Geology of Damsites on Flathead River Mouth to Flathead Lake Lake and Sanders Counties Montana

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GEOLOGY OF DAMSITES ON FLATHEAD RIVER, MOUTH TO FLATHEAD LAKE, LAKE AND SANDERS COUNTIES, MONTANA

By Kenneth S. Soward

ABSTRACT

Eight damsites have been mapped on the Flathead River between river mile 3 and Kerr Dam at mile 72. The river, between miles 0 and 25, flows west across a west-northwestward-trending mountain range; Knowles and Perma damsites are in this section. The other six sites are between mile 25 and Kerr Dam; in this distance the river flows southward along the western edge of the Mission Valley.

The rocks involved in the abutments and foundations of the damsites include hard fine-grained gray to light-gray quartzite, sandy argillite, greenish-gray argillite, diorite, and some metamorphosed argillites of the Precambrian Prichard Formation and Ravalli Group. At places along the edge of the Mission Valley, the Precambrian is overlain by Tertiary(?) weathered talus breccia, conglomerate, sandstone, siltstone, a reddish-brown gritty clay or microbreccia, and volcanic tuff. Overlying the Tertiary(?) and the Precambrian are Pleistocene till, glacial-lake-bed silts, outwash gravel and sand, and Recent alluvium.

Knowles and Perma damsites, near river miles 3.1 and 11 respectively, are alternates for developing the river either by a high dam that would have a flow line at altitude 2,705 feet and back water to Kerr Dam or by run-of-the-river dams in combination with other upstream dams.

At Knowles damsite and downstream, the river has eroded a deep valley along the crest of a gentle anticline. The Prichard Formation is exposed in the valley walls, and glacial-lake-bed silts and sand have filled the lower part of the valley to a depth of 255 feet. Artesian water occurs in the valley fill. The site is feasible only for an earthfill dam. A large rock knob, near the center of the valley, is connected to the north wall by a low saddle and offers an excellent foundation for powerhouse and spillway sites.

At Perma damsite sections *C–C'* at mile 10.9, only 160 feet upstream from Perma Bridge, and *D–D'* at mile 11.3 are possible axes for a dam that would have a flow line between 2,600 and 2,705 feet. The abutments are in strong rock that would be good foundation sites for the appurtenant structures. At *C–C'*, a wide terrace south of the river is underlain by 23–56 feet of pervious sand and gravel. Two spillway sites are on *D–D'*; one is across the rock spur forming the right abutment; the other is along an abandoned high-level channel of Flathead River that swings 2,200 feet south of the left abutment. For a high dam, geological conditions are slightly better at *D–D'* than at *C–C'*. *D–D'* and *E–E'*, at mile 11.9, are possible axes for a dam having a flow line

between altitudes 2,514 and 2,600 feet. At either axis the foundation and right abutment would be unconsolidated lake beds. At *D–D′*, the left abutment is the Prichard Formation and at *E–E′* a diorite sill. The sill would be an excellent foundation for appurtenant structures. Geologically, *E–E′* is the best axis for a low dam.

Damsite 4 at mile 36.4 has argillite of the Ravalli Group in the right (west) abutment and in 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 within 20–25 feet of the river surface at altitude 2,530 feet. In seven drill holes on the left abutment, core recovery above approximate altitude 2,510 feet 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. An extensive blanket upstream and downstream from a dam, or a cutoff wall, or both, are required to reduce the expected percolation through the gravel.

Oxbow damsite at mile 41.3 has quartzite and sandy argillite of good quality in the left (southeast) abutment. The river channel is cut partly in gravel and sand that fill an old melt-water channel and partly in a thick, massive layer of till. In the foundation the till is 85–100 feet thick, and beneath the right (west) abutment it is about 150 feet thick. Glacial-lake-bed silts and very fine sand underlie the till and carry artesian water. About 115 feet of pervious sand and gravel overlie the till and form a part of the right (northwest) abutment. The feasibility of the site depends upon reducing the percolation losses that will occur in the sand and gravel overlying the till in the right abutment and in determining the effect of the artesian water on the foundation.

At the mile 42.9 damsite, till is in the left (east) abutment, in the foundation below the active alluvium, and possibly to altitude 2,670 feet on the right (west) abutment, and very fine sand and glacial-lake-bed silts are above this. The site is feasible for an earth dam. Detailed investigation has not been made, and the locality is mentioned here only as a possible alternative to Oxbow damsite.

Sloan Bridge damsite at mile 44.7 has quartzite in the right (south) abutment and massive till in the foundation and left (north) abutment. Three thin continuous layers of clean to very dirty gravel occur in the till. One at altitude 2,578 feet averages about 14 inches in thickness and is the most pervious. Normal treatment by blanketing or possibly even by grouting should reduce percolation losses to safe values. The site is a very good one for an earth dam.

A powerhouse at the dam would develop 140 feet of head. The site could be developed by construction of a 1-mile tunnel and pressure conduit that would extend from the arm of the reservoir in the Little Bitterroot Valley to a powerhouse site on rock at mile 39. The indicated head is 162 feet. The river channel downstream from the dam is cut in soft, unconsolidated glacial deposits that could be removed easily. By excavating the channel deeper and straightening it downstream from the powerhouse, it is estimated that the head could be increased by as much as 24 feet or to a maximum of 186 feet. Another diversion along one of three possible routes involving an opencut and tunnel, which has a combined length of about 8 miles, could be used to carry water to one of three powerhouse sites near Perma. The gross head ranges from 218 to 225 feet. The geologic feasibility of the tunnel route was not investigated, but a study might be worth while.

Buffalo damsite 2 has beds of sandy argillite and quartzite in the right (west) abutment and in part of the foundation. The remainder of the foundation is in Tertiary(?) rocks. The left (east) abutment is formed by glacial-lake-bed silts underlain by till and possibly by some gravel lenses. There is a small landslide in the left abutment. The pervious gravel lenses and easily erodible lake-bed silts may meet only minimum requirements for a safe abutment. A concrete spillway and other appurtenant works could be placed on the right abutment. The site is feasible only for an earth dam.

Buffalo damsite 1 between miles 67.9 and 68.4 is at the downstream end of a rock gorge. Four axes were studied, two at the extreme downstream end of the gorge and two a short distance upstream in the gorge proper. At the two downstream axes the left abutment is underlain by as much as 52 feet of pervious silt, sand, and gravel intermixed with large blocks as much as 15 feet in diameter. An extensive core wall would be required in the pervious material. The foundation and part of the right abutment at both axes are in quartzite and argillite. The two upstream axes have quartzite and sandy argillite in the abutments and foundations. The axis at mile 68.4 has a smaller section and is considered to be the best. The head lost by constructing a dam upstream from the end of the gorge could be regained by excavating three-tenths of a mile of the river channel downstream from the powerhouse site at mile 68.2.

INTRODUCTION

OBJECT OF THE INVESTIGATION

The investigations on which this report is based are part of the continuing program of evaluating the waterpower potential of streams affecting public lands. Lands potentially valuable for waterpower development are classified and reserved by withdrawal from entry, and these previously withdrawn are appraised to determine if retention in a withdrawal is justified in light of current information. Geologic investigations are an integral part of this evaluation because development of waterpower potential is dependent upon the geologic feasibility of the damsites, reservoir sites, tunnel routes, and powerhouse sites involved.

Geologic conditions are described at eight potential powersites on the lower Flathead River between miles 3 and 72 in Lake and Sanders Counties (fig. 1).

PREVIOUS INVESTIGATIONS

An investigation of the potential damsites and reservoir sites on the lower Flathead River from Flathead Lake to the confluence of the stream with the Clark Fork (of the Columbia River) was made by 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 to the Kerr

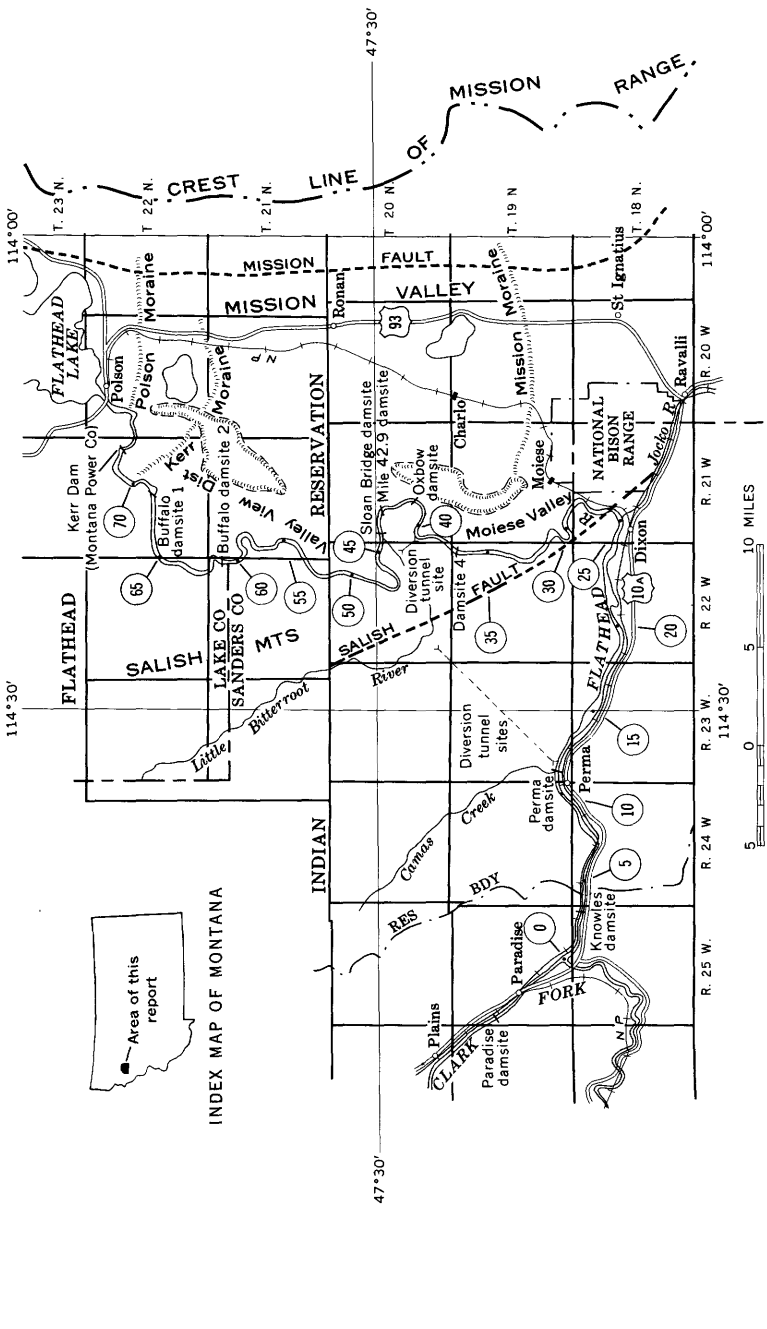

FIGURE 1.—Index map showing location of damsites on the lower Flathead River, Lake and Sanders Counties, Mont.

powerhouse at mile 72. About 1.5 miles of the Clark Fork down stream from the confluence was also mapped. A standard river-survey map of the lower Flathead River was published by the U.S. Geological Survey (1947). Between miles 36 and 72, four prospective damsites were mapped at scales of 1:4,800–1:12,000. A contour interval of 10 feet on the land and 1 foot on the river surface was used. Three of them: Buffalo damsites 1 and 2 and damsite 4 had been selected previously by E. C. LaRue. However, Buffalo damsite 1 as shown on the river-survey map originally was called damsite 2 by LaRue. The Montana Power Co. now refers to this site as the Buffalo Rapids damsite. Buffalo damsite 2 of the present report was called damsite 3 by LaRue. Damsite 4 also was named by him and still retains that name. Oxbow damsite was selected and named by Arthur Johnson from a study of the river-survey map. The mile 42.9 damsite was noted by him but was not mapped because of better topographic conditions at Oxbow.

No damsites were selected by the Geological Survey downstream from mile 36, but at about this time the Corps of Engineers, as part of their investigations of potential damsites on the Columbia River and tributaries, selected and made preliminary investigations at Knowles damsite near river mile 3 and Perma damsite near mile 11 (U.S. Congress, 1952). Explorations at Knowles site made between 1941 and 1945 consisted of mapping, a few seismic lines, and 10 drill holes. At Perma site, seismic surveys were made in 1943 and three 1-inch auger holes drilled in 1944. Both of these sites were eliminated from further consideration by the Corps of Engineers after exploration of Paradise damsite, 4.4 miles downstream from the confluence of the Clark Fork and Flathead Rivers. A multipurpose dam at this site with a flow line at altitude 2,705 feet would inundate the Clark Fork Valley upstream to Superior and all of the Flathead Valley from the river mouth to Kerr Dam. Opposition to the proposed Paradise dam has revived interest in the Knowles damsite.

In 1941, the Corps of Engineers, Portland, Oreg., District, explored the foundations of Buffalo damsites 1 and 2, Oxbow damsite, and damsite 4 by seismic methods. In 1945, the Seattle, Wash., office of the Corps of Engineers drilled four churn-drill holes at the Oxbow damsite. The locations of the seismic lines and the drill holes are shown on plates 2 and 4.

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 (Ross and others, 1955). A report by Clapp (1932) contained a reconnaissance geologic map of northwestern Montana that has a structural cross section through the southern part of the Mission Valley. Pardee (1950, p. 359–406) outlined the Tertiary history of northwestern Montana, and the Pleistocene history has been discussed by Pardee (1910, 1942, 1950), Campbell and others (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 field investigations for this report were carried out at various periods between 1953 and 1959.

The first stage of field investigation extended from September to November 1, 1953. During this period the damsites designated as Buffalo damsites 1 and 2, Oxbow, and damsite 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 at that time. In view of the unfavorable geologic conditions noted at this site, an office study was made for possible alternatives. A site that appeared topographically favorable was found at mile 44.7, just upstream from Sloan Bridge, and it was therefore designated as the Sloan Bridge damsite. Field reconnaissance in May 1954 indicated that the damsite and related features were geologically feasible. Recommendations were made for a special topographic map of the area involved. This map was prepared and published by the U.S. Geological Survey (1956). Advance copies became available on November 1, 1954, and the area was mapped geologically during the period November 3–20, 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 damsite 1, 38 holes at Buffalo damsite 2, and 7 holes at damsite 4. The locations of these holes are shown in the figures relating to the respective sites. The drill cores were made available for examination by the U.S. Geological Survey by courtesy of the Montana Power Co. The logs of the drill cores are not included in this report but are in the files of the U.S. Geological Survey at Washington, D.C., and Great Falls, Mont.

An open-file report on the sites between miles 36 and 72 was released in July 1957, and copies were distributed to interested private parties and governmental agencies.

In August and September 1957, topographic maps were made of Knowles and Perma damsites on a scale of 1 inch to 800 feet (1:9,600), and a contour interval of 10 feet on land and 1 foot on the river surface was used. Topography was carried to an altitude of 2,900 feet. The maps were published in 1959 (U.S. Geol. Survey, 1959). Preliminary copies of these maps were used as a base for geologic mapping in September and October 1957, October 1958, and July 1959. An open-file report on Knowles and Perma damsites was released in August 1960. Copies were distributed to interested private parties and governmental agencies.

The results of any detailed exploratory work done at any of the upstream sites after 1957 or at the downstream sites after July 1959 are not included in this report.

