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

Part 3. MISCELLANEOUS DAM SITES ON THE FLATHEAD RIVER UPSTREAM FROM COLUMBIA FALLS, MONTANA

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CONTENTS

ILLUSTRATIONS

SUMMARY AND CONCLUSIONS

This report describes the limiting geological conditions at a series of proposed dam sites on the Flathead River upstream from the town of Columbia Falls, Mont. Investigations were confined to surface exposures, but in some cases supplementary geophysical investigations were made by the electrical resistivity method to clear up uncertainty concerning conditions underground. In order to segregate certain factors common to all sites, this report is divided into two parts. The first part consists of a brief general account of river development and of the stratigraphy and structure of the rocks over which the river flows. This part attempts to furnish a concise geologic description useful to the hydrologist interested in runoff studies; to separate geologic detail of greater interest to the geologist and hydrologist than to the designing engineer; and to afford a background for the description of the dam and reservoir sites. Detailed descriptions of these sites follow in the second part of the report. For purposes of easy comparison and cross-reference, the sites have been listed below in corresponding order. Point by point, the geologic and associated engineering factors are outlined, and the reasons for the selection or rejection of the various sites are pointed out. These are supplemented by a series of maps and cross-sections.

If a dam could be built at each site listed herein, practically the full potentiality of the river for power would be realized, and control over floods would be very complete. Geologic and engineering conditions, not to mention economic considerations, render the fulfillment of such a dream impracticable. With the possible exception of factors that operate regionally, such as climate and the earthquake hazard, the sites reviewed are hardly equal in any respect. In the following summary they are ranked according to general feasibility. The numbers in parentheses refer to site numbers on plate 12.

A. Sites found to be satisfactory.

(8) Glacier View. Flathead River (North Fork). Vicinity of SW corner sec. 14, T. 33 N., R. 20 W., unsurveyed. Water supply inadequate for complete utilization of reservoir. Merits first consideration in any scheme combining flood control and power development. Several possible sections are available, but further exploration is necessary to determine the most economical. Average altitude of low-water surface is 3,330 feet. Controlling altitude of reservoir surface is 3,865 feet. The pool level, however, probably will not exceed an altitude of 3,650 feet. A rigid dam with pool level at 3,600 feet would stand about 275 feet above stream bed and about 500 feet above foundation; crest length would be about 1,670 feet. The principal defects of this site are width of valley and depth to foundation. (See pls. 23, 24, 25, 26.)

(7) Fool Hen. Flathead River (North Fork). N½ sec. 23, T. 32 N., R. 20 W., unsurveyed. Average altitude low-water stream surface is 3,200 feet. Foundation is shallow. Two dam sections are available at this site. First choice for a high dam is the upper section B–B′, because of somewhat greater security in the right abutment. Maximum height of pool level is 3,400 feet, which marks the upper limit of

gorge section. Spillway requirements are large for low dams, but probably there is room on the left bank for an adequate section if an overflow type of dam is considered undesirable. Storage capacity is limited, but a moderate amount would be developed by a 200-foot dam, the highest possible at this site. (See pls. 21 and 22.)

(2) Bad Rock Canyon. Flathead River. Vicinity of S½ sec. 1 and NW¼ sec. 12, T. 30 N., R. 20 W. Average altitude of low-water surface is 3,020 feet; controlling altitude is about 3,450 feet on the Cedar Creek-Bailey Lake divide, NW¼ sec. 10, T. 31 N., R. 20 W. Route of Great Northern Railway over right abutment at altitude of 3,115 to 3,120 feet limits altitude of pool level to 3,110 feet. Width of gorge at this altitude is 865 to 930 feet. Height of dam above foundation would be about 420 feet, with only 90 feet of freeboard. Spillway requirements are large in proportion to size of dam and the limited capacity of the reservoir, and an adequate section does not exist. (See pls. 14 and 15.)

However, if the restrictions imposed by the railway are ignored, the site becomes of commanding importance because it is the one place where complete control of the upper basin of Flathead River may be obtained. The valley begins to widen rapidly at altitude 3,250 feet, and width at this elevation is about 1,100 feet. A pool level at this altitude would stand about 600 feet above foundation, with freeboard of about 230 feet. Although the valley section is large, depth to bedrock 350 feet or more, valley fill unconsolidated, and spillway requirements are very great, a structure probably could be designed that would control the upper Flathead. If a project of this character could be consummated it would obviate the ultimate necessity for a separate dam on each fork of the river, with attendant problems in synchronous operation, and, in the long view, might be more economical. It merits, therefore, the most extensive consideration and investigation; and the higher it can be built the more effective it will be. But the engineering obstacles and cultural objections confronting it are tremendous. Backwater from such a dam would flood the southwest part of Glacier National Park, require rerouting of part of the Great Northern Railway and U. S. Highway No. 2, and, no doubt, engender other problems. If any other site on the upper Flathead within its limits should be built first, the Bad Rock Canyon site, in its larger aspects, will be invalidated insofar as our forseeable future is concerned.

B. Sites satisfactory for low dams, but not good for high dams.

(4) Coram Canyon. Flathead River. South of center, sec. 5, T. 30 N., R. 19 W. Average altitude of low-water surface is 3,035 feet; controlling altitude is about 3,450 feet on the Cedar Creek-Bailey Lake divide, NW¼ sec. 10, T. 31 N., R. 20 W. Maximum possible altitude of pool level is 3,100 feet without, and 3,120 feet with a dike over right abutment. Two dams are necessary at this site—one, in the main channel, must have a height above foundation of about 100 feet to raise water to 3,100 feet. Valley width at this altitude is about 240 feet. A cut-off channel north of the river necessitates the second dam. With crest at 3,100 feet, it will stand about 70 feet above foundation and have a length of 230 feet. Construction to the 3,120-feet level will require considerable additional work. Spillway requirements are

large, but there is room for an adequate section. Storage capacity is negligible. (See pls. 16 and 17.)

The Coram Canyon site may also be feasible for a long, high, flexible dam with greater storage capacity. Width of valley at altitude 3,250 feet is estimated to be about 7,100 feet. From the cut-off channel to the left abutment bedrock foundation is at the surface or under light cover. Maximum depth of fill in the preglacial channel approaches 500 feet, and height of dam over the constructional terrace that conceals it would be only 100 to 125 feet. This part of the structure would require a deep cut-off. Maximum height of dam to crest at altitude 3,250 feet would be only 250 feet for a limited section in the active gorge. An adequate spillway section is present over the left abutment. In its present form this project is largely suggestive, as suitable means of investigation were not available. It appears, however, to offer interesting possibilities as a partial alternative to the concept of a high dam at Bad Rock Canyon, as it would not control South Fork of Flathead River; but it is open to the same cultural objections that confront the high dam at Bad Rock Canyon.

(6) Upper Canyon Creek. Flathead River (North Fork). NE¼ sec. 27, T. 32 N., R. 20 W., unsurveyed. Average altitude of low-water surface is 3,173 feet. Foundation is shallow. Geologic considerations limit maximum height of pool level to 3,210 feet. A dam built to this altitude would stand 50 feet above foundation and have a crest length of 150 feet. Spillway requirements are large. Storage capacity of reservoir is negligible. The left abutment is weak and there is possibility of leakage around it. (See pls. 19 and 20.)

C. Sites unsatisfactory and rejected.

(1) Columbia Falls. Flathead River. SW¼ sec. 17, T. 30 N., R. 20 W. Average altitude of low-water surface is 2,980 feet. Maximum altitude of pool level is 3,020 feet. Width of valley at that level is 570 feet. Depth to foundation is unknown but probably is at least 200 or 300 feet. This site is situated wholly in poorly consolidated glacial deposits. Right abutment is underlain by an extensive spring zone subject to reversal of flow, and is weak and dangerous. Foundation uncertain. Spillway requirements large; facilities inadequate. Storage capacity of reservoir negligible. (See pl. 13; fig. 10.)

(5) Lower Canyon Creek. Flathead River (North Fork). West center of sec. 35, T. 32 N., R. 20 W. Average altitude of low-water surface is 3,150 feet. The upper limit of the gorge section is at 3,185 feet, and width of valley is 330 feet, but rock in the left abutment extends up to only 3,170 feet. Maximum height of dam is thus restricted to about 30 feet above foundation. A 50-foot dam would necessitate a long cut-off wall over the left abutment. This abutment is weakened by the presence of many joints, and it may be relatively thin because of a buried gorge of unknown depth and character a short distance to the east. Spillway requirements are large. Storage is negligible. (See pl. 18; fig. 11.)

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By C. E. Erdmann

INTRODUCTION

OBJECT OF INVESTIGATION

This report describes geologic conditions at a series of localities on the Flathead River upstream from the town of Columbia Falls, which have been designated as prospective dam and reservoir sites on topographic grounds. Its purpose is to define the limiting conditions at each, designating those which have promise as feasible projects and eliminating those which do not. These objectives provide a basis for water-utilization studies and administrative procedures by which the storage possibilities and their relations to power and flood control are combined into a practical scheme for the utilization of the entire river, so that the Federal laws pertaining to classification of streams with respect to water-power resources can be exercised effectively.

The sites studied and reported upon are listed in the table that follows, and their locations are shown on plate 12.

Names and locations of dam sites studied

[See pl. 12]

Site	No. on map	Stream	Location (approximate)
Columbia Falls (Talbot)	1	Flathead River	SW¼ sec. 17, T. 30 N., R. 20 W.
Bad Rock Canyon (Coram)	2	do	Vicinity of S½ sec. 1 and NW¼ sec. 12, T. 30 N., R. 20 W.
Hungry Horse [1]	3	South Fork Flathead River.	Center sec. 21, T. 30 N., R. 20 W.
Coram Canyon (upper Coram).	4	Flathead River	South center sec. 5, T. 30 N., R. 19 W.
Lower Canyon Creek (Miller).	5	Flathead River (North Fork).	West center sec. 35, T. 32 N., R. 20 W.
Canyon Creek	6	do	NE¼ sec. 27, T. 32 N., R. 20 W., unsurveyed.
Fool Hen	7	do	N½ sec. 23, T. 32 N., R. 20 W., unsurveyed.
Glacier View	8	do	Vicinity of SW. corner sec. 14, T. 33 N., R. 20 W., unsurveyed

[1] Described separately. See Erdmann, C. E., Geology of Hungry Horse dam and reservoir site, South Fork Flathead River, Flathead County, Mont.: U. S. Geol. Survey Water-Supply Paper 866-B, 1944.

Plate 12 also shows three dam sites on the Middle Fork of Flathead River—(9) Kootenai Creek No. 1, (10) Kootenai Creek No. 2, (11) Dirtyface dam site—and (12) Singleshot dam site on Bear Creek. Although these sites are not described in this report, brief reference is made to the Kootenai Creek sites and the Nyack basin, and their location is therefore shown on the index map.

With the exception of Hungry Horse dam site, one abutment or the other of all proposed sites is easily accessible by automobile road. Instructions for reaching them are given in the detailed descriptions in the second part of this report.

Upstream from its confluence with the Middle Fork of the Flathead River, the main Flathead, locally known as the North Fork, forms the west boundary of Glacier National Park. Thus, the east (left) abutments and portions of the foundation of all dam sites on the North Fork are National Park property. The other portions of those sites are in the Flathead National Forest. Except for the site near the town of Columbia Falls, all the others not so divided lie within the Forest but are not necessarily the property of the United States. Four of those sites, including those controlling the largest reservoir basins, are thus included partially within the precincts of a National Park. Inasmuch as one of the functions of the Geological Survey is to investigate the technical feasibility of all proposed dam sites on Federal lands rather than to recommend the necessity for construction at any of them, the special situation created by the future possibility of a dam or a reservoir overlapping Glacier National Park is not considered in this report beyond pointing out the present-day cultural and engineering effects of impounding water to various levels. Public necessity at some future time will determine whether there is need for such development, and public sentiment at that time will outline the action to be followed.

PREVIOUS INVESTIGATIONS

The earliest known geologic observations on the upper Flathead River, called Akinesahtl by the Indians, were made near where the stream crosses the Forty-ninth Parallel by George Gibbs during his exploration of the Northwest Boundary of the United States in 1860. Unfortunately, the manuscript of the general and scientific reports of this expedition was lost before it could be printed.[1] Incomplete reference to this work was made later by Gibbs in an account of the physical geography of the region.[2] Just before that, in connection

[1] Baker, Marcus, Survey of the northwestern boundary of the United States, 1857–61: U. S. Geol. Survey Bull. 174, 1900. This report gives a concise history of the northwestern boundary, its establishment, survey and marking, references to all known material, and an account of the two searches for the lost manuscript.

[2] Gibbs, George, Physical geography of the northwestern boundary of the United States: Jour. Amer. Geog. Soc. vol. 4, pp. 383–387, 1874.

with explorations for a railroad from the Mississippi River to the Pacific Ocean, A. W. Tinkham explored the Flathead River below Flathead Lake, the west side of the Lake, and the river from the lake to the mouth of the Middle Fork, which he ascended to Cut Bank Pass [3] via Nyack Creek. These operations were carried out from October 10 to October 21, 1853. The reports do not treat of the geology, but there is a general description of the topography. The valley of the North Fork of Flathead River has been described by Ayres in his account of the Flathead Forest Reserve.[4]

A reconnaissance of the water-power possibilities of the Flathead River has been made for the Forest Service by E. W. Kramer.[5] This report briefly mentions the Coram, Canyon Creek, and Glacier View dam sites. It has been quoted in part by the Army Engineers in their voluminous report on the Columbia River and its minor tributaries.[6]

Detailed geologic work has not been done in the valley of the upper Flathead River in the United States, but numerous publications treat of the region in a general way. The most informative are included in the following list, and each in turn makes reference to many other papers:

1875. Dawson, G. M., in British Boundary Commission Report on the Geology and Resources of the Region in the Vicinity of the Forty-ninth Parallel.

1886. Dawson, G. M., in Canada Geol. Survey Annual Rept.

1902. Willis, Bailey, Stratigraphy and structure, Lewis and Livingston ranges: Geol. Soc. Amer. Bull., vol. 13, pp. 305–352.

1912. Daly, R. A., Geology of the North American cordillera at the 49th parallel: Geol. Survey Canada Mem. 38.

1916. MacKenzie, J. D., Geology of the Flathead coal area: Canada Dept. Mines, Geol. Survey, Mem. 87, Geol. ser. No. 73, Ottawa.

