinuous gravel deposits, and basins, some holding bonds or marshes; all are characteristic of stream beds in rocky channels (Pl. 2, fig. 2). One of the larger gravel deposits (B on Pl. 2, fig. 2) rises from a hollow below an obstructing rock hump to a rounded bar. It extends south to the top of the slope descending to the river opposite Perma where it takes the form of a high eddy deposit, a result, apparently, of the commingling of the stream from the gap with that flowing down the Perma narrows.

Rainbow Lake Pass.—Particularly impressive evidences of stream action appear in Rainbow Lake Pass, a steep-sided trenchlike valley (Pl. 4) which extends, at an elevated position, from the northwest corner of Camas Prairie Basin through the dividing range to Plains Basin on the west.

General Form and Relations: The Camas Prairie side of the pass has two entrances that converge near the mountain axis, about a third of the way across. The northern entrance, which is traversed by the



NORTHERN PART OF CAMAS PRAIRIE BASIN

Plains to Elmo automobile highway, is about half a mile wide, and the southern entrance is somewhat narrower. Both commence at an altitude of about 3650 feet at the heads of small valleys that ascend gradually from the floor of the basin some 700 feet below. The pass is about 6 miles long. Its profile descends westward a total of about 50 feet most of which takes place in the branches just above the junction.

Rainbow Lake (Pl. 6, fig. 1) occupies a depression in a narrowed stretch of the pass just below the junction of the two branches. Allowing for small seasonal fluctuations its surface averages about 3600 feet in altitude as determined by aneroid. The lake is fed by two small streams, has no visible outlet, and the water remains fresh.

The pass widens from about half a mile at the lake to nearly a mile where it comes out of the mountains to Plains basin at the west. A view of it from points within the basin, however, is obstructed by a prominent elevation called Locust Hill standing directly in front of the entrance. From Locust Hill a low foothill ridge, parallel to the mountains east of the basin, extends south to the Clark Fork River at Plains (Fig. 4). Between this ridge and the mountains is the relatively narrow valley of Boyer Creek.

South of Locust Hill shelflike terraces are perched along both sides of the foothill ridge within 100 feet of the top. They are about 3550 feet in altitude, 1½ miles long, and toward the south, where the dividing ridge becomes lower, they approach a gap and meet to form a narrow junction. The terrace (Pl. 4) on the western side of the ridge overlooks Plains Basin from a height of 1000 feet. At its southern end the terrace on the eastern side of the ridge is built out about half way across the valley of Boyer Creek and stands about 500 feet above the stream bed. Northward it widens until it extends across the valley. Together these terraces compose Boyer Bench. The Plains to Elmo automobile highway goes up Boyer Creek and gradually ascends the eastern front of the terrace.

CHANNEL EROSION: Rainbow Lake Pass exhibits strikingly the effects of a former large and rapid westward-flowing current. Above the lake the floors of both branches have been severely scoured, exposing the bedrock which remains bare except for a thin rubble of its own fragments loosened by Recent weathering (Pl. 6, fig. 2). The floor is furrowed with channel depressions, several of them holding ponds or marshes (Pl. 4). Upstream angles of prominent knobs are slightly rounded as by water. To a height of 200 feet or more prominent surfaces on the side slopes are bare, though farther up similar surfaces are smoothly covered. The depression occupied by Rainbow Lake re-

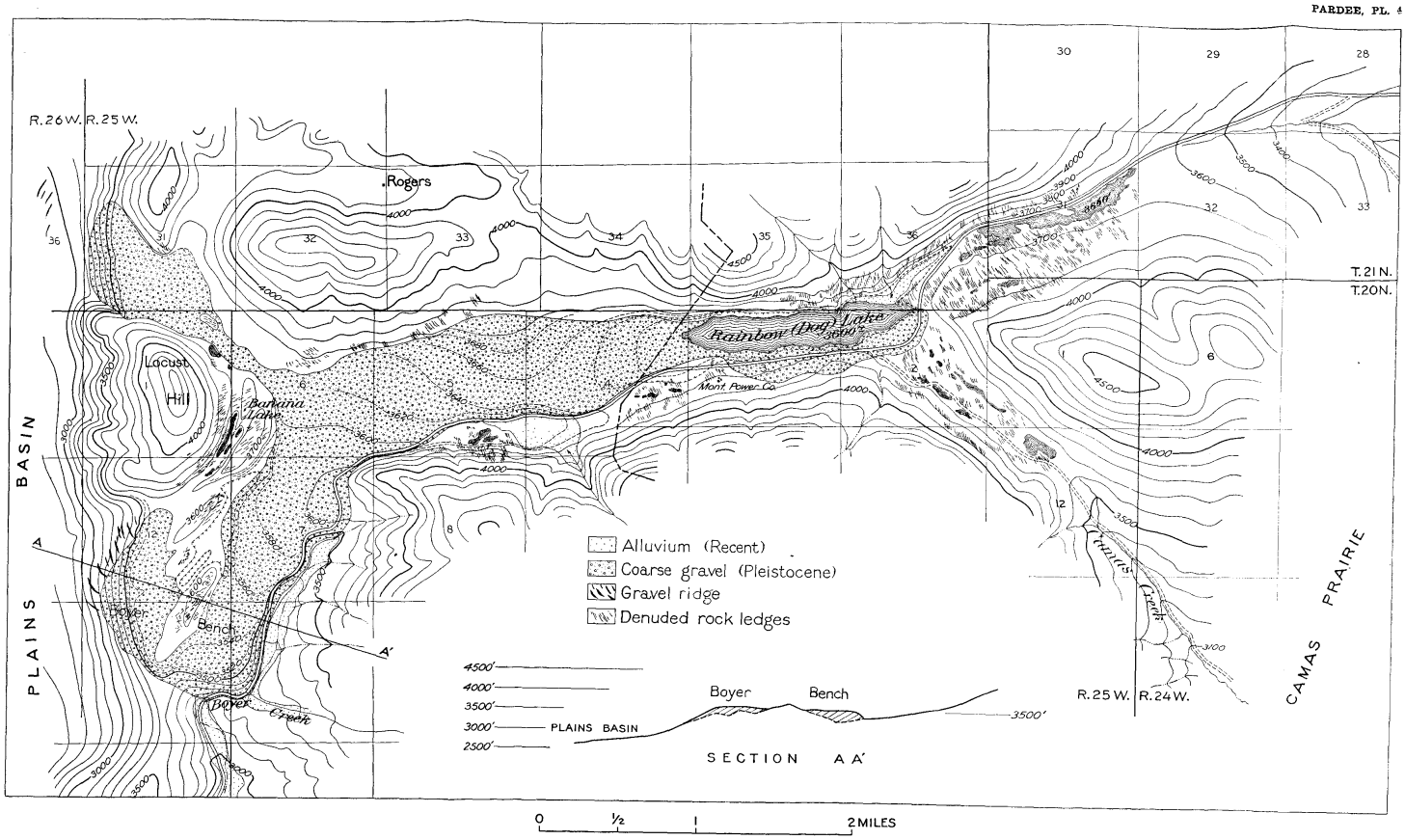
sembles a hollow or "plunge pool" that would be excavated below a rapids by the combined currents from the two branches.