ACKNOWLEDGMENTS

Many thanks are due those who participated in the work leading to preparation of this report. The investigations of the damsites between miles 36 and 72 were carried on under the supervision of C. E. Erdmann, regional geologist at that time, of the U.S. Geological Survey, Great Falls, Mont. The work on Knowles and Perma damsites was supervised by A. F. Bateman, Jr., regional geologist. Their critical reviews of the geology, findings, proposals, and report are reflected throughout. Arthur Johnson, chief, Branch of Waterpower Classification, U.S. Geological Survey, supervised the mapping of the stream and damsites from 1936 to 1945 and procured the Sloan Bridge, Knowles, and Perma damsite maps.

The Corps of Engineers, Seattle, Wash., supplied the results of its seismic investigations and core drillings at the various sites.

The Montana Power Co. furnished the drill cores from its exploratory work at Buffalo damsites 1 and 2 and damsite 4. H. H. Cochrane, consulting engineer, and G. M. Jones, construction engineer, Montana Power Co., visited the Sloan Bridge powersite 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 regularity and continuity, steep parallel walls, and generally 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. 82) 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 relation also pertains southward in Montana. The floor of the trench does not have a continuous gradient, and low stream divides separate it into at least six 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 ranges 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. (See fig. 1.)

The low mountain range along the west side of the Rock Mountain Trench has been known for years as the Flathead Mountains (Daly, 1912). 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 as shown on U.S. Geological Survey map of Nyack quadrangle, Clapp (1932, p. 14) suggested that the name of the Flathead Mountains be changed to Selish Range, the Indian name of the Flathead tribe. In the meantime, Erdmann (1941, p. 7, footnote 22) noted that Selish 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.

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 1/4–1/2 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. The preglacial Mission Valley probably lay to the east of this ridge and contained the ancestral Flathead River as a southward-flowing stream. These side valleys and Mission Valley have been integrated topographically by glacial fill.

FLATHEAD RIVER

TERMINOLOGY AND LOCATION

The Flathead River, one of the upper tributaries of the Columbia River, has its headwaters in the mountainous areas 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. 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.

All the damsites with the exception of Knowles are in the Flathead Indian Reservation. The Knowles site is 1 mile downstream (west) of the reservation boundary. About 98 percent of the Knowles reservoir site is in the reservation.

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, although there are a few 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 because rock is in the streambed and the canyon walls. Kerr Dam has been built in the middle part at mile 72.05. With maximum pool level at altitude 2,893 feet, a 5-mile stretch of the upper rapids is drowned out, and Flathead Lake is utilized as a reservoir. Buffalo damsite 1 is 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, although there are a few short slopes of 17–20 feet per mile.

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, and there are a few very short lengths in excess of 5 feet per mile. Five of the eight damsites described in this report are 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 require 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.

STRATIGRAPHY

Rock formations at the damsites are of the Precambrian Belt Series, Prichard Formation and Ravalli Group; Tertiary(?) talus breccia and lake-bed deposits; Pleistocene glacial deposits; and Recent alluvium.

PRECAMBRIAN

PRICHARD FORMATION

The Prichard Formation is exposed over a distance of nearly 30 miles from a point 3.5 miles west of Dixon to Plains. It is a thick sequence of very fine to fine-grained quartzite, impure quartzite, and argillite. The total thickness of the formation is not known, but Wallace and Hosterman (1956, p. 578–579) described an almost continuous section nearly 17,000 feet thick in the canyon of the Clark Fork River upstream from its junction with Flathead River. Gibson (1946, p. 9) listed the thickness of the Prichard Formation in northwestern Montana and adjacent parts of Idaho as ranging from 7,000 to 20,000 feet.

A minimum stratigraphic section of 11,000 feet is exposed almost continuously across the eastern two-thirds of the north half of Perma damsite and for another mile upstream to Race Horse Gulch. Additional strata probably are present east of Race Horse Gulch.

The dip of the beds throughout this distance is almost vertical or slightly overturned to the east. In the damsite area the section includes two sills and a zone of metamorphosed Prichard strata.

Individual beds of the Prichard Formation are light gray, dark gray, or greenish gray on fresh surfaces and moderate reddish brown on weathered surfaces and along many fractures. Color classification is according to the 'Rock-Color Chart" (Goddard and others, 1948). In some areas, moderate reddish brown is the characteristic color of the rock mass. Strata range in thickness from paper thin to 15 feet. Ripple marks and desiccation cracks are present in some of the argillaceous layers. Biotite is disseminated throughout the rock, and a few quartzite beds have a spotted appearance because of recrystallized and bunched biotite. Hornblende also occurs in some of the spots. Pyrite is present, and a few garnets were noted in some beds in the western part of Perma damsite.

RAVALLI GROUP

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 base of the Siyeh Limestone or the Wallace Formation, so the group composes 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 threefold 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 included the beds of the two argillite formations under the general term "Ravalli group." More recently, however, the new Geologic Map of Montana (Ross, 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 Formation in ascending order. The Burke consists of gray siliceous shale and sericitic quartzite; 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'Alene district, the Revett quartzite 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 damsites is unknown.

Rocks of the Ravalli Group crop out at five of the eight sites studied and in the ridge between the Little Bitterroot River and the powerhouse site at river mile 39. Exposures occur also in the Salish Mountains to the west of Mission Valley and in the low range of northward-trending hills that stand about one-third of the width of the valley out from the western side. The rock at the damsites consists in general of hard fine-grained gray to light-gray quartzite and some greenish-gray 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 Ravalli Group is soft, friable, and porous, and its color ranges from light gray through greenish gray to tan. The upper 3–30 feet is intensely weathered, the effect diminishing to moderate or slight in the succeeding 20–40 feet of depth. If structures were to be built in these localities, the highly weathered rock would have to be removed.

IGNEOUS ROCKS

Sills crop out at both Knowles and Perma damsites but are involved in only two of the possible axes at Perma. The fine- to medium-grained rocks are dark gray, dark-greenish gray, and greenish black. Minerals that can be recognized readily with a hand lens are dull-greenish black amphibole and quartz. Plagioclase is difficult to identify, and in the sill north of Perma Bridge it appears to be lacking. The rocks are classified as diorites.

Copper minerals occur at a few places in the sills.

METAMORPHIC ROCKS

At Perma damsite, the sill that crosses the river 300 feet east of the bridge is overlain by a zone of metamorphosed Prichard strata as much as 900 feet thick. At Knowles damsite, the igneous rocks that outcrop in the southeast part of the map are overlain by metamorphosed Prichard.

Most of these metamorphosed rocks are recrystallized biotite quartzite without noticeable texture. Bedding, which is relatively conspicious in the Prichard Formation, has been completely obliterated. Northeast of Perma Bridge, where metamorphism was more intense and where some material may have been added from the intrusive rock, a gneissic texture has been developed in part of the zone. When examined with a hand lens, the rock appears to grade from a quartz amphibolite gneiss to recrystallized biotite quartzite.

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. Although clastic sedimentary rocks of Tertiary age that crop out along lower Flathead River have a somewhat different lithology than the so-called lake beds, their stratigraphic assignment has been inferred mainly from their relations to the underlying Precambrian terrane and in part from their composition. On this basis, rocks of supposed Tertiary age occur at three of the damsites examined for this report, and they may also be involved in the portal areas of the tunnel lines of the Sloan Bridge powersite. 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 that contain considerable clay matrix. These facies grade into more regularly bedded sandstone and siltstone and are probably covered by a waterlain gritty reddish-brown clay or microbreccia that grades into volcanic tuff at the top. No bed or 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 having bentonitic characteristics in the waterlain residual or in the 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 water-laid tuff is exposed on the right bank at Buffalo damsite 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 damsite 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 damsite 4. Thus proceeding downstream through the damsites one descends through the Tertiary(?) section. Detailed accounts of the lithology and engineering properties of these rocks are given in the individual damsite descriptions.

QUATERNARY

PLEISTOCENE

Three terminal moraines occur in Mission Valley: the St. Ignatius, Mission, and Polson, and they mark successive invasions by lobes of the waning Cordilleran ice sheet. Noble (1952) correlated them with the early (Iowan), middle, and late (Mankato) stades of the Wisconsin Glaciation of central North America. Alden tentatively correlated 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 Valley and Jocko River Valley indicate the glacier extended into the latter (Noble, 1952, p. 80). 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 5–6 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, and there is a contiguous lateral moraine south and west of Kerr Dam.

The drift of the Mission glacier is fresh and unweathered. At Sloan Bridge damsite it is generally in very compact massive tight layers (fig. 6) 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 purple quartzite and siliceous argillite. The average diameter of the pebbles is about 2½ inches, although a few pieces are as much as 10 inches in diameter. 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, which is 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), 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 beaches 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 Noble (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 stages of the last or Wisconsin Glaciation. A brief effort will be made here to relate the various observed silt deposits to their respective lakes.

EARLY WISCONSIN LAKE DEPOSITS

Light-gray clayey lake-bed silts have been recovered in drill holes 4, 5, and 7 at damsite 4. A few miles upstream at Oxbow damsite, beds of fine-grained clastics described as clay, silty loam, and sand on Corps of Engineers' churn-drill logs for holes 2, 3, and 4 were recovered from below altitudes 2,450–2,460 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 glacier of the Wisconsin Glaciation once occupied this part of Moiese Valley.

MIDDLE WISCONSIN LAKE DEPOSITS

Extensive deposits of glacial-lake-bed silts are found in the Valley View district, at the north end of Moiese Valley, eastward into Mission Valley, and south of the terminal moraine of the Mission glacier. Noble (1952) correlated these lake deposits with the glaciation of the valley during middle Wisconsin or Mission time, when a few glacial lakes that had varying surface altitudes evidently occupied parts 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, and another arm extended along the east edge of the Salish Mountains in the Valley View district. Silts that are found at an altitude of nearly 3,000 feet in these arms probably were deposited in this glacial lake.

Other lake-bed silts whose surfaces are 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 the till 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 stage. 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 4,269 feet.

Small-scale shoreline features that were formed on the hills above an altitude of 3,200 feet indicate that the lake surface stood for only short periods at any one level. Pardee (1942) 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, p. 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 Glaciation.

Between Perma and Plains, five unusual depositional features called "gulch fills or gravel bars" by Alden (1953, p. 158–160) have been deposited just inside the gulch mouth between altitudes 3,000 and 3,500 feet. Alden believed these fills were deposited in glacial Lake Missoula when it stood at these high levels. The material was washed down the gulches into the lake and was partly rearranged into a bar by wave action. The gulch fills have a steep slope toward the valley, and the top edge of the fill is ridged with a shallow depression behind it. Pardee (1942, p. 1589–93) believed the fills were formed by unusually large currents set up by the rapid draining of glacial Lake Missoula. He called them "high eddy deposits."

One of these fills along this section of the Flathead River is about 2,500 feet north and slightly west of the bridge at Perma. Another is well exposed in Knowles Creek valley about 3,000 feet from the Flathead River. The partly exposed material in the fills is loose, unconsolidated gravel.

RECENT

Active alluvium, those deposits of silt, sand, and gravel that are subject to movement during yearly high water, and inactive alluvium, those deposits that are subject to movement only in a year of highest water levels, are present along the stream channels. Talus deposits are at the base of some rock slopes. Minor landslides have occurred along the river in the till and glacial-lake-bed silts. A few slides are between damsite 4 and the proposed Sloan Bridge powerhouse site at mile 39.

STRUCTURAL GEOLOGY

Geologic structure along this reach of the river has not been mapped in detail and even the broader features are only partly known. From Dixon to its mouth, the Flathead River flows west and cuts diagonally across the northwestward-trending ranges in this area. From Polson south to near Dixon, the river is located along the west edge of two smaller valleys that are topographically integrated with the main part of the Mission Valley to the east. The Salish Mountains lie a short distance west of the river.

At Knowles damsite the river parallels the axis of an anticline trending west-northwest. From a cursory inspection of the valley walls downstream from the site, it was concluded that the anticline extends downstream to the junction of the Flathead and Clark Fork Rivers. Wallace and Hosterman (1956, p. 579) mentioned that the Clark Fork River follows a major breached anticline from the mouth of the Flathead River northwest to the vicinity of Plains.

From 4 miles upstream to 3 miles downstream from Perma damsite, Flathead River flows across a large southward-trending fold. The beds in the east limb dip almost vertically or are slightly overturned to the east. In the west limb, the beds dip at a low angle to the southwest. The crest of the fold crosses the river immediately downstream from Perma Bridge. This structure is outlined strikingly on the geologic map of Montana by two sills that have been intruded over a wide area. Both sills are exposed at Perma damsite, one along the eastern edge of the map and the other at Perma Bridge (pl. 1). Immediately south of the damsite the fold closes and the beds loop around to the west to form a southeastward-plunging nose. About 1½ miles downstream from Perma Bridge, the sill that crosses at the bridge loops back to the north side of the river and is exposed for about 4 miles where it trends northward or parallel to the east limb.

No major faults cross the damsites, but 4–10 miles southeast of Knowles and 10–15 miles south of Perma, there is an area through which many major faults of the Coeur d'Alenes extend (Wallace and Hosterman, 1956, pl. 48 and p. 588–597).

MISSION VALLEY COMPARTMENT

Mission Valley is the most southerly compartment of the Rocky Mountain Trench. The valley is bounded on the east by the west-facing faultline scarp of the Mission fault which separates the almost parallel fault-block Mission Range from the trench.

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

State of movement	*Amount of displacement in the vicinity of McDonald Peak (feet)*
Pre-late Tertiary peneplain	9,000
Post-peneplain pre-middle Pleistocene	6,000
Probable middle Pleistocene	2,000
	17,000

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, p. 83–84) 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. He also concluded that 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 most 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 generally dip away. The medical 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 of the integration of the Mission Valley compartment by glacial fill, and from the viewpoint of geologic structure suggests that the damsites between miles 36 and 72 are 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 northwest and moderate dips to the east. Local details are given in the damsite 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 damsite. About 60 feet of crushed rock and gouge is along the fault whose attitude is a strike of N. 5° W., and a dip of 75° E. The hanging wall appears to have moved to the north and down.

MATERIAL FOR CONSTRUCTION

CONCRETE AGGREGATE

In the vicinity of Knowles and Perma damsites, sand and gravel are available at only a few places along the Flathead River. All the deposits examined appear to be deficient in medium and fine sand.

The Corps of Engineers investigated aggregate deposits along the Clark Fork River 2.3 miles upstream from the confluence with the Flathead River or 1.5 miles upstream from U.S. Highway 10-A bridge across the Clark Fork. Another deposit investigated was a gravel pit half a mile east of Paradise. The river deposit contains pebbles and cobbles that have a calcite coating and considerable decomposed rock. The Paradise pit is on a terrace which is at an altitude of nearly 2,525 feet. An area roughly 1,500 by 900 feet is underlain by an estimated thickness of 20–25 feet of gravel. Particles in the gravel are subround and 1–2 percent are slightly to deeply weathered. The average maximum size is 4–5 inches in diameter. Near the top of the pit, the undersides of most of the pebbles and cobbles are coated with calcite, but at a depth of 15 feet, about 50 percent are coated.

