GEOLOGY OF POWER SITES ON THE UPPER TRIBUTARIES OF THE COLUMBIA RIVER IN IDAHO AND MONTANA

PART 4. INTERIM REPORT ON SELECTED POWER SITES BETWEEN MILES 36 AND 72, FLATHEAD RIVER BELOW FLATHEAD LAKE, LAKE AND SANDERS COUNTIES, MONTANA

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PART 4. INTERIM REPORT ON SELECTED POWER SITES BETWEEN MILES 36 AND 72, FLATHEAD RIVER BELOW FLATHEAD LAKE, LAKE AND SANDERS COUNTIES, MONTANA

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SUMMARY AND CONCLUSIONS

Six potential power sites occur on the lower Flathead River between river mile 36.0 and the Kerr Dam, which is at mile 72.0. The head available between these points is 175 feet.

The reach of the river that contains the power sites is located along the western edge of the Mission Valley, one of the connected intermontane valleys or compartments of the Rocky Mountain Trench in Montana. The rocks involved in the abutments and foundations of the dam sites include hard, fine-grained, gray to light-gray quartzite and sandy argillite and greenish-gray argillite of the Precambrian Ravalli group; weathered talus breccia, conglomerates, sandstone, siltstone, a reddish-brown, gritty clay or microbreccia, and volcanic tuff of supposed Tertiary(?) age; till, glacial lake-bed silts, and glacial outwash gravel and sand of the Pleistocene epoch; and Recent alluvium.

Buffalo dam site No. 1. This site is between miles 67.9 and 68.4 in the NE¼ sec. 21 and NW¼ sec. 22, T. 22 N., R. 21 W. Four possible axes were studied. The one designated as line 4 is considered to be the best, as very good quartzite and sandy argillite are in the foundation and abutments, with no faults or other known structural defects. This axis is suitable for a concrete dam. The Montana Power Co. has partially explored line 1 with 13 core holes, but this axis seems infeasible even for an earth-fill dam unless an expensive core wall is constructed in the pervious fluvial material in the left (southeast) abutment. Line 2 is infeasible for the same reason. Line 3 has quartzite in the abutments and foundation, but the cross section is much larger and a fault may be present in the foundation. A total head of 64 feet can be developed at any of these axes by excavation of the stream channel between the powerhouse sites and the downstream end of the canyon. (See pl. 1.)

Buffalo dam site No. 2 is at mile 60.7 in the N½NE¼ sec. 1, T. 21 N., R. 22 W. There are very good beds of sandy argillite and quartzite present in the right (west) abutment and beneath a part of the river channel. The remainder of the channel is underlain by interbedded gritty clay or microbreccia, siltstone, sand, sandstone, conglomerate, and slightly reworked talus breccia of Tertiary(?) age. The left (east) abutment is formed by glacial lake-bed silts underlain by till and possibly by pervious reworked glacial material.

A small landslide is in the left abutment. The Montana Power Co. has explored the site with 38 core drill holes, but additional exploration of the left abutment by test pits and trenches is necessary because of poor core recovery there. The possibility of gravel lenses in or below the glacial lake bed silts, and the easily erodible silts themselves, make it appear that the left abutment may meet only minimum requirements for a safe site. A concrete spillway and other appurtenant works could be placed on the right abutment but the left abutment would be feasible only for an earth-fill dam. Ninety feet of head can be developed. (See pl. 2.)

Sloan Bridge power site. The dam site is at river mile 44.7 in the SE¼NW¼ and NE¼SW¼ sec. 18, T. 20 N., R. 21 W. The right (south) abutment is quartzite, but the foundation and left (north) abutment are massive till. Three thin, continuous layers of clean to very dirty gravel occur in the till. The one at elevation 2,578 feet averages about 14 inches in thickness and is the most pervious. Treatment by blanketing the outcrop up- and downstream from the dam should reduce percolation losses and velocity of the water moving through this bed to safe values. The site is a very good one for an earth dam.

This power site would allow four possible schemes for the development of the river. A powerhouse at the dam could develop 146 feet of head. By construction of a 1-mile diversion tunnel and pressure conduit from the arm of the reservoir in the Little Bitterroot Valley to a powerhouse at mile 39.0, a head of approximately

167 feet is available. Possibly this could be increased up to a maximum of 191 feet by excavation of the river channel downstream from the powerhouse. By construction of a 7-mile diversion tunnel and opencut conduit from the Little Bitterroot Valley to a powerhouse at mile 13.0, a head of 225 feet is possible for the power site. The geologic feasibility of this tunnel route was not investigated, but a study would be worthwhile.

Two diversion routes are possible to the powerhouse at mile 39. That preferable geologically has a total length of about 5,560 feet and would involve about 2,840 feet of pressure tunnel, about 2,370 feet of pressure conduit laid in an opencut, and about 350 feet of penstock. The alternative is 330 feet shorter but has a longer pressure tunnel section of about 3,780 feet, about 1,100 feet of pressure conduit, and 350 feet of penstock. The powerhouse site is on rock of fair quality. (See pl. 3.)

Oxbow dam site. Location is at mile 41.3 in the NE¼ sec. 28, T. 20 N., R. 21 W. Quartzite and sandy argillite of good quality are in the left (southeast) abutment. The river channel has been cut partly in gravel and sand that fill an old meltwater channel and in a thick, massive layer of till. In the foundation the till is 85 to 100 feet thick, and beneath the right (west) abutment it is about 150 feet thick. Glacial lake-bed silts and very fine-grained sand underlie the till, and carry artesian water. About

115 feet of pervious sand and gravel overlies the till and forms a portion of the right (northwest) abutment. The feasibility of the site depends upon tying the right abutment to till exposure north of the site and in determining the effect of the artesian water on the foundation. Maximum head available at the site is 157 feet. (See pl. 4.)

Mile 42.9 power site. Location is in the SE¼ sec. 17, T. 20 N., R. 21 W. Till is in the left (east) abutment, in the foundation below the active alluvium, and possibly to 2,670 on the right (west) abutment, with very fine-grained sand and glacial lake-bed silts above this. The site is feasible for an earth dam, and 150 feet of head could be developed. Detailed investigation has not been made; and the locality is mentioned here only as a possible alternative to Oxbow dam site.

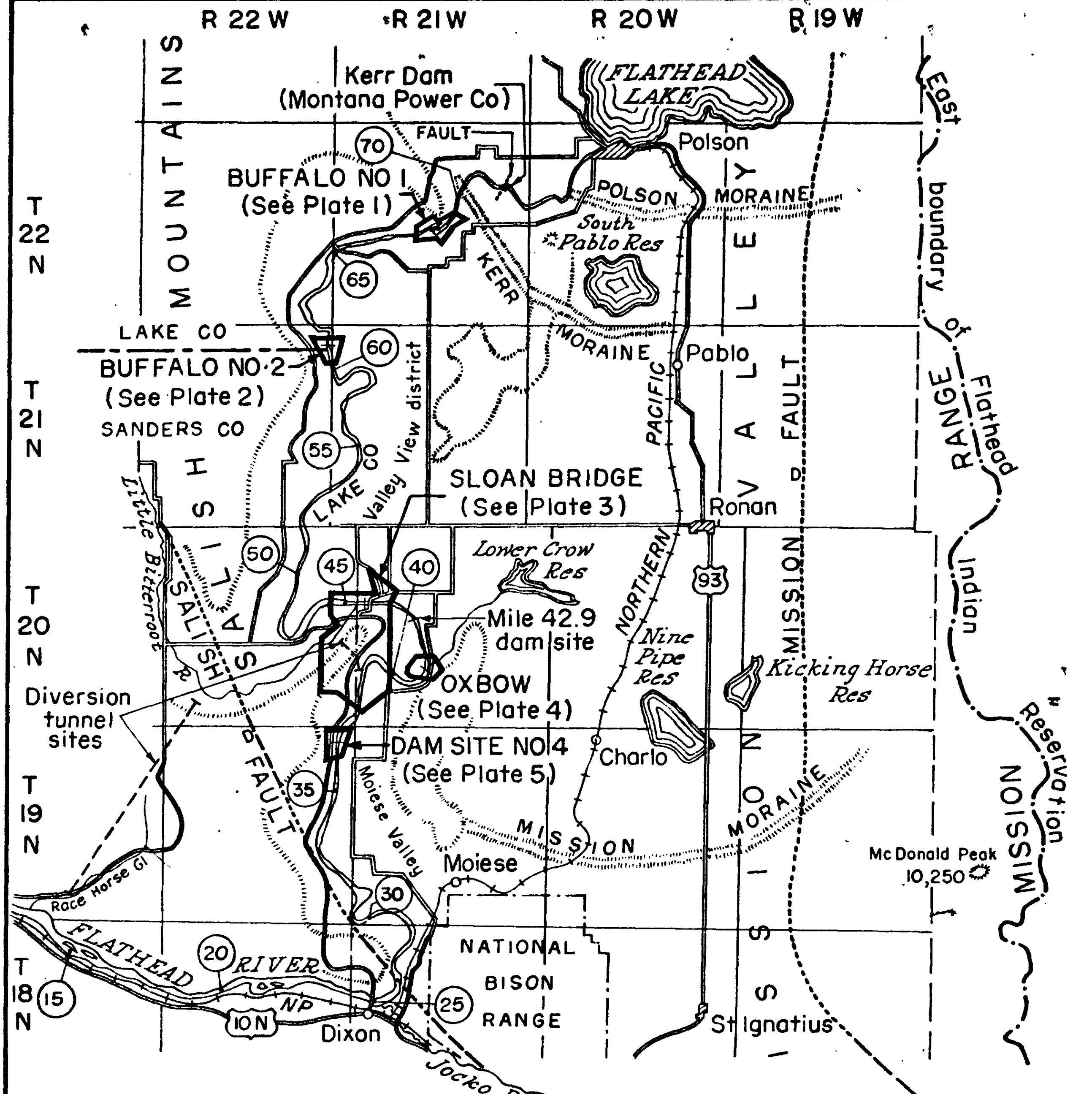
Dam site No. 4. This site is at mile 36.4 near the center of sec. 1, T. 19 N., R. 22 W. Very good argillite of the Ravalli group is in the right (west) abutment and part of the foundation. Tertiary(?) talus breccia overlies the Ravalli in the foundation and is at depth on the left (east) abutment. It is in turn overlain by interbedded glacial lake-bed silts, till, and sand to 20 to 25 feet below the river surface at 2,530. Core recovery above approximate altitude 2,510 feet in seven drill holes on the left abutment was too poor to determine definitely the character of the material, but the abutment appears to be composed of open, pervious sand and gravel and some beds of silt. Additional exploration is required, but unless water can be prevented from entering or moving through the permeable gravels, the site is not feasible. (See pl. 5.)

INTRODUCTION

Object of the Investigation

This report describes geologic conditions at six potential power sites on the Flathead River from mile 72.0 to 36.0 in the Flathead Indian Reservation, Lake and Sanders Counties, Montana. The sites were examined to determine their limiting geological features and to outline the next steps necessary for an orderly and complete investigation.

The investigations on which this report is based are a part of the continuing program of evaluating the water-power potential of streams affecting public lands in order to classify and reserve by withdrawal from entry lands potentially valuable for water-power development, as well as appraise the water-power value of lands that have been previously withdrawn to determine if retention in a withdrawal is justified in light of currently available information. Geologic investigations are considered an integral part of an evaluation of water-power resources as the relation between the geologic feasibility of dam sites, reservoir sites, tunnel routes, and powerhouse sites, and water-power potential is obvious.



EXPLANATION

(25) River mileage
With respect to mouth of river

INDEX MAP OF POWER AND TUNNEL SITES
LOWER FLATHEAD RIVER
FLATHEAD INDIAN RESERVATION
LAKE AND SANDERS COUNTIES, MONTANA

Previous Investigations

An investigation of the potential power and reservoir sites on the lower Flathead River from Flathead Lake to the confluence of the stream with the Clark Fork River was made by E. C. LaRue (1913). Previous to this, the U. S. Reclamation Service, the Indian Service, and a few private individuals had investigated the possibilities of producing power in the reach of the river from the lake outlet to the vicinity of the present Kerr Dam.

From 1936 to 1945, the U. S. Geological Survey mapped the Flathead River from its confluence with the Clark Fork of Columbia River to the Kerr powerhouse at mile 72.0. About 1.5 miles of the Clark Fork downstream from the confluence was mapped, also. A standard river-survey map of the lower Flathead River was published (U. S. Geological Survey, 1947) on a scale of 2 inches to the mile (1:31,680), with a contour interval of 20 feet on the land and 5 feet on the river surface. Four prospective dam sites were mapped at scales of 1:4,800 to 1:12,000, with a contour interval of 10 feet on the land and 1 foot on the river surface. Three of them: Buffalo dam sites Nos. 1 and 2, and Dam site No. 4, had been selected previously by E. C. LaRue. However, Buffalo dam site No. 1 of the river-survey map originally was called Dam site No. 2 by LaRue. The Montana Power Co. now refers to this site as the Buffalo Rapids dam site. Buffalo dam site No. 2 of the present report was called Dam site No. 3 by LaRue. Dam site No. 4 also was named by him and still retains that name. Oxbow dam site was selected and named by Arthur Johnson from a study of the river-survey map. The Mile 42.9 dam site was noted by him, but was not mapped because of better topographic conditions at Oxbow dam site.

In 1941, the Corps of Engineers, Portland, Oregon District, explored the foundations of Buffalo dam sites Nos. 1 and 2, Oxbow dam site, and Dam site No. 4 by seismic methods. In 1945, the Seattle, Washington office of the Corps of Engineers drilled four churn drill holes at the Oxbow dam site. The locations of the seismic lines are shown on plates 1, 2, 4, and 5, and the seismic data sheets and logs of the drill holes are included in the Appendix.

The geologic structure and history of the Rocky Mountains in the vicinity of the Mission Valley has not been investigated in detail, but the geology of the area is covered by the Geologic Map of Montana (1955). A report by Clapp (1932) contains a reconnaissance geologic map of northwestern Montana with a structural cross section through the southern part of the Mission Valley. Pardee (1950, p. 359-406) has outlined the Tertiary history of northwestern Montana, and the Pleistocene history has been discussed by Pardee (1910, 1942, 1950), Campbell (1915), Davis (1920), Noble (1952), and

Alden (1953). The paper by Noble is the most comprehensive and detailed study of the glacial history and deposits of the Mission Valley, related glacial features of the Mission Range, and history of glacial Lake Missoula.

Present Investigations

The first stage of field investigation extended from September 9 to November 1, 1953. During this period the dam sites designated as Buffalo dam sites Nos. 1 and 2, Oxbow, and Dam site No. 4 were examined. Many unfavorable geologic features were noted at all but the first. Particular attention was given to the Oxbow site, as development there would utilize about 90 percent of the available head in the reach of the river under consideration, mile 36.0 to 72.0. In view of the unfavorable geologic conditions noted at this site, an office study was made for possible alternatives. An alternative site that appeared favorable topographically was found at mile 44.7, just upstream from Sloan Bridge, and was therefore designated as the Sloan Bridge power site. Field reconnaissance in May 1954 indicated that the dam site and related features were geologically feasible. Recommendations were made for a special topographic map of the area involved. This map was prepared and issued as a supplemental sheet to Plan and Profile of Flathead River, Mouth to Flathead Lake.[1/] Advance

1/ Plan, Flathead River, Montana, Sloan Bridge Dam Site. Scale 1:12,000; Contour interval 20 feet. Published 1956.

copies became available on November 1, 1954, and the area was mapped geologically during the period November 3 to 20, 1954.

The Montana Power Co., in compliance with preliminary permits from the Federal Power Commission, has carried out a program of core drilling at three of the sites considered in this report. Thirteen holes were drilled along tentative axis A-A' at Buffalo dam site No. 1, 38 holes at Buffalo dam site No. 2, and 7 holes at Dam site No. 4. The locations of these holes are shown in the plates relating to the respective sites. The drill cores were made available for examination by the Geological Survey by courtesy of the Montana Power Co. The logs of the drill cores are included in the Appendix.

Supervision and Acknowledgments

Many thanks are due those who participated in the work leading to preparation of this report. The work was carried on under the supervision of C. E. Erdmann, regional geologist, of the Geological Survey, Great Falls, Mont. His outline of the geological problems and critical reviews of the findings, proposals, and report are reflected throughout. Arthur Johnson, Chief, Water and Power Branch, U. S. Geological Survey, supervised the mapping of the stream and dam sites from 1936 to 1945, and procured the Sloan Bridge dam site map. He and F. A. Johnson, regional hydraulic engineer, Tacoma, Wash., have

offered encouragement and advice on certain phases of the proposed development schemes. Miss R. A. M. Schmidt assisted briefly with the mapping on Buffalo dam site No. 2, and W. L. Rohrer assisted with the reconnaissance of the Sloan Bridge power site.