GRAVEL DEPOSIT: Below the lake and along its south side a deposit of coarse stony gravel covers the floor of the pass. Beyond the pass this deposit fills the space to Locust Hill, where it divides into a smaller branch—extending through a gap at the north and expanding in a terrace at the edge of Plains Basin—and a larger branch that turns south into Boyer Creek Valley to form the eastward-facing terrace of Boyer Bench. The entire deposit is poorly sorted, slightly to moderately water-worn pebbles, cobbles, and boulders, most of them between 2 inches and 1 foot in diameter with a variable but generally scanty proportion of smaller pebbles, sand, and silt but no clay. The deposit is not cemented and but slightly compacted. Slightly water-worn to angular fragments, some of them 5 or 6 feet in length, are widely and irregularly scattered through it. A layer 2 or 3 feet thick of "dry gravel," an aggregate of loose stones without sand or other fine matrix, is spread over much of the surface. Included in this layer are fragments of rounded cobbles presumably split apart by frost action since they came to place.

Recent highway excavations along the east front of Boyer Bench expose below the "dry gravel" or other superficial layers a more or less distinct downslope or fore-set bedding (Pl. 8, fig. 1). In some places the beds are lenslike and composed of relatively small pebbles and cobbles in an abundant sandy matrix. In other places the beds are irregular, relatively coarse, and almost without finer material, thus largely consisting of voids. Except for an occasional erratic, the gravel consists of rocks like the outcrops in Rainbow Lake Pass. Most of them are sandstone and argillite of the Prichard formation and Ravalli group which, because of a slaty parting, tend to separate into slabs. A few are blocky fragments of diorite.

Throughout its area the gravel deposit exhibits the surface characteristics of alluvial stream beds. Of these the minor features include ridges, channels, and basins mostly 5 to 10 feet high or deep but which locally reach 40 feet. The larger features are barlike forms. One of these rises gradually from the lower end of the lake to a height of 70 or 80 feet (Pl. 4). The bar is banked along the north side of the pass opposite a denuded slope on the south side that rises from a channel depression, partly filled with Recent alluvium. Another bar is heaped against the south spur end at the entrance to the pass, a position opposite the scoured east side of Locust Hill.

The ridge at the south of Locust Hill gives evidence of having been overflowed by a large stream from the east. Material eroded from it



RAINBOW LAKE PASS

forms the western part of Boyer Bench. The surface of this deposit is somewhat roughened with small channels and basins except along the front where it is smoothed by a deposit of later beach gravel.

These features apparently were formed by a huge current swinging from side to side as it moved swiftly through the pass eroding the outsides of bends and depositing gravel bars on the insides. Beyond the pass the stream severely scoured the opposing slope of Locust Hill. There it divided and a smaller part passing around to the north formed an embankment at the edge of Plains Basin. The larger part turned south into the valley of Boyer Creek, deposited the east-facing terrace of Boyer Bench, and, at the same time, overflowed the dividing ridge and formed the terrace facing Plains Basin. The flow was of brief duration, and both branches followed the tendency of a stream passing into deep water to build out a deltaic bar as the channel bed falls away. Presumably the flow started when the surface of the arm of the glacial lake in Plains Basin fell below the surface of the arm in Camas Prairie Basin. It ceased when equilibrium was restored between the two basins or when the water surface in both fell below the pass.

Giant ripple marks of Camas Prairie.—Camas Prairie is distinguished by a number of unique ridges that have the form, structure, and arrangement of ordinary ripple marks but are so large that the term "ripple mark" seems inappropriate. It is retained, however, for want of a better one. Except for a few inconspicuous ones below Big Creek Pass, the ridges (Pl. 3) are grouped in belts appended to the other three northern gaps—namely, Duck Pond, Markle, and Wills Creek passes, a relationship suggesting formation by currents entering the basin through those channels. The relative scarcity of similar ridges below Big Creek Pass might be explained by the relatively small size of its stream.