In addition to these, there are five other potential sand and gravel deposits along the Flathead River within reasonable distances of the damsites. A possible deposit is three-tenths of a mile S. 40° E. of the Clark Fork Bridge. Sand and gravel are exposed in a terrace to the south. If the upper terrace is not underlain by gravel, the deposit may be less than 100,000 cubic yards. Although some weathered rock is in the gravel, the material appears suitable for aggregate and should be investigated.

Gravel and sand are in the fans at the mouth of Robertson, Seepay, and Magpie Creeks, at river miles 4.2, 7.2, and 17 respectively. At Robertson Creek the deposit contains many cobbles and large blocks, some as much as 4 feet in diameter, but is lacking in sand. The individual particles are subround to subangular. At Seepay Creek the gravel is 80 percent quartzite and 20 percent diorite and contains many oversized boulders, some as much as 24 inches in diameter. The rocks are fresh, but many fragments are stained with limonite. The gravel appears deficient in sand, especially in the medium and fine sizes. Sufficient material is available to supply all the aggregate needed. At Magpie Creek the fan contains subangular to subround gravel that is 95 percent quartzite and 5 percent diorite. Except for slight weathering on 5 percent of the gravel, the rocks are fresh. Some boulders are 24 inches in diameter, but parts of the deposit contain only small-sized gravel and sand.

The terrace south of Perma Bridge is underlain by sand and sandy gravel. In one of three 1-inch sampler holes drilled here, a 28-foot thick layer of medium to fine sand and a 7-foot thick layer of sandy gravel were penetrated at depths of 12–47 feet (section *C''–C'''*, pl. 1).

Gravel is in the large gulch fills in Knowles Creek valley, in the small valley north of river mile 6 about 3 miles upstream from Knowles damsite, and in the fill 1 mile north-northwest of Perma Bridge. The material in the gulch fill in Knowles Creek valley is discussed under Knowles damsite. The other fills probably are composed of similar material.

A search was not made for aggregate in the vicinity of the damsites upstream from mile 36, but great volumes of sand and gravel lie close to all sites with the possible exception of Buffalo damsite 2. West of damsite 4 and south of Oxbow, the floor of Moiese Valley is underlain by sand and gravel. At Oxbow, the bench that forms the right (west) abutment is underlain by sand and gravel. These beds extend some distance to the north to a point within a few miles of Sloan Bridge damsite.

At Buffalo damsite 2, the closest sources of aggregate would be the gravel bars along the river. Other possible sources of gravel are deposits along the flank and at the south end of the rock ridge that divides the Valley View district from the main part of the valley to the east. The Polson moraine is an excellent source of aggregate and possibly parts of the Kerr moraine may contain some gravel. Similarly, sources of aggregate for Buffalo damsite 1 include the river channel and possibly the flat downstream from the site or the Polson moraine. Some deposits may occur in the vicinity of the Kerr moraine.

EMBANKMENT MATERIALS

At Knowles and Perma damsites, the main source of embankment material is the lake beds that underlie the terraces upstream and downstream from the damsites. The clayey silt and very fine sand in the lake beds along the north side of Perma damsite are composed mainly of rock flour. This material would make an acceptable embankment if it is well protected. Similar lake beds are exposed on the south side of the river 1.5 miles downstream from Perma, 2.25 miles upstream from Knowles, and on the north side of the river 3.5 miles upstream from Knowles. Sufficient quantities appear to be available.

Some lake beds exposed on the south side of the river at Perma contain a considerable amount of plastic clay. Similar beds probably are in the proposed borrow areas, especially close or along the valley walls, and selective stripping may be necessary.

Upstream from mile 36, lake-bed silts similar to those at Knowles and Perma are near all the damsites.

The tills related to the Sloan Bridge lobe and to the Kerr moraine would make acceptable embankment materials. They would be as tight as the lake-bed silts and would have a considerably higher shearing strength. The best exposure of these tills is in the left (north) abutment of Sloan Bridge damsite extending downstream to a point 1,600 feet north of Oxbow damsite. Till is exposed on the east side of the river immediately downstream from Oxbow damsite and in the river bank 3,800 feet upstream from cross section *G–G′* at damsite 4 (pl. 2). At Buffalo damsite 1, till is exposed 3,000 feet east of cross section *B–B′* and at the upstream (east) end of the map area (pl. 4).

RIPRAP

Riprap is available in many talus deposits along the base of the valley walls. The talus blocks range considerably in size, depending upon the number of fractures in the rock. The largest blocks can be secured from quartzite beds in the Prichard Formation or from the diorite sills. An examination of the talus slopes will indicate the size of blocks that can be expected from any bed and is the best method of searching for a quarry site.

At Knowles damsite, blocks as much as 2–3 feet in diameter are in the talus slope southwest of Robertson Creek in the southeast corner of the map. Many large blocks are in the fan at the east edge of the damsite map (pl. 1).

At Perma damsite, blocks as much as 3 feet in diameter can be quarried from the metamorphosed Prichard and the diorite sill south of Perma. Quartzite beds east of the line *D–D′*, and south of the river, as shown on plate 1, would yield large blocks. However, the best source of large riprap is the diorite sill in the northeast corner of Perma damsite map. Large blocks, some of them 7–8 feet in diameter, are in the talus from the sill. The sill is exposed south of the river and 3 miles downstream from Perma. It probably would yield large blocks in these areas.

Riprap for a dam upstream from mile 36 can be quarried from some of the quartzitic beds in the Ravalli Group at places within reasonable distances of any of the sites. A thick quartzite bed crops out in the hills east of Moiese Valley. The same bed or a similar one is exposed near the road near the SE. cor. sec. 35, T. 21 N., R. 21 W.

POWERSITES

DEVELOPMENT

The tailrace of Kerr Dam, which is at 2,705 feet, is the maximum pool level for any dam developed along this reach of the river. Maximum development of any one of the sites discussed in this report would inundate the upstream sites. The locations of the prospective sites are shown on the index map, figure 1. Table 1 lists the possible developments at the various sites with the exception that developments at lower altitudes than 2,705 feet are not shown for the Knowles and Perma damsites. The total height of any dam would be from 25 to 40 feet greater than the hydraulic head. This would include an allowance of 10 feet for freeboard, 5–20 feet for depth of water in the river, and 10 feet for alluvium in the riverbed.

Supplemental or alternate means of development are suggested for damsite 4, Sloan Bridge powersite, and Buffalo damsite 1. The schemes are outlined under the sections describing the damsites.

It is worthwhile mentioning that the suggestion for increasing the head for a powerhouse at damsite 4 or for one at mile 39 for the Sloan Bridge damsite by channel improvements and deepening downstream from the powerhouse would have two direct benefits for a run-of-the-river development. It would add an increment of power at a reasonable cost. Also, it would reduce the cost of relocating the Northern Pacific Railway tracks by lowering the flow line and thereby the number of miles of track that would have to be moved for any run-of-the-river dam downstream from Dixon.

TABLE 1.—*Possible hydroelectric developments on Flathead River between miles 3 and 72*

Damsite	Plate	Location	River mile	Altitude of water surface	Possible head [1]	Remarks
Buffalo 1	4	NE¼ sec. 21 and NW¼ sec. 22, T. 22 N., R. 21 W.	68.4	2,655	64	Recommended axis at 68.4. About 14 ft of this head would be developed by placing the powerhouse at mile 68.2 and excavating to mouth of gorge at 67.9.
Buffalo 2	4	N½SE¼ sec. 1, T.21 N., R. 22 W.	60.7	2,615	26	Reservoir to tailrace of Buffalo damsite 1.
					90	Reservoir to tailrace of Kerr powerhouse.
Sloan Bridge has four possible schemes of development.	3	(1) SE¼NW¼ and NE¼SW¼ sec. 18, T. 20 N., R. 21 W.	44.7	2,565	140	Reservoir to tailrace of Kerr powerhouse. Possible heads are based on water surface altitudes given on the Sloan Bridge damsite map (U.S. Geol. Survey, 1956).
		(2) Powerhouse: SW¼NW¼ sec. 30, T. 20 N., R. 21 W.	39.0	2,543	162	Involves a 1-mile tunnel and pressure conduit from Little Bitterroot to powerhouse.
		(3) Powerhouse	39.0	2,543	186	The additional head of 24 ft over (2) is gained by excavating channel downstream from powerhouse.
		(4) Powerhouse—three possible sites in secs. 30, 32, or 33, T. 19 N., R. 23 W.	13.0	2,480	218–225	Involves a diversion tunnel and opencut with a combined length of about 8 miles leading to one of three possible powerhouse sites between miles 11 and 13. Geologic feasibility of the routes unknown.
Oxbow	2	NW¼ sec. 28 and NE¼ sec. 29, T. 20 N., R. 21 W.	41.3	2,548	67	Reservoir to Buffalo damsite 2.
					93	Reservoir to Buffalo damsite 1.
					157	Reservoir to tailrace of Kerr powerhouse.
Mile 42.9		SE¼ sec. 17, T. 20 N., R. 21 W.	42.9	2,555	150	No detailed investigations made. Possible alternative to Oxbow damsite.
4	2	Center sec. 1, T. 19 N., R. 22 W.	36.4	2,530	18	Reservoir to Oxbow damsite.
					85	Reservoir to Buffalo damsite 2.
					111	Reservoir to Buffalo damsite 1. Additional head of about 16 ft. could be gained by excavating the channel downstream.
Perma	1	Possible axes in NW¼ sec. 31; C N½ sec. 31 and NE¼ sec. 31, T. 19 N.; R. 23 W.	10.9 11.3 11.9	2,480 2,483	225	Axis line at 11.9 has narrowest section for low head dams with flow lines at 2,530, 2,548, or 2,559 ft.
Knowles	1	Center and E½ sec. 1, T. 18 N., R. 25 W.	3.1	2,470	235	

[1] Maximum altitude pool level for any reservoir is 2,705 ft, the altitude of Kerr powerhouse tailrace.

KNOWLES DAMSITE

LOCATION AND ACCESSIBILITY

Knowles damsite, which takes its name from the railroad siding near the center of the map (pl. 1), is 3 miles upstream from the mouth of Flathead River. Paradise is 5 miles from the west edge of the damsite map, and Perma is 6.4 miles from the east edge.

U.S. Highway 10–A follows the left bank of the river, making this abutment readily accessible. The right abutment is reached most easily by crossing the river in a boat. It is also accessible via logging roads that meet the county highway 1 mile north of Perma Bridge. The passenger line of the Northern Pacific Railway follows the right bank of the river, and the right abutment can be reached on foot by crossing the river on the railroad bridge 3.5 miles upstream.

TOPOGRAPHY

Near altitude 2,500 feet, the valley walls rise steeply from the floor to 4,000–4,600 feet. The right wall stands on steep slopes or in cliffs from 2,570 to 2,950 feet. In the downstream third of the map area, a hill that rises to altitude 3,050 feet is partly separated from the right valley wall by an abandoned high-level channel of Flathead River. The hill forms the right abutment for both proposed axes. The left valley wall rises more than 2,000 feet above the river. About a thousand feet south of the river near altitude 2,900 feet, a sharp break or notch interrupts the general slope. Between the river and the notch, the profile of the hillside varies from a sharp shoulder near the center of the map to a concave profile in the downstream third (sections *B–B′* and *A–A′*, pl. 1).

The wide flat-bottomed valley ranges from 1,100 to 2.400 feet in width between rock outcrops on either side of the river. At the narrowest part, a small rounded knob of rock about 800 feet across protrudes through the valley fill and rises to altitude 2,650 feet. The knob is 500–1,300 feet south of the right wall and is joined to it by a narrow curving neck of rock covered at two places by alluvium or talus. On the north side of the river, two small terraces have been cut into the lacustrine deposits at altitudes 2,490 and 2,525 feet. In the eastern part of the map, on both sides of the river, alluvial fans cover the lake beds.

When the site was mapped, the river surface at section *A–A′* was at altitude 2,470.3 and at *B–B′* it was 2,471. The stream gradient through the site is 1.0 foot per mile.

GEOLOGY

STRATIGRAPHY

PRECAMBRIAN

The Prichard Formation, intrusive rocks, and metamorphosed Prichard strata make up the bedrock at Knowles damsite. The Prichard Formation is the only rock exposed at the proposed axes.

Impure quartzite and argillite make up the lower part of the left abutment from the river at 2.470–2,900 feet, but above 2,900 feet and in the right abutment, quartzite predominates. The quartzite is light gray but has increasing amounts of argillaceous material and its color grades to dark gray. Weathered surfaces are moderate reddish brown, and this color is typical of the Prichard in exposures or in talus deposits.

Igneous rocks are exposed sporadically on the right valley wall along a line that trends N. 50° W. The rock is a fine-grained diorite that probably occurs as a dike intruded along a minor shear or fault zone. On the left side of the river, a small mass of fine-grained diorite crops out southwest of Robertson Creek in an exposure surrounded by talus except at two places where it is overlain by metamorphosed Prichard. The intrusive probably is a sill. Chalcopyrite and arsenopyrite are found along a few narrow veins in the diorite.

The metamorphosed Prichard grades from a gneissic biotite quartzite near the contact with the diorite to a recrystallized biotite quartzite some distance away. A small mass of recrystallized biotite quartzite extends through the talus at the southeast corner of the map.

No igneous or metamorphic rocks were observed in the vicinity of either axis line.

QUATERNARY

The entire valley bottom is covered by alluvium underlain by glacial lake beds that are not exposed in the map area. Depth to bedrock in the valley bottom and character of the valley fill were explored by 10 holes drilled by the Corps of Engineers in 1944–45. The holes, numbered 1–7 and 11–13, are shown on plate 1. Field logs of holes 1–6 are available and interpreted logs of holes 7 and 11–13 are given on a Corps of Engineers' map of the damsite. One to 3-foot drive samples generally were taken at 10-foot intervals in the unconsolidated lake beds, and as a result, contacts between the different strata were not determined accurately.

The soft, unconsolidated sediments making up the fill can be differentiated into two and in some places three zones. In the deeper parts of the valley, plastic clay overlies bedrock. The upper surface of this zone is at altitude 2,300 feet at section *B–B′* and 2,335 feet at section *A–A′*. At *B–B′*, a layer of silt about 45 feet thick is above the clay. Overlying the clay at *A–A′* and the silt at *B–B′* is a thick zone of interbedded fine sand and silt having layers of silty clay, medium sand, and some very fine gravel either in beds or mixed with the sand. Beneath the alluvium in the river channel the top of the sand-silt zone is at 2,440–2,460 feet. On the terraces north of the river and in the reentrant on the south side, the top of the lake beds is a few inches to 10 feet beneath the ground surface.

In the sand-silt zone some layers contain considerable clay. In drill hole 1, from 2,448 to 2,365.5 feet, and in drill hole 4, from 2,450 to 2,410 feet, silty clay and interbedded fine sand and silty clay were recovered. Bedding was observed in a few cores from the sand-silt zone, and the silty clay from drill hole 1 is varved. This upper zone appears to be similar to the interbedded lake beds of sand and silt that crop out at Perma damsite and along the Flathead River between the damsites. In the lower clay zone, silt beds are interbedded with clay, and the beds probably are varved. All the valley fill beneath the alluvium appears to be glacial lake beds. Below the river surface, the lake beds are saturated.

The lowest altitudes at which bedrock was found are 2.212 feet in drill hole 13, 2,213 in hole 5, and 2,215 in hole 12.