1918. Rose, B., Crowsnest, and Flathead coal areas, British Columbia: Canada Dept. Mines, Geol. Survey, summary report, 1917, pt. C.

1931. Clapp, C. H., and Deiss, C. F., Correlation of Montana Algonkian formations. Bull. Geol. Soc. Amer., vol. 42, pp. 673–696.

1932. Clapp, C. H., Geology of a portion of the Rocky Mountains of northwestern Montana: Montana Bur. Mines and Geology, Mem. 4, Butte. This paper includes a small scale geologic map, and a fairly complete bibliography on the geology of northwestern Montana.

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[3] Tinkham, A. W., Report as to the railroad practicability of the line of the Marias Pass of the northern Little Blackfoot trail, and of the southern Nez Perces trail: House of Representatives 33rd Cong., 2d Sess. Ex. Doc. 91, vol. 1, pp. 277; 371–374, 1855. Stevens, Isaac I., Governor of Washington Terr., Narrative and final report of explorations for a route for a pacific railroad near the Forty-seventh and Forty-ninth parallels of north latitude from St. Paul to Puget Sound: 36th Congress, 1st Sess., House of Representatives, Ex. Doc. 56. p. 164, 1860. Campbell, M. R., The Glacier National Park, A Popular Guide to its Scenery and Geology: U. S. Geol. Survey Bull. 600, p. 5, 1914.

[4] Ayres, H. B., The Flathead forest reserve: U. S. Geol. Survey, 20th Ann. Rept., Pt. 5, pp. 281–282, 1900.

[5] Kramer, E. W., "Water Power in Montana," Jan. 28, 1931. Manuscript report to the U. S. Forest Service.

[6] Columbia River and Minor Tributaries: Repts. Dist. Eng., Seattle, Wash., Pt. 2, and Portland, Oreg., Pt. 3, 73rd Congress, 1st Sess., H. Doc. 103, vol. 2, pp. 802–805, 1934.

1932. LINK, T. A., Oil seepages in Belt series of Rocky Mountains near International Boundary. Amer. Assoc. Petroleum Geologists, Bull., vol. 16, pp. 786–796. This paper contains a cross section of North Fork Valley at the 49th Parallel and many references to Canadian geologic literature on North Fork region in British Columbia.

1935. Deiss, C. F., Cambrian-Algonkian unconformity in western Montana: Geol. Soc. America Bull., vol. 46, pp. 95–124.

An excellent base map of the region showing the topography of the Flathead basin above the confluence of the Middle Fork with the main river has been prepared by the Forest Service and the National Park Service [7] for official use. Campbell's description of Glacier National Park includes a topographic map of the Park. The topographic map of the Kintla Lakes quadrangle, Geological Survey, United States Department of the Interior, shows the valley of the upper Flathead in Montana, and includes the entire Glacier View reservoir area except for a small arm above Christensen's ranch on Camas Creek. Adjacent areas in British Columbia are shown on the Pincher Creek Sheet of the Surveyor General's Office, on which the topography is shown by hachures and is much generalized; but the map area of MacKenzie's report, covering nearly 50 square miles, is on a special topographic base.

PRESENT INVESTIGATION

Field work was carried out chiefly during 1934, 1935, and 1936 by the engineers and geologists of the Conservation Branch of the Geological Survey and additional miscellaneous geologic details were added by the writer during brief visits in 1936, 1937, and 1938. The complete study involved three distinct phases: topographic, geologic, and geophysical.

TOPOGRAPHY

As part of a comprehensive plan of Montana River surveys, the Flathead River with its principal tributaries has been mapped on a scale of two inches to the mile (1 : 31, 680). On January 1, 1947, the status of the mapping project was as follows: *Lower Flathead River,* complete from confluence with Clark Fork River near Paradise, Mont., to the Kerr dam near Polson, Mont.[8] *Flathead Lake,* a map based on aerial photography is available for official use. *Upper Flathead River,* Flathead Lake to Canadian Boundary is complete.[8] Seven dam sites were mapped on this section of the river between Columbia Falls and Glacier View Canyon. *South Fork of Flathead River,* surveys are complete.[9] One detailed dam-site survey has

[7] U. S. Dept. Agriculture, Forest Service and U. S. Dept. of Interior, National Park Service, Cooperative Map of Glacier National Park and portions of the Blackfeet, Lewis and Clark, and Flathead National Forests, Montana Principal Meridian, Mont., 1929, Reprinted in 1935.

[8] River survey maps in preparation.

[9] U. S. Geological Survey, Plan and profile of South Fork of Flathead River from mouth to mile 44 with dam site, 1937; Plan and profile of South Fork Flathead River, Mont., above mile 44, and tributaries, 1939.

been made at Hungry Horse. *Middle Fork of Flathead River*, surveys are complete from confluence with main Flathead to 5 miles above the mouth of Bear Creek.[10] Two dam sites have been surveyed in detail on this stream, but have not been mapped geologically.

Land contours were taken at 20-foot intervals and carried to elevations 200 feet above stream. Five-foot contours were taken on the water surface. Possible dam sites were mapped on a scale of 400 feet to the inch, with a land-contour interval of 10 feet, and a water-contour interval of 1 foot. Topography at dam sites was carried well above the altitude of the probable crest of the dam, and in the reservoir areas the contour of the highest pool level was run out. In all cases except the Glacier View reservoir, the river surveys are sufficiently extensive to include the corresponding reservoir areas. This work was directed in 1934 by W. C. G. Senkpiel, and in 1935, 1936, and 1939, by Arthur Johnson, Hydraulic Engineers of the Geological Survey.

GEOLOGY

The geologic examinations of all dam-site areas except the Coram Canyon site were made by the writer within the period July 7 to September 20, 1934. The Coram Canyon site was investigated during late September and early October 1935. Preliminary study of the Fool Hen and Glacier View sites indicated the desirability of additional field work, which also was carried out during October 1935. The geologic investigation of the Glacier View project, the most elaborate undertaken on the main Flathead River, involved two distinct studies: the dam site, where conditions are relatively simple; and an inquiry into the possibility of leakage from the storage reservoir, which appeared to be such that the full potentialities of the project for river regulation and flood control were seriously limited and that for power seriously reduced. The 1935 studies were confined chiefly to these reservoir problems.

Practically all this field work had been carried out before the topography of the project was completed. Bases for geologic mapping were made available from topographic mapping by photographing the field sheets. The accompanying geologic maps show only the bare outline of the topography as traced from the 50-foot contours on the photographs. However, profiles of the cross sections are taken from the 10-foot contours. Because of the dense forest vegetation, the places at which observations were made were located by means of tape and compass traverses from bench marks and reference points purposely set by the topographers. In some places, the ground was

[10] U. S. Geological Survey, Plan and profile of Middle Fork of Flathead River, Mont., mouth to mile 49. 1943.

surveyed by means of traverses spaced at 100-foot intervals parallel to the probable dam axes.

GEOPHYSICS

An electrical geophysical investigation to determine depth to bedrock has been made at the Columbia Falls, Bad Rock Canyon, Upper and Lower Canyon Creek, Fool Hen, and Glacier View dam sites with the standard Gish-Rooney technique. During 1934, this work was carried out by B. E. Jones, chief, Water and Power Division, Geological Survey, and R. K. Thies, junior geologist, Geological Survey. In 1935, it was extended by Mr. Thies and A. F. Bateman, Jr., under the direction of the writer. Interpretations of the 1934 work have been made largely by Jones and Thies; Bateman and Erdmann have interpreted the data obtained in 1935. Geophysical work at the Coram Canyon site was not undertaken because the problematical value of the site did not warrant a thorough investigation of the large tract that would have to be covered.

All significant features relative to these projects are believed to have been seen, and the geologic and geophysical investigations are thought to have covered the features that may affect dam construction. An effort has been made to incorporate these data into a report for the engineer rather than the geologist, and quantitative expression has been attempted and special applications pointed out wherever possible. However, this detail cannot be maintained for the investigation of the Glacier View reservoir. The area is too large and significant exposures too few to establish more than generalizations. Where numerical expressions are used, they are for illustrative purposes only, to suggest orders of magnitude, and should not be taken literally. Furthermore, because of the character of the investigation, comprehensive study of many fascinating regional geologic problems has been omitted.

VEGETATION

Ayres [13] and Whitford [14] have listed and described the character of the vegetation, both trees and shrubs, which is very dense and sometimes almost impenetrable. Except in the burned areas, and in the open country around Columbia Falls and along the river, visibility in the summer months is usually limited to 100 feet or less. Field work was thus greatly impeded, for thorough search was necessary in order that no small but significant exposures be overlooked.

CLIMATE

The following climatic summary is based upon records of the United States Weather Bureau stations at Columbia Falls and Bel-

[13] Ayres, H. B., op. cit.

[14] Whitford, H. N., The forest trees: Univ. of Montana Bull. 17, pp. 215–229, 1903.

ton, from the time of their establishment to 1936 inclusive, or 43 and 16 years, respectively. The altitude at Columbia Falls is 3,100 feet; that at Belton, 3,213 feet. Belton is about 100 feet lower than the foundation level at Glacier View dam site, and its climate is typical of all sites on the Flathead River within the mountains, or upstream from Columbia Falls.

Summary of climate at Columbia Falls and Belton, Mont.

[From records of U. S. Department of Agriculture, Weather Bureau: To 1930, Climatic summary of the United States, section 7, western Montana; 1931-36, Climatological data for the United States by sections, annual summary, pt. 5 of vols. 17-23]

Record	Columbia Falls	Belton
Annual precipitation .... inches..	20.84	26.52
Annual snowfall .... inches..	[1] 70.4	123.9
Mean temperature .... °F..	43.3	42.1
Highest recorded temperature .... °F..	103	101
Lowest recorded temperature .... °F..	−35	−42

[1] Record to 1930, inclusive.

Mean temperature records indicate that freezing temperature will prevail for about 4 months a year, December to March, inclusive. Ice conditions in any reservoir will be essentially similar to those in Lake McDonald near Belton.

Recent stream-gaging records indicate that the average annual runoff from the North Fork Basin of the Flathead is equivalent to about 26 inches of rainfall, or approximately the mean annual precipitation at Belton.[15] The average discharge for 1934 and 1935 was 1,886,000 acre-feet. More data on runoff and power resources will be supplied in a river utilization report now in course of preparation.

ACKNOWLEDGMENTS

Many thanks are due those with whom the writer was associated in the field. Mr. B. E. Jones, chief of the Water and Power Division of the Geological Survey, has given the fullest cooperation in connection with the geophysical investigations; Mr. W. C. G. Senkpiel and Mr. Arthur Johnson, under whose supervision the river, dam site, and special surveys were made, have at all times aided and encouraged the topographers in the painstaking task of making the topographic maps faithfully show the relationship between the land forms and the geology. Mr. Roland K. Thies assisted with the geophysical work in 1934 and 1935. Mr. A. F. Bateman, Jr., assisted with geophysics and geology in 1935. Mr. John S. James was the writer's assistant in 1934, and Mr. Garvin Hurwitz was geologic assistant in 1935. The officials and staff of the United States Forest Service at Kalispell and at the

[15] Surface water supply of the United States, North Pacific Slope: U. S. Geol. Survey Water-Supply Papers 692, 707, 722, 733, 737, 752, 767, 792, 812.

Big Creek Ranger Station facilitated our work in many ways, and thanks are due them for their effective cooperation. I am also indebted to the residents of Columbia Falls, Polebridge, and Trail Creek for accommodations to our various field parties throughout the entire course of the investigation.

The Corps of Engineers, United States Army, Seattle, Wash., carried out a seismograph investigation of Fool Hen dam site in 1943, and some exploratory drilling at Bad Rock Canyon, Fool Hen, and Glacier View dam sites in 1944. The Bureau of Reclamation, United States Department of the Interior, also drilled at Bad Rock Canyon in 1944, and at the buried Abbott Gorge of Hungry Horse reservoir site in 1945. Grateful acknowledgment is made here to the officials of these bureaus for furnishing results of these investigations. Incomplete as they are, they have served as a check on our preliminary work and have served to clarify and extend information developed by the Geological Survey. I am especially indebted to Mr. Fred O. Jones, geologist, Bureau of Reclamation, for information and discussion on the Bad Rock Canyon site.

Thanks are also due Miss Ninetta Davis, Mr. Richard N. Doolittle, and Mr. J. J. O'Riley for assistance in the preparation of the drawings and tables that accompany this report.

FLATHEAD RIVER

Flathead River is one of the major streams of northwestern Montana. Variations in regimen, valley origin, and glaciation, the diverse nature of the country through which it flows, and its intricate drainage pattern testify that its history has been far from simple. Later it will be shown that the portion here considered is in reality an integrated series of streams, each of which developed independently up to a certain stage. All these events have left their mark and are significant to dam-site investigation. In the stream floor, they are expressed chiefly in abrupt variations in depth and character of fill, in the frequent lack of coincidence in gradient upon bedrock and stream bed, and in local changes in gradient.

NOMENCLATURE

Systematic consideration of a suitable nomenclature for a river so complex as the entire Flathead is beyond the scope of this report, which treats only of the stream above the town of Columbia Falls, and its major tributaries, the Middle Fork and the South Fork.[16] (See pl. 12.) For the sake of conciseness, the stretch of river through Bad Rock Canyon to the mouth of the Middle Fork will be referred

[16] Erdmann, C. E., Geology of the Hungry Horse dam and reservoir site, South Fork Flathead River, Flathead County, Mont.: U. S. Geol. Survey Water-Supply Paper 866-B, 1944.

to as the main Flathead, and its upstream extension will be designated as the Flathead (North Fork) in compromise between official nomenclature and popular usage.

FLOOD DISCHARGE

The total drainage area of the upper Flathead River above Columbia Falls is about 4,500 square miles. This basin is subdivided approximately as follows: South Fork, about 1,735 square miles; Middle Fork, about 1,119 square miles; and Flathead (North Fork) about 1,650 square miles. The maximum recorded discharges of these rivers took place during the period June 19 to 21, 1916, when the following records were made: the Middle Fork, 49,000 second-feet; the South Fork, 46,200 second-feet; the Flathead (North Fork), 29,500 second-feet. At Columbia Falls, the maximum recorded discharge was obtained June 5, 1923, when the flow was 102,000 second-feet. Measurements were not made at Columbia Falls during the June flood of 1916, but the sum of the floods from the component basins, 124,700 second-feet, exceeds the observed maximum.