The distribution, linear form, and arrangement of the ripple-mark ridges as mapped were obtained from aerial photographs (by the U. S. Forest Service) of the belt below Duck Pond Pass, and by pace and compass traverses of the belts below Markle and Wills Creek passes. An unmapped part of the Wills Creek Pass belt extends 1 mile or more farther south. The ridges range from 1 foot or less to 50 feet in amplitude and from a few feet to as much as 500 feet in wave length, but the mean height is between 15 and 30 feet and the wave length about 250 feet. Most of the smaller ridges occur toward the lower (basinward) ends of the belts, and the exceptionally high ones near the middle. Toward the lower end of the belt in front of Duck Pond Pass the ridges gradually decrease in size until they fade out completely.

Individual ridges are from a few rods to half a mile or more in length. Their axes are slightly curved, and convex forward (toward the basin). Their crests are rather wide and rounded and with few exceptions their cross profiles are asymmetrical, the southern or downstream sides being the steeper. As exposed in a pit in one of the ridges about 3½ miles south of Wills Creek Pass (near the southeast corner of sec. 12, T. 19 N., R. 24 W.) the gravel is largely subrounded pebbles ranging from 8 to 20 millimeters in diameter. Sandy matrix is rather scant, the mass is loosely compacted, distinctly stratified, and throughout the cross section the dip of the bedding is parallel to the steeper south (downstream) side (Pl. 3). Toward the pass the gravel of the ridges coarsens, but no other exposures of the structure were seen. In comparable situations the ridges in front of Markle and Duck Pond passes are of similar composition and texture.

The giant ripple marks lie on a smooth bedrock surface that rises gently from the interior flat to the bordering mountains, and, according to the direction which they happen to take across this surface, their profiles are sloping or horizontal. Toward the passes they are overlain by the bar-like deposit of coarse gravel at the end of each channel. All appear to have been formed by large currents plunging over the north rim and continuing with decreasing velocity out into the basin. Such currents might have formed when the water surface in Camas Prairie Basin first became lower than the water surface in Little Bitterroot Basin thus causing masses of water to pass over the ridge, chiefly through the gaps. The initial direction and momentum of the descending masses of water plus increased specific gravity due to the fine sediment picked up on the way would tend to hold the currents to the bottom for a considerable distance.

Giant ripple marks in plains basin.—Gravel ridges that resemble the giant ripple marks of Camas Prairie and are probably similar in origin appear in two places at the eastern side of Plains Basin below Rainbow Lake Pass (Pl. 4, Sec. 12, T. 20 N., R. 26 W., Sec. 36, T. 21 N., R. 26 W.). They are relatively inconspicuous and were first observed in the aerial protographs. The larger ones (Sec. 12, T. 20 N., R. 26 W.) form a group in the path of the stream which overflowed the ridge south of Locust Hill. They are 10 to 20 feet high, 200 to 500 feet apart, and their axes are normal to the course of a current descending to Plains Basin. A group of lower and less definite ridges (Sec. 36 T. 21 N., R. 26 W.) bear a similar relation to the stream that reached Plains Basin north of Locust Hill.

Stream-denuded surfaces in narrows.—Mention has been made of rock surfaces in the gaps around Camas Prairie Basin, in particular Rainbow Lake Pass, that appear as if washed bare of waste mantle except for

FIGURE 1. BEACHES OF GLACIAL LAKE MISSOULA
Northeast side of Missoula Valley at O'Keefe Creek. Hill is about 1000 feet high, summit is slightly above 4150-foot beach which marks highest lake stage. Aerial photo by U. S. Forest Service.

FIGURE 2. PARADISE NARROWS
High eddy deposit with pond at back outlined at B. Light rectilinear streaks are trenches along major joints or shear zones and partly filled with Recent talus. Aerial photo by U. S. Forest Service.

BEACHES AND HIGH EDDY DEPOSIT

FIGURE 1. RAINBOW LAKE
Fills depression in floor of the pass.

FIGURE 2. BEDROCK FLOOR
Surface denuded of waste. Joints opened by weathering.

RAINBOW LAKE PASS

Recent rubble. A similar condition on a much greater scale appears in the narrows along the Clark Fork and the Flathead rivers through which the ponded waters of the Missoula and the Mission groups of basins escaped. In these sluiceways all humps, knobs, and other convexities of the bedrock that project through the sediments of the valley floor or stand out on the adjoining slopes are manifestly bare of a normal waste mantle to heights varying from several hundred to a thousand feet or more. In contrast, comparable slopes at higher altitudes are smoothly covered, as a rule, to a depth of several feet. Thus in the Alberton Narrows below the Missoula group of basins, prominent surfaces on the side slopes are bare several hundred feet up. Knobs and ridges that project above the present flood plain including rock benches 200 feet high on the south side of the river at the entrance to the narrows, and also just below Alberton, are largely denuded of residual mantle or soil. Farther down, in Quinn's Narrows, similar conditions exist.