The Corps of Engineers, Seattle, Wash., supplied the results of its seismic investigations at Buffalo dam sites Nos. 1 and 2, Oxbow dam site, and Dam site No. 4, as well as logs of the churn drill holes at Oxbow dam site.

The Montana Power Co. furnished the drill cores from its exploratory work at Buffalo dam sites Nos. 1 and 2, and Dam site No. 4. H. H. Cochrane, consulting engineer, and C. M. Jones, construction engineer, Montana Power Co., supplemented these basic geologic data with collateral discussions of river development, and also visited the Sloan Bridge power site with the writer.

GEOGRAPHY

Northwestern Montana is in the Northern Rocky Mountain physiographic province. The mountain ranges vary in trend from a few degrees west of north to almost west; and some of the northwest ranges are separated by long, narrow, intermontane valleys. Because of their general regularity and continuity, steep parallel walls, and more or less flat, open bottoms, Daly (1912, p. 26) called such valleys "trenches," and named the most prominent and persistent the Rocky Mountain Trench. This feature can be recognized in British Columbia as a continuous depression over a distance of about 900 miles, and it continues 130 miles southeast into Montana where it appears to broaden, shallow, and lose its identity in the vicinity of Dixon and St. Ignatius. Although the mechanics of its origin are unknown, any lineament a thousand miles or more in length obviously must be of tectonic origin; and, for British Columbia, North and Henderson (1954, p. 62) have remarked, "The Trench appears to form the physiographic and structural boundary between the Rocky Mountains on the east and the en echelon ranges of the Interior Cordilleran systems on the west." Quite likely this relationship also pertains southward in Montana. The floor of the Trench does not have a continuous gradient, and low stream divides separate it into a number of basins or compartments. Those in Montana are, from north to south: Tobacco Plains, Flathead Valley, and Mission Valley.

Mission Valley

Mission Valley is approximately 30 miles long and extends south from the town of Polson on Flathead Lake to the National Bison Range on the south. Width varies evenly from 14 to 16 miles between the high and imposing Mission Range escarpment on the east and the low range to the west known as the Salish Mountains.[2/] (See fig. 1.)

2/ The low mountain range along the west side of the Rocky Mountain Trench has been known for years as the Flathead Mountains (Daly, 1906). In view of the conflict of this name with the much better known and more imposing Flathead Range east of the South Fork of the Flathead River (U. S. Geological Survey, Nyack quadrangle), Clapp (1932, p. 14) suggested that the name of the Flathead Mountains be changed to "Salish" Range, the Indian name of the Flathead tribe, and which has not otherwise been used. In the meantime, Erdmann (1941, p. 7, footnote 22) noted that "Salish" was apparently a misspelling of Salish; and the name Salish Mountains was used subsequently in one of his reports (1947, p. 141). This usage will be continued in this report.

All of this area lies within the Flathead Indian Reservation, whose Agency is near Dixon; and an abundance of water for irrigation, good soil, and mild climate make it one of the richest farming communities in the state.

From near Moiese to the shore of Flathead Lake west of Polson, the flat floor of the valley is diversified by a series of low rock and morainal hills that stand one-quarter to one-half its width out from the west side. In Tps. 19 and 20 N., R. 21 W., the southern group of these hills separates a small compartment known as Moiese Valley from the eastern part of Mission Valley; and the hills in T. 21 N., R. 21 W., and T. 22 N., R. 20 W., mark off the Valley View district in a similar manner. There seems to be no reason to doubt that the preglacial Mission Valley lay to the east of this ridge and contained the ancestral Flathead River as a south-flowing stream. These side valleys and Mission Valley have been integrated topographically by glacial fill whose distribution and composition will be mentioned in the section on Glacial Geology.

Flathead River

Terminology and location

The Flathead River, one of the upper tributaries of the Columbia River, has its headwaters in the mountainous area in western Montana between the Continental Divide and the Rocky Mountain Trench. Only a few small streams enter the river from the country west of the Trench. From Columbia Falls to Dixon for a distance of about 95 miles, the river flows south in the Trench. The middle third of this section is occupied by Flathead Lake, one of the largest bodies of fresh water in the western United States. Upstream from the lake the river is referred to as the upper Flathead River, and the section downstream from the lake is referred to as the lower Flathead River.

Lower Flathead River discharges from the southwest corner of the lake. From the outlet the stream flows about 12 miles west southwest and then turns and flows along the west sides of the Valley View district and Moiese Valley. These areas, this reach of river, and the dam sites along it are the only elements of Mission Valley of immediate concern to this report. Lower Flathead River leaves the Moiese Valley section of Mission Valley at Dixon and flows west for about 25 miles to its confluence with the Clark Fork of the Columbia River 2.5 miles east of Paradise.

Stream gradient

Before construction of Kerr Dam, which was placed in operation April 11, 1938, the average unregulated level of Flathead Lake stood at about altitude 2,880 feet. The lake level was maintained by a series of resistant bedrock ledges extending southeast from the Salish Mountains, across which the outlet stream has been superimposed for a distance of about 10 miles. The river drops about 240 feet in crossing this barrier, which terminates at mile 67.55; and its profile throughout is generally convex, with occasional local gradients as high as 35 feet per mile. Rather than a characteristic of physiographic youth, however, some of this convexity may be due to exhumation of the southwest slope of the buried mountain ridge. This is the stretch of good sites for masonry dams, with rock in stream bed and canyon walls. Kerr Dam has been built in the middle part at mile 72.05. With maximum pool level at altitude 2,893, a 5-mile stretch of the upper rapids is drowned out, and Flathead Lake is utilized as a reservoir. Buffalo dam site No. 1 is located at mile 68.4 just upstream from the lower end of the rock barrier. The average gradient from the last rock exposures at the downstream end of the gorge to tailwater at Kerr Dam is about 14.5 feet per mile, with occasional short slopes of 17 to 20 feet per mile; which means, of course, that storage capacity in the canyon section is very limited.

The remainder of lower Flathead River from its confluence with the Clark Fork River to the mouth of the gorge section at mile 67.55 exhibits a normal, but very flat, hyperbolic profile. It is divided naturally into the upstream section between mile 67.55 and the mouth of Jocko River at mile 25.4, and a downstream section from the Jocko to the temporary base level of the Clark Fork at mile 0. The upstream section of 42.1 miles has an average gradient of about 3.2 feet per mile, with only an occasional very short length in excess of 5 feet per mile. Five of the 6 dam sites described in this report occur in this stretch, and the river's regimen over the soft, poorly consolidated Tertiary and Pleistocene valley fill has had such a marked effect upon the characteristics of the sites that, where they are suitable at all, wide-base dams are required. Also, the low banks and the low gradient requires fairly involved plans to develop maximum power drops and storage capacities.

The 25.4-mile terminal course of the river apparently occupies an extension of the well-graded consequent valley of Jocko River, but the name lower Flathead prevails because that stream has the greater discharge. The gradient of this stretch is only about 1.5 feet per mile. No dam sites have been designated along it as yet, and no geologic examination has been made.

STRATIGRAPHY

Rock formations at the dam sites are the Ravalli group of the Precambrian; Tertiary(?) talus breccia and lake-bed deposits; Pleistocene glacial deposits; and Recent alluvium.

Precambrian

The Ravalli group is a monotonous assemblage of argillite, quartzite, and siliceous shale, whose total thickness is estimated to be about 9,000 or 10,000 feet in the area covered by this report. Boundaries of the group were not observed, and the underlying formation is unknown. The top, however, is defined by the Siyeh or the Wallace formation, so the group comprises a large element of the lower part of the Belt series.

Various workers in the Northern Rocky Mountains have divided the Ravalli group into two or three formations, none of which are persistent regionally. As a matter of fact, the formations were defined first and the group name was given later because of the difficulty with which the units could be recognized. Clapp (1932), following the pioneer work of Bailey Willis, recognized a three-fold division into the Grinnell, Appekunny, and Altyn formations, in descending order, in Glacier National Park, the Altyn not being present west of the Continental Divide. Erdmann (1947, p. 130) found interfingering of the gray-green Appekunny with dull purplish-red rocks like the Grinnell in Bad Rock Canyon, where the Flathead River crosses the north end of the Swan Range. West and south of Bad Rock Canyon, Erdmann includes the beds of the two argillite formations under the general term Ravalli group. More recently, however, the new Geologic Map of Montana (1955) extends the Appekunny and Grinnell formations southward throughout the length of the Swan and Mission Ranges. In the Coeur d'Alene district of Idaho, Calkins (1909) recognized the Burke, Revett, and St. Regis formations in ascending order. The Burke consists of grayish siliceous shales and sericitic quartzites; the Revett is a hard, white quartzite; and the St. Regis consists of purple and green siliceous shale and quartzitic sandstone. North and east of the Coeur d'Alenes the Revett is not distinctly recognizable, and the Burke and St. Regis formations cannot be differentiated sharply. None of these formations or their equivalents were recognized in the area mapped for this report.

Hence, the stratigraphic position within the group of the rocks at the dam sites is unknown.

Rocks of the Ravalli group crop out at five of the six sites studied and in the ridge between the Little Bitterroot River and the powerhouse site at river mile 39.0. Exposures occur also in the Salish Mountains to the west of Mission Valley and in the low range of north-trending hills that stand about one-third of the width of the valley out from the western side. The rock at the dam sites consists in general of hard, fine-grained gray to light-gray quartzite, with some greenish-grey siliceous argillite and argillite, in beds or layers that range in thickness from a fraction of an inch to 4 feet. Except where it is overlain by Tertiary(?) rocks it is strong, insoluble, fresh to only slightly weathered, and very good for the foundation of a dam or any of the appurtenant structures. Beneath the Tertiary(?) fill, however, the eroded surface of the Ravalli group is soft, friable, and porous, with colors varying from light gray through greenish gray to tan. The upper 3 to 30 feet is intensely weathered, the effect diminishing to moderate or slight in the succeeding 20 to 40 feet of depth. If structures were to be built in these localities, the highly weathered rock would have to be removed.

Tertiary(?)

So-called lake beds of late Eocene, early Oligocene, and possibly Miocene age have been recognized from fossil contents in some of the intermontane basins drained by the upper Flathead River. The lithology of the so-called lake beds that crop out along lower Flathead River does not correspond, and their stratigraphic assignment has been inferred from their composition and relationships to the underlying Precambrian terrane. On this basis rocks of supposed Tertiary age occur at three of the dam sites examined for this report, and they may also be involved in the portal areas of the tunnel lines of the Sloan Bridge power site. Exposures are patchy and thin and occur over a vertical range of about 175 feet, but this interval should not be construed as an indication of overall thickness. The small, scattered outcrops indicate only the probable general sequence and cannot be combined into a composite section.

A generalized section consists of a complex basal unit that includes variable amounts of moderately coarse talus breccia derived exclusively from the locally weathered Ravalli group, and other near-source detritus in various stages of disintegration or reworking, from fanglomerate to finer-grained, impure sandstone or wacke-type rocks that are poorly sorted and contain considerable clay matrix. These facies grade into more regularly bedded sandstones and siltstones, and are probably covered by a waterlain gritty, reddish-brown clay or microbreccia that grades into volcanic tuff at the top. No bed of clay or claystone free of grit has been observed, and it does not seem likely that one has resulted from complete residual weathering of the argillite. The occurrence of clay with bentonitic characteristics in the waterlain residual or near shore facies suggests sporadic introduction of tuffaceous material into the Tertiary lakes culminating locally in deposition of the tuff. Any of these facies may overlap directly on to the Ravalli group or the overlying breccia. In this arrangement so-called lake beds indicate deposition along the west margin of a basin undergoing fill; and presumably the finer grained clastic units would greatly increase in thickness basinward.

The waterlain tuff is exposed on the right bank at Buffalo dam site No. 1 just downstream from the gorge section, and also near river level intermittently through its reservoir area. All facies except the tuff occur at Buffalo dam site No. 2. Weathered talus breccia also crops out sparingly in the lower part of the valley of the Little Bitterroot River, and may be concealed in the right bank of lower Flathead River by terrace deposits opposite mile 39, but the largest and most typical exposure is in the lower right abutment of Dam site No. 4. Thus proceeding downstream through the dam sites one descends through the Tertiary(?) section. Detailed accounts of the lithology and engineering properties of these rocks are given in the individual dam site descriptions.

Quaternary

Pleistocene

Three terminal moraines occur in Mission Valley: the St. Ignatius, Mission, and Polson, and mark successive invasions by lobes of the waning Cordilleran ice sheet. Noble (1952) correlates them with the early (Iowan), middle, and late (Mankato) substages of the Wisconsin continental glaciers of central North America. Alden tentatively correlates deposits of the earliest identifiable glaciation in the valley as Illinoian or Wisconsin (Iowan).

St. Ignatius Moraine

Weathered, clayey, light-brown drift is found a few miles south and southeast of St. Ignatius. A few deposits of till near the divide between Mission and Jocko River Valleys indicates the glacier extended into the latter (Noble, 1950, p. 60). Stony till near Dixon also may be related to the St. Ignatius glacier (Alden, 1953, p. 90).

Mission Moraine

The terminal moraine of the middle Wisconsin Mission glacier stands 5 to 6 miles north of St. Ignatius, and extends east and a little northeast from the south end of the southernmost of the medial hills to the Mission Range.

A lobe of the glacier that deposited this moraine pushed between the medial hills and westward beyond the present mouth of the Little Bitterroot River, into the Valley View district, and south into the Moiese Valley. At Sloan Bridge, for which this lobe is here named, and a few miles east, its till occurs to altitude 2,800 feet, but to the west and south the surface of this layer descends rapidly, indicating that the ice did not advance any great distance in these directions.

A low recessional moraine, the Kerr moraine (Noble, 1952), is found south of South Pablo Reservoir, with a contiguous lateral moraine south and west of Kerr Dam.

The drift of the Mission glaciation is fresh and unweathered. At Sloan Bridge power site it is generally in very compact, massive, tight layers (see fig. 3) that consist of an ungraded, mechanical mixture of approximately 30 percent gravel and 70 percent sand, silt, and clay. The gravels are subrounded to rounded, fresh, hard, red, greenish-gray, light-gray, and purplish colored quartzite and siliceous argillite. The average diameter of the pebbles is about 2½ inches, with a few pieces up to 10 inches through. The matrix is a very pale orange to grayish-orange, slightly calcareous mixture of silt, sand, and clay. In a few places the matrix is pink to reddish pink and lemon yellow, evidently reflecting inclusions of material from Tertiary(?) beds.

Polson Moraine

The last of the Wisconsin glaciers is represented by the Polson moraine, a ridge of sand and gravel that blocks the valley at the south end of Flathead Lake.

Glacial-Lake Deposits in Mission and Related Valleys

Pioneer investigations in western Montana valleys by Pardee (1910, pp. 376-386) outlined evidence indicating the former presence of a high-level lake during the closing stages of the ice age. Part of this evidence consists of shoreline features, and as a series of benches are displayed prominently on the mountain sides in the vicinity of Missoula, the lake they represent has been named for that city. Much later Alden (1953, p. 158) and Nobles (1952) suggested that lake-bed silts at various altitudes up to 3,000 feet in Mission Valley and Little Bitterroot Valley might be related to even earlier lakes. There is reason to believe that lakes were present in the region at one level or another during at least three substages of the last or Wisconsin stage. A brief effort will be made here to relate the various silt deposits encountered during this study to their respective lakes.

Early Wisconsin lake deposits.—Light-grey clayey lake-bed silts have been recovered in drill holes 4, 5, and 7 at Dam site No. 4 (see Appendix). A *few* miles upstream at Oxbow dam site, sediments described as "clay," "silty loam," and "sand" on Corps of Engineers churn drill logs (Appendix, logs 2, 3, and 4) were recovered from below altitudes 2,450 to 2,460 feet beneath massive till apparently laid down by the Sloan Bridge lobe of the Mission glacier. The lithologic resemblance of the clays from these two localities, which are quite different from the fresh, nonplastic, yellowish-brown silts at the surface, and their stratigraphic position, may be evidence that a lake related to the St. Ignatius substage of the Wisconsin glaciation once occupied this part of Kolese valley.