DEVELOPMENT OF DRAINAGE

Flathead (North Fork) Valley upstream from Glacier View Canyon, as originally formed, was part of a broad structural basin flanked in Montana on the northeast by the Livingston Range and on the west and southwest by Apgar Mountain and Demers Ridge, which mark the eastern termination of the Whitefish Range block. (See fig. 9.) Southward, a similar basin between the Flathead and the Swan Ranges now makes the valley of the South Fork. A smaller trough, here called the Nyack basin, lay to the southeast between the Flathead Range and the southern part of the Livingston Range. Each possessed its own temporary base level and system of internal or centripetal drainage. Sediments from tributary streams began to aggrade the basin floors, and as time passed, the thickness of the deposits became so great as to fill the basins and overlap the rims or lowest points in the inclosing divides, resulting in an integration of drainage.

The constructional surface upon which the final drainage integration was accomplished must have attained such a relatively high level that it may have been as much as 150 miles long, but it probably was never more than 10 or 12 miles wide. Remnants of soft basin deposits of Tertiary age have been noted at altitudes as high as 3,900–4,000 feet, or 600 to 900 feet above the levels of the largest streams, but the principal surface of integration probably stood at least 1,000 feet higher. During this epoch, the relief of the inclosing hills appeared low.

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Upon the completion of this epoch down cutting began, and the master streams entrenched themselves in the poorly consolidated sediments as fast as the hard rock of the spillway over the barrier ranges could be reduced. Entrenchment was so deep at some places that the rivers were soon superimposed upon the hard pre-Cambrian terrain, wholly out of adjustment with the attitude of its strata and buried topography. Thus, the stream later to be known as the Middle Fork cut its way out of the Nyack Basin (see pl. 12) into the larger trough between the Whitefish and Livingston Ranges; and this basin integrated with the Rocky Mountain trench over the Swan Range at Bad Rock Canyon. The events were not simultaneous but followed a definite order dependent upon the controlling altitudes of the basin divides; and apparently some control has been exercised by independent movements on the faults controlling the basin structure. With renewal of movement upon the faults, the cycle was repeated for any basin again closed. This was evidently the case for the Nyack Basin and the Flathead (North Fork) Basin above Glacier View Canyon. At the same time, there seems to have been a small exterior basin, here called Coram Basin, east of Teakettle Mountain, south of Apgar Mountain, and west of the north end of the Flathead Range. Its outlet was through Bad Rock Canyon, which appears not to have been closed after the first period of superimposition. One of its

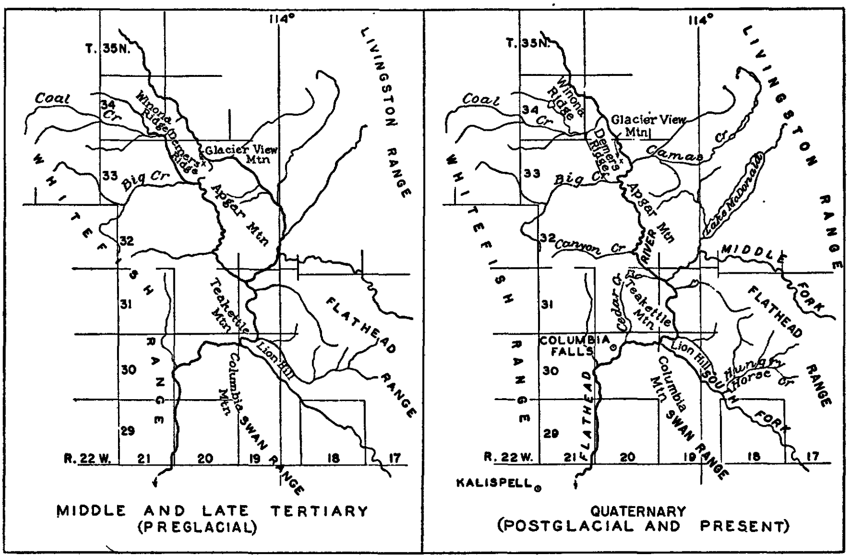

FIGURE 9.—Map showing probable major drainage changes of the upper Flathead River, Flathead County, Mont.

principal tributaries was the south-flowing consequent stream west of Apgar Mountain, here named Apgar River but now constituting the Flathead (North Fork) between Middle Fork and Big Creek. This relationship is strongly asserted by the topography and drainage pattern in the neighborhood of Glacier View Mountain. The generalized drainage pattern at the close of the first epoch of river superimposition is shown in figure 9 (Tertiary).

After the second epoch of basin filling, superimposition occured again. The present course of the Flathead (North Fork) through Glacier View Canyon was established over the divide connecting Apgar Mountain and Demers Ridge. This change resulted in the abandonment of the old subsequent valley east of Apgar Mountain, and the capture of its headwaters by Apgar River. (See fig. 9, Quaternary.) These events well illustrate the complex character of this branch of Flathead River. Its upper reaches are in a subsequent valley of structural origin; the lower part flows through a consequent valley; and the short connecting stretch is superimposed and is younger than the parts it joins. Below Middle Fork, it again enters a superimposed valley, probably later made antecedent by successive minor movements on the Swan fault. Another change that took place at this time was the loss of part of the headwaters of Apgar River to Coal Creek, which had succeeded in cutting through the Winona-Demers Ridge. These changes, with the later blocking of the subsequent valley by glacial debris, were responsible for the creation of the Glacier View reservoir, the largest storage basin in the upper Flathead drainage basin.

The Middle Fork of Flathead River has had a somewhat parallel history. Originally integrated with the first exterior drainage through Bad Rock Canyon, its basin was later closed by post-Oligocene movement on the Flathead fault. The new barrier has only recently been overcome, as is testified by the narrow gorge above Belton, which widens headward into Nyack Basin.

Two major epochs of river superimposition are thus fairly well established. More critical study of their relationships, especially to the history of the South Fork drainage, may indicate that there were others.

SUMMARY OF GLACIAL HISTORY

Geologic mapping has revealed two, perhaps three, distinct sheets of boulder clay or till, the youngest belonging to the Wisconsin glacial stage. The routes of the pre-Wisconsin glaciers are not certainly known, but from observations of their deposits at scattered localities, it seems probable that they followed the same paths as the Wisconsin glaciers, whose routes can be outlined with considerable detail by means of their deposits and their effect upon the present-day topography. The main lobe of the Wisconsin Cordilleran ice sheet moved southward through the Rocky Mountain Trench west of the Whitefish and Swan Ranges. Another smaller lobe descended Flathead (North Fork) Valley, splitting into two parts on the north end of Apgar Mountain. The west (right) branch continued on down Flathead (North Fork) Valley to the north end of Teakettle Mountain, where it was largely deflected to the southwest, uniting with the lobe in the Rocky Mountain Trench at Parker Hill, 5 miles north of Columbia Falls. The east (left) branch moved southward along the east flank of Apgar Mountain to the vicinity of Apgar, 2 miles north of Belton, where it was deflected westward, chiefly by the glaciers descending McDonald Creek. Five miles to the southwest, near the present mouth of the Middle Fork, this composite glacier received more ice from the part of the Flathead (North Fork) glacier deflected east of Teakettle Mountain. Moving southward, it received further increments of ice from the South Fork glacier in the sector north of Lion Hill. At this place it was deflected westward through Bad Rock Canyon of the Flathead River, uniting with the main ice lobe just east of Columbia Falls.

These successive epochs of alpine glaciation wrought many changes in the Tertiary valleys, chiefly through widening, deepening, and filling. Typical of them are the conditions at Upper Canyon Creek and Coram Canyon dam sites, where the river flows through shallow postglacial gorges to one side of the main valley, which is now choked with glacial debris. During the last ice epoch and probably in the earlier ones also, the Flathead Valley, at least below Flathead Lake, became flooded by glacial Lake Missoula to a maximum altitude nearly 1,400 feet above the present level of Flathead Lake. At these times the valleys described in this report were probably occupied by ice. During the last period of deglaciation, however, the melt water doubtless formed temporary ponds at many places, and some of these ponds may have become part of the lake before it drained away. Inflowing streams heavily laden with reworked till poured into the upper reaches of these ponded valleys, forming numerous constructional features such as terraces and deltas. These are now largely upstream from the more valuable dam sites.

STRATIGRAPHY

The bedrock formations of the Upper Flathead drainage basin are of widely divergent ages. Predominant are the old hard rocks of the pre-Cambrian Belt series. Strata of Paleozoic and Mesozoic age crop out in the upper reaches of the Flathead (North Fork) and the Middle Fork, but they are not involved in any of the dam sites, although they may be present under cover in the Glacier View reservoir area. Soft young rocks of Tertiary age rest unconformably upon the older strata in the broad structural valleys, and glacial drift and alluvium cover all systems indiscriminately. With one exception, all the dam sites are in the rocks of the Belt series, but the surficial Quaternary deposits are involved in each. Some knowledge of the stratigraphy of these formations is therefore essential before the geology at the dam sites can be wholly understood.

PRE-CAMBRIAN PERIOD

BELT SERIES

On the basis of lithology, this thick sequence of sedimentary rocks has been subdivided into three parts, which constitute mappable units. These are, from oldest to youngest, the Ravalli group, the Siyeh limestone, the Missoula group.

In their original state these rocks were made up of well-bedded deposits of fine-grained, clayey siltstone, somewhat smaller quantities of clayey magnesium limestone, and still less of sandstone. Over wide areas, before the youngest part of the series (Missoula group) had been deposited, the two older units were intruded by masses of basic igneous rock, and in some places their surface was covered by submarine lava flows. After the greater part of the Missoula group had been deposited, or even during its deposition, igneous activity was resumed. In their present condition the rocks of the Belt series are of kinds commonly described as argillite, metargillite, siliceous dolomitic limestone, and quartzite. The igneous rocks associated with them approach basalt and diabase in character.

With the exception of argillite and metargillite, these terms are more or less familiar to the engineer, as they define rock types encountered frequently. An argillite may be defined as a metamorphosed mudstone, siltstone, or shale that does not show the marked cleavage characteristic of slate, although it is recrystallized to about the same extent. A metargillite [17] is even more thoroughly recrystallized, but it still retains its originial structures and does not show marked evidence of schistosity or slaty cleavage.

RAVALLI GROUP

Rocks of the Ravalli group constitute the basal unit of the Belt series in the Mission Range and south part of the Swan Range in northwest Montana; and, according to Clapp, [18] include, in descending order, the Grinnell, Appekunny, and Altyn formations of the Belt

[17] Daly, R. A., Geology of the North American cordillera at the 49th parallel: Canada Geol. Survey Mem. 38, pt. 1, pp. 68–69.

[18] Clapp, C. H., Geology of a portion of the Rocky Mountains of Northwestern Montana, Montana Bur. Mines and Geology, Mem. 4, p. 22, 1932.

series in Glacier National Park. Clapp mapped the Appekunny and Grinnell formations along the west base of the Swan Range, through Bad Rock Canyon dam site, into Teakettle Mountain. Willis, [19] in his original description of the strata in Glacier Park, remarked:

> It is possible that more detailed study may develop the fact that the Grinnell and Appekunny argillites are really phases of one great formation, and that the line of distinction between them is one diagonal to the stratification.

Field work incident to the present report has demonstrated interfingering of the gray-green Appekunny lithology with the dull, purplish-red Grinnell lithology in the 2,400 feet of strata occupying the Grinnell horizon in Bad Rock Canyon, and it confirms Lewis' observation. Thus, despite Clapp's supposed identification, [20] the terms Appekunny and Grinnell have lost their significance in the northern Swan Range. Where similar conditions prevail farther west and south, the beds included in these two argillite formations are embraced under the general term Ravalli group. Stratigraphic nomenclature will be simplified if this terminology is applied to the strata below the Siyeh limestone in the northern Swan Range. However, along the Flathead River west of Glacier Park, at Fool Hen dam site, what appears to be typical Grinnell argillite crops out in normal position immediately below the Siyeh limestone. Consequently, at that locality the rocks below the Siyeh have been called Grinnell (?) argillite.

Most of the rock of the Ravalli group is strong, hard, tough, and tenacious, as well as very insoluble, and is suited admirably for dam foundations. Bedding is distinct and predominantly heavy; and individual massive layers are made up of thin irregular laminae sometimes differing in color. The red rock is somewhat more sandy and a little coarser-grained. The green rock is interbedded more frequently with tan quartzite.

Under the microscope, the metargillites are seen to consist of a a compact felted mass of sericite, quartz, and chloritoid matter, the largest grains averaging 0.025 to 0.035 millimeter in diameter. Evidence of bedding is practically obliterated, and there is an incipient foliation. Some secondary growth of quartz grains is apparent. Feldspar occurs in the coarser, sandy layers; and chlorite is especially abundant where there has been movement along bedding surfaces.

Local details of the formation are furnished in the individual damsite descriptions.

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[19] Willis, Bailey, Stratigraphy and structure, Lewis and Livingston ranges: Geol. Soc. Amer. Bull. vol. 13, p. 322, 1902.

[20] Op. cit., pl. 1.

SIYEH LIMESTONE

The Siyeh limestone is widely distributed in all of the great mountain blocks in this part of Montana. It is exposed on the upper walls of Bad Rock Canyon and at the Coram Canyon, Hungry Horse, and Fool Hen dam sites. The character of the formation and its relation to the overlying and underlying formations have been described in considerable detail in the report on Hungry Horse dam and reservoir site,[21] and it need not be reviewed here except to mention that it is a strongly bedded, slightly metamorphosed, siliceous, dolomitic limestone. Local variations from this general condition are mentioned in the descriptions of the other sites.

In Glacier National Park, according to Willis: [22]

> The top of the Siyeh limestone, considered as a lithologic formation over that part of the area where it was observed, coincided with an extrusive igneous sheet, which was clearly erupted prior to the deposition of the succeeding strata, and exhibits the ropy flow structures incident to flow and cooling at the surface.