To the north in the valley of Flathead River denuded rock surfaces begin to show conspicuously along McDonald Narrows, the first noteworthy constriction of the valley below the Mission group of basins. There a spur projects from the north side of the valley, bare of waste to a height estimated at 1000 feet, the slope above being normally covered (Pl. 7, fig. 3). At Perma, 6 miles farther down, the surface mantle is scoured from a rock bench 400 to 600 feet high (Pl. 2, fig. 3) exposing the small scale irregularities of the rock surface as well as several larger trenches and a basin that holds a pond (Pl. 2, fig. 2).

Continuing down through the Perma and Paradise narrows into Plains Basin and on through the Eddy Narrows (Pl. 1, fig. 3) prominent rock surfaces are likewise denuded to a height of 1000 feet or more above the river.

Along the somewhat wider stretches of Clark Fork Valley between the Alberton Narrows and Quinn's Narrows similar conditions are less noticeable, but even there a normal waste mantle is generally absent from the more prominent knobs and spurs. The moderately wide stretch of valley from Thompson River down to the Idaho State line has not been examined in detail, but the lower slopes of Tuscor Hill and other projecting spurs are noticeably bare.

High eddy deposits.—Sediment from confined turbulent streams active enough to keep their channels clear is commonly deposited in recesses along the sides by eddying currents. The gravel bodies described below are thought to be of such an origin. They are like the eddy deposits of ordinary streams that are confined to steep-sided channels, but their production calls for streams of unusual magnitude.

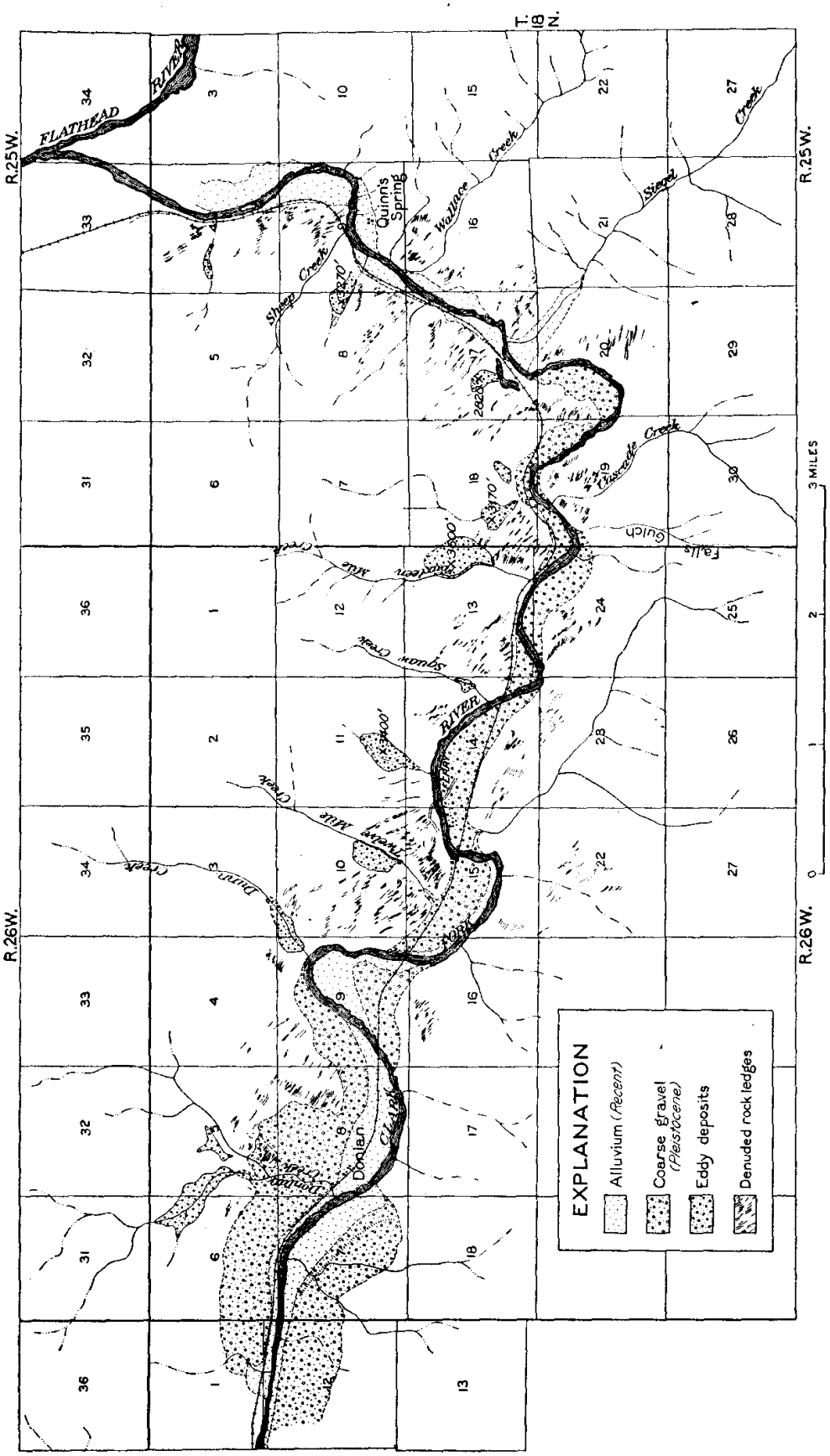


FIGURE 8.—*Quinn's Narrows*

Denuded rock ledges indicated by lines parallel to their trends.

The high eddy deposits occur in side gulches, pockets, or other entrants along the sides of the different narrows. The locations of a number and the heights they attain, as approximately determined by aneroid barometer or triangulation with a Brunton compass, are given in Table 1.