Knowles Creek valley is partly blocked by a gulch fill or gravel bar that lies 1,000–2,800 feet up the valley from its mouth. The lower edge of the fill is near altitude 2,770 feet, and the top is at 3,281. At one time the gravel bar extended completely across Knowles Valley, but since draining of glacial Lake Missoula, Knowles Creek has eroded a deep narrow cut in the bar. The eroded material has been deposited in an alluvial fan extending from the foot of the fill to the river.

A logging road up Knowles Creek valley exposes the gulch fill from altitude 2,800 to 2,950 feet. The material is made up of subangular to subround gravel; 80–85 percent of the deposit is between one-fourth and 1 inch, and 10 percent is between 1 and 4 inches. Fines are lacking, but a thin film of silt coats many of the rock particles. About 85 percent of the gravel is from the Prichard Formation, 5 percent from the Ravalli Group, and 10 percent from the Missoula Group. Igneous and metamorphic rock are also present. The particles are generally fresh except that 1 percent are completely weathered and 5 percent or less are slightly weathered. A few large flat boulders are horizontal and suggest that the deposit was laid down in water.

Recent alluvium consisting of silt, sand, and a small amount of gravel is exposed in the valley bottom and in the riverbed. The thickness of the alluvium ranges from a few inches to an estimated maximum of 15 feet. A small patch of sand and gravel at altitude 2,745 feet in the northwest corner of the map probably was deposited by the Flathead River when it flowed in the high-level channel north of the rock hill in the right abutment. Large talus deposits having some soil cover parts of the valley walls.

At the upstream edge of the map, alluvial fans occur on both sides of the river. The fan on the north side contains material similar to that in the gulch fill from which it is derived, except for a greater

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percentage of large angular blocks of Prichard. The fan on the south side of the river is composed of gravel, boulders, and blocks, many of which are more than 2 feet in diameter, and a small amount of sand.

STRUCTURE

FOLDS

At Knowles damsite, the river parallels the axis of the west-northwestward-trending anticline described previously. Dip of the bedding is into both valley walls. On the left valley wall, the strike ranges N. 15° W. at the eastern edge of the map area to N. 90° W. at the western edge (pl. 1). Dip ranges from 22° to 47° SW. In the roadcut 400–700 feet downstream from the intersection of section *B–B′* and Highway 10–A, the rock has flowed, and the bedding is squeezed and distorted.

On the right abutment, the strike of the beds is N. 30°–90° W. and the dip is 12°–52° N., except where minor northward-trending folds or rolls occur. These minor structural features are especially common in the lower part of the abutment and in the rock hill near the center of the valley. On the rock knob, the strike ranges from N. 32° to 46° E., and the dip ranges from 25° to 36° SE. In the small exposures northeast of the hill, the strike of the beds swings even more to the northeast and the dip flattens.

FAULTS

No large faults are exposed at the site; however, one may be concealed in the large talus-filled draw along the north side of the map. This draw is alined along a prominent trend line that, on aerial photographs, can be traced about 5 miles to the east-southeast where it appears to die out and 3.5 miles to the west-northwest where it passes beneath the fill in the Clark Fork Valley, The dike on the right abutment has been intruded along a minor fault or shear zone. At the easternmost exposure of igneous rock, the Prichard beds to the southwest have an almost vertical dip, whereas those on the northeast dip steeply to the southwest. At the west end of the outcrop, there is a narrow shear zone striking N. 60° W. and dipping 88° NE. The rock southwest of the dike may have moved down relative to that on the northeast side. East of the north end of *B–B′* a small draw filled with talus may mark the approximate location of the fault. Minor faults or shear zones probably govern the development and location of long talus-filled draws that extend down the valley walls. The small rock knob on the right abutment upstream from section *B–B′* is separated from the main wall by a small sharp downfold or a minor fault. On the north abutment, there are two prominent bedding slips and a few zones of shearing that almost parallel the bedding.

JOINTS

The rock is moderately jointed and, in addition, certain beds are cut by fracture cleavage. The joints combined with the cleavage results in mechanical breakdown of the rock, giving rise to extensive talus deposits at the base of many slopes.

The strike and dip of the joints range considerably across the damsite. Where the attitude of the beds is constant, the joints fall into fairly well defined sets. A forecast of the probable effects of the joints on rock could be made by a detailed study of an area.

In the more argillaceous beds, the joints parallel to the bedding are the most numerous, but in the quartzite beds they are more widely spaced and not as conspicuous. Throughout the damsite area most of the other joints have high angles of dip. Two major sets have a general strike to the north and in the quartzite beds on the right abutment cut the rock into small blocks. Other complimentary joints, more widely spaced and not as obvious, strike west-northwest or more nearly parallel to the river.

In the upper few feet of bedrock, the joints range from open to tight. In roadcuts at depths of 5–10 feet, they appear tight except that many joint faces are stained reddish-brown by limonite. Although water has moved along these joints, their narrow width indicates that the grout take would be small.

GROUND-WATER CONDITIONS

Surface indications of ground water at Knowles damsite consist of a small spring on the right abutment 400 feet upstream from section *B–B′* and a seep and marshy area on the left abutment 1,200 feet downstream from *B–B′*. Meteoric water is moving down the valley walls along the contact between the pervious overburden and bedrock. At the point where the relatively tight lake beds rest against bedrock, the water emerges at the ground surface and flows for a short distance before it sinks into alluvium.

Preliminary investigations by the Corps of Engineers show that water under hydrostatic head occurs in the valley fill at two altitudes. In drill hole 5, artesian water was found in a bed at altitude 2,354 feet, or 115.2 feet below the top of the casing. Observations in two well points near drill hole 12 disclosed that water under hydrostatic pressure exists in the sand and silt strata below an upper clay strata. The ground-water surface and the well-point water surfaces were different. Considerable lag occurred between fluctuations in the river surface and adjustment of the ground-water surface. Other water tests and observations were taken during drilling of holes 1–6, logs of which are available and which are listed as follows.

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Water tests, drill holes 1–6, Knowles damsite

Hole	Depth (ft)	Altitude (ft)	Time (min)	Pressure (psi)	Volume (cfm)	Casing (in.)	Remarks
1	90	2,381	9	180	0.0	3	Medium sand and silty clay.
1	106	2,366	6	180	.0	3	Hole at top of bedrock. With casing on bedrock, sand and silt filled hole from 2,357.5 to 2,390.5 ft overnight.
2	0–145	2,470–2,325					Water losses in sands while churning past bottom of casing were 5–15 gpm. Loss was complete, 20 gpm between 45–54 and 130–140 ft.
2	90–93	2,380–2,377	7	20	1.3(?)	3	Hole in fine sand at base of bed of very fine gravel.
2	159–161	2,311–2,309					Water loss complete into 2-foot thick bed of coarse sand interbedded in plastic clay.
3	21–25	2,449–2,445	5	70	4.0		Four-foot sample taken with 2-in. sample barrel before pressure tests were taken.
3	30–34	2,440–2,436	5	70	4.0		Test in fine silty sand.
3	45–49	2,425–2,421	5	70	4.2		Test in clay.
4	20	2,461					Water table 10 ft below river surface.
4	179	2,302			.00016	6	Water level in casing dropped 4.5 ft in 91 hr. 4-in. tools in hole. Clayey silt.
4	190	2,291			.236	6	Water level in casing dropped 7.4 ft in 6 min and 11.3 ft in 9 min. Clay. Bedrock at 195.5 ft.
5	100–101	2,369–2,368	1	100	.0	6	Sandy loam.
5	116	2,354					Water rose to top of casing. Silty sand.
6	35–36	2,435–2,434	10	5	5.36	6	Sand.
6	85–87	2,384–2,382	5	20	2.88	6	Silty sand.

PERMEABILITY

The water tests show that the zone of interbedded sand, silt, and gravel in the upper part of the foundation above altitude 2,335 feet at section *A–A′* and 2,345 feet at *B–B′* is moderately permeable. Even within this zone, however, the permeability of the various layers ranges greatly, as shown by the wide range of water losses.

Percolation of water through the matrix of rock in the abutments will be nil. Seepage along joints and other fractures will occur but probably will be small, as the partings are fairly tight at shallow depths. Grouting should seal the larger openings and reduce leakage to a minimum.

DAM SECTIONS

Knowles damsite is feasible only for an earthfill dam. The thick fill of saturated clay and silt beds in the valley bottom will require careful investigation and application of special engineering and construction techniques to overcome its defects. The Prichard Formation in the abutments and in the small rock knob 500–1,300 feet south of the right wall is strong and sound and is a good foundation for any appurtenant structures. Any defects in the rock will be minor and can be overcome easily by normal construction methods.

GEOLOGIC SECTION A–A′

At altitude 2,715 feet, the valley is 3,960 feet wide. At 2,560 feet, it is divided into two parts by a rock knob. The distance from the left abutment to the knob is 1,520 feet, and from the knob to the right abutment, it is 860 feet. At 2,500 feet, the valley is 1,150 feet wide, and at the river surface at 2,470 feet, it is 660 feet wide. On the left abutment, rock crops out above altitude 2,490 feet, and on the right abutment, rock is exposed almost continuously from altitude 2,500 feet on the south side of the knob to the north valley wall. Development at this axis can be by an earth dam in the river part and a large concrete wing dam extending from the knob to the north abutment (fig. 2).

All appurtenant structures can be located on rock. Diversion of the river is possible either by construction of a tunnel in the left abutment a tunnel through the rock knob on the north side of the river, or by an overflow across a concrete dam in the topographic and bedrock saddle between the knob and right abutment. Rock in the left abutment is strong and sound. A tunnel in it normally would not require support. The cover above a large diameter tunnel, however, will be very thin unless the centerline is a least 300 feet south of U.S. Highway 10-A. The strike of the beds is approximately parallel to the river, and the dip is to the south. This may result in minor overbreak. The rock in the knob on the north side of the river ranges considerably in strength. The top 30 feet and the upstream side of the knob are broken extensively by fracture cleavage. Underlying this zone are 50–60 feet of quartzite beds that range from 3 inches to 5 feet in thicknss. Beneath the quartzite are more highly fractured beds. Detailed testing is necessary to determine the maximum size tunnel that could be driven without support. From field examination, it is estimated to be about 20 feet. The rock in the knob would make a strong, sound powerhouse site.

GEOLOGIC SECTION B-B′

The valley at altitude 2,715 feet is 2,360 feet wide; at 2,560 it is 2,050 feet wide; at 2,500 it is 1,560 feet wide, and at the river surface at 2,471, it is 760 feet wide. On the left abutment rock is exposed from the highway at 2,495–2,850 feet. On the right abutment, rock crops out 1,150 feet north of the river near altitude 2,550 feet and is exposed to above 2,900 feet. Between the river and the abutment, a buried rock bench at altitude 2,400 feet is covered by 70–130 feet of interbedded fine-grained sand and silt. Overlying the lake beds is a 10–20-foot-thick layer of alluvium.

All appurtenant structures can be located in rock. On the left abutment, a diversion tunnel could be driven in strong, sound quartzite. Even large diameter tunnels would not have to be lined except at the portals. The long talus-filled draw 300 feet downstream from *B–B′* may conceal a minor fault or shear zone with broken rock that might cause some trouble in a tunnel. Rock in a small point that

FIGURE 2.—Right (north) abutment of Knowles damsite. Parts of geologic sections *A–A′* and *B–B′*, which are possible axis lines, are shown. Along *A–A′*, rock is exposed almost continuously from the knob on the left side of the panorama to the steep valley wall. October 1958.

extends to the left bank of the river 500 feet downstream from *B–B′* is solid and strong and would make a good foundation for a powerhouse site.

On the right abutment, the valley wall is an almost vertical cliff from altitude 2,550 to 2,700 feet and above 2,700 feet slopes at an angle of 50°. In the lower part of the abutment, fracture cleavage has reduced the strength of the rock. A tunnel in this abutment probably could be driven without support, but the rock should be investigated carefully. A spillway site would be in rock of good quality, but the steep slopes would require a considerable amount of rock excavation. From 250 to 500 feet downstream from line *B–B′* and 10–20 feet back from the almost vertical cliff face, a large mass of rock is breaking away from the cliff along a fracture that is as much as 1.5 feet wide and open to a depth of about 30 feet. Other open fractures may be present in the abutment.

COMPARISON OF AXES

A–A′ is the best axis from a geologic viewpoint, but the cross-sectional area of the valley below altitude 2,715 feet is considerably greater than at *B–B′* The volume of material required in a dam at *A–A′*, however, probably would not be proportionately larger, because the valley at *B–B′* is wider at lower altitudes than at *A–A′*. The greater volume of material in the lower part of a dam compared to that in the upper part would compensate for the additional length of *A–A′*. At altitude 2,560 feet, the cross-sectional area of the valley at the two sections is nearly equal. Line *A–A′* would allow considerable latitude in the choice of design and location of appurtenant structures.

ENGINEERING CONSIDERATIONS

Because of the thick sequence of fine-grained unconsolidated lacustrine sediments in the foundation, feasibility of the site cannot be determined from geologic investigations alone. As previously mentioned, the Corps of Engineers has drilled a few holes and made laboratory tests on samples from them to determine the engineering properties of the various materials. From this preliminary work, they concluded that the critical factors involved in the design and construction of an earth dam at Knowles site are the possibilities of shear failure in the foundation and of excessive and differential settlement of the foundation and embankment.

The possibility of shear failures resulting from the load applied in placing embankment is great because of the saturated condition, the fine grain, and the low permeability of the materials in the foundation. The escape of water displaced by adjustments due to load will be very slow, and high pore pressures will be built up. On the basis of their limited exploration and testing, personnel of the Corps of Engineers calculated that for this reason only 17–34 feet of embankment could be built up safely in one construction season without applying special drainage methods to the foundation. They also estimated that total settlement in the foundation and embankment would be about 18 feet.

EXPLORATION

Although the valley fill has been explored by 10 drill holes, additional holes are needed to investigate thoroughly the character of the fill. Continuous sampling from the ground surface to the bottom of the hole is necessary. This should not be difficult in the very fine grained glacial lake beds. Additional water tests are needed to determine the permeability of the beds. A search should be made to outline the extent of the bed carrying artesian water at altitude 2,369 feet in drill hole 5.

At section *A–A′* the first work should be to trace the bedrock surface between the knob and the north abutment. At *B–B′* the rock in the right (north) abutment is of slightly poorer quality and should be explored first. Detailed explorations are necessary if any appurtenant structures are planned for this abutment. On the left abutment the rock along *B–B′* should be tested by a few holes, and the rock beneath the talus-filled draw 300 feet west of the section should be investigated by angle drill holes.

RESERVOIR SITE

The reservoir for a high dam having a flow line at altitude 2,705 feet would extend 69 miles up the Flathead River to Kerr Dam at river mile 72. About 22 miles, or 30 percent, of the reservoir would lie in the transverse valley that extends from Dixon to Knowles. The remaining 47 miles would lie along the western edge of two small valleys partly separated from the Mission Valley on the east by low bedrock ridges.

The approximate area and volume of Knowles reservoir at altitude 2,705 feet is 44,000 acres and 5,200,000 acre-feet. Active storage would be about 3,080,000 acre-feet.