This condition has not been observed at any place where the top of the Siyeh limestone was seen in the area covered by this report. Although the passage into the Missoula group appears to be transitional, it may possibly be marked by a nonevident disconformity.

MISSOULA GROUP

Rocks assigned to the Missoula group and perhaps equivalent to the Libby formation and the Striped Peak formation of northwestern Montana and northern Idaho crop out at the upper and lower Canyon Creek, Fool Hen, and Glacier View dam sites.

As observed on Flathead (North Fork) River between the Glacier View and lower Canyon Creek dam sites, the strata of the Missoula group consist of thin-bedded red and dull gray-green argillite and metargillite and red and brownish quartzite. Dolomitic beds are present locally, as are occasional thin algal layers. The red beds have a marked resemblance to the red facies of the Ravalli group, for which they may easily be mistaken unless their stratigraphic position is known. In general, the Missoula strata are slightly coarser-grained than the red argillite of the Ravalli group; they are thinner-bedded, more thoroughly ripple-marked, and exhibit casts of salt crystals and clastic mica (muscovite), and their red color inclines more to vermillion and less to purple.

The stratigraphic interval from the top of the Siyeh limestone near the confluence of Nicola Creek with Big Creek, NE¼NE¼ sec. 12, T. 32 N., R. 22 W., to the base of the lower lava flow at Glacier View

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21 Erdmann, C. E., Geology of the Hungry Horse dam and reservoir site, South Fork Flathead River, Flathead County, Mont.: U. S. Geol. Survey, Water-Supply Paper 866-B, 1944.

22 Willis, Bailey, op. cit., p. 324.

dam site was determined by reconnaissance methods and found to be about 22,200 feet. Another 1,000 feet of strata can be observed between the upper and lower lava sheets at the dam site. The interval between the top of the upper flow and the highest argillite of the Missoula group on the east side of Apgar Mountain is unknown, but can hardly be less than 2,000 feet. The total measurable thickness of this group is thus in the neighborhood of 25,000 feet. The top has not been observed in this part of Montana, but at North Kootenay Pass in British Columbia, Rose [23] noted that—

> * * * the Kintla formation which is here largely composed of reddish argillite and quartzite, at the top of the Lewis series, is separated from the Middle Cambrian shale and limestone by 200 to 300 feet of reddish-white sandstone with a conglomerate layer, containing pebbles of white and opalescent quartz up to one-half inch in diameter at the base. This conglomerate marks a disconformity between the Kintla formation at the top of the Lewis series and the overlying rocks, and it is suggested that it be used provisionally as the dividing line between the Pre-Cambrian and the Cambrian. The conglomerate and the overlying sandstone may then be considered to represent Lower Cambrian, provisionally.

No attempt has been made to subdivide the great thickness of the group into formations, and except in a general way, it is not possible to assign the rocks at the dam sites to specific horizons. In the northern part of Glacier National Park, Willis [24] subdivided the rocks above the Siyeh limestone into the Shepard [24a] and Kintla formations, and Daly [25] has contributed additional details to Willis' brief original description. The Shepard formation consists chiefly of a highly siliceous dolomite, varying in thickness from 600 to 700 feet, and resting conformably upon the Purcell basalt. It is overlain conformably by about 800 feet of "deep red argillaceous quartzites and siliceous shales, with marked white quartzites and occasional calcareous beds," which constitute the Kintla argillite. Nonpersistent beds of amygdaloidal lava occur in each formation. Their combined thickness is but 1,500 feet and the equivalent section 15 miles south is about 15 times as great. Whether this stratigraphic change is due to erosion or deposition is not known, but it probably represents the southward thickening of sediments into the Cordilleran geosyncline. Although the Missoula group on Flathead (North Fork) River contains strata that are identical in character with those making up the Shepard and Kintla formations, it has been impossible to distinguish these two formations positively southwest of their type area.

[23] Rose, B., Crowsnest and Flathead coal areas, British Columbia: Canada Dept. Mines, Geol. Survey, summary rept., 1917, p. 29C, pt. C, 1918.
[24] Willis, Bailey, op. cit., p. 324.
[24a] Named for Shepard Glacier, as spelled by the Board on Geographical Names.
[25] Daly, R. A., op. cit., pt. 1, pp. 77–83.

PALEOZOIC AND MESOZOIC

Strata of Paleozoic and Mesozoic age crop out in Flathead (North Fork) Valley near the International Boundary, and rocks of equivalent age have been identified in the upper tributaries of Middle Fork of Flathead River. Reference is made here only to their occurrence in the Flathead (North Fork) Valley, which must be given some consideration in evaluating the economic geology of the Glacier View reservoir site. Willis [26] first noted limestone of Mississippian age younger than the Madison limestone (lower Mississippian) in Yakinikak Creek, sec. 33, T. 37 N., R. 22 W., 4 miles west of the river, and Daly [27] later found both Mississippian and Devonian rocks a short distance northwest. As might be expected from the reconnaissance character of this work, these accounts are fragmentary and little more than locality notes. The stratigraphic descriptions of MacKenzie [28] and Rose,[29] however, are sufficiently complete to provide a new student of the district with a working basis, and the reader is referred to their reports for further details.

TERTIARY

OLIGOCENE OR MIOCENE

KISHENEHN (?) FORMATION [30]

Considerable sections of each of the structural basins of the upper Flathead drainage area are underlain by thin and evenly bedded sediments, which are believed to have been laid down in the basins when they contained fresh-water lakes. Passing reference has been made to those in the upper Flathead (North Fork) Valley by nearly every scientific visitor.[31] Erdmann [32] has mentioned the coal-bearing rocks on the South Fork of Flathead River, but very little is known about these strata in the Nyack Basin. The following account, therefore, deals only with the formation as exposed in the Glacier View reservoir area. Although the formation was first recognized in British Columbia, by Dawson, and later by Willis in Montana, Daly was the first to apply the name, which was taken from a neighboring creek. Because neither the top nor the bottom has been observed, accurate estimates as to thickness are not available. Just above

[26] Willis, Bailey, op. cit., p. 325.

[27] Daly, R. A., op. cit., pt. 1, pp. 113–114.

[28] MacKenzie, J. D., Geology of the Flathead coal area: Canada Dept. Mines, Geol. Survey, Mem. 87, geol. ser. no. 73, Ottawa, 1916.

[29] Rose, B., Crowsnest and Flathead coal areas, British Columbia: Canada Dept. Mines, Geol. Survey, summary rept., 1917, pt. C, pp. 28 C–35, C, 1918.

[30] Also spelled Kishinena and Kishenena.

[31] Dawson, G. M., Canada, Geol. Survey, Ann. Rept., pt. B, p. 52, 1885. Daly, R. A., op. cit., pt. 1, pp. 86–88. Willis, Bailey, op. cit., p. 327. MacKenzie, J. D., op. cit., pp. 32–36. Rose, B., op. cit., p. 31 C.

[32] Erdmann, C. E., op. cit., pp. 62–63.

the international boundary, about 250 feet of different beds are exposed in cut banks along the river, and these were considered by Daly to represent a total thickness of about 500 feet. Farther downstream, center sec. 12, T. 36 N., R. 22 W., 700 feet of strata tentatively assigned to the formation were drilled in the Kintla well. This may be accepted as a minimum thickness, but the maximum may be many times greater. If exposures are continuous under alluvial cover between the North Fork coal mine and the mouth of McGee Creek, and the dip remains constant at about 40°, the thickness of the formation is at least 8,400 feet, and may be considerably more. The most plausible explanation for this condition is sedimentation concomitant with deepening of the basin by faulting. Evidence supporting this conclusion has been observed within the Kishenehn formation in British Columbia by MacKenzie, and the relationships between the Tertiary strata and the oldest glacial deposits in Montana indicate that the faults were still active in early Pleistocene time.

Two or three distinct facies of the Tertiary rocks have been recognized: gray and brownish clay and siltstone with layers of impure lignitic coal; light-gray to red calcareous siltstone and fresh-water limestone; and soft light greenish-gray siltstone, sandstone and drab clays. Locally boulder beds are intercalated with the finer sediments, indicating the effect of flood deposition. On Couldrey Creek in British Columbia, a short distance north of the International Boundary, bituminous clays and marls crop out. MacKenzie's description of these rocks, which have been reported as "oil shale" is quoted at length in the account of the economic resources of the Glacier View reservoir site. The carbonaceous rocks crop out in a narrow strip along the west side of the upper Flathead (North Fork) Basin, and locally contain workable deposits of lignite as at The Coal Banks. Structural relations indicate that they probably are the oldest of the Tertiary strata, whereas the calcareous facies and reddish clays may be much later. Whether they are conformable or not is unknown. In reporting upon fossil collections made by Daly from unstated horizons in the Kishenehn, T. W. Stanton wrote [33] that they

> consist entirely of fresh water shells belonging to the genera *Sphaerium*, *Valvata* (?), *Physa*, *Planorbis*, and *Limnaea*. Similar forms occur as early as the Fort Union, now regarded as earliest Eocene [Paleocene], but there is nothing in the fossils themselves to prevent their reference to a much later horizon in the Tertiary, because they all belong to modern types that have persisted to the present day, though it should be stated that their nearest known relatives among western fossil species are in the Eocene.

[33] Stanton, T. W., in Daly, R. A., op. cit., pt. 1, p. 87.

Willis regarded it as probably Miocene or Pliocene. Considerations of structural geology indicate that the basins did not form until after the development of the Lewis overthrust fault, which probably is later than Fort Union. This affords some basis for assigning the beds within them to the Oligocene or Miocene epochs of the Tertiary.

QUATERNARY

The Pleistocene and Recent deposits of the upper Flathead River, particularly for the stretch between the South Fork and the Middle Fork, were studied in connection with the investigation of Hungry Horse dam and reservoir site because their character and relationships are revealed more fully there by fairly extensive exposures.[34] Three till sheets, referred respectively to the (1) Kansan (?) stage, (2) Illinoian (?) stage or Iowan (?) substage of the Wisconsin, and (3) Wisconsin glacial stage, are separated by two series of interglacial deposits. The latest, or Wisconsin stage of glaciation in Flathead (North Fork) and Middle Fork Valleys destroyed, disarranged, or buried what remained of the earlier deposits, and the superficial late Wisconsin lacustrine deposits also have largely disappeared. In consequence, throughout these valleys the surface, where not bedrock, usually consists of terminal and valley moraine, fluvioglacial and outwash deposits. At two localities only have earlier glacial deposits been observed. Near the junction of Camas and McGee Creeks, SE¼SE¼ sec. 7, T. 33 N., R. 19 W., in Glacier View reservoir site, a highly weathered and bleached boulder clay crops out in the right bank of McGee Creek. Its relations with the underlying red calcareous siltstone of the Kishenehn (?) formation are unconformable. This old till resembles closely in color, character of weathering, and pebble content the boulder clay of the Kansan (?) stage at the head of Coram Canyon, and on the basis of these characteristics, it is tentatively referred to that horizon. Although of very restricted extent, this exposure is of interest in that it suggests the occurrence of this formation in the McGee Meadows divide area and because the dip of gravel lenses in the till indicates early Pleistocene movement upon the Flathead fault. A somewhat similar occurrence was noted on the right bank of the Middle Fork, west center of sec. 10, T. 30 N., R. 16 W., but field work has been insufficient to determine the precise character of the deposit, which may not be glacial. Two or three boulder beds intercalated with dull-red clay appear to rest conformably upon gray siltstone, clays, and carbonaceous shale which resemble the Kishenehn (?) formation. The main reason for suggesting that these beds may be Pleistocene is that they are somewhat less indurated and have

[34] Erdmann, C. E., Geology of the Hungry Horse dam and reservoir site, South Fork of Flathead River, Flathead County, Mont.: U. S. Geol. Survey Water-Supply Paper 866-B, pp. 63-77, 1944.

lower dips than unmistakable Tertiary rocks a short distance downstream.

Only the valley moraine, the fluvioglacial, and outwash deposits are involved in the dam sites, and local details of their character and distribution are given in the accompanying descriptions. During the Wisconsin glacial stage, Flathead (North Fork) Valley below Big Creek was occupied by a deep, narrow alpine glacier, which discharged from the great ice field that filled the upper part of the valley. Lateral moraines blanket the walls, in places reaching 600 to 700 feet above the present river level. The material consists largely of gray to buff silt and clay, which has developed in large part from scour and in lesser amount from the destruction of the Tertiary "lake beds." Intermixed are variable amounts of small rock fragments due to plucking, and occasionally there is a very large erratic block. Stream cobbles and gravels derived from earlier terrace and river deposits are abundant locally. When not reworked this till is compact and relatively impermeable, as is indicated by occasional pot-hole lakes. Elsewhere, however, and particularly in the valley bottoms, it has been rehandled extensively by water and resorted into various sizes controlled by the competency and capacity of the stream. Excellent results of this process are exhibited at the Upper Canyon Creek and Fool Hen dam sites.

More typical outwash deposits occur in the vicinity of the Columbia Falls dam site. Water wells in the vicinity have penetrated the fill to depths of about 350 feet, but bedrock has not been encountered.

Deposits of recent alluvium, sand, and gravel are most abundant at the Bad Rock Canyon and Glacier View dam sites, where they fill the stream channel to depths of from 250 to 350 feet. The upper part of this material is hard, fresh loose gravel from the Belt rocks, but with depth it probably will be found to be cemented by buff calcareous silt into compact conglomerate.

Owing to the comparatively recent occurrence of the last glaciation, talus deposits are small and thin and are found only in the vicinity of the higher and steeper cliffs. At some places the young or active talus overlies the glacial debris.