TABLE 1.—*Location and height of High Eddy Deposits in the Clark Fork and Flathead River Valleys*

No.	Location	Height above valley floor (feet)
	PERMA NARROWS (FIG. 5)	
1	Vanderburg Creek (secs. 4, 9)	680
2	E. of Perma (sec. 5)	600
3	W. of Perma (N. ½ sec. 1)	700
4	W. of Perma (center sec. 1)	900
5	W. of Perma (sec. 2)	1000
6	N. of Seepay Creek (sec. 3)	660
7	Burgess Creek (secs. 8, 9)	320
8	E. of Twin Gulch (sec. 4)	300
9	Twin Gulch (Stouts Bar) (secs. 4, 5)	820
10	Robertson Creek (sec. 7)	600
11	E. of Knowles (secs. 5, 6)	840
12	E. of Knowles (sec. 6)	1100
13	NW. of Knowles (sec. 36)	856
14	W. of Knowles (sec. 35)	1200
	PARADISE NARROWS (FIG. 6)	
15	McLaughlin Creek (sec. 21)	610
16	Paradise Gulch (sec. 17)	920
17	W. of Paradise Gulch (sec. 8)	970
18	E. of Henry Creek (secs. 6, 7)	1120
19	Henry Creek (secs. 1, 36)	630
	QUINN'S NARROWS (FIG. 8)	
20	Opposite Quinn's Springs (secs. 8, 9)	790
21	Opposite Siegel Creek (sec. 17)	320

TABLE 1.—*Location and height of High Eddy Deposits in the Clark Fork and Flathead River Valleys—Continued*

No.	Location	Height above valley floor (feet)
22	Opposite Cascade Creek (sec. 18)	575
23	Fourteen Mile Creek (sec. 13)	1035
24	Opposite CCC Ferry (sec. 11)	855
25	Twelve Mile Creek (sec. 10)	645
26	Dunn Creek (secs. 9, 10)	325
27	Donlan Creek (secs. 5, 6)	625
	EDDY NARROWS	
28	S. side below Weeksville	750
29	Poacher Gulch	650
30	Quartz Creek	1000
31	Malone Creek	675
32	Under Kookoosint Ridge	1075

Similar deposits are present in several recesses in Boyer Creek Valley (Fig. 4) along the east side of Plains Basin below Rainbow Lake Pass. More detailed examinations of the different narrows, particularly the more thickly timbered sides, would doubtless reveal others.

The high eddy deposits are characterized by a steep front slope, a rounded top, and a level or gentle back slope as illustrated, for example, by the deposit (No. 16, Table 1) in Paradise Gulch. This body, set somewhat back of the spur end cliffs, begins about 300 feet above the river and rises at a 30-degree slope 600 feet more to a wide rounded top at an altitude of 3400 feet (aneroid). Toward the back its surface descends gradually 100 feet or so to an undrained depression containing a pond (Pl. 5, fig. 2). Back of the depression the buried gulch channel reappears. Another body (No. 18) in the second gulch to the west reaches an extreme height of 1120 feet (about 3500 feet altitude). The profile of its top rises gradually to the west. At the back is a small flat. Still another deposit (No. 9) that is very conspicuous (Pl. 7, fig. 1) from the highway in the valley fills out the lower part of Twin Gulch even with the valley side, its rounded top being about 800 feet above the river. The back slope descends to an alluvial flat drained by a trench at the east.

High eddy deposits formed in gulches with active streams have been more or less washed away. One in the valley of Henry Creek (No. 19) has been separated into two parts, and another (No. 12) in a gulch east

FIGURE 1. STOUT'S BAR
In Twin Gulch on north side of Perma Narrows 2 miles east of Knowles (Fig. 5). Top rises gradually toward left. Maximum height above river about 800 feet. Adjoining rock slopes on right and left cleanly scoured of waste.

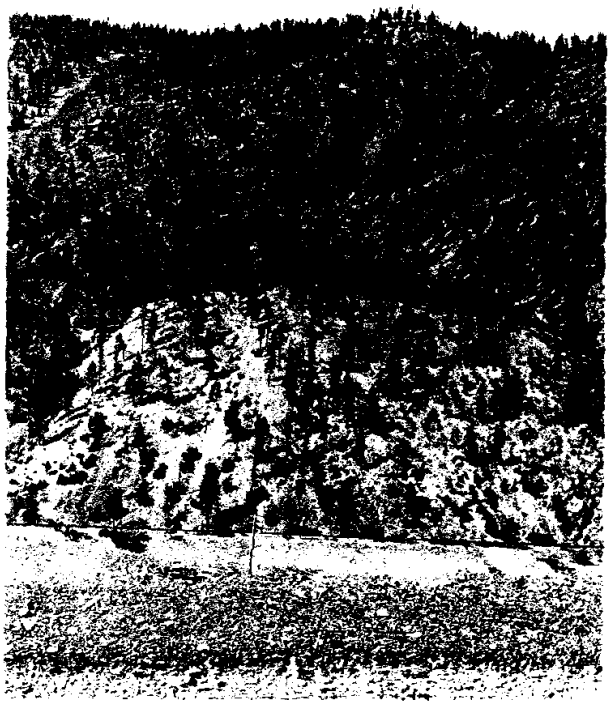


FIGURE 2. NORTH SIDE OF QUINN'S NARROWS OPPOSITE SIEGEL CREEK.

FIGURE 3. NORTH SIDE OF MCDONALD NARROWS
Denuded rock spur with deposit in shallow depression. Varved silt forms terrace at foot of slope.