Middle Wisconsin lake deposits.—Extensive deposits of glacial lake-bed silts are found in the Valley View district, at the north end of Kolese Valley, and eastward into Mission Valley, and south of the terminal moraine of the Mission glacier. Noble (1952) correlates these lake deposits with the middle Wisconsin or Mission glaciation of the valley, when a number of glacial lakes with varying surface altitudes evidently occupied portions of the Mission Valley.

When the Sloan Bridge ice lobe stood against the rock ridge south of the bridge, it probably dammed Little Bitterroot River, and formed a temporary lake. An arm of this lake extended up Little Bitterroot Valley, with another arm along the east edge of the Salish Mountains in the Valley View district. Silts found to near altitude 3,000 feet in these arms probably were deposited in this glacial lake.

Other lake-bed silts with their surface near altitude 2,840 feet apparently are related to a later lake formed by a dam that was beyond the limits of Mission Valley. These silts overlap the south face of the Mission moraine, the till in the Sloan Bridge area and in the Valley View district.

Late Wisconsin lakes (Lake Missoula).—The last and greatest flooding of Mission Valley occurred toward the close of the Mankato substage. Shoreline features on the south face of the Polson moraine are thought to be related to the waning stages of this lake and thus date it as occupying Mission Valley shortly after the emplacement of the moraine. Prior to the period of its culmination, lobes of the Cordilleran ice sheet came down the Purcell Trench past Bonners Ferry, Idaho, and through Bull Lake Valley from the Kootenai River drainage and effectively blocked Clark Fork Valley for about 25 miles between Pend Oreille Lake and Noxon, Mont. Ultimately the water behind this enormous ice dam attained levels corresponding to present altitudes of 4,260 feet.

Small scale shoreline features developed on the hills above 3,200 feet indicate the lake surface stood for only short periods at any one level. Pardee (1942) has suggested that the drainage of the lake was extremely rapid once the ice dam was breached. It appears that the life of the lake was very short at least in its higher stages when the flow line was above 3,100 feet.

Only a minor amount of lake-bed silts is found above altitude 3,100 feet in the Mission and related valleys. The scarcity of lake-bed silts due to Lake Missoula is indicated by nondeposition of silt on the Mission moraine and in other arms of the great lake (Alden, 1953, pp. 156-157). The thick, extensive deposits of lake-bed silts below altitude 3,100 feet appear to be related to the middle of the Wisconsin stage.

Recent

Active and inactive alluvium is present along the stream channel, and talus deposits are found at the base of some rock slopes. Minor landslides have occured along the river in the till and glacial lake-bed silts. A few slides are between Dam site No. 4 and the proposed Sloan Bridge powerhouse site at mile 39.0.

STRUCTURAL GEOLOGY

Mission Valley Compartment

Mission Valley is the most southerly compartment of the Rocky Mountain Trench; and the extent to which its features have been influenced by Trench tectonics should now be examined. Throughout its course in Montana many of the features that characterize it in British Columbia appear to be absent, especially along the west side. The east side, however, continues to truncate the northwest trend of the great fault-block ranges that lie to the east. Locally, the mountain and trench structures are almost parallel, and for purposes of this report the west-facing fault-line scarp of the Mission fault on the west side of the Mission Range may be considered as the east boundary of the Mission Valley compartment.

Pardee (1950, p. 395) and Noble (1952, p. 28) consider the Mission fault to be a normal fault, with a dip of about 45° to the west and downthrow to the west; but Clapp (1932, pl. 1) shows it as a high-angle reverse fault in his cross sections, and as one of the Swan, Flathead, Roosevelt fault system to the east. Pardee estimates the maximum throw on the Mission fault at a point east of St. Ignatius to be 8,000 feet or more, with the movement occurring in late Tertiary or early Quaternary time. Noble indicates the total displacement is in the vicinity of 17,000 feet, with the movement occurring in three stages:

Stage of Movement	Amount of displacement Vicinity McDonald Peak
Pre-late Tertiary peneplain	9,000 feet
Post-peneplain pre-middle Pleistocene	6,000 feet
Probable middle Pleistocene	2,000 feet
	17,000 feet

By analogy with the Flathead fault, which may be a member of the same system farther east, a total displacement of 17,000 feet is of the right order, although still probably not the maximum. If these faults operated at about the same time, and it seems likely that they did, the first stage of movement probably took place toward the close of Eocene time or in the early Oligocene, and the second stage during late Oligocene or early Miocene. Considered as a locus of possible earthquake shocks, the probable middle Pleistocene movement is significant. However, Noble found no disturbance of any of the middle or late Wisconsin tills that blanket the trace of the fault, which suggests there has been no movement on it since middle Wisconsin time at least. Hence, the probability of earthquakes originating in the Mission fault may be about the same as Erdmann (1944, pp. 63-64) estimated for the Flathead fault. He concluded that reservoir water load or even relatively nearby earthquakes would not cause activation of the Flathead fault. If movement occurred, it would be in connection with subsidence of the floor of some adjacent structural basin. Any resulting earthquake would be of relatively high intensity, 9 or 10 on the Rossi-Forel scale at the epicenter, and that Hungry Horse dam should be designed to withstand shocks of that magnitude.

Structural definition of the west side of the Mission Valley compartment is not so well established. The west side of the Salish Mountains is limited by the Salish fault, which has tilted the block to the east; and topographic definition by the dip slope is only fair. The distance between the Salish fault and the Mission fault is about

25 miles, about twice the width of tectonic blocks in this part of Montana, or even for any part of the Rocky Mountain Trench; so one may question if the Salish Mountains block persists so far eastward without interruption. Also, this variety of structure is not typical of the Rocky Mountain Trench, from which the bordering ranges usually dip away. The medial rock ridges of Mission Valley appear to have stratigraphic and structural continuity with the Salish Mountains. It may be conjectured, therefore, that this block terminates under cover east of the ridges against the west structural boundary of the Trench. This supposition brings the preglacial Mission Valley and the Rocky Mountain Trench into coincidence; but this can hardly be called supporting evidence of a concealed fault. Also, it is in line with the previous conclusion (p. 15) of the integration of the Mission Valley compartment by glacial fill; and from the viewpoint of geologic structure suggests that the dam sites are situated in the Salish Mountains block rather than the Rocky Mountain Trench.

Salish Mountains Block

Rocks of the Ravalli group in lower Flathead Valley and along the back slope of the range have a general strike to the north or north-northwest and moderate dips to the east. Local details are given in the dam site descriptions and their accompanying maps.

A transcurrent or tear fault crops out on both banks of Flathead River about 700 feet downstream from Kerr Dam powerhouse and, judging from the width of the shear zone, appears to have substantial displacement. The river crosses the fault almost at right angles, and the zone of gouge and broken rock is about 110 feet wide. The strike of the fault is approximately N. 30° E., but the dip could not be determined. The attitude of the beds on both sides of the fault indicate the rock on the southeast side has moved up relative to the northwest side.

A large strike-slip fault has been exposed by the excavation for the Moiese Valley canal about 1,800 feet east-northeast of Oxbow dam site. About 60 feet of crushed rock and gouge is along the fault whose attitude is strike N. 5° W., dip 75° E. The hanging wall appears to have moved to the north and down.

POWER-SITE DESCRIPTIONS

General

The dam and reservoir sites discussed in this report are located on the Flathead River, 5 to 41 miles downstream from Flathead Lake, between river miles 72.0 and 36.0, above the confluence with the Clark Fork River. Kerr Dam, the existing power development downstream from Flathead Lake, has a powerhouse tailrace elevation of 2,705 feet. This elevation is the maximum pool level for all of the prospective downstream developments except Dam site No. 4. The topography at this site limits the maximum flow level that logically could be considered to about 2,641 feet. The locations of the prospective sites are shown on the index map, figure 1, and the possible developments at each are listed in table 1.

The entire fall of 175 feet in this reach of the river could be developed by one installation at Sloan Bridge power site with a powerhouse site at mile 39.0, or by several combinations of Dam site No. 4 and an upstream site. It is suggested that additional head or fall of the river downstream from Dam site No. 4 or from the proposed mile 39.0 powerhouse site could be developed by excavation of the river channel below those sites. The estimated maximum head that could be gained is about 16 feet for Dam site No. 4 and about 24 feet for the powerhouse site at mile 39.0. The estimated total fall that could be developed by either scheme is 191 feet.

Partial control of the stream flow in lower Flathead River by upstream dams and slight adjustments in the plane-table datum used for the river-survey maps might reduce the maximum indicated head for the various sites by 3 to 5 feet.

The east (left) bank of the river is accessible in many places from a very good system of county roads that serves the farmers on the irrigated land in the Valley View district. (See fig. 1.) Light wooden structures bridge the river at two places: the Buffalo Bridge at river mile 65.1 and the Sloan Bridge at mile 44.5. The west (right) side of the river is accessible from a county road varying from one-half to 2 miles back from the stream. From Buffalo Bridge to 4 miles west of Sloan Bridge the road is a trail, passable only during good weather. From Sloan Bridge to Dixon the road varies from poor to good.

Table 1

POSSIBLE HYDROELECTRIC DEVELOPMENTS ON FLATHEAD RIVER BETWEEN MILES 36.0 AND 72.0

Dam site	Pl.	Location	River mile	Alt. w. s.	Possible head 1/	Remarks
Buffalo No. 1	1	NE¼ sec. 21 and NW¼ sec. 22, T. 22 N., R. 21 W.	68.4	2655	64	Recommended axis at 68.4. About 14 feet of this head would be developed by placing the powerhouse at mile 68.2 and excavating to mouth of gorge at 67.9.
Buffalo No. 2	2	N½ SE¼ sec. 1, T. 21 N., R. 22 W.	60.7	2615	26 90	Reservoir to tailrace of Buffalo dam site No. 1. Reservoir to tailrace of Kerr powerhouse.
Sloan Bridge power site	3	(1) SE¼NW¼ and NE¼SW¼ sec. 18, T. 20 N., R. 21 W.	44.7	2559	146	Reservoir to tailrace of Kerr powerhouse.
(Four possible schemes of development)		(2) Powerhouse: SW¼NW¼ sec. 30, T. 20 N., R. 21 W.	39.0		167	Involves a 1-mile tunnel and pressure conduit from Little Bitterroot to powerhouse.
		(3) Powerhouse	39.0		191	The additional head of 24 feet over (2) is gained by excavating channel downstream from powerhouse.
		(4) Powerhouse: SW¼ sec. 33, T. 19 N., R. 23 W.	13.0	2480	225	Involves a diversion tunnel and opencut with a combined length of approximately 7 miles. Geologic feasibility of the route unknown.
Oxbow	4	NW¼ sec. 28 and NE¼ sec. 29, T. 20 N., R. 21 W.	41.3	2548	67 93 157	Reservoir to Buffalo dam site No. 2. Reservoir to Buffalo dam site No. 1. Reservoir to tailrace of Kerr powerhouse.
Mile 42.9		SE¼ sec. 17, T. 20 N., R. 21 W.	42.9	2555	150	No detailed investigations made. Possible alternative to Oxbow dam site.
No. 4	5	Center sec. 1, T. 19 N., R. 22 W.	36.4	2530	18 85 111	Reservoir to Oxbow dam site. Reservoir to Buffalo dam site No. 2. Reservoir to Buffalo dam site No. 1. Additional head of about 16 feet could be gained by excavating the channel downstream.

1/ Maximum altitude pool level for any reservoir is 2,705 feet, the elevation of Kerr powerhouse tailrace.

Buffalo Dam Site No. 1

(See pl. 1)

Location and Accessibility

Buffalo dam site No. 1 can be located at one of several axis lines between river miles 67.9 and 66.4, approximately 9.5 miles downstream from the town of Polson and 4 miles below Kerr Dam. The land location is the NE¼ sec. 21 and the NW¼ sec. 22, T. 22 N., R. 21 W.

Both abutments of the site are accessible by car. The right (northwest) abutment can be reached by a dirt road that leaves the county road near the center of sec. 16, T. 22 N., R. 21 W., and runs southeast to the site. The left abutment can be reached by leaving the county road at a point 0.8 miles east of the Buffalo Bridge in the SW¼ sec. 19 and following a dirt road east-northeast for 2.2 miles.

Topography

The site is in a deep, fairly narrow gorge where for about 1.4 miles the Flathead River has been superimposed across the end of a ridge of the Ravalli group that extends southeast from the Salish Mountains. The steep right wall of the gorge is cut in rock and at the highest point the rim of the canyon is 450 to 500 feet above the river surface. The more gentle left wall of the gorge is cut partly in rock and partly in glacial deposits, and rises only 350 to 400 feet above the river.

The downstream portion of the gorge is "Z" shaped, and the river makes two sharp bends with a change of direction of approximately 90° at each. Upstream of the first bend the river flows S. 30° W., then N. 30° W., and finally S. 45° W., as it leaves the gorge. Axis lines 1, 2, and 3 shown in geologic sections A-A', B-B', and C-C', respectively, are located downstream from the lower bend, and axis 4 shown in section D-D' is located between the bends.

Between river mile 67.90 (altitude 2,641 feet) at the downstream end of the gorge section and mile 69.45 (altitude 2,672 feet) at the upstream end, the river falls 31 feet with an average gradient of 20.0 feet per mile. In this section, however, there are four rapids with drops of five to eight feet in each. Between mile 69.45 and mile 72.05 (altitude 2,705 feet) at the tailrace of Kerr Dam the river falls 33 feet with a gradient of 12.7 feet per mile.

Geology

Precambrian

The Ravalli group consists of approximately 85 percent quartzite and sandy argillite and 15 percent argillite. The quartzites are light gray to medium light gray, fine- to very fine-grained, and in beds that range from a fraction of an inch to 36 inches in thickness. The argillites are greenish gray to light gray, and range from a fraction of an inch to 10 inches in thickness. Many minute rust-brown specks are scattered throughout the quartzite where small crystals of pyrite have weathered to limonite, but in the argillite only those crystals near joints or other openings have been weathered. Many of the joints in the rock have limonite staining along their surfaces. Small flakes of muscovite have developed parallel to the bedding in some of the argillite.

The Ravalli group at Buffalo dam site No. 1 is fresh, insoluble, strong, and competent to support any dam considered for the site.

Tertiary(?)

Rocks of supposed Tertiary(?) age are exposed both up and downstream from the gorge section. One outcrop extends for about 150 feet between altitudes 2,660 to 2,680 feet on the right bank only 120 feet downstream from section A-A'. Here the rock is a grayish-orange to light-brown, soft, massive, fine-grained, partially devitrified, water-lain, volcanic tuff that is light in weight and highly porous. Although this rock is very compact and homogeneous, there is a minor amount of clastic material embedded in it that has been derived from the Belt series. A few small angular fragments of highly weathered light-gray quartzite apparently are near source, but there is also a scattering of small waterworn pebbles that suggest it may be water lain. These properties make it unsuitable for a foundation for a concrete dam, and considerable further investigation would be necessary to ascertain if it would make a satisfactory foundation for a wide-base type of dam. The thickness and attitude of this tuff cannot be determined by methods of surface geology because of the limited extent of the exposure.

Tertiary(?) rocks may be present in drill hole 12 and churn drill holes A and B. Some of the core recovered from these holes contained completely to moderately weathered, angular to subrounded, pieces of argillite and quartzite embedded in a sandy silt to a waxy clay matrix. The material is similar to the weathered talus breccia exposed at some of the downstream sites, but it also resembles fault gouge. It may be possible that drill hole 12 is in weathered gouge material from the fault thought to be east of the hole.

Quaternary

Pleistocene.--Till was recovered in drill holes 11, 12, and churn drill holes A and B. The till is composed of rounded to subrounded pebbles of red and light-gray quartzite and greenish-gray argillite embedded in a pale-brown to grayish-orange sandy silt.

Recent.--A fluvial deposit (Qf) makes a constructional terrace at altitude 2,700 to 2,710 feet along the left (southeast) bank downstream from the rock knob near the center of the NW¼SW¼ sec. 22. Its surface is characterized by very large angular blocks of Ravalli group that are up to 15 feet through, in a matrix of silt, some sand, and gravel. The size and distribution of the blocks suggests they were torn out of the canyon by a great flood. Similar material is present northeast of drill hole 4 on the right abutment. Drill holes 10 and 11 on the left abutment penetrated 51 and 52 feet of this material.

Active stream alluvium is present along the river channel, and talus covers a large part of the canyon walls upstream from the first sharp bend in the gorge section.