ECONOMIC FEATURES

At altitude 2,705 feet, the reservoir would flood 35.5 miles of the Northern Pacific Railway tracks. About 28.5 miles of the passenger line between Paradise and Missoula is within the reservoir area and 7.0 miles of a branch line from Dixon to Polson. About 22.8 miles of U.S. Highway 10–A would be covered by the reservoir waters. Other cultural features that would be flooded include: the town of Dixon, village of Perma, Flathead Indian Agency, Headquarters of the National Bison Range, four county bridges, part of a 10-inch petroleum production line, part of a high-voltage powerline, and a few ranches and farms.

A reservoir having a flow line at 2,530 feet would cover 22–23 miles of the Northern Pacific passenger line and 2.5 miles of the branch line. About 17 miles of Highway 10–A would be flooded. Relocation of these communication lines would be considerably cheaper for a low dam than for one with a flow line at 2,705 feet.

GEOLOGY

The geology of the reservoir site from either Knowles or Perma to about 3 miles north of Dixon is similar to that at the damsites. Glacial lake beds and alluvium fill the valley bottom, probably extending about 250 feet below the river surface. The valley walls are made up of the Prichard Formation from the sites to a point 4 miles west of Dixon and by the Ravalli Group from that point to Kerr Dam. From 3 miles north of Dixon to Kerr Dam, the small valleys are partly filled with glacial deposits. The river channel is cut in till, lake beds, and outwash material, except at a few places where the river flows along the valley walls and has cut into strata of the Ravalli Group and Tertiary(?) formations.

The reservoir is tight. The only leakage that can occur will be in the vicinity of the damsite.

PERMA DAMSITE

LOCATION AND ACCESSIBILITY

Perma damsite is at the small settlement of Perma on the Northern Pacific Railway and U.S. Highway 10–A. Both the railroad and highway are on the left (south) side of the valley. Perma Bridge crosses the river and provides easy access to the right (north) abutment. A hard-surfaced county highway crosses the bridge and continues north to Camas Prairie and Hot Springs (pl. 1).

Geologic section *C–C′*, one of two possible axes for a high dam, is at river mile 10.9, only 130 feet upstream from the bridge. Section *D–D′*, an alternate axis, is at river mile 11.3, about 2,300 feet upstream from the bridge and 200 feet from the mouth of Camas Creek. *E–E′*, a possible axis line for a low dam, is at river mile 11.9, about 5,250 feet upstream from the bridge. Sections *C–C′* and *D–D′* are in the NW¼ sec. 31, T. 19 N., R. 23 W., except for the right abutment and possible spillway site for *D–D′*, which are in the SW¼ sec. 30. *E–E′* is in the NE¼ sec. 31.

TOPOGRAPHY

Topography of the downstream 25 miles of the Flathead River valley is much the same. At Perma damsite, the valley is wide and flat bottomed, ranging from 1,650 to 3,000 feet in width between the rock walls. The floor is underlain by a thick fill of lacustrine beds generally covered by alluvium. Small terraces have been cut at altitudes 2,500–2,510 and 2,545–2,560 feet. From altitude 2,550 feet to the upper limits of the topographic map at 2,900 feet, the rock walls slope at angles ranging from 13° to 33°. At 2,900 feet the valley is 4,000–5,400 feet wide.

Camas Creek flows from the north into Flathead River 2,200 feet upstream from the bridge. This tributary valley is 700 feet wide throughout the downstream 2,000 feet that has been mapped.

An abandoned high-level channel of Flathead River leaves the present valley 0.8 mile southeast of the junction of U.S. Highway 10–A and the county highway, swings about 2,000 feet south of the main valley, and rejoins it 0.2 mile southeast of the road junction. The channel is 4,100 feet long, and for 3,500 feet of its length the bottom is above 2,700 feet. The drainage divide is near altitude 2,845 feet. The walls are steep—30 feet above the floor the channel is 200–250 feet wide, and 100 feet above the floor it is 350–400 feet wide.

When the site was mapped, the river surface was at altitude 2,479.4 feet at geologic section *C–C′*, 2,480.3 at *D–D′*, and 2,483.0 at *E–E′*. The stream gradient through the damsite map area is 3.6 feet per mile.

GEOLOGY

STRATIGRAPHY

PRECAMBRIAN

Bedrock at Perma damsite includes sedimentary rocks of the Prichard Formation, two sills, and a 650–900-foot-thick zone of metamorphosed rocks of the Prichard Formation.

The Prichard Formation has been subjected to static and dynamic metamorphism and is composed of compact, hard, strong rocks. The quartzite is light gray, and the more argillaceous layers are dark gray. Weathered surfaces are moderate reddish brown. This color is typical of weathered Prichard, but it is not as conspicuous at Perma damsite as in the rocks that are exposed farther west. The beds generally range from paper thin to 24 inches in thickness; however, in a few areas, massive quartzite beds are as much as 10–12 feet thick. Bedding is shown by variations in color shades, grain size, and mineral content. Ripple marks and a few desiccation cracks are found. Biotite crystals are disseminated throughout the rock. In a few quartzite beds, biotite is bunched with minor amounts of hornblende to give a spotted appearance to the rock. Some pyrite is present.

The larger of the two sills exposed at the damsite is 360 feet thick, forms prominent outcrops, and crosses the river near the eastern edge of the map area. The fine-grained massive dark-greenish-gray rock contains a great deal of hornblende and some quartz, as determined by examination with a hand lens. Plagioclase is difficult to distinguish, but twinning can be seen in a few crystals. The rock is classified as a diorite.

The second sill crosses the river 200 feet upstream from Perma Bridge. North of the river, it is standing on edge and is 150–160 feet thick. In the valley wall south of the river, the sill is bent in a sharp fold, and the dip changes from almost vertical to about 30° S. West of the crest of the fold, the sill increases in thickness; so that 400 feet south of the intersection of the highways it is approximately 200 feet thick; 1,050 feet S. 45° W. of the junction it is 360 feet thick; and at the southwest corner of the map it is approximately 475 feet thick. The upper surface of the sill is difficult to determine, because the igneous rock grades into the overlying metamorphosed Prichard Formation.

The sill is mainly diorite, but in places south of the river the fine- to medium-grained rock contains enough quartz to be a quartz diorite. North of the river, part of the sill appears to be lacking in plagioclase, and the minerals in the rock are greenish-black amphibole and white to colorless quartz. The rock in this area is an amphibolite or quartz amphibolite.

Small areas of igneous rock are present on either rim of the abandoned high-level channel about 1,400 feet S. 40° E., and S. 55° E. of the highway junction. On the east side of the channel, an almost vertical sill 25–30 feet wide separates the metamorphosed strata from the normal strata of the Prichard Formation. The sill is near the crest of the sharp fold, and from a few poor exposures near the rim it was inferred that is crosses the channel beneath the talus fill. On the west side of the channel, the igneous rock crops out over a wide area. Although the contacts are concealed, the dip of the overlying Prichard beds is about 30° S. Hence, the wider exposure is the result of the flatter dip and the almost level bench on which the outcrop occurs. From a megascopic examination the rock was classified as an amphibolite composed of 85–90 percent hornblende, 10–12 percent quartz, and a minor amount of plagioclase.

The Prichard Formation has been metamorphosed for 650–900 feet stratigraphically above the sill at Perma Bridge. On the left valley wall where the rocks dip to the south, the metamorphosed zone overlies the sill, but on the right side of the valley where the dip of the sill is almost vertical, it lies to the east. The intensity of metamorphism decreases from the sill upward. In the right valley wall near the contact, amphibole makes up as much as 40 percent of the rock but decreases to about 1 percent 450 feet from the sill.

The remainder is quartz and biotite, which makes up 10–20 percent of the total rock. Megascopically, the metamorphosed zone can be divided into three bands: (1) quartz amphibolite gneiss extends from the sill out 50–100 feet, (2) amphibolite quartz gneiss from 50–100 to 200–400 feet, and (3) recrystallized biotite quartzite from 200 to 400 feet to the eastern or upper edge of the metamorphosed zone 650–900 feet from the sill. In the first two bands a gneissic texture has developed, but in the third band the impure biotite quartzite has recrystallized without development of a noticeable texture. Below the sill, the country rock has been metamorphosed for only a few inches from the contact.

The sill at the east edge of the map does not have a metamorphosed zone associated with it.

QUATERNARY

Glacial-lake beds are exposed along the north riverbank in the upstream one-third of the map area, in cuts along the road up Camas Creek, and along U.S. Highway 10–A in the eastern half of the map. The lake beds are composed of alternate layers of clayey silt and silt and a few layers of very fine sand. The clayey silt beds range from paper thin to 1 inch in thickness, and the interbedded pale-orange silt and sand layers are $\frac{1}{32}$–35 inches in thickness. Along the riverbank upstream from the mouth of Camas Creek, pale-yellowish-brown limestone concretions are weathering from a few beds.

No deep holes have been drilled at Perma damsite. In one of the holes at Knowles, rock was 257 feet below the river surface at altitude 2,212 feet. If the stream gradient of the preglacial Flathead River were the same as that of the present stream, bedrock at Perma damsite would be at altitude 2,222 feet.

A large gulch fill extends from altitude 2,625 to 2,987 feet in the northwest part of the damsite map area. There are no exposures of the fill, but its composition can be inferred from gravel, subangular to subround cobbles, and many large angular blocks that are on the ground surface. Two small springs issue near the base of the fill.

Recent alluvium consisting of loam, silt, sand, and sand and gravel are exposed on terraces and slopes in the valley bottom. On the north side of the river the alluvium probably does not exceed 10 feet in thickness except in a few places. South of the river in the western two-thirds of the map area an old river channel has been cut into the lake beds (section *C''–C'''*, pl. 1). Explorations by the Corps of Engineers in 1945 show that as much as 47 feet of pervious silt, sand and sand and gravel underlie the terrace along section

A–A'. The top of the underlying lake beds was at altitude 2,449 feet in one hole.

In a few places, long talus slopes extend down the valley walls onto the lake beds and alluvium. Although the outrush of waters from the recurrent draining of the glacial lakes probably removed most of the preglacial talus, some deposits that were in draws or gullies may have been protected. Those talus deposits that extend below the general level of the valley floor offer excellent paths for water in a reservoir to escape into a permeable bed in the fill.

STRUCTURE

FOLDS

The crest of the large fold previously described crosses the western half of the damsite map. Closure on the southern end of the fold is well shown by the diorite sill that crosses the river at Perma Bridge. From the north edge of the map to about 400 feet south of U.S. Highway 10–A, the sill strikes N. 3° W. and dips vertically. Its attitude is parallel to bedding in the Prichard exposed to the west. From about 400 feet to 1,000 feet south of the highway, the first exposure west of the sill is S. 23° W., 34° SE., and at the southwest edge of the map the attitude of the beds has changed to N. 81° W., 30° SW.

North of the river the axial surface of the fold has an approximate strike of N. 7° W. and a steep dip to the west. A short distance south of the river, the surface curves to the south-southeast, and its trace extends through the sharp bend in the sill and continues along the abandoned high-level channel to the south edge of the map. From the sharp bend in the sill to the southeast, the axis of the fold plunges southeast at a moderate angle.

ATTITUDE OF BEDS

The beds in the limb of the anticline east and northeast of the trace of the axial surface have an almost vertical dip and generally are overturned to the east. The strike of the beds ranges from N. 8° W. to N. 10° E., and the dip ranges from 86° E. to 70° W. West and southwest of the trace of the axial surface, the strike of the beds ranges from N. 9° to 80° W., and the dip ranges from 15° to 38° SW. Near the axis of the fold the strike of the beds varies, generally swinging from southeast to north and the dip changes from southwest to east.

FAULTS

No large faults were discovered at the site. In the southeast corner of the map an inferred fault cuts the sill. Strike is approximately S. 67° W., and estimated displacement is 100 feet. Crushed zones 1–10 inches thick occur along both contacts of the sill at the east of the map. Bedding faults occur in the argillaceous strata.

JOINTS

Strata of the Prichard Formation are well jointed. In the area east of the axial trace of the fold, where the beds dip at high angles, there are four prominent joint sets, plus miscellaneous joints. The attitudes of the sets are:

Set	Strike	Dip
1	N. 7° W.–N. 8° E.	74° W.–73° E.
2	N. 72°–87° E.	53° SE.–87° NW.
3	N. 8°–80° W.	19° SW.–12° NE.
4	N. 50°–87° W.	31°–83° NE.

The joints in set 1 are parallel to the bedding and are the most conspicuous. Their spacing in the argillaceous beds ranges from ⅛ to 12 inches and in the quartzite beds from a few inches to 10 feet. The high angle of dip of the joints in set 1 combined with the strike, which is almost directly into either abutment, tends to reduce the possibility of high percolation losses along them except in the vicinity of the spillway site on the right abutment at *D–D′*. The joints in the other three sets strike more nearly parallel to the river and would be better seepage paths. Limonite stains occur along many joints to depths of 12 feet and more below the ground surface. Generally, the joints appear tight and only moderate losses are expected. Grouting should seal the openings. The joints in set 3 in combination with those in 2 and 4 produce steps at a few places on the hillside.

In the diorite sill at the east edge of the map area the attitude of the joints varies somewhat from that in the sedimentary rocks. Three major and two minor sets cut the sill, and they have the following strikes and dips:

Set	Strike	Dip
1	N. 20° W.–N. 3 °E.	73° E.–73° W.
2	N. 70°–85° E.	54°–80° SE.
3	N. 68°–73° E.	25°–43° SE.
4	N. 85° W.–N. 70° E.	33°–47° N.
5	N. 20°–35° E.	78°–88° SE.

The major sets are 1, 2, and 3, and the minor sets are 4 and 5. Occasionally, some shearing is found along fractures in set 3. Cement grouting will effectively seal most of the openings in the rock.

West of the axial trace of the fold the joint sets are:

Set	Strike	Dip
1	N. 83°–89° W.	25°–34° SW.
2	N. 10°–47° E.	57°–86° NW.
3	N. 19°–35° W.	50°–87° NE.
4	N. 65° W.	43°–88° NE.

GROUND-WATER CONDITIONS

At the west end of the abandoned high-level channel of the river, a small flow of water disappears into the talus. The water reappears in the marshy area south of the highway junction. (See pl. 1)

Two small springs issue near the base of the gulch fill on the north side of the river.

An artesian well, drilled by the Northern Pacific Railway, is 475 feet N. 40° W. of the highway intersection. The well flows at a rate of 1 gpm (gallon per minute) from a depth of 217 feet. Maintenance personnel at Perma estimate that flow is now about half of what it was when the well was first drilled.

PERMEABILITY

No water tests have been made at the site. At section *C–C′*, the sand and gravel beds in the valley bottom south of the river are the most permeable. Similar materials must be present beneath the river at the other axes. The lake beds underlying the gravel, sand, and silt are relatively impermeable.

In the rock abutment, percolation through the pores will be nil, but there will be a small amount of seepage along joints and other fractures. Grouting will seal the larger openings and reduce leakage to a minimum.

DAM SECTIONS

Because the foundation is formed by a thick fill of unconsolidated lake beds composed of silt, clay, and sand, Perma damsite is feasible only for an earthfill-type dam. Careful investigation, engineering, and construction techniques will be required to overcome the defects. Rock in the abutments is hard and strong, and wherever present would make a good to excellent foundation for any appurtenant structures.

The same foundation defects and possible methods for correction hold for Perma damsite as are outlined under Engineering considerations for the Knowles damsite.

GEOLOGIC SECTION C–C′

At *C–C′*, the valley is 3,020 feet wide at altitude 2,715 feet and 1,650 feet wide near the floor at 2,500 feet (figs. 3, 4 and pl. 1).