IGNEOUS ROCKS

Extensive exposures of both intrusive and extrusive basic igneous rocks are found associated with sedimentary formations of the Belt series in the mountains along the International Boundary and in Glacier National Park, [35] and it is no surprise, therefore, to encounter

[35] Daly, R. A., Geology of the North American cordillera at the forty-ninth parallel: Canada Dept. Mines, Geol. Survey, Mem. 38, pt. I, chap. 9, pp. 207–220, Ottawa, 1912. Finlay, G. I., Igneous Rocks of the Algonkian Series [Lewis and Livingston Ranges, Mont.]: Geol. Soc. Amer. Bull., vol. 13, pp. 349–352, 1902. Burling, L. D., Ellipsoidal lavas in the Glacier National Park, Mont.: Jour. Geology, vol. 24, pp. 235–237, 1916.

similar rocks a short distance to the south in the country along the Flathead (North Fork) River. With few exceptions, these rocks are petrographically similar. The dikes have served as feeders to the sills and lava flows, and all are grouped under the term Purcell basalt (the Purcell lava of Daly). Chemically these lavas are related to the basalts, as is indicated by the following analysis, [36] and Daly believes that they represent "the pure, original magma that, at the end of Siyeh time, underlay the Rocky Mountain and Purcell Mountain system at the Forty-ninth Parallel." [37]

Analysis of Purcell lava [Purcell basalt]

	Percent		*Percent*
SiO_2	41. 50	K_2O	0. 22
TiO_2	3. 33	H_2O at 110° C	. 21
Al_2O_3	17. 09	H_2O above 110° C	6. 99
Fe_2O_3	3. 31	CO_2	0
FeO	10. 08	P_2O_5	1. 08
MnO	Trace		
MgO	12. 74		100. 36
CaO	. 97		
Na_2O	2. 84	Specific gravity	2. 792

The eruptions began at the close of Siyeh time and continued intermittently throughout upper Missoula time, thus occupying practically all of late pre-Cambrian time.

A rock, possibly of intrusive origin, with some remnants of ophitic texture crops out at the north end of Fool Hen dam-site, upstream from any possible dam sections. (See pl. 21.) For this reason and because all significant contacts are covered by glacial drift, no particular effort was made to determine the nature of the body and its relationships to the enclosing rocks. What little is known is indicated diagrammatically in plate 22. The mass appears to have been localized at the boundary between the Grinnell (?) argillite and Siyeh limestone, but it does not persist eastward along the strike of this contact. More recent exposures developed by road work have revealed masses of gray and white chert, and some rock with nodular structures that resemble those found in the submarine lava flows to be mentioned presently. This suggests that it may be a plug or pipe of small diameter feeding one of these flows, or it may be a faulted flow. Although the north Fool Hen fault appears to have some controlling relationship, it is very much later and truncates the north side of the mass. This contact is relatively sharp and clean; the south side of the mass has a brecciated contact with Grinnell (?) argillite, but it has not been determined definitely if it is an intrusive or a tectonic boundary.

[36] Daly, R. A., op. cit., pt. I, p. 209.
[37] Daly, R. A., op. cit., pt. I, p. 219.

The rock is dull green in color, and on the north side there is a mottling of darker green splotches that may be a quarter of an inch in diameter. Under the microscope these appear to be vesicles filled chiefly with chlorite. Alteration is very complete, and all the primary ferromagnesian minerals are now chlorite. Leucoxene is also abundant, suggesting the former presence of titaniferous magnetite. Laths of the original plagioclase are still preserved, although heavily attacked, and the relationship of the fresh rock to the chloritic pseudomorphs shows that it probably was diabase.

Extrusive igneous rocks appear at Glacier View dam site in the form of two thick sheets intercalated with the argillite of the Missoula group. Stratigraphically the interval between the top of the lower and the base of the upper body is about 1,000 feet; and the base of the lower sheet is about 22,200 feet above the top of the Siyeh limestone. Typical "pillow-lava" structure noted in the upper mass on the north slope of Huckleberry Mountain suggests beyond reasonable doubt that it represents a lava flow poured out over wet mud or into water. The spheroidal facies quickly grades upward into amygdaloidal lava, showing that the water was not very deep, and numerous thin, irregular bands and nodules of chert in the rock probably represent silica precipitated by reaction between molten lava and sea water. The total thickness of the upper flow is about 160 feet. Pillow lava was not observed in the lower mass whose thickness is about 100 feet, but it possesses corresponding features in the form of amygdaloidal structure and chert bands, so it probably originated under similar conditions. Contacts have not been seen below the pillow lava, but those under the amygdaloidal are sharp, clean, and accordant. In such places, the argillite has been baked to a very hard, dark-green, siliceous rock resembling hornfels. The upper contacts are also conformable, but there is no evidence of thermal metamorphism in the overlying rock. On the assumption that the lavas were erupted uniformly over the flat bottom of a shallow-water body, structural considerations point out that their areal distribution and correlation within the limits of Glacier View dam site are as shown on plate 24.

In either flow the rock is typical of the Purcell basalt, whose characteristics are well known because of the work of Daly. Petrographic descriptions will therefore not be offered. Alteration is complete, and most of the ferromagnesian minerals have been replaced by chlorite. In consequence, the prevailing color of the rock is dull grayish green. The texture of the pillow lava is extremely dense and can be resolved only under the microscope. Associated with it, filling the interstices, is a dense, dark-green, brecciated material that probably represents decrepitated mud and lava, which have been rolled and squeezed between the billows of lava. Under the microscope colloidal structures are conspicuous. The coarser-grained amygdaloid frequently exhibits light-colored phenocrysts of plagioclase on the weathered surface, but these are not distinguishable on freshly broken rock. The texture of this material resembles amphibolite, but microscopically it is a typical diabase with vesicles filled with chlorite and carbonates. These features usually appear on the weathered rock as a mottling of dark green or light gray.

STRUCTURAL GEOLOGY

Principles of mountain structure, the probability of movement along the faults, and probability of earthquakes in this part of Montana were treated at some length by the writer in a report [38] on Hungry Horse dam and reservoir site, and as the same conditions prevail along the Middle Fork and Flathead (North Fork) Rivers, they need not be reviewed again. Most of the dam sites are on the gigantic tectonic block of the Swan Range or its northern extension, the Whitefish Range, but the Flathead Range block and the Livingston Range also are involved. From just above Glacier View dam site to just downstream from Columbia Falls dam site the main Flathead flows upon the Swan-Whitefish block; and from Belton to its confluence with the main river, the Middle Fork flows upon it too. Upstream from Belton, the Middle Fork crosses the north end of the Flathead Range, and its higher tributaries drain some of the south part of the Livingston Range. The broad open basin containing the Flathead (North Fork) above Glacier View dam site is a structural depression, related to the Flathead block, and flanked on the east and west, respectively, by the Livingston and Whitefish Ranges.

SWAN RANGE BLOCK

This large and important element of the mountains is limited on the west by the Swan fault and on the east by the Flathead fault. Both are high-angle reverse or upthrust faults, with the upthrown side on the east. Usually their traces are concealed by alluvium in the floor of the adjacent valley. Differential movement between them has rotated or tilted the entire mountain mass to the northeast. As a consequence, structural conditions at any given place usually consist of a relatively low northeast dip, which has a tendency to swing northward as one moves up the Flathead (North Fork) River. Local details of this dip are given in the dam-site descriptions that follow. Aside from the dip, the principal structural element that effects the dam sites is the jointing. At some localities it is complete, and as many as nine sets of joints can be identified. The dam-site descriptions also contain these details, but the nature of this report does not allow consideration

[38] Erdmann, C. E., op. cit.

of the mechanics of jointing and its relation to the tectonic features. Except in the northeastern part of the block, local or transverse faulting is uncommon, but shearing parallel to the strike of the beds sometimes occurs near formation boundaries and is probably due to differences in the elasticity and strength of the rocks.

FOOL HEN FAULTS

Two normal faults, approximately parallel and nearly three-quarters of a mile apart, with direction of dip opposed, strike across Flathead (North Fork) Valley at Fool Hen dam site. This has resulted in a horst, an upthrown block between two downthrown blocks, through which the river has cut a narrow gorge, creating the dam site. The upper, or North Fool Hen fault, strikes S. 82° E., dips 88° N., and has a stratigraphic throw of about 3,600 feet. South Fool Hen fault strikes N. 70° E., dips 79° S., and has a stratigraphic throw which cannot be less than 7,000 feet. Circumstances have not permitted the tracing of the faults outside of the dam-site area, and their age and relationship to the Tertiary faults, which control the regional structure, is unknown. Although exploration of Fool Hen dam site is incomplete, the shallow depth to bedrock and the comparatively small size of the preglacial river channel (pl. 22, D–D′), suggest that the uplift of this block across the path of the stream was comparatively late. As far as the dam site is concerned the condition is local, and a more complete description is given in the section on Fool Hen dam site. (See pp. 188–190.)

FLATHEAD RANGE BLOCK

In many respects, this mountain range is the homologue of the Swan Range which adjoins it to the west, for it bears the same rock formations, which have similar attitudes. It is limited on the east by the Roosevelt fault. Differential movements between the Flathead and Roosevelt faults have tilted the Range to the northeast, but the dips within the northern end are somewhat greater than those opposite in the Swan Range block. This may be due to the middle or late Tertiary movement on the Flathead fault, which was responsible for the second closing of the Nyack Basin, but which apparently did not affect the mountains to the west. In cutting through the barrier thus raised across its course, Middle Fork has formed the gorge just upstream from Belton.

The Flathead Range terminates abruptly as a positive mass between the Middle Fork and Lake McDonald in a manner analogous to that by which the Mission Range terminates just north of the town of Big Fork at the north end of Flathead Lake. In the case of the Mission Range, the disappearance is clearly due to the northwest tilt of the mountain block, for from points on the west side of Flathead Lake, the uniform crestline of the range is seen to have a constant northward slope, which finally carries it below the lacustrine plain at the head of Flathead Lake. Evidently this was accomplished by a more or less uniform decrease in throw of the Mission fault to the northwest, as the range was rotated to the northeast and the south end elevated. The result is that the Mission Range appears to terminate at the south end of the structural basin that is flanked on the east by the Swan Range and on the west by the Salish Mountains.

Topographic conditions make it difficult to obtain such a comprehensive view of the crestline of the Flathead Range, but it is evident that it does not have the uniform northwest pitch of the Mission Range. Nevertheless, it exhibits the same relationship to the Flathead (North Fork) Basin as the Mission Range does to Flathead Valley above the Lake, and the Livingston and Whitefish Ranges are, respectively, the counterparts of the Swan Range and Salish Mountains. The similarity even extends down to identical courses for the transverse valleys of Swan River across the north end of the Mission Range and the Middle Fork of Flathead River across the north end of the Flathead Range.[39] Evidence for the maintenance of character of the Flathead fault and its progressive decrease in throw to the northwest occurs near the junction of Camas and Dutch Creeks, center of SW¼, sec. 7, T. 33 N., R. 19 W., Glacier National Park, where the lessening upward movement on the east side of the prolongation of the fault has apparently just been sufficient to raise the calcareous facies of the Kishenehn (?) formation above the level of Camas Creek. Thus, there is some reason to believe that North Fork Basin is the depressed extension of the Flathead Range block. Numerous other explanations have been suggested, such as a simple graben structure,[40] a modified ramp valley,[41] and even a window in the Lewis overthrust fault[42]; but none of them explains the relationship of the basin to the associated structural elements so simply or so well as that offered here.

MATERIALS FOR CONSTRUCTION

Native materials suitable for dam construction are not numerous in the upper Flathead region, and nearly everything needed would have

39 Clapp, C. H., Geologic Map with structure sections of a portion of the Rocky Mountains of northwestern Montana: Montana Bur. Mines and Geology, Mem. 4, pl. I, Butte, 1932.

40 Willis, Bailey, Stratigraphy and structure, Lewis and Livingston ranges: Geol. Soc. Amer. Bull. vol. 13, pp. 343, 344, 1902. Daly, R. A., op. cit., pp. 599, 602. MacKenzie, J. D., op. cit., p. 6. Rose, B., op. cit., p. 35C.

41 Link, T. A., Oil seepages in Belt series of Rocky Mountains near international boundary: Am. Assoc. Petroleum Geologist Bull., vol. 16, p. 787, fig. 1.

42 Olsson, A. A., A report on the geology of the Flathead region of southeastern British Columbia, Jan. 6, 1934, private consulting report.

to be imported. The situation of the various sites with respect to rail and truck transportation is outlined briefly in the section on dam sites.

Cement.—The composition of the Siyeh limestone is too high in magnesium for use in the manufacture of Portland Cement, and the marls and calcareous silts of the Kishenehn (?) formation carry too much iron oxide. Probably the best possible source to try first would be the upper Mississippian limestone on Yakinikak Creek. Nothing is known about their chemical composition, and they are relatively inaccessible to all sites except Glacier View.

Coal.—The Flathead (North Fork) coal mine is the only local source of coal at present, but other seams could probably be opened up in Coal Creek. This coal is entirely a low-grade lignite, which does not store particularly well. For large-scale operations, the best local source of coal is the Flathead District in British Columbia, about 5 miles north of the boundary. Coals in this district are of Kootenai age and are of bituminous rank.

Concrete aggregate.—This material can probably be supplied locally, depending on what dam site is involved. Among the best materials are some of the massive siliceous facies of the Siyeh limestone, the less argillaceous parts of the Ravalli group, some of the quartzites of the Missoula group, and the massive diabasic portions of the Purcell basalt. One of the principal characteristics of much of the rock is the close spacing of the joints; if it is used for aggregate, it should be crushed to dimensions less than the smallest joint blocks in order to avoid planes of weakness. If the river gravels are to be washed for sand, stream pebbles of argillite may be available for aggregate. Most of those in the active gravels are hard, smoothly rounded, and impervious. Pebbles and cobbles from the boulder clay should be examined closely to see if they have been softened by weathering. Extensive exploration and testing will be required to locate suitable aggregate material.

Electric power.—The Mountain States Power Co. has a small plant at Big Fork, and their nearest trunk line is at Columbia Falls. The Montana Power Co.'s new plant at Kerr dam below Polson is now operating, and probably any demand could be met.

Glacial drift.—Valley moraine material is abundant at some sites. Due to the well-bedded, thoroughly jointed rocks which have contributed to it, it is not particularly bouldery. Stream cobbles from ancient terraces and river beds have been incorporated locally. Silt and clay from the attrition of the glacier, and the unconsolidated Tertiary formations and small rock fragments are the chief constituents. Sand is not an important component. The deposits are so heterogeneous that it would be difficult to predict their composition even after partial exploration by test pits. Where abundant, this material would be suitable for earth dams. The largest deposits of glacial clay and silt occur on Flathead River just above Coram, and the older drift appears to be better suited for earthen dam material than the Wisconsin till.

Masonry.—Some of the considerations which apply to concrete aggregate also apply to rock for masonry or rubble. Plentiful supplies occur in the Siyeh limestone, Ravalli group, and the Purcell basalt if the less-jointed portions are selected. Its abundance at some of the sites suggests consideration of rock-fill dams.