Structural Features

__Faults.__—A fault (here called the Island fault) cuts the Ravalli group 300 feet west of where the line common to sections 21 and 22 intersects the right bank of the river, and a breccia zone 6 to 8 feet wide contains extremely sheared, broken, and pulverized rock. The direction and amount of movement could not be determined, but the fault appears to be normal. The strike is S. 5°–10° W., and the dip is 55° W. This bearing would carry it just east of the rock island immediately downstream from mile 68.0, for which it has been named, and through B.M. 2562 on the left bank.

The long, narrow re-entrant valley up the right bank north of mile 68.2, the considerable depth of water in the elbow-bend at that locality, and the sharp west face of the rock knob near the center of the NE¼NE¼ sec. 22, combine to suggest the possibility that a zone of weakness or possibly another fault (here called the Knob fault) lies in the bed of the river just west of the knob. Actual exposures have not been seen, but the alignment of these topographic features is approximately parallel to the Island fault, and it may have a similar attitude. Although the Knob fault thus far is hypothetical, its more or less central position may affect three prospective dam axes and a powerhouse site, and thorough exploration should be undertaken to ascertain whether or not it exists as postulated.

On the right abutment drill hole 4 penetrated 17 feet of crushed rock from altitude 2,656 to 2,642 feet. This is believed to imply another north-trending fault, but no further information is available.

Minor faults striking N. 2°-30° W., with dips that range from 55° to 70° SW., have combined with bedding plane slips to produce a zone of broken and sheared rock 600 feet wide in the right wall of the canyon between miles 68.6 and 68.76. Vertical displacements of a few inches to about 10 feet have resulted in crush zones varying from a single paper-thin seam of gouge to breccias 10 feet thick. The crush zones along the bedding faults vary in thickness from a fraction of an inch to about 1 foot. A reverse fault with 6 to 10 feet of crushed rock and gouge is present at mile 68.72. The approximate strike of this fault is N. 30° W., and the dip is 70° SW.

<u>Attitude of the beds</u>.—From mile 67.8 to 68.2, the strike of the beds varies from N. 47° to 75° W., and the dip from 13° to 20° NE. The average strike in this reach is N. 55° W., and the average dip is 15° NE. Between mile 68.2 and 68.6, the strike varies from N. 15° to 37° W., and the dip from 15° to 31° NE., with an average strike of N. 26° W., and a dip of 18° NE. From mile 68.6 to 69.3, the strike varies from N. 10° to 29° W., and the dip from 16° to 33° NE., with an average strike of N. 16° W., and dip of 26° NE.

Joints.—The most important joints are those parallel to the bedding. They are tight and spaced a fraction of an inch to 36 inches apart.

Other joints listed in the order of frequency of occurrence have the following strikes and dips: N. 69°-85° E., 68°-88° SE; N. 62°-88° W., 67°-78° SW.; N. 56°-70° E., 75°-86° NW.; and N. 30°-53° W., 70°-78° SW. They are tight or have only limonite staining along the joint surfaces.

Possible Axis Lines

Four possible axes, included as portions of geologic sections A-A', B-B', C-C', and D-D', are shown on plate 1. Line 1, in section A-A', was selected for investigation by the Montana Power Company. Possible axes 2, 3, and 4, are alternatives proposed as a result of this study.

Axis line 1, Section A-A'

Axis 1 at mile 67.92 is located in part on an exposure of the Ravalli group at the mouth of the gorge section. Very good rock is in the river bed and the right abutment to altitude 2,682 feet, or to within 23 feet of the normal pool level of the reservoir.

The surface of the rock descends to the northwest, and fluvial material is in the right abutment from 2,705 to 2,669, at drill hole 4. This axis could be located on rock to altitude 2,705 feet and probably higher if it were extended to the northeast instead of northwest from the angle point near drill hole 3.

The terrace on the left abutment is supported by pervious fluvial material 33 to 52 feet thick containing large erratic blocks. Below its base at altitude 2,654 to 2,650 feet (drill holes 10 to 13) is a thin bed of till, 3 to 20 feet thick, and possibly a small lens of Tertiary(?) talus breccia resting on the Ravalli group.

No core was recovered in the fluvial material except for a few pieces of light-gray and red quartzite and greenish-gray argillite from drill hole 12. The poor core recovery and the surface exposures of this material suggest that it is unsuitable for an abutment of a dam because of its probably high permeability. To prevent excessive percolation through the abutment, a core wall probably would have to be put down and carried to bedrock or to the till overlying the Ravalli. It does not appear possible to drive piling because of the large blocks of rocks.

If the Island fault is projected to the south, the intersection with this axis occurs between drill holes 12 and 13. Broken rock and three minor gouge zones 0.5 to 1.0 foot thick were encountered in drill hole 12.

If line 1 were to used as an axis, the powerhouse for an earth-fill dam would be on alluvial material downstream from the last exposure of Ravalli rock in the river channel.

The information secured from Montana Power Company's core holes is summarized in Table 2, and complete logs are given in the Appendix.

Table 2

Summary logs of drill holes along axis 1

D.H. No.	Fluvial deposit 1/ 2/	Till	Tertiary(?) weathered talus breccia	Ravalli group	Remarks
1	0-4 (overburden) 2,660-2,656 3/	-	-	4-121 2,656-2,539	Vertical
2	0-2 (overburden) 2,672-2,670	-	-	2-130 2,670-2,542	Vertical
3	0-15.5 (overburden) 2,695-2,680	-	-	15.5-41 2,680-2,654	0-13 No core 13-15.5 Gravel
4	0-36 2,705-2,669	-	-	36-91 2,669-2,614	Vertical
5	-	-	-	0-223 2,642-2,541	Bear. S.11°E. Dip 27°
6	-	-	-	0-68 2,643-2,579	Bear. S.11°E. Dip 70°
7	-	-	-	0-168 2,642-2,435	Bear. N.11°W. Dip 40°
8	-	-	-	0-78 2,644-2,566	Vertical
9	-	-	-	0-129 2,646-2,602	Bear. S.11°E. Dip 20°
10	0-51 2,705-2,654	-	-	51-81 2,654-2,624	Vertical
11	0-52 2,707-2,655	52-64 2,655-2,643	-	64-111 2,643-2,596	Vertical
12	0-33 4/ 2,712-2,679	33-53 2,679-2,659	53-68 2,659-2,644	68-100 2,644-2,612	Vertical
13	0-36 2,716-2,680	36-39 2,680-2,677	-	39-68 2,677-2,648	Vertical
CDH					
A	-	0-40(?) 2,718-2,678	40(?)-80(?) 2,678-2,638	-	Vertical
B	-	0-40(?) 2,735-2,695	40(?)-71(?) 2,695-2,664	-	Vertical

1/ Depths in feet
2/ No core recovered in fluvial deposit in drill holes 1, 2, 3, 10, 11, and 13
3/ Altitudes in feet
4/ Core recovery too poor to identify material

Axis line 2, Section B-B'

An axis at line 2, mile 66.03, would have the same defects as those at A-A', but to a somewhat lesser degree. The main advantage is that the area of the section below 2,705 is reduced by slightly more than one-fourth.

The right abutment is on very good rock that is exposed to altitude 2,705 feet, and probably could be found still higher to the north. Rock with only a thin cover of gravel is believed to be in the foundation except where the Island fault crosses near the center of the channel. This zone could be treated adequately by trenching, cutoff shafts, and cement grouting of the rock.

In the left abutment bedrock is exposed to altitude 2,670 feet. Seismic line 5, located 400 feet southeast of the river along section B-B' and 190 feet northeast, indicates bedrock is at altitude 2,663, or that the bedrock surface slopes gently down from where it is exposed in the river bank. The overburden is the same fluvial deposit as that at axis 1, and would require similar treatment. A core wall varying from 30 to 50 feet in height and up to 550 feet long would be required to prevent percolation through the abutment. Testing may reveal deposits of impervious till in this area that would reduce the size of the required cutoff.

The supposed Knob fault may cross the section near the left valley side wall.

A diversion tunnel could be driven in the right abutment but the rock cover probably would be so thin that the tunnel would have to be lined. Two to three hundred feet downstream from the axis the rock surface would decline to the level of the roof of the tunnel.

Excavation of the rock in the river channel downstream from the axis would permit the recovery of any head lost by moving the dam and powerhouse upstream.

Axis line 3, Section C-C'

Axis 3, at mile 66.16, is the first location in the gorge that would place rock in both abutments as well as the foundation. This line is suitable for a concrete dam. The cross sectional area below altitude 2,705 feet is approximately 20 percent less than at axis 1.

Very good rock is in the right abutment from the river surface to altitude 2,775 feet. Good rock is believed to extend across most of the foundation, but the river channel is quite deep and the bottom cannot be seen from the bank. The supposed Knob fault may be present near the left bank. In the left abutment, a mixture of silt, sand, and gravel overlies bedrock up to altitude 2,700 feet. The overburden appears to be fairly thin and good rock probably underlies it. Above 2,700 feet bedrock is exposed in a number of small outcrops on a ridge that rises to 2,800.

An excellent location for a diversion tunnel is available in the right abutment in the vicinity of cross section E-E'. There is adequate room here to locate the tunnel upstream from the Island fault in this area.

Axis line 4, Section D-D'

Axis 4, at mile 68.38, is a very good site for a concrete dam. (See fig. 2.) The canyon is approximately 400 feet wide at altitude 2,705, and the vertical distance from the river surface to the normal flow line is only 50 feet. The cross sectional area of the canyon below 2,705 at axis 4 is about 40 percent less than for the section at axis 1.

Bedrock is exposed in both abutments and across most of the river bed. The strike of the beds in the vicinity of the axis ranges from N. 15° to 37° W., or approximately parallel to the river channel, and the dip is 14° to 31° NE., into the right abutment. No large faults are known or suspected. The rock in the right abutment is of poorer quality than in the foundation or the left abutment. The zone of minor faults exposed from mile 68.6 to 68.76 is in the right abutment approximately 350 to 500 feet back from the river. On the right bank, about 250 feet downstream, there are two minor shears with 1 to 7 inches of crushed rock and gouge along them. Projection of their strikes carries them into the center of the river channel at the proposed axis.

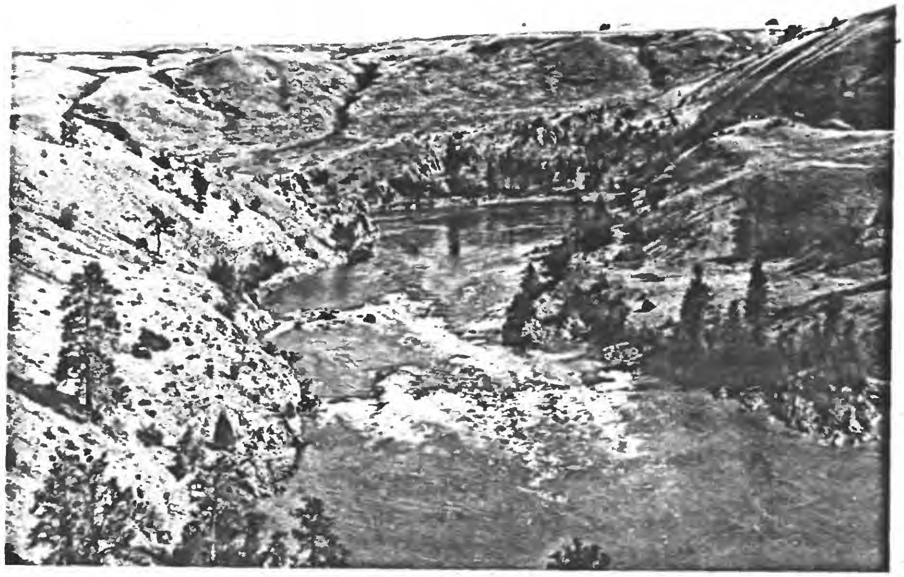


Figure 2. - View looking upstream through axis line 4, which is just downstream from the head of the upper rapids. A possible powerhouse site is off the right side of the picture, and water could be conducted to the penstocks through a forebay located on the small lower bench at the right of the view.

A small spring issues on the right bank 170 feet upstream from the suggested axis. Seepage may be from the river around the bend, apparently along open seams and joints through the rock in the point. Seepage probably will occur along similar fractures in the right abutment, but grouting of the rock should correct it.

If required, a diversion tunnel could be located in the right abutment. Although the rock here is cut by a few small faults and numerous joints, it should stand without lining. If a tunnel is considered through the ridge with intake portal near mile 63.7, the first 150 to 200 feet of the route will be in an area of sheared rock. The reach of the tunnel in this zone probably will require support.

A proposed powerhouse site is on the northwest side of the rock knob that forms the left abutment for this axis line. Water could be conducted to the penstocks through a forebay excavated into the north and northeast side of the rock knob. (See fig. 2.) Bedrock is not exposed at the powerhouse site, but is believed to be at shallow depth. The suspected Knob fault may cut the Ravalli group west of the rock knob, and the powerhouse site should be carefully explored.

A powerhouse at this location would lose approximately 9 feet of head compared to one at the downstream end of the gorge. This head could easily be recovered by excavation of the rock in the channel between the downstream end of the gorge and the powerhouse site.

Exploration of the axis by diamond drill core holes on 200-foot spacing should be adequate.

Choice of axis

Of the four proposed axes, line 4 is the most favorable from both a geologic and, very likely, economic standpoint. Geologically the site is the best, as it offers solid rock abutments and foundation that do not contain any known or suspected major defects. Rock at the surface is hard and fresh, and no excessive excavation should be required to remove poor rock. If needed, a good diversion tunnel site is available in the right abutment. The cross sectional area of the gorge below altitude 2,705 feet is approximately 40 percent less than at axis 1, and a dam here would require substantially less concrete than at any of the downstream sites. Future maintenance costs of a small concrete dam securely anchored in good, sound rock should be considerably less than that of the larger structures required at the other axes. Loss of water through the rock would be negligible.

Axis 3 is the second best site. Geologically it is as feasible as axis 4, but a larger dam would be required. On the basis of present information, axes 1 and 2 are infeasible, as large to prohibitive water loss will occur unless core walls are put in on their left (southeast) abutments.

Reservoir site

From any of the four possible axis locations discussed to the upstream end of the gorge at river mile 69.45, the walls are tight quartzite and argillite.

Upstream from the gorge section, Tertiary(?) tuffaceous rocks similar to those exposed downstream from axis 1 are exposed to approximate altitude 2,710 feet, where they are overlain by glacial deposits. These rocks are tight, and no substantial leakage would occur from the reservoir.

Buffalo Dam Site No. 2

(See pl. 2)

Location and Accessibility

This site is in the NE¼SE¼ sec. 1, T. 21 N., R. 22 W., at river mile 60.7, only 7.2 miles downstream from Buffalo dam site No. 1, and 11.3 miles below Kerr Dam.

Both abutments are accessible by car in periods of good weather, but during the spring or prolonged rainy spells, the road and trails may be impassable. The right abutment can be reached by following a poorly maintained county road south for about four miles from the Buffalo Bridge. The left (east) abutment can be reached by leaving the county road one-half mile southeast of the bridge and following a trail approximately 3.6 miles to the south.

Topography

The Flathead River flows south along the west edge of the Valley View district. The river has entrenched itself into the glacial fill in the valley, and has cut down and into a buried rock spur that extends out from the low mountains on the west. The river is cutting across the spur just where the Ravalli group descends below the valley fill of glacial drift and Tertiary(?) rock. The harder rock of the right (west) abutment deflects the river to the east, and as a result the channel at the possible axis is approximately 700 feet wide, or about twice the average width of the channel above and below the site. In low water stages a small island extends about 800 feet downstream from the proposed axis, and the main flow of the river is between it and the left (east) abutment.

The right (west) abutment has an average slope of approximately 10° up to near altitude 2,750, and the left (east) one has an average slope of 15° to the same elevation. The left abutment is at the end of a ridge that runs about 1,000 feet to the east and then trends north-northeast. Its crest line varies from altitude 2,780 to 2,800 feet. About 2,000 feet northeast of the abutment, the width between the 2,700-foot contours is only 1,600 feet.

The fall between Kerr powerhouse tailrace and the probable axis line at mile 60.7, altitude 2,615, is 90 feet. Between this site and the downstream end of the gorge at Buffalo dam site No. 1 (altitude 2,641), there is a fall of 26 feet, and the stream gradient is 3.6 feet per mile. Through the site the gradient is approximately 14 feet per mile.