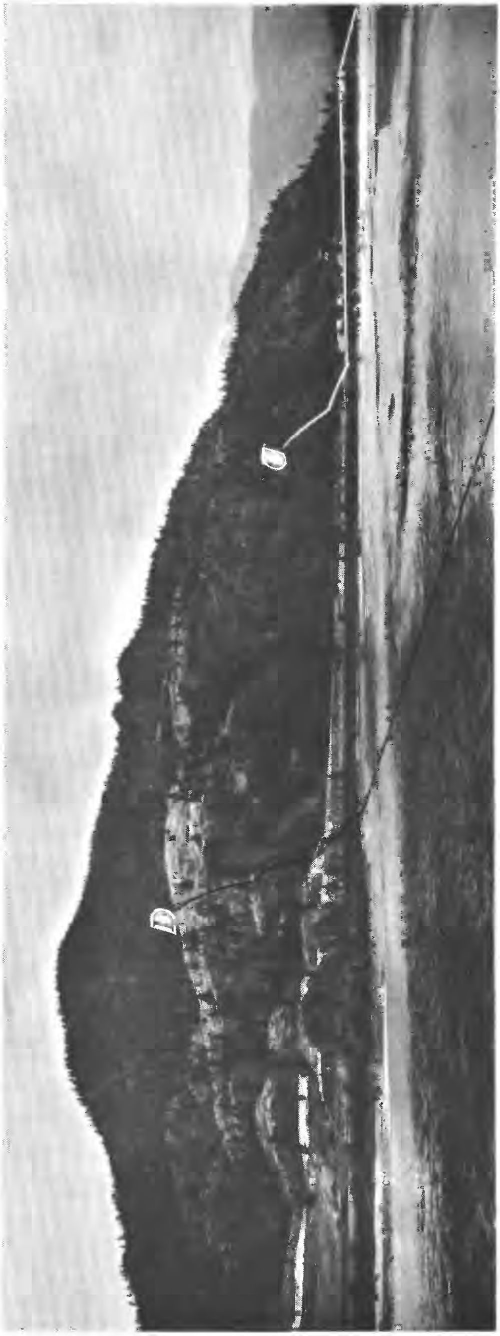

FIGURE 3.—Panorama of the downstream two-thirds of the left (south) abutment, Perma damsite. The approximate locations of parts of sections $C–C'$ and $D–D'$ are shown.

FIGURE 4.—Right (north) valley wall at Perma damsite. To the left was deposited in glacial Lake Missoula. At D', the rock spur that forms the skyline is part of one of the high gulch fills or gravel bars that of the ridge that forms the abutment at C–C' and immediately below the right abutment for axis D–D' is a possible spillway site. Water would be spilled into Camas Creek valley, which is at the center of the photograph, and then returned to the river through a channel excavated in the lake beds in the lower part of the valley. September 1957.

The terrace south of the river is underlain by pervious beds of gravel, sand, and silt down to altitude 2,444 feet. Below this are the relatively impervious glacial-lake beds. Geologic conditions beneath the terrace are shown in detail on section *C''–C'''*, plate 1, an enlargement of part of section *C–C'* based on the Corps of Engineers 1-inch sampler holes and their map, "Perma Dam Site, Geologic Profile, Axis of Dam." Beneath the river channel the depth to undisturbed lake beds is not known. Drill holes at Knowles damsite show 20–30 feet of water and alluvium over the lake beds. If conditions are similar at Perma, the lake beds are between altitudes 2,450 and 2,460 feet.

No major defects were found in the rock in either abutment. In the left abutment, shattered and broken rock probably occurs in the vicinity of maximum folding along the axial plane trace. On the right abutment west of *C–C'*, there are some thin-bedded argillaceous layers that are not as strong or resistant to corrosion as the other rocks in the point. However, even this rock is strong and well suited for a foundation.

GEOLOGIC SECTION D–D'

The crest length of a dam at this section would be about 3,100 feet. This includes a valley section of 2,800 feet and a proposed spillway site 300 feet wide along the crest of the ridge east of the intersection of *D–D'* and *F–F'* (figs. 3, 4 and pl. 1). Rock in the ridge is moderately sound and strong but may contain some minor bedding-plane faults concealed beneath the talus on the hillside. The beds strike N. 2° W. to N. 10° E., and are slightly overturned to the east and dip from 80° to 88° W. A spillway contracted here would discharge into Camas Creek about 2,000 feet upstream from its mouth. To return the water to the river a short distance downstream from the toe of a dam, a channel could be excavated through the lacustrine beds in the valley fill 700–1,000 feet west-northwest of the mouth of Camas Creek. A second spillway site for this axis is along the abandoned high-level channel south of the river. A rock cut a few feet to 165 feet deep and 3,500 feet long between the 2,680-foot contours would be required. Water from the spillway would reenter the river at least 1,200 feet downstream from line *D–D'*.

The valley bottom is 1,900 feet wide between rock outcrops at *D–D'*, but a short distance upstream it narrows to 1,700 feet. At this latter location, lake beds underlie a terrace so that the width of the valley that can be underlain by pervious alluvium is 1,300 feet. Sand and gravel beneath the riverbed is estimated to be about 25 feet thick or to extend to altitude 2,445 feet.

GEOLOGIC SECTION E-E'

The narrowest section for a low-head dam is at *E–E'*. The valley is 1,350 feet wide at altitude 2,530 feet, 1,500 feet at 2,548, and 2,125 feet at 2,559. Reservoir flow lines at altitudes 2,530, 2,548, and 2,559 feet would back water to damsite 4, Oxbow, and Sloan Bridge damsites, respectively. For the two highest reservoir levels, the dam would have to be tied to the north valley wall by a low wing dam.

The right abutment is underlain by lacustrine silts and very fine grained sands. The left abutment is underlain by the massive almost vertical diorite sill that extends south from the river. For 800 feet, the river skirts the east or upstream side of the sill. West of the sill, lacustrine beds overlap onto it, and the bedrock surface probably descends at a steep slope. Because the sill stands almost vertically and the adjacent beds have been removed by erosion, any diversion and penstock tunnels driven through the sill would be of a minimum length. The rock is strong and massive and is an excellent foundation for any appurtenant structures. Even with a relatively thin cover, a diversion tunnel would require no lining.

The depth to tight lake beds beneath the river is the same as that estimated for lines *C–C'* and *D–D'*. The maximum width of the valley underlain by the sand and gravel is considerably less, however, because the distance between lake-bed exposures in the north abutment and the sill in the south abutment is only 1,000 feet.

COMPARISON OF AXES

For a dam having a flow line between 2,600 and 2,705 feet, geologic sections *C–C'* and *D–D'* may be considered as possible axes. At either axis, both abutments and foundations for all appurtenant structures could be in rock. In addition, there would be considerable choice of locations for powerhouse, spillway, and other structures. From a geological viewpoint, *D–D'* has a slight advantage over *C–C'* because the cross-sectional area of pervious sand and gravel in the valley bottom probably is smaller. Furthermore, safety could be increased by separation of the spillway from the earth dam. The small rock point on the left abutment allows a choice of several sites for the powerhouse and diversion tunnel.

Geologic sections *D–D'* and *E–E'* are the best axes for a low-level dam having a flow line between altitudes 2,514 and 2,600 feet. Between 2,514 and 2,560 the foundation and right abutment are on unconsolidated materials, but the left abutment is on rock. Between 2,560 and 2,600 feet both abutments are on rock. At all altitudes, section *E–E'* is the better axis, because the cross-sectional area of

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the valley is smaller and the massive sill furnishes an exceptionally strong, sound foundation for appurtenant structures.

EXPLORATION

Preliminary exploration at Perma damsite should be made in the valley bottom or dam foundation. First, the depth, width, and permeability of the sand and gravel fill, south of the river at *C–C′* or in the river at *D–D′* and *E–E′*, must be determined. Second, undisturbed samples of the lake beds below the sand and gravel are required for shear and consolidation tests. Careful tests are necessary to check the thickness and permeability of the artesian aquifer in the lake beds.

In the areas of pervious fill, drill holes must be used below the water table, which is generally at river level. Where lake beds are exposed, test pits can be used if necessary for sampling, at least to the water table. Bedrock in the valley walls can be explored by diamond-drill holes. In the right abutment at section *C–C′* and in both abutments at *D–D′*, vertical holes will be approximately parallel to the bedding. Water losses in these holes will be less representative than in angle holes.

RESERVOIR SITE

The reservoir behind a high dam having a flow line at altitude 2,705 feet would be 61 miles long. The approximate area and volume are 40,700 acres and 4,750,000 acre-feet. About 28.2 miles of the Northern Pacific Railway tracks including 21.2 miles of the passenger line and 7 miles of the branch line to Polson and 15 miles of U.S. Highway 10–A would be inundated. All of the cultural features flooded by the high level Knowles reservoir would be flooded by a high dam at section *C–C′* at Perma with the exception of some farm land between the two sites. A dam at section *D–D′* would not flood Perma or Perma Bridge. A dam at section *E–E′* having a reservoir flow line at 2,530 feet would flood about 14.7 miles of the main passenger track, 2.5 miles of the branch line, and 9 miles of Highway 10–A.

The geology of the reservoir site is the same as that for Knowles damsite.

DAMSITE 4

LOCATION AND ACCESSIBILITY

This site is just south of the center of sec. 1, T. 19 N., R. 22 W., at mile 36.4. It is 25.5 miles upstream from Perma, 4.9 miles downstream from Oxbow damsite, 8.3 miles below Sloan Bridge damsite, and 24.3 miles below Buffalo damsite 2. (See fig. 1.)

Both abutments are accessible by car. The right (west) abutment is approximately 5 miles south of Sloan Bridge via an unimproved country 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 damsite 4, the Flathead River is flowing in Moiese Valley, a small valley about 8 miles long and 2–4 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 (west) abutment rises to 2,700 feet on a slope of approximately 12°. Above 2,700 feet the slope of the hillside increases, and the hills rise to an approximate altitude of 3,500 feet. The left (east) 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 damsite 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. 2.) The rock ranges from a light- to dark-greenish-gray sandy argillite to a very fine-grained light-gray quartzite. It is firm, generally fresh, and the beds range from half an 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 *G–G′*. This outcrop is the largest and most complete exposure of this unit on lower Flathead River. Angular to subround fragments and blocks of almost completely weathered argillite and quartzite as much as 3 feet in diameter are embedded in a matrix of silt and sand. The size of the blocks decreases, 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 range in color from very light gray 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 *I–I'*, pl. 2) 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, and there is Recent alluvium along the river channel.

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

The left (east) abutment is underlain by reworked glacial deposits. Active and inactive alluvium occur along the river, and older alluvium overlain by 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 1–5, drilled in a line parallel to the river (see section *I–I'*, pl. 2), the core recovery was too poor in the upper 30–37 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 2,515–2,505 feet, or to 15–25 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 2,524 feet 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, half an inch to 4 inches in diameter. Section *G–G'* is a short distance north of the drill holes and show 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 having varves and a few seams of very fine grained sand predominate in the core recovered in this part of the section. The lake-bed silts in drill hole 5 below altitude 2,442 feet and in hole 7 below 2,453 feet 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 glacier.

In the abutment east of drill hole 7, the top of the silt bed is believed to be near 2,580. Gravel and sand probably overlie the silt and form the constructional terrace east of the hole, but there are no exposures. Seismic spread 8, which is 200 feet east of drill hole 7 and at altitude 2,624 feet, has 64 feet of material that has velocities comparable to those where gravel and sand are known to be present. The change of stratification at the depth of 64 feet or altitude 2,560 feet is only 5 feet above the base of the silt bed reported at 2,555 feet in drill hole 7. Possibly, the upper layer of lake-bed silts, shown in sections *F–F′* and *G–G′*, plate 2, thins to the east.

STRUCTURAL FEATURES

The strike of the beds on the right (west) abutment is N. 48°–68° 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. 35°–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 *F–F′* 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 bench mark 2542. Here, two bedding-plane slips having seams of tight fresh gouge ranging 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 of which has tight joints spaced half an inch to 4 feet apart paralleling 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. Most of the joints are tight.

GROUND-WATER CONDITIONS

Artesian water was found in drill holes 3, 5, 6, and 7 at depths as shown in the following table.

Hole	Depth to water	Altitude of water	Estimated flow (gpm)	Altitude to which water rose	Aquifer
3	98	2, 444	4	[1] 2, 549	Probably Quaternary. Conglomerate bed about 7 ft above the Ravalli Group.
5	112	2, 430	2–3	--------	Layer of sand and gravel 3 ft thick overlying the Ravalli Group.
6	122–124	2, 447–2, 445	4	[2] 2, 570	Probably a bed of sand and gravel 4–6 ft above the depth at which water was reported.
7	150–171	2, 425–2, 404	1	[3] 2, 579	Water was noted at end of shift. Probably Tertiary(?) talus breccia below altitude 2,425 ft.

[1] 10 ft above ground surface.
[2] 7 ft above ground surface.
[3] 5 ft above ground surface.

The artesian water appears to be related to the sand and gravel bed that overlies the Ravalli Group in holes 2–5 from altitude 2,475 down to 2,430 feet. (See section *I–I′*, pl. 2.) 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 soure beyond the limits of the Moiese Valley. The artesian water could be related to the flow found at the Oxbow damsite at altitude 2,452–2,460 feet. A careful check should be made for artesian water in any holes drilled in the river channel.

A small spring occurs at altitude 2,578 feet on the left abutment approximately 1,450 feet north-northeast of bench mark 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 maximum pool level is not limited by topography, but the profile of the valley is such that the most practical and economical dam would have a pool level at altitude 2,641 feet. This dam would have a hydraulic head of about 111 feet and would back water to the downstream edge of the gorge below Buffalo damsite 1. If the site were developed to the maximum pool level of 2,705 feet, the head would be 175 feet. A long-wing dam 55–75 feet high and about 8,000 feet long would be required. Part of the dam would extend from near the east end of section *G–G′* across the Moiese Valley to the low hill that forms the east side of the valley. A dam having a flow line at altitude 2,615 feet would have a head of 85 feet and would back water to Buffalo damsite 2.

POSSIBILITY OF ADDITIONAL HEAD BY DOWNSTREAM CHANNEL IMPROVEMENTS

The hydraulic head of this powersite development could be increased by excavation of the river channel downstream from the site. It is feasible to consider winning the additional head, because the channel is mainly in deposits of till, outwash gravel, and lake-bed silts. A dragline could excavate these materials without much difficulty.

The head that can be gained will depend upon the gradient decided on for the channel and the distance the excavation can be carried downstream. The choice of these factors depends upon a study of this reach of the river by means of a model and future exploration of the channel. Between miles 36 and 22.1 the stream ranges 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 were excavated to this gradient from mile 24.9 and there was minor straightening of the channel, the head at damsite 4 could be increased about 16 feet. If the channel improvement were started at mile 29, the head could be increased 12–14 feet.

Rock occurs in the right riverbank between miles 33.3 and 32.0 and may be in the bank at mile 28. At both localities, however, the left (east) bank is on alluvium or glacial deposits, and rock excavation can be avoided by moving the channel into that bank. These areas should be checked by drill holes.

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 found in drill holes 1–5 from the ground surface near altitude 2,542 feet down to 2,515 feet. East of these holes the abutment appears to be pervious sand and gravel, except for the thick bed of silt reported in drill hole 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 earthfill dam unless percolation through the gravel beds can be prevented.