Natural gas.—The Cut Bank District in Glacier County is the nearest source of natural gas. The distance to the field from Coram along the Great Northern Railway is about 100 miles.

Pozzuolanitic materials.—No deposits of this character occur in the region.

Sand.—Suitable deposits of sand for cement probably exist in some of the glacial outwash deposits along Flathead River near Columbia Falls, and in the high terraces on the Middle Fork near Java.

Timber.—Abundant supplies for concrete forms, other rough material and fuel are available. Sawmills could be set up locally.

Water supply.—Abundant and good.

DESCRIPTIONS OF DAM AND RESERVOIR SITES

COLUMBIA FALLS DAM SITE

(See pls. 12, 13; fig. 10)

Location.—SW¼ sec. 17, T. 30 N., R. 20 W., at Geological Survey gaging cable.

Accessibility.—The north abutment, about 1½ miles south of Columbia Falls, can be reached easily by driving in through the old Talbot place. Automobiles also can reach the south abutment but only by a roundabout drive.

Catchment area.—Entire Upper Flathead Basin totaling about 4,500 square miles. Maximum reported discharge, 102,000 second-feet, June 5, 1923. This was probably exceeded on June 19 to 21, 1916, when the sum of the discharge of the three branches was 124,700 second-feet, and also in 1894.

Stream gradient.—Six to seven feet per mile.

Purpose.—Unknown.

Apparent possible height of dam.—Topography limits apparent maximum possible height to about 50 feet above stream bed, or a crest altitude of about 3,020 feet. At this altitude, the length of crest would be 570 feet.

Valley profile.—A shallow "U" in the flat fluvioglacial plain bordering the mountain front.

Character and depth of valley fill.—Alluvium consisting of sand and gravel derived from reworked glacial deposits, which were derived in turn from pre-Cambrian and Tertiary formations and older glacial deposits. Occasionally there is a very large glacial erratic torn from the hard pre-Cambrian strata. The depth of the alluvial fill and the depth to bedrock are unknown.

The stream gravel is probably unconsolidated to depths of about 25 feet. At greater depths it is mixed with interstitial tan calcareous silt or clay and is hard and firm. This cemented gravel may be underlain by older glacial deposits or Tertiary "lake beds." The bedrock floor of the valley is probably argillite of the Ravalli group. The depth to this argillite, as estimated by projecting the bedrock floor from Bad Rock Canyon at a gradient of 6.75 feet per mile, is about 335 feet. However, the course of the river today may not coincide with the axis of the ancient stream that eroded Bad Rock Canyon so deeply, and the depth may be less. A straight prolongation of the deep valley from Bad Rock Canyon places it just north of Columbia Falls.

In 1935, a single resistivity determination was made on the right bank, the center stake being on the proposed dam axis. The curve is not easily interpretable because of the similarity in resistivity values of the glacial drift, Tertiary "lake beds" and argillite of the Ravalli group. The two halves of the curve are quite symmetrical and conditions appear to be uniform. It is of the three-layer type, but not strongly so. Analysis indicates an upper layer 25 feet thick, with a resistivity of 20,500 ohm/cm. The second layer has a thickness of 20 feet, an apparent resistivity of 29,000 ohm/cm, and a calculated resistivity of about 47,700 ohm/cm. The calculated resistivity of the third layer is about 57,300 ohm/cm.

Geologic interpretations of this analysis suggest that the first layer is unconsolidated river gravel. The resistivity is lower than similar gravels in Bad Rock Canyon and elsewhere upstream, but this is probably because the traverse was run below a horizon of springs the water from which contains about twice as much bicarbonate (HCO_3) as the river water. The second layer may be either lime-cemented river gravel or glacial boulder clay as far as resistivity values are concerned. Interpretation as cemented river gravel is preferred because such gravels were observed at about this depth in bridge-pier excavations not far upstream. The top of the third layer can be interpreted as bedrock, on the basis of resistivity value, or as glacial drift. The shallow depth argues against bedrock, but the uniformity and persistence of the material is a point in its favor. Glacial boulder clay might show similar characteristics. In this instance, interpretations of geologic and resistivity data do not agree;

greater weight should be put upon the geologic evidence because the amount of resistivity work is so small that it is not conclusive. In my opinion, the third layer consists of glacial drift.

Country rock.—See figure 10 for section. Glacial deposits consisting of an alternation of sheets of glacial till with layers of glacial-outwash (fluvioglacial) material.

Dips.—Slight depositional dip to southwest.

Fractures (joints).—None. Material unconsolidated.

Faults.—None observed in the glacial deposits. However, the Swan fault, which forms the east boundary of the Rocky Mountain trench, probably crosses the bedrock floor of the river valley about 2½ miles southwest of the dam site.

Ground water.—Occurs near the surface along the river, and in the vicinity of Columbia Falls, as a series of springs. These are confined to the right bank of the river and are regarded as the reappearance of Cedar Creek, a small perennial stream that disappears in a sink about a mile north of Columbia Falls. In the north abutment, beginning 600 feet upstream from the gaging cable, and extending downstream for 1,200 feet, are a total of 43 small but active springs. The volume of water flowing from them is considerable, and when the locality was visited in July 1934, the total flow was estimated roughly to be about 5 second-feet.

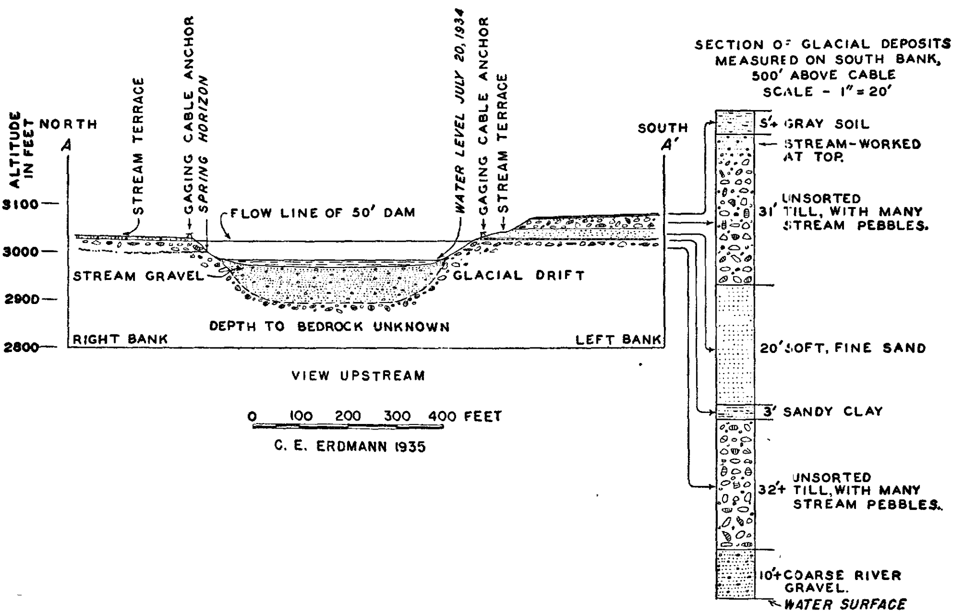

FIGURE 10.—Geologic cross section at Columbia Falls dam site along stream-gaging cable, sec. 17, T. 30 N., R. 20 W., Flathead County, Mont.

Farther to the south and southeast, in areas topographically higher, water is found at depths of 100 feet or more.

Permeability.—That of the unsorted till or boulder clay is relatively low. Till containing a high percentage of stream gravel and sand is more permeable than that derived directly from the hard-rock formations. The unconsolidated alluvium and especially the soft, fine sand are quite permeable. The lime-cemented gravel underlying the active alluvium is probably impermeable except along joints. However, the most permeable zones are the contacts between the various types of material in the glacial deposits. The volume of flow from some of these springs probably indicates a cavernous condition.

Dam section.—Only one possible section is available. It occurs directly below the gaging cable. There can be no other choice, and consequently no comparison is possible.

Foundation conditions.—Bedrock at this site probably lies too deep to be reached by excavation, and any structure considered would have to rest upon the valley fill. The unconsolidated stream gravel is not satisfactory foundation material. The unstable character of this gravel is attested by the washing out on at least two occasions of the pier foundations of the old county bridge at Columbia Falls about half a mile upstream. The records of these bridge foundations and the cause of their failure should be investigated in connection with any complete study of foundation conditions at this site.

The material underlying the active gravels will probably provide a suitable foundation, whether it consists of lime-cemented gravel, boulder clay, or argillite of the Ravalli group. The cemented gravel is hard and compact, impermeable except along solution channels or joints, and in thick masses its bearing power probably is rather high. Its thickness is likely to vary with depositional conditions and cementation, and it is susceptible to solution. If boulder clay is present, it too will be firm, compact, and impermeable, but not so hard as the cemented gravel. The possibility of encountering argillite seems very small, but if found, its character should be essentially that of the formation in the abutments of the Bad Rock Canyon dam site.

Abutments.—The south abutment stands about 100 feet above stream bed, and contains the stratigraphic section shown in figure 10. Fine, unconsolidated sand, 20 feet thick, forms the middle portion. The base of this bed has the same altitude (3,020 feet) as a narrow erosional terrace on the same bank downstream from the gaging cable, indicating that it is easily erosible. The crest of any dam would have to be kept below the base of this bed, or to an elevation about 40 feet above stream floor. This restriction is enforced automatically by the fact that the north abutment is about 40 feet lower than the south abutment.

The spring zone described under "Ground Water" on page 145 occurs in the north abutment at altitudes of 2,990 to 2,995 feet. If a dam were to raise water to an altitude of only 3,000 feet, the flow of the springs upstream from the gaging cable (dam axis) would be reversed, and the spring flow, as well as the inflowing river water would bypass the north (right) abutment. Under a 30- or 40-foot head the flow would be so considerable as to wash out the north abutment quickly and entirely. Conditions favoring such an occurrence are so widespread in that area that a cut-off wall to arrest the bypassing water would be prohibitively long. These defects are so serious that they alone are sufficient to condemn the entire site.

Recommendations.—This site may be dismissed from further consideration for the following reasons: (1) Deep foundation with respect to the greatest possible height of dam; (2) condition in the north (right) abutment dangerous and difficult to remedy; (3) large spillway capacity required for so small a dam; (4) expenditure required to overcome the defects of this site greatly out of proportion to the benefits to be derived; (5) a dam at this locality would be an especial menace to all settlements in the river valley between it and Flathead Lake.

BAD ROCK CANYON DAM SITE

(See pls. 12, 14, and 15)

Location.—In Bad Rock Canyon in the vicinity of NW¼ sec. 12, T. 30 N., R. 20 W.

Accessibility.—United States Highway No. 2 passes over south (left) abutment, about 5 miles east of Columbia Falls. The Great Northern Railway passes above the north (right) abutment. Coram, the nearest shipping point is about 3 miles east along the railway; Columbia Falls is about 3½ miles west.

Catchment area.—Entire upper Flathead Basin, approximately 4,500 square miles. Maximum flood, about 125,000 second-feet.

Stream gradient.—About 7 feet per mile through the dam site. Cutting is taking place along the north side.

Purpose.—Power, river regulation, and flood control.

Valley profile.—A deep, wide, flaring U-shaped notch. This gorge, known locally as Bad Rock Canyon, separates Columbia Mountain on the south from Teakettle Mountain on the north. On the right bank, about 800 feet downstream from the railroad tunnel, is a remnant of a rock-cut bench, and on the left bank, opposite the tunnel, is a prominent bench covered with glacial outwash. One of the problems of this site is whether or not this bench is a constructional terrace, or a rock terrace lightly mantled with glacial drift. The first interpretation is favored in this report.

Only the lower part of the gorge is shown in the profile in plate 15. On the narrowest section, normal to the river through Corps of Engineers' drill hole No. 1, the characteristics of the valley above altitude 3,250 feet are illustrated by topographic data obtained by the Corps of Engineers in 1935:

Altitude (feet):	*Width of valley (feet)*	Altitude (feet):	*Width of valley (feet)*
3,500	2, 030	3,350	1, 400
3,450	1, 875	3,300	1, 240
3,400	1, 655	3,250	1, 100

Apparent possible height of dam.—The maximum possible height of dam at Bad Rock Canyon is about 430 feet above mean water surface. The controlling altitude, with main body of reservoir in the Coram-Belton intermontane basin, is about 3,450 feet (aneroid) and is situated on the Cedar Creek-Bailey Lake divide in NW¼ sec. 10, T. 31 N., R. 20 W., Flathead County. The locality is a small swamp, just below the North Fork road about 6 miles north of Columbia Falls, which separates Teakettle Mountain on the southeast from the Whitefish Range on the north. One lobe of the North Fork Glacier passed through this saddle and deposited a terminal moraine that is now called Parker Hill. The summit level of this hill, over which the road used to pass, stands about altitude 3,635 (aneroid), and the valley between Teakettle Mountain and the Whitefish Range is known locally as the Parker Hill Pass. Topographic mapping has not been carried out in this vicinity, and the width of the divide at various elevations below the summit cannot be furnished.

The concept of a high dam in Bad Rock Canyon is subject to the severe cultural restriction of the track level of the Great Northern Railway at altitude 3,115 to 3,120 feet over the left abutment. This condition was respected during the preliminary investigation of the site, and topographic mapping was carried from river level at altitude 3,020 feet only up to altitude 3,200 feet. Obviously, to avoid disturbing the railway, a dam should not be raised above altitude 3,110 feet, which would allow the track only 5 to 10 feet of freeboard. This would permit a dam to stand 90 feet above stream surface, or about 117 feet above stream bed. As will be shown later, the height above foundation would be about 420 feet, which gives a rather poor ratio for effective height of dam.

However, if the limitations imposed by the railway are ignored, as they should be for a complete inventory of the potentialities of the site, the locality commands more attention because it is the one place where entire control of the upper basin of the Flathead River may be obtained. This would obviate the ultimate necessity for a dam in each fork of the river, with attendant problems in synchronous operation, and, in the long view, might be more economical. It merits, therefore, the most extensive consideration and investigation, because if any other dam be built first, the Bad Rock Canyon site, in its larger aspects, may be invalidated insofar as our foreseeable future is concerned.