Geology

Quartzite and argillite of the Ravalli group are overlain unconformably by Tertiary(?) rocks, and both in turn are overlain unconformably by Pleistocene glacial deposits and Recent alluvium.

Precambrian

The Ravalli group consists of quartzite interbedded with argillite. The rock is very fine-grained, greenish-gray to medium light-gray in color, thin-bedded, in layers ranging from ¼-inch to 12 inches in thickness, with an average of about 6 inches.

Bedrock is exposed along the right (west) river bank for about 1,000 feet and at the upstream end of the small island. The approximate upper limit of the outcrops along the river is near altitude 2,650 feet. For about 600 feet upstream from the island and for about 450 feet out from the right bank, or almost two-thirds of the distance across the river, bedrock appears to be present in the river bottom. In the small gully on the right abutment just south of section A-A', bedrock is exposed up to altitude 2,680 feet, and in two gullies farther south it is exposed near altitude 2,750 feet.

In the center part of the exposure along the river, the rock is generally fresh, but around the margins and wherever it is overlain by Tertiary(?), there is a zone of intensely weathered rock. This zone is from 3 to 30 feet thick in the drill holes, with 20 to 40 feet, and possibly more, of moderately weathered rock beneath it. The weathered rock ranges from white to light brown in color, is friable, porous, and breaks easily in the fingers, with some fragments even crumbling to a silty sand.

The unweathered Ravalli group is good foundation rock, appears to be watertight, and is capable of supporting a concrete dam section and any of the appurtenant structures. Because the rock is thin bedded and cut by many joints, it would be subject to corrasion by rapidly moving or falling water.

Tertiary(?)

Tertiary(?) beds are involved to an important extent in the foundation and left abutment of Buffalo dam site No. 2. Basal talus breccia crops out in the right (west) bank to altitude 2,640 upstream from the exposure of Ravalli rock and to 2,660 feet downstream. Breccia was recovered from some of the drill holes east and south of the bedrock exposure. For about 600 feet downstream from the Ravalli exposure, reddish-brown, gritty clay or microbreccia, which probably overlies the breccia, is exposed from the river surface to about altitude 2,650. Low in the left bank opposite the center of the island, the gritty clay is exposed; however, at depth in the left abutment, talus breccia is overlain by beds of conglomerate, sandstone, siltstone, and unconsolidated sand. The core holes show that for about 350 feet east from the left bank at section B-B', plate 2, the surface of the Tertiary(?) deposits is approximately level, but to the east it apparently descends at a steep slope into an old valley. Here it is overlain by drift.

The talus breccia consists of light-gray to dark yellowish-orange, angular to subangular blocks and pieces of argillite, some up to three feet in diameter. The blocks probably were weathered more or less completely before being broken and involved in the debris, and their interstices are occupied by light-gray to dark yellowish-orange clay and sand. Average thickness of this unit is about 20 feet. Mass properties such as hardness and bearing power generally are low and variable. Permeability likewise is variable, and may be appreciable except where the matrix is clay. Minor water loss therefore may be expected through this unit. The overlying conglomerate or fanglomerate represents further reworking. With an increase in the stratigraphic interval from the talus, the fragments and pebbles of argillite and quartzite become systematically more rounded and smaller, ranging from coarse sand to 2 inches in diameter. Weathering has progressed almost to total loss of cementing substance and strength. The matrix material is yellowish-gray to dark yellowish-orange clay and fine-grained sand, which makes a larger percentage of the whole than it did in the talus. The strength or bearing power of the conglomerate-fanglomerate facies therefore is variable and low, and its single redeeming feature is its probable low permeability.

The conglomerate beds grade upward into layers of friable, white to yellowish-gray or light-buff silt, sand, and very fine-grained clayey sandstone that represent still more advanced stages in the disintegration of the talus. These last named facies, however, usually have been observed only in drill cores from the left abutment as they are too soft and unconsolidated to endure as ledges at the surface. Obviously, such low-strength, permeable rocks are unfavorable for either the foundation or abutments of a dam. The gritty clays or microbreccias, whose heterogeneity makes them difficult to describe and name, contain accumulations of poorly sorted angular, sand- to grit-sized particles of argillite and quartzite, and probably some tuff embedded in clay. Their principal constituent is dark- to medium reddish-brown waxy clay, whose color and tendency to absorb water suggest that it consists largely of minerals of the bentonite group, such as montmorillonite. The rock appears very impermeable; it is not hard when dry, and becomes extremely soft and plastic when wet. The strength and bearing power of these gritty clays is low and uncertain, and even moderate loading probably would result in unbalanced pressures and differential settlement.

In summary, the Tertiary(?) rocks at this site are not suitable as a foundation for a concrete structure, and are only of fair quality for the foundation of an earth dam. Very extensive tests should be made to determine the engineering properties of all rock types involved before any plans for development at this site are formulated.

Quaternary

Pleistocene till, glacial lake-bed silts, and a conglomerate bed unconformably overlie both the Precambrian and Tertiary(?).

The conglomerate bed is 6 to 12 inches thick where it is exposed 400 feet north and 500 feet south of drill hole 1. It is composed of subangular to subrounded gravel and cobbles embedded in a matrix of fine- to coarse-grained sand. In drill holes 21, 22, 23, and 27, the conglomerate may be present, although logged with the Tertiary(?), and the bed may be 6 to 8 feet thick in these holes.

Till with fresh to weathered pebbles of quartzite and argillite embedded in a gray, silty clay matrix is exposed in the vicinity of drill hole 1. In drill hole 27 till was recovered from 2,650 feet, the highest altitude at which it was found, down to the bottom of the hole at 2,588. Thin beds of till were encountered in holes 25 and 26.

Glacial lake-bed silts constitute the majority of the Quaternary material exposed. On the right (west) abutment a thin layer of lake-bed silt overlies the Tertiary(?) and Precambrian rocks. In the left (east) abutment the lake-bed silts overlie the Tertiary(?) and till, and also occur in the ridge to the east and northeast of the site.

The silts are composed of rock flour, light buff in color, non-plastic, well-bedded, with layers ranging from a fraction of an inch to 2 inches in thickness. Grain sizes range from about 0.017 mm. down to 0.0017 mm., or from the middle of the silt size down to the middle of the clay size on the Wentworth grain-size scale. The material is calcareous and might be subject to solution losses. A small sample digested in dilute hydrochloric acid lost 10.6 percent by weight.

A lens of clean sand and gravel is present in the lake-bed silt 300 feet west of where the east line of section 1 intersects the left (south) bank of the river. The top of the lens varies from 11 to 22 feet above the river surface or from approximate altitude 2,630 to 2,641 feet. Only the upper 2 to 4 feet of the gravel bed is exposed above the alluvium on the river bank, so the total thickness and the extent are not known. It is possible that the lens was encountered in drill hole 27, where no core was recovered from a 20-foot interval between altitudes 2,650 to 2,670 feet.

Recent deposits include a terrace along the southwest side of the ridge that forms the left abutment. Silt, sand, gravel, and boulders are exposed at the surface and extend from the vicinity of drill hole 1 to the southeast.

Active and inactive stream alluvium are present in the river bottom and along the banks.

A small landslide, which extends from a few feet above the water surface to altitude 2,700 feet, is present on the left (east) abutment from 150 feet upstream of drill hole 2 to 500 feet downstream. What is possibly an older slide is located about 300 feet southeast of drill hole 1.

Structural Features

The strike of the Ravalli group ranges from N. 58° to 66° W., and the dip ranges from 8° to 10° NE. In the vicinity of BM 2742, in the southwest corner of the mapped area, the beds strike N. 20°-30° E., and dip 5°-10° NW.

The most important and numerous joints are those parallel to the bedding. They are spaced from 1/4 to 12 inches apart and appear to be tight. Another set of prominent joints strike N. 54°-64° W., and dip 63°-90° NE.

Observations on the fracture cleavage at two places gave bearings of N. 4° W., dip 50° SW., and N. 7° E., dip 45° NW.

Possible Axis Lines

Section B-B', plate 2, gives the approximate location for an axis line for the site. The right abutment and a portion of the foundation is on rock of good enough quality to support a concrete dam, spillway, and powerhouse structure. However, the rock south of a line through drill holes 14, 10, and 4, or about 100 feet south of the section, is weathered to a considerable depth, and it is of too poor quality for a foundation for a concrete structure. The left (east) abutment and a portion of the foundation is in Tertiary(?) beds and glacial deposits, and if proved safe, would be suitable only for an earth-fill dam. The section is drawn across the landslide in the belief that the plane along which the slide moved did not extend down into the Tertiary(?) rock, and only a small amount of material above it would have to be excavated and wasted. If the plane of failure is in Tertiary(?) rock, it may be at such a depth that the slide could not be removed economically.

The valley is narrower at section C-C' than at B-B', but owing to the presence of Tertiary(?) deposits, rock conditions in the foundation and right abutment are much poorer. As a result, C-C' must be considered inferior to B-B' as an axis.

Feasibility

On the basis of present information and exploration, the feasibility of the site for a dam to altitude 2,705 feet has not been proved conclusively. Additional exploration is needed to prove that the left (east) abutment can be made safe. No seeps or springs were found at the site, but permeable gravel beds along which large amounts of water could escape from a reservoir may be present. If piping and washing occurred in the lake-bed silts surrounding such a gravel bed, the left abutment and ridge that forms the natural earth dam to the east would be endangered. The small landslide in the left abutment is not suitable material against which a dam can be placed.

Even if it is determined that the left abutment is suitable, it probably will meet only the minimum requirements for a safe site.

Exploration required

Additional exploration is required on the left (east) abutment and in the foundation. Work should be directed towards exploration of the landslide and a search for the possible presence of a continuous gravel lens through the ridge to the east of the site. The gravel lens exposed northeast of the site is a linear feature and the extent and direction of its major axis is not known. The relationship of the gravel lens and the zone from which no core was recovered in drill hole 27 should be investigated.

It is suggested that trenches and a few test pits be used to explore the abutment, because core recovery in the Ex, or 1-5/8 inch diameter, core holes already put down has been very poor in zones of sand and gravel or reworked glacial materials.

Reservoir site

Glacial deposits of lake-bed silts, till, reworked glacial material, and alluvium cover the entire reservoir area upstream from Buffalo dam site No. 2.

Sloan Bridge Power Site

(See pl. 3)

Location and Accessibility

The proposed dam site is at river mile 44.7 in the SE¼NW¼ and the NE¼SW¼ sec. 18, T. 20 N., R. 21 W. In addition to power development at the site itself, there are three other possibilities for utilization of the head plus an increment gained by locating the powerhouse downstream from the dam. The appurtenant works for the alternative schemes become very widespread. (See fig. 1.) Thus, with a powerhouse site at river mile 39.0, about 6 miles downstream from the dam site, a conduit line would have to extend from the center of sec. 24, T. 20 N., R. 22 W., to the SW¼NE¼ sec. 30, T. 20 N., R. 22 W. With a powerhouse site at mile 13.0, a tunnel and opencut would be necessary from the NW¼SW¼ sec. 32, T. 20 N., R. 22 W., to the head of Race Horse Gulch in the NW¼NW¼ sec. 34, T. 19 N., R. 23 W.

All features of the project are readily accessible by car. The county road between Ronan and Hot Springs crosses the river at Sloan Bridge, just 0.2 mile downstream from the site, and follows along the right bank through the site. The intake area for the tunnel to mile 39.0 can be reached by driving 0.7 mile upstream on the east side of the Little Bitterroot Valley and then walking 1,200 feet farther. The discharge end and powerhouse site are 2.7 miles south of the bridge along the county road to Dixon.

Topography

In its course to the south along the west side of the Valley View district the Flathead River enters the lower part of the former valley of the Little Bitterroot River. (See fig. 1, p. 7.) To leave it the stream is forced to make a 180 degree turn to the northeast and then skirt around the end of a prominent rock ridge that trends northeast. The proposed dam site is located at the north end of this ridge, where the river is flowing to the east. A short distance downstream the river swings to the right in a sweeping bend that brings it against the southeast slope of the ridge, and it is forced to turn from a west-northwest course to the south.

The confluence of the Flathead and Little Bitterroot rivers is at mile 44.95, only a quarter of a mile upstream from the suggested axes. An abandoned channel of the latter stream on the right abutment at altitude 2,640 feet indicates the confluence formerly was downstream near mile 44.0. (Meinzer, 1916, p. 13.)

Both rivers have cut their channels mainly in lake-bed silts and drift related to the Mission glaciation. As the streams entrenched themselves, they encountered hard Ravalli rock, and their channels were forced to the north into softer, more easily eroded glacial deposits. This shifting has resulted in the formation of three river-cut terraces on the right (south) abutment at altitudes 2,710, 2,630, and 2,585 feet. The left (north) abutment rises in a steep slope from the river surface at altitude 2,559 feet to the main valley floor at about 2,800. This slope is now being dissected by a number of short, steep-walled gullies with flat-topped ridges between them. These ridges end in almost vertical cliffs that extend from the river to altitudes varying from 2,620 to 2,700 feet. The cliffs have been caused by a combination of two factors: About 20 feet above the river surface there is a thin lens of gravel that upon removal allows the overlying till to break along vertical planes. Secondly, the Little Bitterroot River has built a small bar of blocks and boulders into the Flathead River and deflects that stream to the northeast, where it impinges on and actively erodes the left bank.

From the confluence of the rivers to mile 39.0, the Flathead has a fall of 21 feet or an average stream gradient of 3½ feet per mile. However, through the dam site area the gradient is only 2 feet per mile.

In the vicinity of the proposed conduit route to the mile 39.0 powerhouse site, the rock ridge rises to about altitude 3,300 feet, and it is about 3,000 feet wide at altitude 2,780. Southeast of the ridge there is a constructional glacial terrace at approximate altitude 2,750 to 2,740 feet. Sections D-D' and E-E' are drawn along two possible conduit routes.

Geology

Precambrian

The Ravalli group is extensively exposed above altitudes 2,700-2,800 feet in the ridge south southwest of the dam site. A few outcrops are below this level in the Little Bitterroot Valley, and at mile 39.0 a few small outcrops occur from the river surface up to 2,700 feet.

The rock is fine- to very fine-grained, light-gray to greenish-gray quartzite interbedded with some greenish-gray argillite beds. The quartzite beds range from a fraction of an inch up to 36 inches in thickness, and a few argillite beds are up to 12 inches in thickness. Most of the Ravalli rock is fresh and unweathered; however, at a few places beneath or near exposures of Tertiary(?) local weathering is slight to intense.

Tertiary(?)

Three exposures of Tertiary(?) rocks are in the Little Bitterroot Valley southwest of the dam site. Along the right river bank near the center of section 24, or about 50 feet downstream from where geologic section E-E' crosses the river, there is a small exposure of mottled light-brown, light-gray, and greenish-gray silty clay with pieces of moderately to completely weathered light-gray and red quartzite embedded in it. Tertiary(?) talus breccia with angular pieces of completely weathered, cream to dark yellowish-orange quartzite is exposed on the southeast valley wall at altitude 2,850 feet, about 800 feet southwest of section E-E'. A similar talus breccia with a lens of light-brown silty claystone is exposed in the river bank in the SE¼SE¼ sec. 13.

In the NW¼NW¼ sec. 30, west of river mile 39.0, talus breccia embedded in light-brown to reddish-brown clayey silt is in surface depressions in the Ravalli.

Quaternary

Pleistocene glacial deposits related to the Mission glaciation have been deposited in the valley bottoms and on the Ravalli and Tertiary(?) rocks up to altitudes 2,750 to 2,820 feet. Along the river in the vicinity of the proposed dam site, till is exposed continuously in the left bank from a few feet above the river surface to about altitude 2,780 feet. Glacial lake-bed silts overlie the till and extend to the top of the slope at about 2,820 feet. On the right (south) bank scattered outcrops of till extend up to about 2,720 feet. Lake-bed silts overlie the till and crop out up to 2,750-2,800 feet.

The till is in massive, tight layers ranging from 8 to 60 feet in thickness, and it consists of an ungraded, mechanical mixture of approximately 30 percent gravel and 70 percent sand, silt, and clay. (See fig. 3.) The gravel is subround to round, fresh, hard, red, greenish-grey, light-gray, and purplish quartzite and siliceous argillite. Average diameter of the pebbles is 2½ inches, with a few cobbles up to 10 inches through. The matrix is a very pale-orange to grayish-orange, slightly calcareous mixture of sand, silt, and clay.