FIGURE 1. GRAVEL OF BOYER BENCH
Road grade up east front of terrace.

FIGURE 2. BEACHES ON WEST SIDE OF BOYER BENCH
Uppermost beaches turn into gap at right and end in small spitlike embayments.

FIGURE 3. GRAVEL WITH FRAGMENTS OF VARVED SILT
Pit (Fig. 4, Sec. 9, T. 20 N., R. 26 W.) east of Clark Fork River near entrance to Eddy Narrows.

of Knowles has been extensively cut away on the east side. In contrast, deposits that have been protected from stream cutting remain unmodified as illustrated by one in Quinn's Narrows (No. 21) that occupies a niche (Pl. 7, fig. 2) in the valley wall opposite Siegel Creek.

The gravel of the high eddy deposits consists of partly rounded pebbles mostly less than 2 inches in diameter in an abundant sandy matrix. In places the gravel is coarser, and a few large rough slabs like the rock of adjoining ledges usually are scattered through the mass. Gravel pits in deposits on Dunn Creek (No. 26) and on the west side of Boyer Creek Valley just above Plains expose distinct fore-set bedding.

At first glance the high eddy deposits suggest such features as deltas, bay-mouth bars, or terrace remnants of an alluvial valley fill. Attempts, however, to explain them as such meet with difficulties. Their back slopes descend in the opposite direction to the rising surface of a delta, and many of the larger ones are in pockets or disproportionately short gulches. Although a lagoonlike depression is generally present at the back the blockading ridge, unlike the horizontal top of a bay-mouth bar, has a sloping or rounded profile. The deposits, though situated in narrows where wave action was too weak to develop noticeable strand lines, are generally larger than the beaches and bars that were formed by the relatively strong waves in the wider basins. In addition their vertical distribution is without relation to any definite still stands of the lake. An interpretation of the deposits as remnants of a gravel fill of the river valley seems definitely disproved by their forms, vertical distribution, and the lack of correlative remnants of such an extensive deposit outside the narrows. On the other hand their diminutive counterparts may be observed in almost any rough-sided ditch or gutter after a flood has subsided.

Coarse gravel deposits in Clark Fork Valley.—Certain deposits of coarse bouldery gravel in Clark Fork Valley apparently are remnants of more extensive bodies laid down by a huge and rapid stream. One of these partly covered by sand and silt occupies a large area in the western part of Plains Basin. Its cross profile is slightly convex and along the east it has been partly cut away by the river from which it rises as a terrace 100 feet or more high (Pl. 1, fig. 1). Westward it extends to the side of the valley causing Swamp Creek to turn abruptly northward and hug the foot of the mountains (Fig. 4). The form and situation of this body suggests a channel deposit of a huge stream projected from Paradise Narrows, spreading and slackening somewhat as it crossed the basin to the outlet, the Eddy Narrows.

Where it enters the Clark Fork Valley just below the Eddy Narrows, the Thompson River has cut through a superficial layer of comparatively fine gravel (Fig. 2) and exposed a mass of large boulders over which it descends in a rapids. The position of the boulder mass suggests deposition by a huge stream rushing out of the Eddy Narrows.

About 4 miles below the Eddy Narrows a deposit of coarse gravel (Fig. 2), partly concealed by a superficial cover of fine sand, occupies a large area in the Clark Fork Valley adjoining Thompson Falls. From a terrace front facing the river it rises very gradually into a rounded barlike form that extends to the northeast side of the valley and turns the drainage from the mountains to a northward course along its margin. The form, position, and extent of this mass suggest a bar deposited by a stream large enough to have occupied the full width of the valley. Apparently the current turned against the southwest side from which it was deflected across the valley by a precipitous wall (Flatiron Ridge) below Thompson Falls, thus completing a wide bend. The current eroded the outside of the bend and deposited a bar on the inside. In the vicinity of Thompson Falls several large angular rocks lie on or in the gravel deposit. These may have been detached from ledges that crop out just above the town or transported from a distance by floating ice.

AREA AND VOLUME OF THE GLACIAL LAKE

The maximum altitude of the water surface in Glacial Lake Missoula is placed at 4200 feet as indicated by the uppermost of a series of beaches (Pardee, 1910). Repeated checks with the aneroid have indicated that the altitude of the highest definite beach is 4150 feet, although some doubtful beach gravel was found in one place (divide east of Oliver Gulch in T. 21 N., R. 22 W.) near the 4200-foot level. The outline of the lake at the 4150-foot level (Fig. 3) has been prepared with the aid of topographic maps and other surveys that were made after 1910. As thus determined, the area of the lake in round figures was 2900 square miles, and its volume 500 cubic miles. The areas, average depths, and volumes of water held by the different arms of the lake are roughly estimated (Table 2).

DEVELOPMENT OF THE UNUSUAL CURRENTS

Apparently the ice dam failed sufficiently to permit a sudden great outrush of water. The arm of the lake just above the dam was affected first, and there being no obstacle to its free discharge its surface fell rapidly throughout. Beyond Thompson River, however, the outflow was restricted by the Eddy Narrows and successively held back by the

several narrows farther up. The lowered water surface in the arm above the dam induced a strong current through Eddy Narrows which lowered the water surface in the Plains Arm. As a result inflows were caused through Rainbow Lake Pass from Camas Prairie Arm and through the

TABLE 2.—*Approximate areas, depths, and volumes of arms of Glacial Lake Missoula*
The water surface was at 4150 feet altitude.