At sections *F–F′* and *G–G′*, both of which may be considered as possible axis lines, the right (west) abutment and a part 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 *G–G′*. 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 feet. Approximately five core holes spaced 200 feet apart should be put down along section *G–G′* east of drill hole 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 *F–F′* 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 *G–G′*.

OXBOW DAMSITE

LOCATION AND ACCESSIBILITY

Oxbow damsite is located mainly in the NW¼ sec. 28, T. 20 N., R. 21 W., with a small part 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 damsite 2, 26.6 miles from Buffalo damsite 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 SE. cor. of sec. 18, T. 20 N., R. 21 W. From here, a trail can be followed along the north line of sec. 20 to near the quarter corner, where it swings southeast for about six-tenths of a mile and then south to the edge of the second bench above the river in the NW¼ sec. 28.

TOPOGRAPHY

Oxbow damsite 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, 5 and pl. 2.) The river is flowing to the southwest at the site.

The left (southeast) abutment is on hard Precambrian rocks that rises from the river surface at altitude 2,548 feet up to 2,750 feet on a slope of 27°. Above this the slope flattens, but the hills rise another 600–800 feet above the level of the valley fill. The right

FIGURE 5.—View looking northeast through Oxbow damsite from a point eight-tenths of a 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 at an altitude of 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 face 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 to altitude 2,650 feet.

(northwest) abutment is on glacial deposits in which the river has cut two terraces. The lower terrace at 2,570 feet is about 350–400 feet wide at its broadest part. From here ground surface rises on a slope of about 30° to 2,660 feet, where a terrace about 300 feet wide is present 600–900 feet from the river. To the northwest the ground surface rises gradually at an angle of 3°–4° to about altitude 2,800 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 quartzite and a few layers of argillite, and it is similar to the rocks at the upstream sites. The rock is fine-grained, firm, and unweathered, and the beds range from 0.25 to 30 inches in thickness. Many small outcrops are in the hillside from the river surface at altitude 2,548 to 2,670 feet; none from 2,670 to 2,725 feet, the general level of the Moiese Valley Canal, but above 2,725 feet, 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 feet the strike is N. 25°–87° 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 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, 26–27 inches wide, that has 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 2,660–2,725 feet suggests that one may be present there.

QUATERNARY

PLEISTOCENE

Surface and subsurface exploration of the Oxbow damsite reveals 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 sand, and some gravel probably deposited in a glacial lake related to the St. Ignatius glacier. In three churn-drill holes the base of the till is at altitude 2,452–2,460 feet, and the top is approximately at altitude 2,580 feet in the right abutment. Beneath the river channel the bed is 85–90 feet thick, but under the right abutment it is about 125 feet thick.

In the riverbank above churn-drill hole 2, till is exposed to about altitude 2,580 feet, and reworked glacial material overlies it to 2,650. On the right (west) 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 a thousand feet upstream, or near mile 42, it is at 2,610 feet; at mile 42.4, it is at 2,670 feet; and at mile 42.6, it is at 2,680 feet.

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 pink 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 many 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 hillside. In the vicinity of section *A–A′* (pl. 2), till occurs between altitude 2,570 and 2,725 feet, but downstream from the area of rock outcrops, the top of the till is about at 2,690 feet. Overlying it are lake-bed silts that are exposed to about 2,770 feet.

The right abutment above altitude 2,580 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 southwest approximately parallel to Crow Creek Valley until it reached Oxbow damsite. 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 N½SE¼ 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 close to the center of the channel, sand and gravel were recovered from the ground surface at altitude 2,690 down to 2,578 feet. The character of the fill in the melt-water channel can be seen in the exposure above churn-drill hole 2 and in the roadcut 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 sand of widely varying permeability. (See section B–B′, pl. 2.)

RECENT

Active stream alluvium of silt, sand, and gravel is in the river bottom and along the banks to an altitude 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 altitude 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 found 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 gpm.[1] Before the flow was sealed off, the contractor pulled the casing, and the Corps of Engineers had to pump 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 gpm.

An artesian flow commenced 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.

About 130 feet south-southeast of drill hole 4, two small springs, having a combined flow of 0.5–1.0 gpm, emerge from the riverbank. 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 small size of the deposits probably is due to annual removal by flood runoff of the river.

Apparently, the artesian aquifer is a layer of very fine sand and sand and gravel underlying the massive till bed. (See sections *A–A′* and *B–B′*, pl. 2.) 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 ARTESIAN WATER

The potential danger from artesian water is great, as shown by the piping that took place at depth beneath drill hole 2 and the subsequent settling of the ground around the hole. Although the 80–100 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 hydraulic head of 157 feet. Construction at Buffalo damsite 1 would limit the normal water surface to 2,641 feet and a head of 93 feet, and a dam at Buffalo 2 would limit the surface to 2,615 feet and a head of 67 feet.

[1] Letter from the Corps of Engineers, Seattle, Wash., to F. A. Johnson, regional hydraulic engineer, Tacoma, Wash., dated Sept. 14, 1953.

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

POSSIBLE AXIS LINE

Geologic section *A–A′*, plate 2, 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 formation 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 southwest side of the spur, the rock surface may descend steeply beneath the till and lake beds there.

In the foundation, 10–25 feet of active and inactive alluvium is estimated to overlie the till.

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

FEASIBILITY

The feasibility of Oxbow damsite 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 permeable beds could be sealed off by tying an impervious blanket to the till that is at or near altitude 2,580 feet in the right abutment (section *A–A′*, pl. 2).

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. Two trenches excavated in the right riverbank and a line of drill holes along section *A–A′* should adequately check on the surface of the till.

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 sec. 20 between the abutment of the dam and the rock ridge in the NE¼ of sec. 19.

A few drill holes will be required to check on the source, pressure, and volume of the artesian water found 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 damsite 2.

MILE 42.9 DAMSITE

An alternative damsite 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 (fig. 1). The left (northeast) abutment can be reached by leaving the county road in the SW¼ sec. 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 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 few short steep-walled gullies. The right (southwest) abutment rises on a more gentle slope, and small terraces have been cut by the river at altitude 2,721, 2,680, and 2,580 feet.

The stream gradient through the site is about 2 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 damsite 1 or 2 would have heads of 86 and 60 feet respectively.

GEOLOGY

Pleistocene glacial deposits of till, very fine 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 damsite 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 2,655, 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 2,555–2,637 feet 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 grain 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 15–25 feet below the river surface or between altitudes 2,540–2,530 feet.

Active stream alluvium is along the river channel, and inactive stream alluvium is on the lower 2,580-foot terrace. Older alluvium is on the higher terraces and to the west. There are a few small alluvial fans at the mouth of the small draws.

FEASIBILITY

The reach of the river in the vicinity of mile 42.9 appears to be a prospective damsite. 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, and glacial-lake-bed silts and very fine grained sand from 2,670 to 2,705 feet. A dam high enough to back water to either Buffalo damsite 1 or 2 would have till in both abutments. The site is feasible only for an earthfill 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 damsite. 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 feet. Artesian water may be 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 found. A few 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.

SLOAN BRIDGE DAMSITE

LOCATION AND ACCESSIBILITY

The proposed damsite is at river mile 44.7 in the SE¼NW¼ and the NE¼SW¼ sec. 18, T. 20 N., R. 21 W. The powerhouse would be located at the dam or at river mile 39. In addition to a powerhouse site at the dam, powerhouse sites are proposed near river miles 39 and 12.

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 damsite and follows along the right bank through the site. The intake area for the tunnel to a powerhouse at mile 39 can be reached by driving seven-tenths of a mile upstream on the east side of the Little Bitterroot Valley and then walking 1,200 feet farther. The discharge end and powerhouse sites 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.) To leave it the stream is forced to make a 180° turn to the northeast and then skirt around the end of a prominent rock ridge that trends northeast. The proposed damsite 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 axis. 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. (Meinzer, 1916, p. 13.)

Both rivers have cut their channels mainly in lake-bed silts and drift related to the Mission glacier. As the streams entrenched themselves, the hard Ravalli rock forced their channels 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 feet. This slope is now being dissected by many short steep-walled gullies which have flat-topped ridges between them. These ridges end in almost vertical cliffs that extend from the river to altitudes ranging 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, the Flathead has a fall of almost 22 feet or an average stream gradient of 3.6 feet per mile. Through the damsite area, however, the gradient is only 2 feet per mile.

In the vicinity of the proposed conduit route to the mile 39 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 2,780–2,740 feet. Sections *D–D′* and *E–E′* (pl. 3) 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 damsite. A few outcrops are below this level in the Little Bitterroot Valley, and at mile 39 a few small outcrops occur from the river surface up to 2,700 feet.

The rock is very fine to fine-grained light 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 as much as 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 damsite. Along the right riverbank near the center of section 24, or about 50 feet downstream from where geologic section *E–E′* crosses the Little Bitterroot River, there is a small exposure of mottled light-brown, light-gray, and greenish-gray silty clay in which pieces of moderately to completely weathered light-gray and red quartzite are embedded. Tertiary(?) talus breccia, which is composed of 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 having a lens of light-brown silty claystone is exposed in the riverbank in the SE¼SE¼ sec. 13.

In the NW¼NW¼ sec. 30, west of river mile 39, talus breccia embedded in light- to reddish-brown clayey silt is in surface depressions in the Ravalli.

QUATERNARY

Pleistocene glacial deposits related to the Mission glacier have been deposited in the valley bottoms and on the Ravalli and Tertiary(?) rocks up to altitudes 2,750–2,820 feet. Along the river in the vicinity of the proposed damsite, 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. 6.) The gravel is subround to round and is composed of fresh hard quartzite and siliceous argillite that is red, greenish-gray, light-gray, and purple. The average diameter of the pebbles is 2½ inches, and there are a few cobbles as much as 10 inches in diameter. The matrix is a very-pale- 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 damsite 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 and a small amount of sand, overlain by a bed of calcareous rock flour. (See fig. 7.) 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

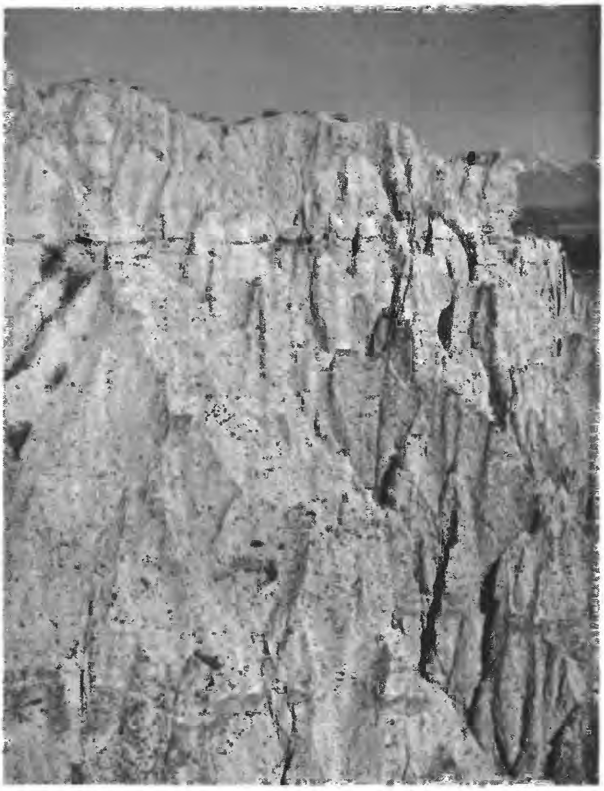

FIGURE 6.—Massive till of the Mission moraine in the left (north) abutment at the Sloan Bridge damsite. A thin bed of reworked material, mainly silt with a few lenses of gravel, is present near the top of the bank at altitude 2,694 feet, or about 11 feet below the normal pool level of the proposed reservoir. A discontinuous bed of slightly reworked material at altitude 2,651 feet can be seen near the bottom of the photograph. May 18, 1954.

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.

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

The upper layer near altitude 2,694 feet is 30–36 inches thick and contains lake-bed silts and a few thin discontinuous gravel lenses. (See fig. 6.) The bed appears to be relatively tight and should give no trouble.

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FIGURE 7.—Closeup 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. May 18, 1954

In a gully about 2,500 feet northeast of the bridge, till is exposed from altitude 2,607 to 2,836 feet, and lake-bed silts overlie it from 2,836–2,865. Stratified till is at altitude 2,655–2,665 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 on the bench about 800 feet west (upstream), 4 feet of silt overlies 14 feet of tight bouldery till in which angular blocks of quartzite 2 feet in diameter 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 damsite about 2 miles to the southeast, the base of this bed was found to be near altitude 2,455. West of river mile 39, the glacial deposits are thin and extend up on the Ravalli and Tertiary(?) rocks to about altitude 2,700.

Deposits of Recent active alluvium are in the river channel and on the riverbanks to about 2,570 feet. Inactive alluvium covers the low terraces and slopes from 2,570 to about 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. 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, and low to moderate dips are to the northwest, but at a few places on the southeast side, the strike is northwest, and low dips are to the northeast. At the northeast end of the ridge in NE¼NE¼ sec. 19, however, the strike is northwest, and low dips are to the southwest.

In a draw west of river mile 39, an abrupt change in the altitude 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 changed to N. 22° W., and the dip is 19° NE.

GROUND-WATER CONDITIONS

Artesian water may occur at depth at the damsite. This possibility is indicated by the fact that artesian water was found in the foundation of Oxbow damsite, 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 damsite (Meinzer, 1916, pl. 1). The main part 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. The aquifer probably extends downvalley, however, as two wells, one about 3.5 miles west southwest of the damsite 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., found artesian water.

The wells in the basin generally found the aquifer between 2,501 and 2,543 feet, 16–58 feet lower than the river surface at the damsite. Two wells, one in NW¼ sec. 13, T. 21 N., R. 23 W. and the other in the NW¼ sec. 13 of the same township, however, apparently tapped lower aquifers near altitudes 2,440 and 2,480 feet respectively. These altitudes correlate roughly to those at which artesian water occurs at Oxbow damsite.

High temperature, sodium carbonate mineral content, and the relation of the nearby Camas Hot Springs and the artesian water to an intrusive diorite sill 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.

POSSIBLE AXIS LINES

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 parts 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 3–4 feet through. The strike of the beds is N. 26°–41° E., and the dip is 23°–28° NW.

Inactive alluvium occurs along the sections from about altitude 2,570 to 2,600 feet, and the bench at 2,585 is 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 it 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 2,578 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 141 feet for the head, about 10 feet for freeboard, and about 15 feet for depth of water in the river and necessary excavation in the channel. The site is feasible only for an earthfill dam.

POSSIBLE DEVELOPMENT SCHEMES

AT THE DAMSITE

A powerhouse at the dam would develop a hydraulic head of about 141 feet according to the Sloan Bridge damsite map (U.S. Geol. Survey, 1956). The powerhouse site would be in till.

POWERHOUSE AT MILE 39

Another development is possible by placing the powerhouse at mile 39, about 5.7 miles along the river downstream from the damsite. Water could be conveyed from the arm of the reservoir in Little Bitterroot Valley through the rock ridge by a tunnel and across the terrace on the southeast side of the ridge by a pipeline laid in an opencut. The tunnel and pipeline would be under hydrostatic pressure. The indicated head for this development is 162 feet.