In the left (north) bank three thin, apparently continuous layers of reworked glacial materials are in the till at altitudes 2,578, 2,642, and 2,694 feet. Each is composed of clean gravel, rock flour, and lake-bed silts, and along the river through the dam site they could be correlated between stratigraphic sections taken 975 feet and 2,150 feet upstream from the Sloan Bridge. A fourth layer present at altitude 2,650 feet in the upstream section was not found downstream.

The lowest bed is exposed along the river for about 3,200 feet. At two places it has been removed and replaced by till; however, the removal appears to be local, and a short distance back in the bank the bed very likely is present. This layer consists of clean, extremely pervious gravel with a small amount of sand, overlain by a bed of calcareous rock flour. (See fig. 4.) The gravel layer ranges from 2 inches to 6 feet in thickness, and the silt layer from 4 inches to 3 feet. From approximately 800 feet upstream to 250 feet downstream of the proposed axis lines, the average thickness of the two beds is 14 inches. From 250 feet to 900 feet downstream from the axis lines, the bed thickens to 9 feet, but there is an increase in the amount of sand and silt in the gravel layer.

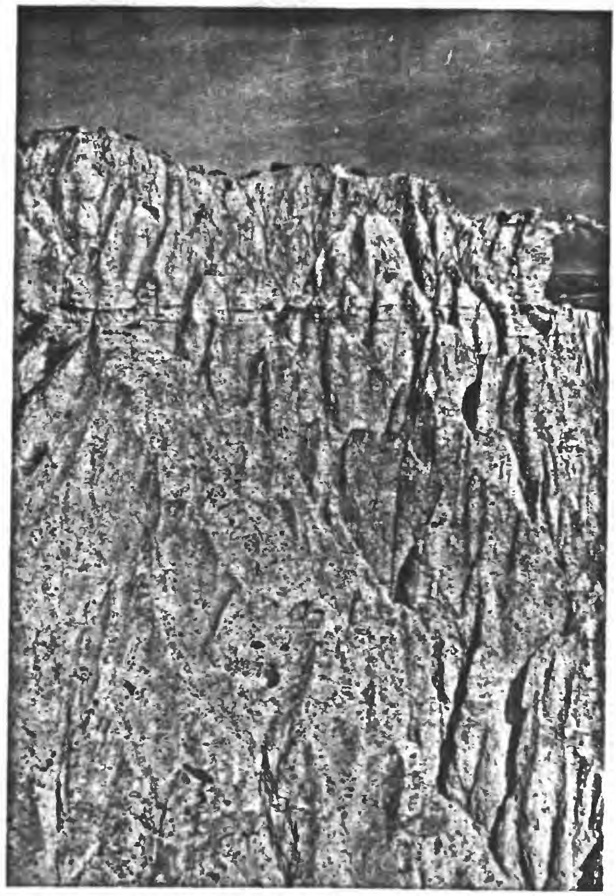


Figure 3. - Massive till of the Mission moraine in the left (north) abutment at the Sloan Bridge site. A thin bed of reworked material, mainly silt with a few lenses of gravel, is present near the top of the bank at altitude 2,694 feet, or about 11 feet below the normal pool level of the proposed reservoir. A discontinuous bed of slightly reworked material at altitude 2,651 feet can be seen near the bottom of the photograph.

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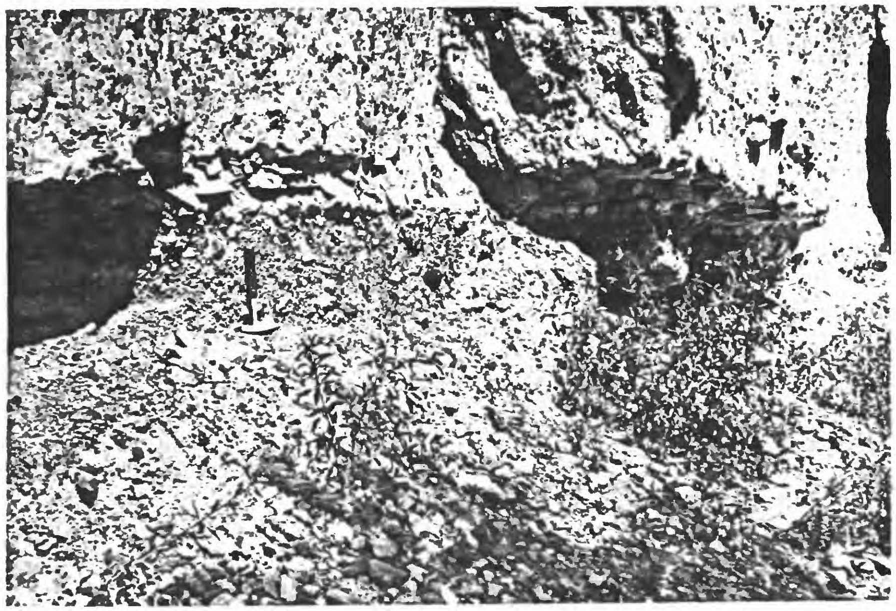

Figure 4. - Close-up view of the pervious, clean gravel and silt bed that is exposed for about 3,200 feet along the left (north) bank of the river from altitude 2,578 to 2,580 feet. At this locality the gravel bed is about 20 inches thick, and it is overlain by 8 inches of lake-bed silts. Tight till is above and below the reworked material.

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The reworked glacial materials at altitude 2,642 feet are in lenses with a maximum thickness of 5 feet. The material is sorted and varies from a clean, pervious gravel, with an average diameter of one-fourth of an inch, to a mixture of gravel, sand, and silt that may be impermeable.

The upper layer near altitude 2,694 feet is 30 to 36 inches thick, and contains lake-bed silts and a few, thin, discontinuous gravel lenses. (See fig. 3.) The bed appears to be relatively tight, and should give no trouble.

In a gully about 2,500 feet northeast of the bridge, till is exposed from altitude 2,607 to 2,636 feet, with lake-bed silts overlying it from 2,836 to 2,865. Stratified till is at altitude 2,655 to 2,665 feet, but the bed could not be correlated with layers of reworked material west (upstream) of Sloan Bridge. There are no outcrops between the river and altitude 2,607 feet, so it is not known if the lower bed of reworked material at the proposed axes extends downstream. Section C-C' gives the expected geologic conditions in this area.

On the right (south) bank in the vicinity of axis line A-A' no till is exposed, but in a dug well located on the bench about 800 feet west (upstream), four feet of silt overlies 14 feet of tight bouldery till in which angular blocks of quartzite 2 feet through are embedded.

Southeast of the ridge glacial deposits are in a constructional terrace to about altitude 2,780 feet. From the surface down to about 2,675 feet, lake-bed silts are exposed, and below this, till crops out down to about 2,580 feet. The base of the till bed probably is at considerable depth, because at Oxbow dam site about 2 miles to the east, the base of this bed was found to be near altitude 2,455. Where the terrace narrows west of river mile 39.0, the glacial deposits are thin, and the Ravalli and Tertiary(?) rocks extend up to about altitude 2,700.

Deposits of Recent active alluvium are in the river channel and on the river banks to about 2,570. Inactive alluvium covers the low terraces and slopes from 2,570 to about 2,580-2,600 feet. Much of the area above the estimated high flood level to the upper level of the glacial deposits is mantled with alluvium, especially along the abandoned channel of the Little Bitterroot River and the flat southeast of mile 39.0. Recent talus deposits are on the steep slopes of the ridge generally above 2,700 feet, and most of the ridge is covered by a thin layer of alluvium mixed with talus and topsoil.

Structural Features

On the northwest side and along the crest of the ridge, the general strike of the Ravalli group is to the northeast, with low to moderate dips to the northwest, but at a few places on the southeast side, the strike is northwest, with low dips to the northeast. At the northeast end of the ridge in NE¼NE¼ sec. 19, however, the strike is northeast, with low dips to the southeast.

In a draw west of river mile 39.0, an abrupt change in the attitude of the beds may indicate a concealed fault between altitude 2,620 and 2,700 feet. Along the river from 2,540 to 2,560 feet, the strike of the beds is N. 5°-12° E., and the dip is 40°-50° SE. From 2,580 to 2,620, the exposed beds have a strike of N. 42°-54° E., and a dip of 32°-69° SE., but in a higher outcrop between 2,700 and 2,720, the strike has changed to N. 22° W., and the dip is 19° NE.

Ground-water conditions

Artesian water may occur at depth at the dam site. This possibility is indicated by the fact that artesian water was found in the foundation of Oxbow dam site, 3.3 miles downstream, at about altitude 2,455 feet. Also, an artesian basin exists in the Little Bitterroot Valley about 12 miles upstream from the dam site (Meinzer, 1916, pl. 1). The main portion of this basin is about 12 miles long and lies between sec. 24, T. 21 N., R. 23 W., and sec. 36, T. 23 N., R. 24 W. However, the aquifer probably extends downvalley, as two wells, one about 3.5 miles west southwest of the dam site in sec. 21, T. 20 N., R. 22 W., and another about 6 miles from the site in SE¼ sec. 30, T. 20 N., R. 22 W., encountered artesian water.

The wells in the basin generally encountered the aquifer between 2,501 and 2,543 feet, or 16 to 58 feet lower than the river surface at the dam site. However, two wells, one in NE¼ sec. 13, T. 21 N., R. 23 W., and the other in the NW¼ sec. 13 of the same township, apparently tapped lower aquifers near altitudes 2,440 and 2,480 feet respectively. These altitudes correlate roughly with the source of the artesian water at Oxbow power site.

High temperatures, sodium carbonate mineral content, and the relationship of the nearby Camas Hot Springs and the artesian water to an intrusive diorite sill have caused Meinzer (1916, p. 33) to conclude that the water comes in part out of deep fissures in the underlying rock and from rather remote sources. Although the level of Flathead Lake is about 100 feet above the head of the wells, the mineral content of the lake and artesian waters is radically different, and these differences would not be likely to be produced by percolation through a gravel bed.

The possibility that these water-bearing beds may not be in the foundation at Sloan Bridge is favorable, however, because the ridge that forms the right abutment may extend out beneath the river. Also, if they had been deposited, the Sloan Bridge lobe of the Mission glacier could have removed them.

A small spring is located 960 feet west of the bend in section A-A', or about 500 feet south-southeast of the bridge across Little Bitterroot River. The water probably is meteoric and from a local source.

Sloan Bridge dam site

<u>Possible Axis Lines</u>

Sections A-A' and B-B' are proposed axis lines. On the left abutment till is exposed from a few feet above the river to near altitude 2,780 feet or considerably above the maximum possible flow line for the site. The main defects of the abutment are the three layers of reworked glacial material in the till. About 250 feet downstream from the lines or 1,150 feet upstream from the bridge, the lower bed thickens to about 9 feet. Although this thicker section might be less permeable, the thinner, cleaner portions of the layer would be easier to treat. If future exploration and water testing of this section show that it is acceptable in the abutment, section B-B' could be shifted downstream to a position more nearly normal to the river.

In the foundation active alluvium is in the river channel and on the banks to about altitude 2,570 feet. Till underlies the alluvium.

On the right abutment, the location of the axis probably will depend upon a suitable foundation for a spillway structure. On the basis of the writer's investigations, line A-A' is preferred, because rock crops out at the bend in the section and probably is at shallow depth beneath the fill in the channel to the southeast. Line B-B' has a shorter crest length, and if rock is at shallow depth on the right abutment, it probably would be a more economical section. The quartzite in section A-A' is of good quality, but it is cut by joints, some of which make blocks 3 to 4 feet through. The strike of the beds is N. 26°-41° E., and the dip is 23°-28° NW.

Inactive alluvium is present along the sections from about altitude 2,570 to 2,600 feet, with the bench at 2,585 being covered by river silt. Along section A-A' from altitude 2,600 to 2,640 feet and along section B-B' to 2,660, the ground surface is covered by angular blocks of quartzite, topsoil, silt, and sand. Beneath this, a thin layer of till may overlie bedrock or possibly Tertiary(?) talus breccia, but is likely that the breccia was removed by glacial scour. Beneath the abandoned channel and in the terrace at 2,720 feet to the southeast, there may be as much as 60 feet of glacial deposits, most likely till.

The powerhouse site for either line would have till in the foundation.

Permeability and Treatment of Gravel Beds

Permeability of the massive till is low; however, permeability of the beds of reworked glacial material in the left abutment will vary from low to high. The bed at altitude 2,576 feet is composed mainly of clean gravel, and it would be the most permeable. Although the volume of water losses along it probably would not be serious, the main danger is that piping and subsidence could occur in the overlying till.

The amount, velocity, and erosive power of the water moving along the beds could be reduced substantially if the length of the path of percolation were made greater than the width of a dam. For the lower layer this could be accomplished easily by blanketing the outcrop with impervious material where it is exposed almost continuously along the river edge and in a few small gullies for about 2,500 feet upstream from the proposed axes. It is even possible that the gravel in the bed may be open enough to allow it to be grouted. A few lines of holes at right angles to the river would allow grout to be introduced, and this would increase the length of the path of percolation by forcing it back or to the north into the abutment.

The two upper beds at altitudes 2,694 and 2,642 feet should have low to medium permeability because they have a high percentage of fines, the gravel along them is in lenses, and the beds themselves appear to pinch out from place to place.

Height and Type of Dam

The maximum altitude of the flow line for a dam at this site is 2,705 feet. The maximum height of a dam would be approximately 165 feet, which would include 146 feet for the head; about 10 feet for freeboard; and about 9 feet for depth of water in the river and necessary excavation in the channel. The site is feasible only for an earth-fill dam.

Reservoir

The reservoir is underlain mainly by till and lake-bed silts. A few small outcrops of the Ravalli group and Tertiary(?) rocks may be present along the west side. With a normal water surface at altitude 2,705 feet, a narrow arm of the reservoir ranging from 0.2 to 1 mile in width will extend 23 miles up the Little Bitterroot Valley. This area is underlain mainly by lake-bed silts.

Other possible development schemes

Powerhouse at Mile 39.0

Another development is possible by placing the powerhouse at mile 39.0, about 5.7 miles downstream from the dam site. Water could be conveyed from the arm of the reservoir in Little Bitterroot Valley through the rock ridge by a pressure tunnel and across the terrace on the southeast side of the ridge by a pressure conduit laid in an open cut. The indicated head for this development is 167 feet.

Sections D-D' and E-E', plate 3, are drawn along proposed conduit routes to the powerhouse. The intake areas at both lines are covered by alluvium, talus, and topsoil; however, quartzite of good quality crops out at a number of places on the canyon wall and in the valley bottom. The strike of the beds ranges from N. 37° to 60° E., and the dip ranges from 11° to 26° NW. The average attitude is strike N. 54°E., dip 17° NW.

The Tertiary(?) talus breccia at altitude 2,650 feet and about 800 feet southeast of the portal site for line E-E' is considerably above the level at which a tunnel would be driven. It is possible that Tertiary(?) rock covered by talus may be at either intake. If so, the quality and strength of the Ravalli rock would be very poor for some distance into the hillside.

Beneath the ridge the tunnel will be in Ravalli rock that should be of very good quality.

To the southeast on the flank of the ridge, Tertiary(?) talus breccia probably rests on completely weathered Ravalli rock. For some distance from the contact, extremely difficult tunneling conditions would prevail. Farther to the southeast glacial deposits in the constructional terrace have been deposited against Tertiary(?) and Ravalli rocks. In these deposits till is below approximate altitude 2,675 feet, and lake-bed silts are above. The bottom grade of a tunnel or opencut here probably would be in the till with the side-walls in the silt. In the terrace about 300 feet southwest of section E-E', Tertiary(?) and Ravalli rocks are exposed above 2,700 feet, and they could extend above the tunnel level for some distance out from the ridge.

The poor geological conditions southeast of the ridge probably preclude a tunnel along either line there, and that section of a conduit would have to be a pressure pipe laid in an opencut. The choice of a line would have to be made chiefly on economic considerations, in which the cost of the excavation and lining for a long tunnel in rock with a relatively short opencut section (E-E') was balanced against the cost of a short tunnel and a longer opencut (D-D').

The total length of a conduit along section D-D' would be about 5,560 feet, and along section E-E' about 5,230 feet. The length of the tunnel beneath the ridge would be about 2,840 feet along section D-D' and 3,700 feet along E-E'. The opencut would be about 2,370 feet in length along section D-D' and 1,100 feet along E-E'. A penstock about 350 feet long would be required from the end of the opencut to the powerhouse. The depth of the opencut will range from a few inches to a maximum of 100 feet.