Character and depth of valley fill.—The surficial deposits in Bad Rock Canyon are of three principal types: (1) glacial drift, (2) Recent alluvium, and (3) Recent talus. The glacial drift, which predominates consists of stratified drift more or less reworked by stream action and is not typical boulder clay. The active alluvium consists of stream gravel and sand derived from the pre-Cambrian argillites and quart ites.

Although far from complete, the exploratory drilling carried out in the canyon has contributed much new information on the character and depth of valley fill. The original (1934) resistivity work was of limited scope because equipment for large electrode separations (greater than 400 feet) was not available; so curves with deep penetration could not be obtained. Nevertheless, most of them revealed a geophysical boundary at depths of 100 to 125 feet. In the absence of any control by drilling, and on the basis of calculated resistivities compared with those obtained by tests on observed formations, the layer below these depths was interpreted as bedrock. This was an error; and its magnitude can be appreciated by noting the distance this boundary (horizontal lines on resistivity depth determinations Nos. 1, 3, 7, 8, 10, and 11, pl. 15) stands above the current interpretation of depth to bedrock.

This new interpretation is based chiefly on borings put down by the Bureau of Reclamation about 1,500 feet downstream from line B–B′, plate 14. Drill hole No. 1 (at the edge of the water, right bank, south of center of SW¼SW¼ sec. 1, T. 30 N., R. 20 W.) reached a depth of 300 feet, elevation 2,715.8, without finding bedrock. Projection of the slope of the rock walls of the canyon, as developed from topography and additional drilling, suggests that this hole might have encountered bedrock if it had been drilled 45 or 50 feet deeper, or about elevation 2,665 feet. Partial confirmation of such a depth has been found in the results of resistivity work carried out in 1935 along the left bank of Flathead River near east quarter corner sec. 5, T. 30 N., R. 19 W., about 2½ or 3 miles above Bad Rock Canyon. These lines are believed to have been run over the left bank of the preglacial valley, so foundation level toward the center may be lower. It is, therefore, not unreasonable to assume that bedrock in Bad Rock Canyon, and in the buried gorge north of Coram Canyon, lies 340 to 360 feet below the surface of Flathead River.

The amount and arrangement of the canyon fill is indicated diagrammatically in plate 15. The downstream section, B–B′, is comparatively simple and shows a bed of Recent alluvium about 100 feet thick resting upon a deeper filling of finer sediment. Obviously, the upper layer has been deposited by the modern Flathead River. Material on or near its surface consists of sand and gravel with occasional boulders and is subject to active transport, while the basal part is more compact and is cemented locally with tan calcareous silt. The second layer consists largely of compact buff silt and fine sand interbedded with thin layers of pinkish-gray clay. These deposits are believed to have been laid down in a body of quiet water and may possibly be contemporaneous with glacial Lake Missoula.

Section A–A′ shows a more complicated arrangement of fill and indicates the rapidity with which changes may take place. The oversimplified conditions indicated have been developed as the more probable of several combinations of resistivity, drill data, and age relationships, and, of course, are largely hypothetical. Difficulty of interpretation is increased by lack of contrast in resistivity between overburden and bedrock. The deposit classified as stratified drift consists of poorly sorted, rudely stratified fluvioglacial sand and gravel that contains pockets of subrounded boulders up to 3 feet in diameter. Resistivity work over this outwash (lines 3, 4, 5, 6, 7, and 8) reveals a geophysical boundary at a depth of about 125 feet that is regarded as a formation or geologic boundary. The apparent resistivities of the underlying layer suggest that it is not silt and fine sand, or "lake beds" as occur in section B–B′. The values obtained approach those for bedrock, but are less than the apparent resistivity of argillite at station 12. For this reason, the second layer has been interpreted as boulder clay or till. Similar relationships can be observed just above Coram Canyon, where the lower layer consists of Kansan (?) till. If this condition prevails in this part of Bad Rock Canyon a firm, compact formation with bearing power sufficient to support a wide base dam exists at moderate depth below the constructional terrace on the left bank. In Recent time Flathead River has entrenched a deep, narrow gorge through these deposits, and Corps of Engineers' drill hole No. 2 shows it to be filled to a depth of 175 feet with gravels and coarse sands of the modern stream, comparable to the upper layer in section B–B′. Lake beds could occur below the bottom of the hole, but they have not been indicated. The fill in this Recent inner gorge poses the most critical foundation problem at Bad Rock Canyon.

Recent talus from rocks of the Ravalli group rests upon the top of the glacial terrace on the south side of the canyon, and some talus derived from Siyeh limestone occurs on the right (north) bank upstream from tunnel No. 5. The talus from Ravalli rocks consists of angular blocks with dimensions up to 10 by 10 by 20 feet, but the talus from the Siyeh limestone is comparatively fine. Both accumulations are very superficial. Older talus deposits apparently were swept away when glaciers moved through the valley.

Just above the railroad track, between the east portal of the tunnel and the trackwalker's house, are remnants of white lacustrine marl and buff or tan silt. Although marl is chiefly a spring deposit, some of these sediments evidently were laid down in marginal lakes related to glaciers that came after the last major period of canyon cutting. They are not involved in the geology of the dam site.

Country rock.—Bedrock consists of the Ravalli group, the top of the 500-foot section involved being approximately 460 feet stratigraphically below the base of the Siyeh limestone. The strata within this zone are dull-gray-green, massive argillites, 5 to 30 feet thick, with occasional thin layers of cream to tan quartzite. All of the rock is thinly and irregularly laminated, but there is no tendency to split along the laminae. Mineralogically the constituents of the beds are quartz, sericite, and chlorite. Some secondary growth of the original quartz grains has taken place, sericite has developed from the original clay content, and chlorite is especially abundant in zones subject to movement. The argillite is very strong, hard, tough, and elastic and is insoluble; its average specific gravity is about 2.7. This section of the Ravalli group is admirably suited for a dam foundation.

Dips.—In the dam-site area, the dip of the Ravalli rocks ranges from 25°, N. 37° E. to 29°, N. 50° E; the average is about 25°, N. 45° E. This direction is practically opposite to the direction of stream flow (pl. 14), and is persistent across the entire Swan Range block.

Joints.—Jointing is the tendency of rock to fracture or crack in more or less definite directions, usually at steep angles to the bedding surfaces, when under stress. At this locality, the argillite of the Ravalli group is well but not excessively jointed. Strong, widely spaced master joints block out a conspicuous series of rock spurs on the north wall of the canyon. One set of these joints strikes about N. 30° W. and dips 45° ± 5° west; the other set strikes about N. 62° E. and dips 48° to 63° S. An occasional joint in the latter set dips steeply northward. Bedding joints separate some of the more massive rock layers and probably should be included in this group of joints.

The bedding joints coincide with the dip of the strata, but occur at greater stratigraphic intervals than the average bedding surfaces. Movement has occurred along them, and has developed narrow zones of weakness along the joints, which weather open. This movement has been toward the direction of present dip, and has caused minor fracture cleavage which dips about 24°, S. 40° W. It is most conspicuous in the maroon argillite. Small overthrust faults occur in some of the thin quartzites, the overriding block moving in the direction of present dip for a foot or so. These features were developed at the same time as the fracture cleavage. Since they were formed, the entire mountain block has been rotated toward the northeast between large faults.

Some movement has occurred along the nearly vertical joints, but it is negligible.

Because of the tough, elastic character of the rock, the surfaces of the steeply inclined fractures are only moderately smooth and nowhere as sharp and clean as those which cut the lower Siyeh limestone.

About six other sets of joints cut the argillite of the Ravalli group. For the most part, they are poorly developed and irregularly spaced. Two of them appear to correspond to the master joints in the Siyeh limestone at Hungry Horse dam site. The difference in strike, dip, and spacing is unquestionably due to the difference in strength and other properties of the two types of rock.

Faults.—The rock at the dam site is not affected by faulting, although its present attitude is the result of such movements. These have taken place chiefly along the Swan and Flathead faults, which bound the Swan Range block within which the dam site is included. The Swan fault trends to the northwest along the front of the range and crosses the Flathead River about 7 miles southwest of the dam site. The main Flathead fault crosses the Middle Fork of Flathead River about 8 miles northeast of the dam site. A shear zone subsidiary to the Flathead fault crosses the river about 2½ miles upstream from the dam site.

The probabilities of movement along these faults have been evaluated in the general section on structural geology and will not be repeated here. Movement along any of the faults in the region would probably create an earthquake whose tremors would pass through the dam site.

Ground-water conditions.—Ground-water conditions at the Bad Rock Canyon dam site are difficult to evaluate because of the general lack of evidence of a deep circulation. Several occurrences of superficial ground water are present. There is a small spring at the trackwalker's house northeast of the dam site at an altitude of 3,135 feet. It is very limy, and its source appears to be in the talus at the base of the Siyeh limestone cliff, which rises behind the house. No other springs were observed along the north side of the river throughout the dam site. However, a few small seeps issue from the talus near the south abutment of the lower site, and from the alluvium along the canyon wall farther downstream. They are so obviously unrelated to the deep flow that they are valueless in estimating ground-water conditions in the Ravalli group.

Because of its density, lack of porosity, and general massiveness, the formation contains only small quantities of ground water, and that chiefly in fractures. These fractures no doubt contribute water to the talus, which is sufficiently porus to act as a reservoir, but for the most part, they facilitate the flow of water to the river. The attitude of the rock favors drainage into the reservoir, rather than leakage from it. The deep ground-water profile is probably much more gentle than the topographic profile of the valley, although the surficial talus springs apparently contradict this conclusion.

Permeability.—Permeability through the rock fabric may be dismissed as negligible. Some leakage will occur through the sheet openings, bedding, and joints. However, the bedding surfaces are generally tight, and the small amount of movement on the bedding joints has produced small quantities of gouge clay, which will form an effective seal. Furthermore, the attitude of the bedding is unfavorable to leakage from the reservoir.

The direction of only one set of joints favors leakage. These are the master joints the strike of which is parallel to the course of the river, or about S. 60° W. The other set of master joints (N. 30° W.) is almost normal to the direction of stream flow. All the other joint sets cross the stream diagonally at various angles.

Comparison of the argillite of the Ravalli group with the Siyeh limestone shows that the argillite is less well bedded and jointed than the limestone, and that the bedding surfaces are tighter and the joint surfaces less smooth and clean; therefore, it appears probable that the permeability per unit volume of the argillite of the Ravalli group is less than that of the Siyeh limestone. For the latter, the constant, K, for cracks 0.0001 foot wide was estimated to be 6×10^{-7}. The constant for cracks of this width in the Ravalli may be somewhat less than half of this value, or about 2.5×10^{-7}.

Inspection of plate 15 shows that of the total cross-sectional area of the gorge below altitude 3,110 (the maximum allowable height of pool level for a dam below track level) 69 to 74 percent is occupied by fluvioglacial deposits, alluvium, boulder clay, and minor amounts of talus. The depth of valley fill below normal stream level varies from 320 to 330 feet. This depth to bedrock foundation is out of proportion to the practicable height of dam.

If a flexible type of dam were considered for this site, considerations of permeability of the argillite of the Ravalli group need concern only the north abutment. The foundation of a flexible-type dam would be the valley fill. The permeability of this diverse material is unknown and difficult to estimate. In general, the unconsolidated gravel would be highly permeable, although the permeability of any individual pebble would be low. The permeability of the cemented gravel would be variable and would depend upon thickness and conditions of cementation; that of the compact boulder clay would be low. The permeability of the fluvioglacial material in the terrace on the south bank probably would be high and uncertain because of the presence of lenses of sand and gravel.

Foundations.—Foundation conditions may be considered from two viewpoints depending on whether the type of dam selected requires establishment on bedrock or on valley fill. The probable cross-sectional profile of the bedrock floor is shown in plate 15. The broad, flat U-form is characteristic of the glaciated gorges in this region. Except for some ridges and furrows where there has been ice-plucking, the rock floor is thought to be relatively smooth, especially where overlain by till, because it is the product of glacial scour. Throughout the dam site, the bedrock gradient probably is very low. However, if a fluviatile stage followed the Kansan (?) glaciation, there may be a narrow inner gorge like those now being cut in bedrock in some of the post-Wisconsin canyons farther upstream. Under fill of the depth now occupying the valley such minor features would be very difficult to ascertain, and drilling on closely spaced centers will be necessary to detect them.

In summary, the Ravalli argillite, if it can be reached, will provide at this locality a foundation that will be more than adequate for any demand that can be made upon it. The principal defect of this foundation is that it is too deep.

Foundations upon the valley fill would be less deep, but difficult problems would arise because of its complex arrangement and variable character. The active or superficial layer of unconsolidated river gravels would have to be removed. If exploration shows that the Wisconsin glaciers failed to sweep the canyon clean of the older fluviatile deposits and till, and if substantial remnants exist, as is suggested in plate 15, A–A′, optimum conditions for a shallow foundation for a wide-base dam may occur. The older drift is likely to be more weathered, clayey, and softer than the young buff till, but it is highly impermeable, and its bearing power in large masses is believed to be adequate, particularly where it has been overridden and compacted by later glaciers.

Unquestionably a foundation on deposits of lake-bed lithology would be difficult because the deposits are soft, fine-grained, and of uncertain bearing power.

If the Recent river gravels, cemented or not, persist to bedrock, as they may in the deep inner valley pictured in plate 15, A–A′, the foundation also will be difficult. Seepage rather than bearing power will be the chief problem, as the gravel is relatively uncompactable because of the large amount of fresh pre-Cambrian pebbles with high crushing resistance. Flow through unconsolidated gravel probably will be uniform, but percolation through the cemented gravels is likely to be variable because of irregular conditions of cementation. These conditions will probably require a deep cut-off wall.

Abutments.—The argillite of the Ravalli group in the valley walls provides sound abutments of essentially equal bearing power, resistance against sliding, and permeability. Similar conditions prevail in the Siyeh limestone, which would be encountered in construction above altitude 3,200 feet in section A–A′, plate 15.

The north abutment of this section should give no trouble, but the south abutment would involve both rock and the fluvioglacial deposits on the terrace. A dike and cut-off wall across this terrace would be essential. In a high wide-base dam these conditions would pertain to the foundation.