Arm	Area (Square miles)	Average depth (Feet)	Volume (Cubic miles)
CLARK FORK VALLEY FROM MONTANA-IDAHO STATE LINE TO MOUTH OF FLATHEAD RIVER			
Lower Clark Fork (State line to Eddy Narrows)	465	1400	123.3
Thompson River Valley	115	600	13.0
Eddy Narrows	20	1380	5.2
Plains Basin	90	1350	23.0
Paradise Narrows	10	1330	2.5
FLATHEAD RIVER VALLEY			
Perma Narrows	10	1280	2.4
Camas Prairie Basin	95	870	15.6
McDonald Narrows	25	1200	5.7
Little Bitterroot Basin	260	900	44.3
Jocko Basin	105	900	17.9
Mission Basin	575	1100	120.0
CLARK FORK VALLEY ABOVE MOUTH OF FLATHEAD RIVER			
Quinn's Narrows	35	1200	8.0
Saint Regis River Valley	175	600	18.2
Superior Arm (Quinn's Narrows to Alberton Narrows)	120	940	21.4
Alberton Narrows	30	900	5.1
Missoula-Ninemile Basin	245	740	34.3
Bitterroot Basin	405	700	53.7
Hellgate Arm (Clark Fork Valley above Missoula Basin)	50	150	1.4
Blackfoot River Valley	65	440	5.4
Totals	2895 square miles		520.4 cubic miles

Paradise and Perma Narrows from that and other arms farther up (Fig. 9). The consequent lowering of the water surface in the Camas Prairie Arm caused an inflow across the submerged northern rim. In succession the other narrows released outflows from the more distant basins. The subsequent behavior of the currents thus generated was controlled largely by such topographic relations as the distribution and capacities of the different basins, the lengths and cross sections of the narrows, and in particular the "bottle necks" formed by the Paradise and Eddy narrows.

VOLUME AND DURATION OF THE UNUSUAL CURRENTS

Evidently the streams were of unusual size but were short-lived because of limited water supply. No precise data, of course, are available. The

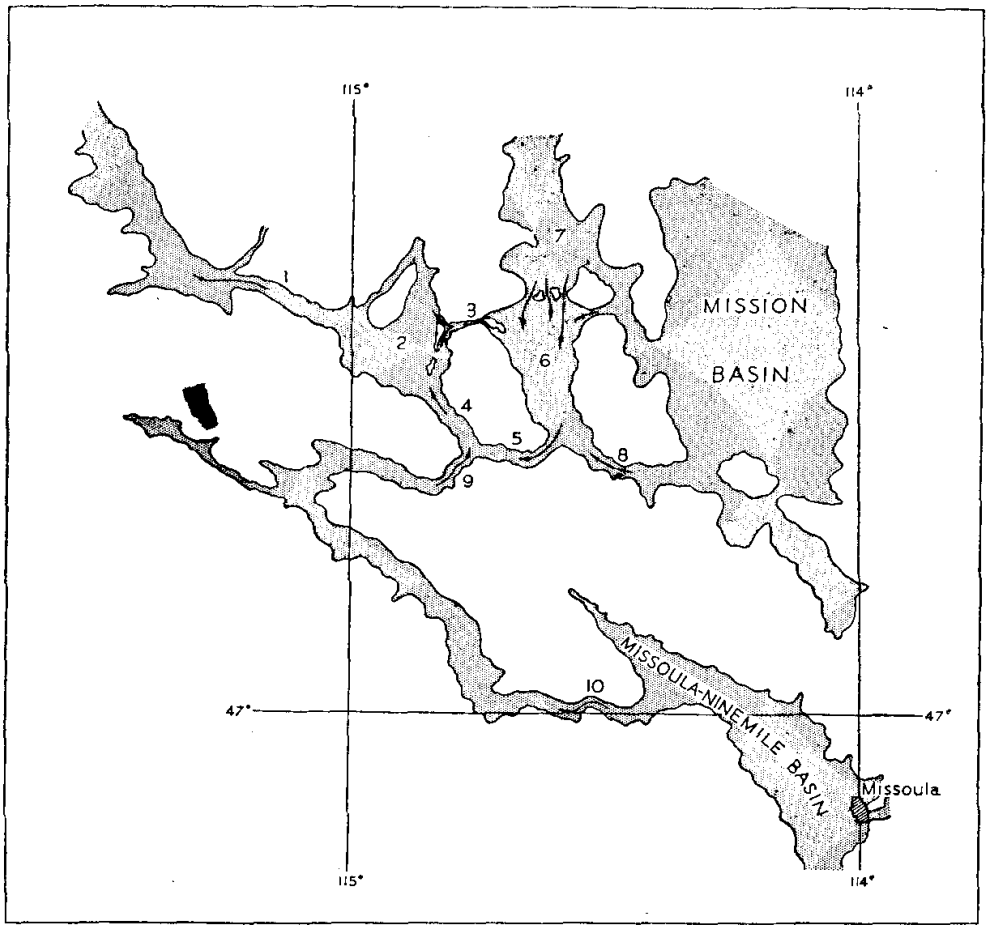


FIGURE 9.—*Central part of Glacial Lake Missoula*

Medium stage.