At the mile 39.0 powerhouse site Ravalli rock is exposed in two outcrops that extend for about 200 feet along the edge of the river and about 50 to 100 feet out from the bank. The rock is slightly broken, weathered, sandy argillite. The strike of the beds is N. 5°-12° E., and the dip is 40°-50° SE.

<u>Development of additional head downstream from Mile 39.0 Powerhouse Site</u>

The hydraulic head of a power plant at mile 39.0 could be increased by excavation of the river channel downstream from that place. It is feasible to consider winning the additional head, because the river channel has been cut mainly in deposits of till, outwash gravel, and lake-bed silts. A dragline should excavate these materials without much difficulty.

The head gained will depend upon the gradient decided on for the channel and the distance the excavation is carried downstream. The choice of these factors should depend upon a study of this reach of the river by means of a model and future exploration of the channel. Between miles 39.0 and 22.1, the gradient of the stream varies from 1.12 to 5.72 feet per mile. The gradient of 1.12 feet is in the reach from mile 30.8 to 26.4, and it may be a slope that would give a satisfactory discharge. If the stream bed were excavated to this gradient from mile 24.9 with minor straightening of the channel, the head at the mile 39.0 powerhouse would be increased about 24 feet. Comparably, about 20 feet of head could be gained by starting the channel deepening at mile 29.0.

There are two drawbacks to this scheme: Erosion may occur in the channel above the powerhouse, with deposition below, and bedrock may be present in the reach of the river that would have to be dredged. A retaining dam, or possibly heavy riprap, upstream from the powerhouse site, may prevent erosion of the stream bed due to the increased gradient there. From miles 36.6 to 35.9, or through Dam site No. 4, and from miles 33.3 to 32.0, rock is in the right bank and extends out under the river. However, at both localities the left (east) bank is alluvium or glacial deposits, and rock excavation can be avoided by moving the channel into that bank. Rock may be present at mile 28.0, but glacial deposits are believed to be in the left bank.

<u>Powerhouse Site at Mile 13.0</u>

Another development of the Sloan Bridge site is possible by diverting the water from the Little Bitterroot Valley about 8 miles above the dam site to a powerhouse site at mile 13.0 on the Flathead River about two miles upstream from Perma. (See fig. 1.) A tunnel and opencut about 7 miles long would be required to carry the water to the head of Race Horse Gulch where a small regulating reservoir could be constructed. A penstock about 4,000 feet in length would be needed to carry the water to the powerhouse. The total difference in head between the normal reservoir surface, altitude 2,705 feet, and the river surface, altitude 2,480 feet, at the powerhouse is 225 feet.

This suggestion was conceived through office study, and none of its features have been examined in the field to determine if they are geologically feasible.

Suggested exploration program

The first exploration of Sloan Bridge power site should be a test of the foundation for beds of reworked glacial material in or beneath the till layer and for artesian water that may be in these pervious layers. The tests should be carried considerably below 2,455 feet, the approximate altitude at which artesian water and lake-bed silts occur at Oxbow power site. If found, samples suitable for testing the consolidation of the various materials under the expected conditions of loading should be taken. This is necessary, because uneven consolidation of the foundation could produce fractures along which artesian water might escape, and piping and subsidence, similar to that which took place at churn drill hole 2 at Oxbow dam site, could occur.

On the right abutment tests are necessary to determine if till is present at shallow depths beneath the overburden. If the material contains many boulders or blocks of quartzite, test pits instead of drill holes may be required to give worthwhile information. In the probable spillway area diamond drill core holes should be satisfactory to investigate the overburden and to check the depth to bedrock. To the south the surface of bedrock should be traced to at least 20 feet above the maximum reservoir pool level.

If the preliminary estimates of costs of the two conduit lines are comparable, exploration would be necessary to determine which line is better geologically. As the geologic conditions below the terrace will vary most, the first work should be done there. A few core holes, spaced about 400 feet apart and drilled to the Kavalli rock or at least to a depth of 35 feet below the expected bottom of the opencut, should be put down along each line. Also, one or two holes should be drilled where the tunnel section probably will end and the opencut will begin.

When a choice has been made for the tentative final alignment, intermediate holes should be drilled with a number of them being extended to the Ravalli. The line of holes should be carried up the hillside until a minimum of 100 feet of good rock is above the roof of the tunnel. Where Tertiary(?) rocks overlie the Ravalli, thorough weathering can be expected in the latter. If core recovery is not adequate in this zone, a shaft should be put down, and an exploratory drift should be driven through the weathered material into good rock. This would give better information on the location of the contact and would indicate the size and extent of the supports required at the tunnel outlet.

The rock at the intake portal should be investigated by core holes on a maximum spacing of 100 feet. If Tertiary(?) rocks overlie the quartzite, an exploratory adit should be driven into the hillside. Even if weathered rock is not present near the surface, a short adit would be of value to show if supports will be required at the portal.

Oxbow Dam Site

(See pl. 4)

Location and Accessibility

Oxbow dam site is located mainly in the NW¼ sec. 28, T. 20 N., R. 21 W., with a small portion of the right abutment in the NE¼ sec. 29. The site is at mile 41.3, only 3.4 miles downstream from the Sloan Bridge site, 19.4 miles from Buffalo dam site No. 2, 26.6 miles from Buffalo dam site No. 1, and 30.7 miles from Kerr Dam.

The left (southeast) abutment is accessible by a very good, all weather, county road that follows through the site along the bank of the river. The right abutment is accessible by car during good weather via an unimproved county road and trails leading to fields west of the site. From Sloan Bridge, this road leads to the southeast corner of sec. 18, T. 20 N., R. 21 W. From here, a trail can be followed along the north line of section 20 to near the quarter-corner, where it swings southeast for about 0.6 of a mile and then south to the edge of the second bench above the river in the NW¼ sec. 28.

Figure 5. - View looking northeast through Oxbow power site from a point 0.8 mile downstream from section A-A'. The section crosses the river from the end of the long rock ridge in the left bank (right side of the photograph) to the group of tall trees at the bend on the right (west) bank. The Moiese Valley Canal near altitude 2,725 feet, which would be approximately 20 feet above the normal reservoir level, can be seen on the rock point. Crow Creek enters the river from the northeast just downstream from the white triangular spur in the center of the view. The bluff on the right (west) bank of the river downstream from the lower terrace is formed by till for one-third of its height, from altitude 2,549 to near 2,580 feet, and reworked glacial material is in the upper two-thirds up to altitude 2,650 feet. The crest line of the Mission Range can be seen in the distance.

Topography

Oxbow power site is just inside the north end and on the east side of the Moiese Valley where the Flathead River touches the low hills. (See figs. 1 and 5.) The river is flowing to the southwest at the site.

The left (southeast) abutment is on hard Precambrian rocks that rise from the river surface at altitude 2,548 feet up to 2,750 on a slope of 27°. Above this the slope flattens, but the hills rise another 600 to 800 feet above the level of the valley fill. The right (northwest) abutment is on glacial deposits in which the river has cut two terraces. The lower terrace at 2,570 is about 350 to 400 feet wide at its broadest part. From here the ground surface rises on a slope of about 30° to 2,660, where a terrace about 300 feet wide is present 600 to 900 feet from the river. To the northwest the ground surface rises gradually at an angle of 3 to 4 degrees to about altitude 2,000 feet.

The stream has a gradient of 4.8 feet per mile through the site.

Geology

Precambrian

The Ravalli group, which is exposed only on the left (southeast) abutment, consists of quartzites with a few layers of argillite, and it is similar in character to the rocks at the upstream sites. The rock is fine-grained, firm, unweathered, with beds that range from 0.25 to 30 inches in thickness. Many small outcrops are in the hillside from the river surface at altitude 2,548 feet to 2,670; none from 2,670 to 2,725, the general level of the Moiese Valley Canal; but above 2,725, rock is exposed extensively. Bedrock is exposed intermittently along the south wall of Crow Creek Valley upstream from the bridge.

Below altitude 2,660 feet the strike of the beds is N. 13° E.-N. 11° W., and the dip is 11°-26° E.; but above 2,725 the strike is N. 25°-27° W., and the dip is 17°-41° NE. From the Crow Creek Bridge to the northeast the strike is N. 22° E.-N. 12° W., and the dip is 22°-42° E.

Two strike-slip faults were exposed by the excavation for the Moiese Valley Canal. About 225 feet southwest of the farther east road crossing of the canal, a zone of crushed rock and gouge about 60 feet wide is exposed. As indicated by a series of notches in the hillside above the outcrop, the bearing of the fault is approximately

N. 5° W., and the dip is 75° E. The hanging wall appears to have moved to the north and down.

Another fault zone, 26 to 27 inches wide, with fresh crushed rock and gouge along it, crops out 550 feet southwest of the crossing. The strike is N. 18° E., and the dip is 76° SE. Drag of the bedding on both sides of the fault indicates the hanging wall has moved to the northeast and down.

No other faults were observed; however, the variation in the attitude of the beds along section A-A' below and above altitudes 2,660 to 2,725 feet suggests that one may be present there.

Quaternary

Pleistocene.—Surface and subsurface exploration of the Oxbow power site reveal that the foundation consists of a massive layer of till that was deposited by the Sloan Bridge lobe of the Mission glacier. The till is underlain by silt, very fine-grained sand, and some gravel probably deposited in a glacial lake related to the St. Ignatius glaciation. In three churn drill holes the base of the till is at altitude 2,452 to 2,460 feet, and the top is approximately at altitude 2,560 feet in the right abutment. Beneath the river channel the bed is 85 to 90 feet thick, but under the right abutment it is about 125 feet thick.

In the slope above churn drill hole 2, till is exposed to about altitude 2,580 feet, with reworked glacial material overlying it to 2,650. On the right bank, at the north end of the map, till crops out from the river surface at 2,549 up to 2,570 feet. The surface of the till rises to the north so that about 1,000 feet upstream, or near mile 42.0, it is at 2,610 feet; at mile 42.4, it is at 2,670; and at mile 42.6, it is at 2,660.

The massive till is tight and compact, and has a pale yellowish-orange to moderate yellowish-orange sand and rock flour matrix, in which fresh, red and green quartzite and greenish-gray argillite pebbles are embedded. North of Crow Creek Bridge the till has a pinkish hue and in the right bank north of the map area the exposures are lemon yellow. These red and yellow shades are due to Tertiary(?) rock picked up by the glacier.

On the left abutment till is exposed at a number of places. Southwest of Crow Creek Bridge there are a few small landslides in a thin layer of till that appears to be smeared on the rock sidehill. On the spur till occurs between altitudes 2,670 and 2,725 feet. Downstream (south) of the spur till is exposed occasionally from 2,570 up to about 2,690, and above this lake-bed silts are exposed to about 2,770.

The right abutment above altitude 2,560 feet is formed by reworked glacial material that probably has been deposited in a melt-water channel eroded in the massive till. The course of the channel appears to have been to the southeast approximately parallel to Crow Creek Valley until it reached Oxbow power site. Here it swung around the rock spur and continued to the south-southeast along the east side of Moiese Valley. The location of the right (north and west) bank of the channel is not known definitely, but north of the site the surface of the till rises gradually. The buried side of the channel probably swings across the N½SW¼ sec. 20 to near the south quarter corner and continues to the south-southwest across the E½NW¼ sec. 29. The edge of the channel probably crosses Flathead River near mile 40.3.

In churn drill hole 1, which may be located close to the center of the channel, sand and gravel were recovered from the ground surface at altitude 2,690 feet down to 2,578. The character of the fill in the melt-water channel can be seen in the exposure above churn drill hole 2 and in the road cut in the southeast (left) bank about 2,000 feet S. 24° W. of the hole. Here there are interbedded layers of till, lake-bed silts, sand and gravel, gravel and cobbles, and fine-grained sand of widely varying permeability. (See sec. B-B', pl. 4.)

Recent.—Active stream alluvium of silt, sand, and gravel is in the river bottom and along the banks to elevations approximately 8 feet above the water surface. Inactive alluvium covers the lower terrace at altitude 2,570 feet on the right abutment, another terrace at the same elevation on the left abutment downstream from the rock spur, and the wide flat where Crow Creek joins the river.

Older alluvium and topsoil cover most of the right abutment above the lower terrace and much of the left abutment.

Ground-water conditions

Artesian water was encountered in churn drill holes 2, 3, and 4. A few days after completion of drill hole 2, water started to flow from the casing at a rate of 60 gallons per minute.[3] Before the flow was sealed off, the contractor pulled the casing, and the Corps of Engineers had to pump about 1,500 sacks of cement, 4 sacks of bentonite, and several cubic yards of sawdust into the hole to cut off the water. Settlement of the ground around the hole was substantial. In October 1953, water was flowing from the hole at the rate of about 0.5 gallon per minute.

An artesian flow developed in drill hole 3 when drilled or shortly after its completion. In October 1953, this flow was about the same as that from drill hole 2.

3/ Letter from the Corps of Engineers, Seattle, Wash., to F. A. Johnson, regional hydraulic engineer, Tacoma, Wash., dated September 14, 1953.

About 130 feet south-southeast of drill hole 4, two small springs, with a combined flow of 0.5 to 1.0 gallon per minute, emerge from the river bank. The springs, which appear to be related to the hole, have built a small deposit of clay and silt at the point of discharge about 4 feet above the river surface. The deposits are small, probably due to annual removal by flood runoff of the river.

Apparently, the artesian aquifer is a layer of very fine-grained sand, and sand and gravel, underlying the massive till bed. (See sec. A-A' and B-B', pl. 4.) The largest flow was from churn drill hole 2 and can be attributed to the layer of sand and gravel between altitudes 2,454 and 2,459 feet. The smaller flows from drill holes 3 and 4 are probably from the somewhat less permeable clayey sand or glacial lake-bed silts below the till.

Danger due to the artesian water

The potential danger from artesian water is great, as shown by the piping that took place at depth beneath drill hole 2, with subsequent settling of the ground around the hole. Although the 80 to 100 feet of till would make an excellent foundation, any uneven settlement of the lake-bed silts after loading would allow cracks and fissures to develop. If these openings extended to the top of the till, the water under hydraulic head could escape along them and carry enough fines with it to cause additional settlement and cracking. The extreme but possible effect of piping and settlement could be impairment of the safety and even failure of the dam.

Height and type of dam

The maximum height of a dam is limited to one with a normal reservoir surface at altitude 2,705 feet and a hydraulic head of 157 feet. Construction at Buffalo dam site No. 1 would limit the normal water surface to 2,641 with a head of 93 feet, and a dam at Buffalo No. 2 would limit the surface to 2,615 with a head of 67 feet.

Even if all defects of the foundation can be overcome, the site is still only feasible for an earth-fill type of dam.

Possible Axis Line

Geologic section A-A', plate 4, is a possible axis line that has been drawn about 200 feet upstream from the smallest valley cross section. Conditions along it will be similar to those along any other line at the site.

For all heights of a dam considered, the left abutment is adequate. Any appurtenant works requiring a rock foundation for reduced costs or increased safety can be located here. The rock is suitable for a large diversion tunnel, and probably would require little or no support.

Beneath the river and valley fill, the slope of the rock surface probably is steeper than it is above. On the southeast side of the spur, the rock surface may descend steeply beneath the till and lake beds there.

In the foundation, 10 to 25 feet of active and inactive alluvium overlies the till.

The right abutment to approximate altitude 2,580 feet is formed by tight till, but between altitudes 2,580 to 2,705 feet the reservoir would rest against 125 feet of pervious reworked glacial materials in the melt water channel.

Feasibility

The feasibility of Oxbow dam site depends upon finding tight material in the right abutment or sealing off these permeable beds from the reservoir, and upon an evaluation of the danger owing to the artesian water in the foundation.

The first of these difficulties might be overcome by blanketing the intake area between the upper surface of the till at altitude 2,580 and the terrace at 2,660 feet from section A-A' upstream to where the edge of the melt water channel rises to 2,660. A small dam, constructed to above altitude 2,705 feet, would have to be set on the terrace and tied to the blanket. A cutoff wall would have to be put through the permeable material above 2,660 feet north of the end of the blanket.

Additional exploration is needed to fully evaluate the danger from the artesian water.