Sections *D–D′* and *E–E′*, plate 3, are drawn along proposed conduit routes to the powerhouse. The total length of a conduit along section *D–D′* would be about 5,550 feet, and along section *E–E′* about 5,250 feet. The length of the tunnel beneath the ridge would be about 2,850 feet along section *D–D′* and 3,800 feet along *E–E′*. The opencut would be about 2,350 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.

The intake areas at both lines are covered by alluvium, talus, and topsoil; however, quartzite of good quality crops out at a few places on the canyon wall and in the valley bottom. The strike of the beds ranges from N. 37° to 80° E., and the dip ranges from 11° to 26° NW. The average attitude is strike N. 54° E., dip 17° NW.

Tertiary(?) talus breccia is exposed about 800 feet southwest and 150 feet above the portal site for line *E–E′*. Breccia, 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 would be in Ravalli rock that should be of very good quality.

On the southeast side of the ridge at tunnel level, Tertiary(?) talus breccia probably rests on completely weathered Ravalli rock. In this area of poor rock, extremely difficult tunneling conditions would prevail. Farther to the southeast, the tunnel, or most likely opencut, would be in glacial deposits. Lake beds that are at the surface in this area extend down to about 2,675 feet below which till probably is present. There is a possibility that Tertiary(?) or Ravalli rocks could be in the bottom of a cut along line *E–E′*, because 300 feet southwest of the section these rocks are exposed at altitude 2,700 feet.

The poor geological conditions southeast of the ridge probably preclude a tunnel along either line there, and that section of conduit would have to be a 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′*).

At the mile 39 powerhouse site, Ravalli rock is exposed in two outcrops that extend for about 200 feet along the edge of the river and about 50–100 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.

SUPPLEMENTAL HEAD BY DOWNSTREAM CHANNEL IMPROVEMENTS

The hydraulic head of a power plant at mile 39 could be increased by excavation of the river channel downstream from it in the same manner as suggested for increasing the head for damsite 4. If the same gradient of 1.12 feet per mile were used, the hydraulic head could be increased up to 24 feet. A steeper gradient or starting the channel improvements upstream would result in less head.

DIVERSION TO THREE POSSIBLE POWERHOUSE SITES NEAR PERMA

Another development of the Sloan Bridge site is possible by diverting the water from the arm of the reservoir that would extend 8 miles up the Little Bitterroot Valley and conveying it by opencut and tunnel to one of three possible powerhouse sites in the vicinity of Perma. From the end of an opencut about 0.5 mile long near the center of sec. 31, T. 20 N., R. 22 W., water could be conveyed by a tunnel about 6.6 miles long to a point in Racehorse Gulch near the NE¼NE¼ sec. 33, T. 19 N., R. 23 W. A small regulating reservoir would be needed in the gulch from which penstocks about 4,000 feet in length would carry the water to a powerhouse near mile 13. A second alinment from sec. 31 would require a pressure tunnel about 7.8 miles long to convey the water to a powerhouse site northeast of river mile 12 in NW¼ sec. 32, T. 19 N., R. 23 W. A third alinement with a tunnel about 7 miles long could carry the water to a powerhouse site in Camas Creek valley in the NE¼NE¼ sec. 30, T. 19 N., R. 23 W. This last site is 1.4 miles up Camas Creek valley from the river, and a cut ranging from 20 feet at the river to 90 feet at the powerhouse site would have to be excavated along the valley in order to gain the maximum head possible for the site. The lower part of Camas Creek valley is filled with glacial deposits. In the Flathead River valley the glacial fill probably is about 255 feet thick, or bedrock is at altitude 2,222 feet. If the lower part of Camas Creek were graded to this, most of the excavation would be in glacial deposits. Some widening of the valley might have to be in rock.

The head for these developments, based on the river surface altitudes on the Perma damsite map, would be about 218 feet at Racehorse Gulch, 221 for mile 12, and 225 for the Camas Creek diversion.

These suggestions are the result of office study, and none of their features have been examined in the field to determine if they are geologically feasible.

SUGGESTED EXPLORATION PROGRAM

The first exploration of Sloan Bridge damsite 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 damsite. 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 damsite, 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 Ravalli 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 alinement, intermediate holes should be drilled and three or four of them 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 near the surface, a short adit would be of value to show if supports will be required at the portal.

RESERVOIR

The reservoir is underlain mainly by till and lake-bed silts. There may be a few small outcrops of the Ravalli Group and Tertiary(?) rocks 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.

BUFFALO DAMSITE 2

LOCATION AND ACCESSIBILITY

This site is in the N½SE¼ sec. 1, T. 21 N., R. 22 W., at river mile 60.7, 7.2 miles downstream from Buffalo damsite 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 4 miles from the Buffalo Bridge. The left (east) abutment can be reached by leaving the county road half a 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 exis 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 feet, and the left (east) one has an average slope of 15° to the same altitude. The left abutment is at the end of a ridge that runs about a thousand feet to the east and then trends north-northeast. Its crest line ranges from altitude 2,780 to 2,280 feet. About 2,000 feet northeast of the abutment, the width beween the 2,700-foot contours is only 1,600 feet.

The fall between Kerr powerhoues tailrace and the probable axis line at mile 60.7, altitude 2,615 feet, is 90 feet. Between this site and the downstream end of the gorge at Buffalo damsite 1, altitude 2,641 feet, there is a fall of 26 feet, and the stream gardient 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 (pl. 4).

PRECAMBRIAN

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

Bedrock is exposed along the right (west) riverbank for about a thousand 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 in the river bottom. In a small gully on the right abutment just south of section *F–F′* 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 central part of the exposure along the river, the rock is generally fresh, but around the margins and wherever it is overlain by Tertiary(?) deposits, there is a zone of intensely weathered rock. This zone is from 3 to 30 feet thick in the drill holes, and beneath it is 20–40 feet, and possibly more, of moderately weathered rock. The weathered rock ranges from white to light brown, is friable, porous, and breaks easily in the fingers; 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 damsite 2. Upstream from the exposure of Ravalli rock and in the right (west) abutment, talus breccia is exposed for a distance of 200 feet along the bank and up to 22 feet above the river surface. Downstream from the Ravalli exposure, reddish-brown gritty clay or microbreccia is exposed for about 600 feet and up to 32 feet above the river. Breccia was recovered in some of the drill holes and east and south of the Ravalli exposure at the upper end of the island. On the left (east) abutment a little north of the center of the island, the gritty clay is exposed. At depth in the left abutment, talus breccia is overlain by beds of conglomerate, sandstone, siltstone, and unconsolidated sand. In the core holes for about 350 feet east from the left bank at section *G–G′*, plate 4, 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 as much as 3 feet in diameter. The blocks probably were weathered almost 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 pebbles 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, generally 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 6–12 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 6–8 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 feet. Thin beds of till were found in holes 25 and 26.

Glacial-lake-bed silts constitute most 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(?) deposits and till and also occur in the ridge to the east and northeast of the site.

The silts are composed of rock flour, are light buff in color, nonplastic, well bedded, and the layers range 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 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 ranges from 11 to 22 feet above the river surface or from approximate altitude 2,630–2,641 feet. Only the upper 2–4 feet of the gravel bed is exposed above the alluvium on the riverbank, so the total thickness and the extent are not known. It is possible that the lens was found in drill hole 27, where no core was recovered from a 20-foot interval between altitudes 2,650–2,670 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 occur in the river bottom and along the banks.

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

STRUCTURAL FEATURES

The strike of the Ravalli Group ranges from N. 58°–66° W., and the dip ranges from 8°–10° NE. In the vicinity of bench mark 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 ¼–12 inches apart and appear to be tight. Another set of well-developed joints strikes N. 54°–64° W., and dips 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 *G–G′*, plate 4, gives the approximate location for an axis line for the site. The right abutment and a part of the foundation is on rock of good enough quality to support a concrete dam, spillway, and powerhouse structure. The rock south of a line through drill holes 14, 10, and 4, or about 100 feet south of the section, however, 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 part of the foundation is in Tertiary(?) beds and glacial deposits and if proved safe would be suitable only for an earthfill 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 *H–H′* than at *G–G′*, but owing to Tertiary(?) deposits, rock conditions in the foundation and right abutment are much poorer. As a result, *H–H′* 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 form 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 relation 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 Bx, or 1⅝ inch diameter, core holes already drilled in zones of sand and gravel or reworked glacial materials has been very poor.

RESERVOIR SITE

Glacial deposits of lake-bed silts, till, reworked glacial material, and alluvium cover the entire reservoir area upstream from Buffalo damsite 2.

LOCATION AND ACCESSIBILITY

BUFFALO DAMSITE 1

Buffalo damsite 1 is between river miles 67.9 and 68.4, 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 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 450–500 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 350–400 feet above the river.

The downstream part of the gorge is Z shaped, and the river makes two sharp bends, and changes direction approximately 90° at each. Upstream from the first bend the river flows S. 30° W., then N. 30° W., and finally S. 45° W., as it leaves the gorge. (See pl. 4.) Geologic sections *A–A′*, *B–B′*, and *C–C′* are downstream from the lower bend, and section *D–D′* is between the bends.

Between river mile 67.90 (altitude 2,641 ft) at the downstream end of the gorge section and mile 69.45 (altitude 2,672 ft) at the upstream end, the river falls 31 feet and has an average gradient of 20 feet per mile. In this section, however, there are four rapids each of which drops 5–8 feet. Between mile 69.45 and mile 72.05 (altitude 2,705 ft) 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 quartzite is 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 argillite is greenish gray to light gray and ranges 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 damsite 1 is fresh, insoluble, strong, and competent to support any dam considered for the site.

TERTIARY(?)

Rocks of supposed Tertiary(?) age are exposed both upstream and downstream from the gorge section. One outcrop extends for about 150 feet between altitudes 2,660–2,680 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 partly 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 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 makes a constructional terrace at altitude 2,700–2,710 feet along the left (southeast) bank downstream from the rock knob near the center of the NW¼NW¼ sec. 22. Its surface is characterized by very large angular blocks of Ravalli Group that are as much as 15 feet in diameter 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 northwest 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 occurs 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 6–8 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, for which it has been named, and through bench mark 2668 on the left bank.

The long, narrow reentrant 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 NW¼NW¼ 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 alinement 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 northward-trending fault, but no further information is available.

Minor faults that strike N. 2°–30° W. and dip 55°–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 68.60 and 68.76. Vertical displacements of a few inches to about 10 feet have resulted in crush zones ranging from a single paper-thin seam of gouge to breccias 10 feet thick. The crush zones

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along the bedding faults range in thickness from a fraction of an inch to about 1 foot. There is a reverse fault that has 6–10 feet of crushed rock and gouge at mile 68.72. The approximate strike of this fault is N. 30° W., and the dip is 70° SW.

ATTITUDE OF THE BEDS

The general strike of the Ravalli beds through the rock gorge is northwest, and the dip is northeast. From mile 67.8 to 68.2 in the vicinity of sections *A–A′*, *B–B′*, and *C–C′*, the strikes range from N. 47° to 75° W., and the dips range from 13° to 20° NE. Between mile 68.2 and 68.6 in the vicinity of section *D–D′*, the strikes are N. 15°–37° W., and the dips are 15°–31° 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., and 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 surface.

POSSIBLE AXIS LINES

Four possible axes, included as parts of geologic sections *A–A′*, *B–B′*, *C–C′*, and *D–D′*, are shown on plate 4. Section *A–A′* was selected for investigation by the Montana Power Co., and the other axes are alternatives proposed as a result of this study.

SECTION A–A′

Section *A–A′* at mile 67.92 is in part on an exposure of the Ravalli Group at the mouth of the gorge section. Very good rock is in the riverbed and in the right abutment to altitude 2,682 feet, or to within 23 feet of the normal pool level of the reservoir. To the northwest the surface of the rock descends, and at drill hole 4, fluvial material is in the right abutment from 2,705 to 2,669 feet. This axis line could be 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 at an altitude of about 2,700 feet is supported by 33–55 feet of fluvial material, and its base is at altitude 2,654–2,680 feet. Beneath this is a bed of till 3–20 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 probable 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 0.5–1.0 foot thick were found in drill hole 12.

If A–A' were to be 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 Co's. core holes is summarized in the following table.

Summary logs of drill holes along geologic section A–A′

[All measurements in feet]

Drill hole	Fluvial deposit [1]		Till		Tertiary(?)		Ravalli Group		Remarks
	Depth	Altitude	Depth	Altitude	Depth	Altitude	Depth	Altitude	
1	[2] 0–4	2,660–2,656					4–121	2,656–2,539	Vertical.
2	0–2	2,672–2,670					2–130	2,670–2,542	Do.
3	[2] 0–15.5	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	Dip 27°; bearing S. 11° E.
6							0–68	2,643–2,579	Dip 70°; bearing S. 11° E.
7							0–168	2,642–2,435	Dip 40°; bearing N. 11° W.
8							0–78	2,644–2,566	Vertical.
9							0–129	2,646–2,602	Dip 20°; bearing S. 11° E.
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	Do.
12	[3] 0–33	2,712–2,679	33–53	2,679–2,659	53–68	2,659–2,644	68–100	2,644–2,612	Do.
13	0–36	2,716–2,680	36–39	2,680–2,677			39–68	2,677–2,648	Do.
CDH [4]									
A			0–40(?)	2,718–2,678	40(?)–80(?)	2,678–2,638			Do.
B			0–40(?)	2,735–2,695	40(?)–71(?)	2,695–2,644			Do.

[1] No core recovered in fluvial deposit in drill holes 1–3, 10, 11, and 13.
[2] Overburden.
[3] Core recovery too poor to identify material.
[4] Churn-drill hole.

SECTION B-B′

An axis at section *B–B′*, mile 68.03, 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 feet 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 that has only a thin cover of gravel probably is 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 feet, or that the bedrock surface slopes gently down from where it is exposed in the riverbank. The overburden is the same fluvial deposit as that at *A–A′* and would require similar treatment. A core wall extending 30–50 feet below the ground surface and as much as 550 feet in length 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.

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.

SECTION C-C′

Section *C–C′*, at mile 68.16, 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 section *A–A′*.

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 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 many 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.

SECTION D–D′

Section *D–D′*, at mile 68.38, is a very good site for a concrete dam. (See fig. 8.) The canyon is approximately 400 feet wide at altitude 2,705 feet, 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 feet at axis 4 is about 40 percent less than that at section *A–A′*.

Bedrock is exposed in both abutments and across most of the riverbeds. 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 from 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 350–500 feet back from the river. On the right bank, about 250 feet downstream, there are two minor shears having 1–7 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 8.—View looking upstream through geologic section *D–D′*, 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. Water coming from the river apparently moves along open seams and joints in the rock 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 68.7, the first 150–200 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. 8.) Bedrock is not exposed at the powerhouse site but probably is 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, the one at section *D–D′* is the most favorable from both a geologic and, very likely, an economic standpoint. Geologically the site is the best, as it offers solid rock abutments and a 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 section *A–A′*, 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.

Section *C–C′* is the second best axis line. Geologically it is as feasible as *D–D′*, but a larger dam would be required. Present information indicates that sections *A–A′* and *B–B′* are not as feasible, because large to prohibitive water loss will occur unless core walls are put in on their left (southeast) abutments.

RESERVOIR SITE

From section *C–C′* 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 section *A–A′* 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 through them.

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