1. Eddy Narrows.
2. Plains Basin.
3. Rainbow Lake Pass.
4. Paradise Narrows.
5. Perma Narrows.
6. Camas Prairie Basin.
7. Little Bitterroot Basin.
8. McDonald Narrows.
9. Quinn's Narrows.
10. Alberton Narrows.

following results, based on formulas for small streams, are introduced merely to give some idea of their size.

Eddy Narrows provided a nearly straight sluiceway 10 miles long with no very prominent projections along the sides to hinder the flow. As indicated by its high eddy deposits and the denudation of its sides the stream was at least 1000 feet deep. Available information of the upper limit is not precise enough to permit a satisfactory determination of the surface gradient, which is therefore assumed to have been the same as the average

descent of the present river bed—namely, 2.3 feet per mile through the 10 mile stretch of the narrows. The average cross section is about 5,900,000 square feet, and the wetted perimeter 9600 feet. Using these figures with the Chezy formula (Merriman, 1931) for rough stone channels gives a velocity of 52.3 feet per second. According to the formula adopted by Manning (Lindquist, 1934) the same figures would indicate a velocity of 78 feet per second. The velocity of the eddying currents is rather closely related to that of the main stream (Leighly, 1934). As determined by a maximum pebble size in general of 3 inches (76 mm. approximately) the currents that formed the high eddy deposits had (Hjulstrom, 1935) a velocity of about 65 feet per second which may be assumed as about the same as the main current. Incidentally, this figure happens to be the mean of the two other determinations. Accepting it as approximately correct the flow through the Eddy Narrows would appear to have reached a peak of 386,500,000 second feet or about 9.46 cubic miles per hour. As only about 380 cubic miles of water was impounded above the Eddy Narrows the maximum flow could not have continued for long. The maximum discharge of the Mississippi River at Natchez in the flood of February 1937 (Williams and Crawford, 1939) was 2,100,000 second feet or about .05 cubic mile per hour.

Sufficient data are not available for even rough estimates of the flows carried by the other narrows or by the wind gaps around Camas Prairie or by Clark Fork Valley near the ice dam. However, according to data compiled by Hjulstrom (1935) the velocity of the stream that formed the giant ripple marks is indicated at one place (gravel pit in SE¼ sec. 12, T. 19 N., R. 24 W.) by a maximum pebble size of 40 mm. to have been 7 feet a second. This current presumably was at least twice as deep as the ripple marks are high, or about 100 feet, and it may have occupied the full width of the basin floor; obviously no estimate is possible without more data.

AGE OF THE UNUSUAL CURRENTS

Although they have remained exposed since the water subsided, the giant ripple marks and other features produced by the unusual currents show very little effect of weathering. Rock surfaces stripped of their surface mantle remain bare except for a relatively thin new cover. Talus aprons generally do not reach more than one third to half way up a cliff (Pl. 2, fig. 1). Except for later stream trenching in a few places, the giant ripple marks look as though they had just emerged. Where protected from stream erosion the high eddy deposits are likewise unmodified. Few of the many channel depressions in the wind gaps

around Camas Prairie Basin have become filled. Large parts of the coarse gravel deposits in Plains Basin and Clark Fork Valley at Thompson Falls have survived attacks by the river. Altogether these conditions suggest an age not greater than Middle Pleistocene.

LAST STAGE OF THE GLACIAL LAKE

Either the rapid outflow was greatly slowed when the lake was partly drained or, if it had become emptied, the basin soon thereafter became, partly at least, refilled, and in this new body of water no unusual currents seem to have developed. The evidence for this delayed drainage or refilling consists mainly of beaches formed on the current-produced features of the preceding outflow.

A series of small beaches are plainly visible on the side of Boyer Bench facing Plains Basin (Pl. 8, fig. 2). From rather faint lines below Locust Hill they become more definite southward where the higher ones, as they turn eastward around the terrace, end in small spitlike embankments. Elsewhere rather faint strand lines are visible on a high eddy deposit along Vanderburg Creek east of Perma (NW¼ sec. 9, T. 18 N., R. 23 W., Fig. 5) and on the basinward side of the coarse gravel deposit in front of Wills Creek Pass (Pl. 3). A small gravel bar continuous with a beach at 3400 feet altitude lies across the lowest part of the stream channel of Markle Pass at its northern entrance. Another blocks the north entrance to a channel about 140 feet higher (Fig. 7). A similar relation between beaches and channel features exists at the northern entrance to Wills Creek Pass.

The highest of the later beaches is at 3540 feet. Whether that figure is the upper limit of the last submergence cannot be positively stated. Where the outflow features are absent present knowledge of the beaches is not sufficient to distinguish the younger from the older.

A relatively slow current during the final outflow may have formed the gravel bar in Plains Basin east of the river near the entrance to the Eddy Narrows. As exposed by a pit along the highway (Pl. 8, fig. 3) the gravel is fine-textured (about 15 to 20 mm., pebble size), clean, and its bedding fore-set. The gravel rests on a platform about 50 feet higher than the river and contains fragments of the varved silt.

SUMMARY

Failure of the ice dam in the Clark Fork Valley near the Idaho-Montana State line permitted the rapid draining of Glacial Lake Missoula estimated to have held 500 cubic miles of water. Rapid falling of the water surface caused huge currents in the narrows between sub-

merged basins. Current-produced features include the unique giant ripple marks of Camas Prairie, a series of gravel ridges having the form, structure, and arrangement of ordinary ripple marks but of incomparable size. The flow through Eddy Narrows is estimated to have reached a maximum of nearly 9½ cubic miles an hour. After the outflow the basin again held a lake which drained away slowly.

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