Suggested exploration program

The next stage of exploration should be directed towards investigating the buried right bank of the melt water channel to determine if the surface of the till rises to near altitude 2,705 feet within a reasonable distance north of the site. A combined program of trenching and core drilling should answer this. Five trenches excavated in the right river bank between miles 41.55 to 42.0 and a line of drill holes approximately parallel to section A-A' and 1,000 feet to the northeast should adequately check on the surface of the till. If results are favorable and impermeable material can be found above 2,705 at a reasonable distance north of section A-A', additional holes still will be needed to trace the channel to the southwest and to investigate the reworked glacial material in it.

If it is found feasible to blanket the reworked glacial material in the melt water channel, it would still be necessary to check for another possible bypass channel in the wide flat in section 20 between the abutment of the dam and the rock ridge in the NE¼ of section 19.

A number of drill holes will be required to check on the source, pressure, and volume of the artesian water encountered in the churn drill holes. Samples suitable for consolidation tests are required from the underlying silts in order to determine the amount of consolidation and settling that would take place if a dam were built.

On the left abutment the rock spur should be explored by diamond drill holes, especially the possible fault zone just below the 2,705 flow line. The buried slope of the rock surface southwest of the point should be outlined to assist planning for a possible diversion tunnel site.

Reservoir site

Glacial deposits of lake-bed silts, till, reworked glacial material, and alluvium cover the entire reservoir site upstream to Buffalo dam site No. 2.

Mile 42.9 Power Site

(See fig. 1)

An alternative power site to both Oxbow and Sloan Bridge exists at mile 42.9 and would warrant further investigations if they prove infeasible.

Location and Accessibility

This site is in the SE¼ sec. 17, T. 20 N., R. 21 W., near mile 42.9. The left (northeast) abutment can be reached by leaving the county road in the SW¼ section 16 and driving to the northwest along the farm roads leading to the fields on the terrace above the site. The right (southwest) abutment can be reached by leaving the Sloan Bridge-Dixon road 0.3 mile east of the bridge and following a trail to the east for about 1.2 miles.

Topography

The left abutment rises from the river surface at altitude 2,555 up to 2,760 feet on a slope of 20°. At the proposed axis line the bank is being dissected by a number of short, steep-walled gullies. The right (southwest) abutment rises on a more gentle slope, and small terraces have been cut by the river at altitudes 2,721, 2,680, and 2,560 feet.

The stream gradient through the site is about 2.0 feet per mile. A dam that would back water to the tailrace of Kerr powerhouse would have a head of 150 feet. Lower dams that would back water to the tailraces of installations at Buffalo dam site Nos. 1 or 2 would have heads of 86 and 60 feet respectively.

Geology

Pleistocene glacial deposits of till, very fine-grained sand, and lake-bed silts overlain in some places by alluvium are exposed in the area. The till is the same massive bed that is at Sloan Bridge to the west and at Oxbow power site to the south.

At mile 42.9, till is in the left (northeast) abutment from 15 to 60 feet above the river surface, and 500 feet upstream it crops out from a few feet above water surface to near altitude 2,750 feet. A 24-inch thick lens of sand and gravel is at 2,665, or about 110 feet above the river.

The right (southwest) abutment is generally covered by alluvium, and only a few outcrops are exposed in the small draws. From the river surface at 2,555 to 2,637 there are no outcrops, but in a small draw about 250 feet upstream from the axis, till is exposed intermittently from 2,637 to 2,672, lake-bed silts from 2,672 to 2,690, and very fine-grained sand from 2,690 to 2,696. At mile 42.6, till is at altitude 2,680 feet, and at mile 42.4 it is exposed from the water surface to 2,670, or to the altitude of the base of the lake-bed silts mentioned above. Till probably is in the foundation about 15 to 25 feet below the river surface or between altitudes 2,540 to 2,530 feet.

Active stream alluvium is along the river channel, with inactive stream alluvium on the lower 2,560 terrace. Older alluvium is on the higher terraces and to the west. A few small alluvial fans are present at the mouths of the small draws.

Feasibility

The reach of the river in the vicinity of mile 42.9 appears to be a prospective power site. For any height dam considered, the left abutment will be in tight till. The right abutment probably will have till in it to altitude 2,670 feet, with glacial lake-bed silts and very fine-grained sand from 2,670 to 2,705. A dam high enough to back water to either Buffalo dam site Nos. 1 or 2 would have till in both abutments. The site is feasible only for an earth-fill dam, and it is a very good one for a dam of relatively low head.

At depth, geologic conditions may be similar to those at the Oxbow power site. The massive till layer may be underlain by very fine-grained sand, glacial lake-bed silts, and some sand and gravel at a depth of approximately 105 feet below the river surface or near 2,450. Artesian water may be present in any pervious material below the till.

Suggested exploration program

Preliminary exploration of the site should include a row of diamond drill core holes spaced 200 feet apart along an axis on the most favorable topographic section at mile 42.9. In the foundation the holes should be carried into the silts and sand beds that possibly underlie the bed of massive till, and samples suitable for consolidation testing should be taken, in order to determine the amount of settling that could occur in them. Every effort should be made to determine the source, pressure, and volume of any artesian flows encountered. A number of holes should be drilled to check for an older channel of the Flathead River that may have been located between the right abutment and the rock ridge 3,000 feet to the west.

Dam Site No. 4

(See pl. 5)

Location and Accessibility

This site is just south of the center of sec. 1, T. 19 N., R. 22 W., at mile 36.4, only 4.9 miles downstream from Oxbow power site, 8.3 miles below Sloan Bridge power site, and 24.3 miles below Buffalo dam site No. 2. It is the farthest downstream of the sites considered in this report. (See fig. 1.)

Both abutments are accessible by car. The right (west) abutment is approximately 5 miles south of Sloan Bridge via an unimproved county road. The left (east) abutment can be reached by leaving the county road at the southeast corner of section 1. A trail runs to the west for 0.2 mile along the section line, until an irrigation ditch forces it to the southeast for 0.1 mile. Here it descends into a wide gully, turns to the northwest, passes beneath a trestle, and then continues for 0.8 mile to the site.

Topography

At Dam site No. 4, the Flathead River is flowing in Moiese Valley, a small southwest compartment of Mission Valley about 8 miles long and 2 to 4 miles wide. The proposed site is near the center of the valley lengthwise and on the west side so that the right (west) abutment is on a small rock spur that extends a short distance out from the Salish Mountains.

From the river surface at altitude 2,530 feet, the right abutment rises to 2,700 feet on a slope of approximately 12 degrees. Above 2,700 feet the slope of the hillside increases, and the hills rise to approximate altitude 3,500 feet. The left abutment is on two terraces cut in glacial outwash. The lower terrace is at altitude 2,555 feet, and the upper at 2,640. This upper terrace is only a few feet below the general level of the valley fill that extends 7,500 feet from the power site to the low hills on the east side of the valley.

The stream has a gradient of 8.3 feet per mile through the site.

Geology

Precambrian

The Ravalli group is exposed on the right (west) abutment in three small rounded rock spurs that extend out from the hillside and descend beneath the alluvium in the river channel. (See pl. 5.) The rock varies from a light to dark greenish-gray sandy argillite to a very fine-grained, light-gray quartzite. It is firm, generally fresh, with beds that range from one-half inch to 4 feet in thickness.

Tertiary(?)

Tertiary(?) talus breccia rests unconformably on the Ravalli group in the right (west) bank where it crops out over a distance of about 1,200 feet north of section B-B'. This outcrop is the largest and most complete exposure of this unit on lower Flathead River. Angular to subround fragments and blocks of more or less thoroughly weathered argillite and quartzite up to 3 feet through are embedded in a matrix of silt and sand. The size of the blocks decrease and the amount of matrix increases away from the contact with the Ravalli rocks. The general color tone is grayish orange to pale yellowish orange, but the individual pieces vary in color from very light grey to light brown. Both the individual rock fragments and the mass as a whole appear to be quite porous.

Talus breccia was recovered in drill holes 1, 2, and 7, and probably would be found in drill hole 6 if it were deeper. Between holes 2 and 3, the breccia pinches out (see section D-D', pl. 5), and is not present to the south in holes 3, 4, and 5.

Quaternary

Pleistocene glacial deposits unconformably overlie both the Precambrian and Tertiary(?) rocks, with Recent alluvium along the river channel.

On the right (west) abutment, glacial lake beds generally covered by silt and topsoil are present at the surface. One small exposure of till was found in a draw 1,000 feet N. 35° W. of the northernmost B.M. 2542.

The left (east) abutment is underlain by reworked glacial deposits. Active and inactive alluvium occurs along the river, and older alluvium with a small amount of topsoil is on the higher slopes and terraces. Alluvial cover effectively prevents any detailed surface geological mapping, and only four small exposures of till related to the Sloan Bridge lobe of the Mission glacier were found in the northern part of the map area and one exposure of silt in the southern part.

In the exploratory holes on the left abutment, reworked and outwash glacial deposits overlie the Ravalli group and Tertiary(?) talus breccia. In drill holes 1 to 5, drilled in a line parallel to the river (see section D-D', pl. 5), the core recovery was too poor in the upper 30 to 37 feet to determine definitely what material is present. From the few pieces of core that were recovered, it appears that gravel occurs down to altitudes 2,515 to 2,505 feet, or to 15 to 25 feet below the surface of the river. The core boxes contained no fines.

Drill holes 1, 6, and 7 show that the gravel bed extends to the east, and its base rises from 2,505 to 2,523-24 between holes 6 and 7. At drill hole 7, the driller reported silt from the ground surface at 2,575 to 2,555, but no core was recovered. In the underlying gravel bed from 2,555 to 2,524, the core recovery was only 16 percent; and the core box contained only red and light-gray quartzite gravel, one-half inch to 4 inches in diameter. Section B-B' is located a short distance north of the drill holes and shows the geologic conditions through them.

Below the gravel there are interbedded glacial lake-bed silts, silt, sand, till, and conglomerate beds. Very pale to grayish-orange glacial lake-bed silts with varves and a few seams of very fine-grained sand predominate in the core recovered in this interval. The lake-bed silts in drill hole 5 below altitude 2,442 and in hole 7 below 2,453 are very light gray to medium light gray and generally more clayey. These silts may have been deposited in a glacial lake related to the early Wisconsin or St. Ignatius glaciation.

In the abutment east of drill hole 7, the top of the silt bed is believed to be near 2,520. Gravel and sand probably overlie the silt and form the constructional terrace east of the hole, but no exposures are present. However, seismic spread number 8, located 200 feet east of drill hole 7 at altitude 2,624, shows there is 64 feet of material with low velocities comparable to those where gravel and sand are known to be present. The change of stratification at the depth of 64 feet is at altitude 2,560 feet and compares closely with the base of the silt bed reported at 2,555 in drill hole 7.

Structural Features

The strike of the beds on the right (west) abutment is N. 48°-66° W., and the dip is 23°-42° NE., except in the southwest corner of the map area where the strike and dip of the beds has changed to N. 34°-58° E., 6°-16° NW.

The right (west) abutment is on the northeast limb of a small, asymmetric anticline that plunges northwest. The crest of the fold crosses the southwest corner of the map, but at section A-A' the axial line is about 1,600 feet west of the river and high on the hillside.

One minor fault was discovered in the right bank 310 feet N. 24° E. of the northernmost 2542 benchmark. Here, two bedding plane slips with seams of tight, fresh gouge varying in thickness from 2 inches to paper thin are separated by 2 feet of broken, slightly weathered rock.

Three joint sets were observed. The most important, with tight joints spaced one-half inch to 4 feet apart, parallels the bedding. The attitudes of the two other fairly prominent sets are: Strike N. 78° W.-S. 85° W., dip 55°-67° S.; and, strike N. 5°-25° E., dip 67°-84° SE. The majority of the joints are tight.

Ground-water conditions

Artesian water was found in drill holes Nos. 3, 5, 6, and 7.

Table 3

Summary of artesian-water conditions at Dam site No. 4

Hole No.	Water at Depth	Water at Altitude	Est. flow gpm	Hydrostatic head	Aquifer
3	98	2,444	4	2,549 10 feet above ground surface	Probably Quaternary. Conglomerate bed about 7 feet above the Ravalli group.
5	112	2,430	2-3		Layer of sand and gravel 3 feet thick on top of the Ravalli group.
6	122	2,447 to 2,445	4	2,570 7 feet above ground surface	Probably a bed of sand and gravel 4 to 6 feet above the depth at which water was reported.
7	150-171	2,425 to 2,404	1	2,579 5 feet above ground surface	Water was noted at end of shift. Probably Tertiary(?) talus breccia below altitude 2,425 feet.

The artesian water appears to be related to the sand and gravel bed that overlies the Ravalli group in holes 2 to 5 from altitude 2,475 down to 2,430 feet. (See section D-D', pl. 5.) Any permeable bed in the reworked glacial material that rests on this aquifer probably would contain water under pressure.

The source of the water is not known, but it may be ground water moving down along the rock surface on the right (west) abutment, or it may come from some source beyond the limits of the Moiese Valley. The artesian water could be related to the flow encountered at the Oxbow power site at altitude 2,452 to 2,460 feet. A careful check should be made for artesian water in any holes drilled in the river channel.

A small spring is present at altitude 2,578 feet on the left abutment approximately 1,450 feet north-northeast of benchmark 2564. The source of this water very likely is seepage from irrigation on the bench to the east, and the water probably is following along the top of the silt bed near altitude 2,580 feet.

Height of dam

The topography at Dam site No. 4 limits the maximum pool level that would likely be considered to about altitude 2,641 feet, as any higher level would require a long dike on the east side of the valley. Table 4 lists the hydraulic head and approximate crest length of dams that would back water to the various upstream sites.

Table 4

Physical dimensions of possible dams at Dam site No. 4

Altitude of normal water surface	Hydraulic head	Point to which tail water would extend	Width of valley at normal water surface	Width of valley with 10 feet of freeboard	Height of dike including 10 feet freeboard
2,705	175	Kerr Dam, mile 72.0	10,100	10,200	55 to 75
2,641	111	Mouth of gorge below Buffalo dam site No. 1, mile 67.9	1,830	6,200	0 to 12
2,615	85	Buffalo dam site No. 2, mile 60.7	1,480	1,730	None required
2,559	29	Sloan Bridge dam site, mile 44.7	730	870	None required
2,548	18	Oxbow dam site, mile 41.3	550	620	None required

Additional head, up to an estimated maximum of 16 feet, could be gained for the site by excavation of the stream channel downstream from the powerhouse, in a manner similar to that proposed for the Sloan Bridge power site.

Feasibility

Additional exploration of the left abutment is necessary before a final decision can be made on the feasibility of the site. In the absence of preventive action, dangerous and excessive water losses would occur through the gravels encountered in drill holes Nos. 1 to 5 from the ground surface near altitude 2,542 feet down to 2,505-15. East of these holes the abutment appears to be pervious sand and gravel, except for the thick bed of silt reported in drill hole No. 7, and water losses would be excessive here, too.

Cutoff walls or blanketing of the intake to the gravel beds would be necessary. The site probably is not feasible even for an earth-fill dam unless percolation through the gravel beds can be prevented.

At sections A-A' and B-B', both of which may be considered as possible axis lines, the right (west) abutment and a portion of the foundation would be on the Ravalli group. This rock would be a very good foundation for a spillway and powerhouse site and would be suitable for a diversion tunnel.

Exploration required

Several core holes and test pits are necessary to complete the exploration along section B-B'. Four test pits are required on the left abutment to check the material underlying the terrace at altitude 2,555 feet and the upper one at 2,640. Approximately five core holes spaced 200 feet apart should be put down along section B-B' east of drill hole No. 7. Every effort should be made to secure maximum core recovery in these holes. The right abutment and foundation should be tested by core holes spaced 200 feet apart. Two lines of drill holes should be put down, one 300 feet upstream and the other 300 feet downstream from the probable axis line. The drill holes along these lines should be spaced no farther apart than 400 feet.

If A-A' is considered for an axis line, the entire line should be drilled and tested by core holes and test pits in a manner similar to the investigation proposed for B-B'.

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APPENDIX

Note: The appendix contains geologic logs of diamond drill core holes at Buffalo dam sites Nos. 1, 2, and Dam site No. 4; summary sheets of logs and soil tests of material from churn drill holes at Oxbow dam site; and seismic foundation exploration data sheets. Because of the limited need for this data, the appendix is included only with copies of the report that are available for consultation at the Geological Survey, Room 1033 (Library), GSA Building, Washington, D. C.; Geological Survey, 416 Electric Building, Great Falls, Montana; Office of the Director, Montana Bureau of Mines and Geology, Montana School of Mines, Butte, Montana; and Geological Survey, 244 Post Office Building, Tacoma, Washington.