Comparison of dam sections.—Two possible low dam sections exist at this site. (See pl. 15.) The upper section, A–A′, has for its north abutment the rocky spur just below the middle of the tunnel spur. The axis extends southeastward to the rock cliff that stands above the river on the stratified drift. Thus, the south rock abutment is buried deeply and would require extensive excavation. For any height of dam less than 50 feet, the south abutment of this section would consist of the stratified drift. This would result in very unequal bearing power of the abutments, the south being weaker and more permeable than the north. The most disadvantageous feature of the north abutment is the presence of the railroad tunnel through the spur. The heavy vibrations set up by the passing trains may eventually weaken the rock above the tunnel, and cause some vibration in a dam attached to this abutment. Foundation conditions are complex and involve two glacial deposits, the older till and the stratified Wisconsin drift, as well as the Recent sand and gravel in the river bed. Other glacial deposits such as Wisconsin till and the beds of glacial Lake Missoula also may be present but have not been revealed by exploration.

The axis of the lower section, B–B′, parallels that of the upper site, and is 950 feet downstream. The north abutment is mantled lightly with fluvioglacial material and would require excavation. A nearly vertical rock cliff makes the south wall of the valley. Foundation conditions are relatively simple and consist of a 100-foot layer of Recent gravel over a deep fill of sediments of probable lake-bed origin.

Comparison of the cross-sectional areas of fill are given in the table on plate 15.

Choice of section.—Section B–B′ appears to have several surficial advantages over A–A′ for a low dam. These are a shorter crest line, better exposure and form of abutments, a somewhat greater area of open valley below crest line, a somewhat smaller area of fill, and a better spillway site. Nevertheless, these favorable attributes seem to be offset more or less completely by the deep and weak foundation. The choice of section must go, therefore, to A–A′, where the foundation appears to have certain elements of strength and the unfavorable areas are of limited extent.

Section A–A′ also appears to have the best foundation conditions for a dam high above track level, although the shortest section is about 600 feet downstream, through Corps of Engineers' drill hole No. 1. The approximate dimensions of the sections at this place are as follows:

Altitude of crest (feet)	Height above river (feet)	Height above foundation (feet)	Length of crest (feet)	Area (square feet)		
				Open	Buried	Total
3,450	430	770	1,875	488,800	162,000	650,800
3,350	330	670	1,400	324,800	162,000	486,800
3,250	230	570	1,100	200,800	162,000	362,800

Because of the considerable depth to foundation, the higher the dam the better the ratio of effective height to total height above foundation. Unfortunately, foundation conditions for this section probably are similar to those illustrated in section B–B′.

Dimensions of possible dam.—In view of the many uncertain conditions at this site, it seems unwise to consider details of size of dam until sufficient information is available to suggest the type of structure most suitable for the site. In general, it appears that it should be a broad-base flexible dam, and it also appears that it will have to be either very small or very large. Convincing arguments for a low dam are difficult to develop.

Appurtenant works.—Spillway requirements for a dam below track level are large because of the lack of storage and because the discharge of the entire river has to be accommodated. Construction of storage dams upstream on the main Flathead, South Fork, or Middle Fork would reduce it materially. Even so, no adequate spillway section appears to be available, and this, aside from the deep foundation, is a major disadvantage of the site. This lack may require consideration of an overflow type of dam. The matter of spillway routes is also difficult for a high dam, although such a structure would have adequate storage capacity. The flare of the left bank at altitude 3,250 feet or the right bank at altitude 3,350 feet suggests possible locations for spillways of moderate capacity.

The most convenient location for a powerhouse for a low dam would be on the rock bench on the right bank. Powerhouses for high dams probably could be incorporated in one or the other of the abutments.

Reservoir area.—The geology of the Bad Rock Canyon reservoir area is covered in part by the descriptions of the Hungry Horse, Coram Canyon, and lower Canyon Creek dam sites, and in part (for the high dams) by the description of the upper Canyon Creek, the Fool Hen, and the Glacier View dam sites. The geology of that part of the reservoir on the Middle Fork above Belton has not been described. Over the area of the Coram basin the surface is occupied chiefly by alluvium and glacial drift. Near the east quarter corner sec. 19, T. 31 N., R. 19 W., there are extensive deposits of gray to purplish-gray silt of probable early Pleistocene age which contain carbonaceous streaks and fragments of carbonized logs. A small amount of prospecting has been done. On the right bank of the river in NE¼NE¼ sec. 19, rather extensive prospecting has been carried on without revealing workable coal deposits. An adit strikes N. 45° W. and follows a carbonaceous zone in reddish-gray clay into the bank for about 500 feet. The dip is about 15° northwest. This formation seems to have been mistaken for the Tertiary coal-bearing rocks which are worked at the North Fork coal mine, lot 8, sec. 33, T. 34 N., R. 20 W. Circumstances did not permit complete investigation of these deposits, but it appears that the lignite is of low rank, very thin and irregular, and probably of no commercial value.

If a low dam at this site were to raise water to altitude 3,100 feet, the impounded water would flood the confluence of the main Flathead with the South Fork, and come within a quarter of a mile of the mouth of the Middle Fork.

The area and capacity for the reservoir of a low dam are given in the following table computed by Arthur Johnson.

Altitude of water surface (feet)	Area (acres)	Capacity (acre-feet)
3, 027	0	0
3, 040	272	1, 720
3, 060	746	11, 950
3, 080	1, 120	30, 610
3, 100	1, 930	61, 110
3, 120	2, 730	107, 700

Water would be backed up the South Fork for about 3 miles above Hungry Horse dam site. If that structure were in existence the pool at its toe would be deepened by about 50 feet. This would interfere with under-drainage of the dam foundation and increase uplift forces.

Water backed up the main Flathead would drown out the Coram Canyon dam site, and the piers of the railway bridge at Coram.

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Construction of this dam would flood also some 17 acres of bottom land now used for small farms. A flood over the remainder of the area, now largely overgrown with second-growth lodgepole pine and tamarack, would cause small damage.

The principal cultural change resulting from development of a reservoir with pool level at 3,110 feet would be the rerouting of United States Highway No. 2 between Columbia Falls and Coram. This road would have to be abandoned for several miles in the vicinity of the mouth of the South Fork. The logical rerouting would be to cross the main Flathead at the bridge just below the mouth of the Middle Fork to the North Fork road northeast of Teakettle Mountain, and thence into Columbia Falls.

For dams with pool levels higher than the grade of the Great Northern Railway, the reservoir would necessitate cultural changes so extensive that it is not possible to consider them here in detail. Among them would be flooding the southwest corner of Glacier National Park, including Belton and Lake McDonald; rerouting the Great Northern Railway, between Columbia Falls and Essex (Walton); and rerouting United States Highway No. 2 between the same localities.

Some idea of the extent of the reservoir may be obtained from the following tabulation:

Probable extent of proposed reservoirs above Bad Rock Canyon

Flathead River (North Fork)

Altitude of crest	End of backwater	Miles above Bad Rock Canyon
3,450	SE cor. sec. 12, T. 34 N., R. 21 W., 10 miles above Glacier View dam site	34
3,350	N½ sec. 10, T. 33 N., R. 19 W., 2½ miles above Glacier View dam site	27
3,250	NE cor. sec. 3, T. 32 N., R. 20 W	20
	Middle Fork	
3,450	SE cor. sec. 36, T. 31 N., R. 17 W., Mile 26 above mouth	34
3,350	SW cor. sec. 17, T. 31 N., R. 17 W., Nyack (Red Eagle Station), Mile 19	26½
3,250	NW cor. sec. 34, T. 32 N., R. 18 W., Mile 11, just below Lincoln Creek	20
	South Fork	
3,450	NW¼ sec. 32, T. 27 N., R. 16 W., Mile 37½, just above Deadhorse Creek	38
3,350	NE¼ sec. 34, T. 28 N., R. 17 W., Mile 29½, 1½ miles below Elk Park R. S.	30
3,250	SE¼ sec. 31, T. 29 N., R. 17 W., Mile 21½, just below Clarinda Creek	22

Estimates of storage capacity for large reservoirs above Bad Rock Canyon have not been made because of incomplete topographic mapping. The capacity of the reservoir of a dam below track level would be small, and probably insufficient to take the head off of a large flood. There would, however, be no question of the efficiency of the larger reservoirs for flood control.

Ground-water conditions favor a tight reservoir, and there appears to be small possibility of leakage except in the vicinity of the prospective dam site, which can be remedied by grouting. Up to altitude 3,400 feet the distance through the Parker Hill saddle (Cedar Creek-Bailey Lake divide) seems to be sufficient to retard seepage from the reservoir, and the filling material consists of tightly packed, impermeable Wisconsin drift that retains water in glacial potholes at Spoon Lake and Bailey Lake. Depth to bedrock at the Cedar Creek divide, NW¼ sec. 10, T. 31 N., R. 20 W., is unknown but is not considered great because exposures of Siyeh limestone from the Whitefish Range extend almost to creek level. There may, therefore, be a bedrock divide above any level to which water may be raised. If the Bad Rock Canyon site should ever be considered for construction to altitude 3,500 feet or higher, the contingencies of leakage through this saddle should be investigated.

Silting in the reservoir will be negligible.

Conclusions and recommendations.—A low dam at Bad Rock Canyon would create about 90 feet of head, which would be useful for power but not for storage or flood control. The site at section A–A′, plate 15, is safe, but it has a rather deep foundation and a very large spillway requirement; presumably necessitating a dam of the overflow type. If pool level were established at altitude 3,110 feet, the Coram Canyon site would be drowned out, a pool 50 feet deep would be created at the toe of Hungry Horse dam, and United States Highway No. 2 would require rerouting northeast of Teakettle Mountain. The site merits consideration, but is of secondary importance in any plan of river development.

However, if the limitations imposed by the railway are ignored, as they should be for a complete inventory of the potentialities of the site, Bad Rock Canyon commands more attention because it is the one place where entire control of the upper basin of Flathead River may be obtained. The controlling altitude for a high dam at Bad Rock Canyon is 3,450 feet. Economical dam sections are available at altitude 3,250 feet for a dam of medium height, and at 3,350 feet or above for a high dam. Section A–A′, plate 15, appears to have the best foundation for a high dam, but the shortest high section is about 600 feet downstream. Depth to bedrock foundation is believed to be about 350 feet in midvalley and may not be attainable. If the old till occurs below the terrace on the left bank (plate 15, A–A′), a comparatively shallow foundation for a wide base dam may occur. This prospect warrants further exploration, and a hole to bedrock foundation should also be put down in midchannel to ascertain depth to bedrock and to see if the Recent gravels are underlain by lake beds at depth.

The history of exploration at Bad Rock Canyon is a good illustration of a too common tendency to terminate investigation of a prospective dam site on the basis of incomplete and unfavorable information. Simply because one boring shows a deep foundation, or weak rock, or some other condition that is regarded as unfavorable to an anticipated or preconceived concept of design is not a scientific reason to terminate investigation of a project. More thorough exploration may reveal unsuspected redeeming features, and complete knowledge of a site may give an engineer of bolder imagination greater scope for originality and freedom of design. With inadequate exploration one will never know reality at a dam site or whether remedial measures can be devised. Today the tendency is to approach the ultimate possibilities of river utilization, but this cannot be achieved by limited objectives in dam-site exploration.

CORAM CANYON DAM SITE

(See pls. 12, 16, and 17)

Location.—South center of sec. 5, T. 30 N., R. 19 W., on the main Flathead River.

Accessibility.—The locality is about 2½ miles upstream from the Bad Rock Canyon dam site. The town of Coram and the railroad bridge over the Flathead River are 1½ miles to the north. The railway follows the southeast spur of Teakettle Mountain, and is about three-fourths of a mile from the gorge section of the dam site at the nearest point. United States Highway No. 2 passes about a quarter of a mile south of the south abutment.

Catchment area.—Entire drainage area of North and Middle Forks of Flathead River, about 2,600 square miles.

Stream gradient.—Six to seven feet per mile through the dam site.

Purpose.—Power, storage, and regulation.

Valley profile.—The cross-sectional profile of Flathead River Valley at this locality is wide and imposing (pl. 17), and benches and terraces characterize the sides and floor. The right wall is formed by the southeast spur of Teakettle Mountain, whose steep side plunges below the fluvioglacial plain nearly a mile north of the river. The south wall of the valley consists of a high, broad lateral moraine flanking the north side of Lion Hill. The highest bench is the irregular surface of this moraine, whose summit level stands approximately at altitude 3,600 feet. This feature descends riverward by a series of steps to the valley plain at 3,150 to 3,100 feet.

A narrow rock ridge plunges northward from the slope connecting the moraine surface with the valley floor, and disappears below the surface about a quarter of a mile north of the river. Below the wide expanse of fluvioglacial deposits north of the end of the ridge lies the buried preglacial and principal glacial channel of Flathead River. This ancient gorge was more than half a mile wide from rim to rim, and of corresponding depth. Projection of the bedrock surface in the valley bottom at Bad Rock Canyon upstream for 2 miles at the rate of 6.75 feet per mile give a rough figure of 2,713 feet for the altitude of the bottom of the buried valley at Coram Canyon. Reference has been made (p. 149) to the resistivity work that was carried on during 1935 on the left bank of Flathead River in the vicinity of the mouth of Abbott Creek about half a mile up river from the head of Coram Canyon. The data obtained were erratic, as might be expected over a buried river bank with tributary gulches. Maximum depths obtained to bedrock were about 350 feet, indicating an altitude for bedrock of about 2,690 feet, but the bedrock level over the midvalley may be somewhat less. Taking an average altitude of 2,700 feet, the depth of the buried valley is about 300 feet lower than the deepest part of the active gorge, and about 450 feet lower than the surface of the outwash that conceals it. (See pl. 17, A–A′.)

Toward the end of the Pleistocene epoch the river was superimposed over the south end of the rock ridge at about altitude 3,150 feet and has incised it sharply, forming the unglaciated gorge in which the dam site is situated. This gorge has no local name, and is called Coram Canyon in this report for the small town of Coram 2 miles upstream. Its total length through the ridge is about one-fourth of a mile. The top or rim is defined by the 3,100-foot contour, and at this altitude it is about 150 feet wide. Mean altitude of water surface is about 3,043 feet, and at this altitude the width is about 100 feet. Just below low water surface (3,025 feet) is a rock bench up to 25 feet wide extending almost continuously along the left bank and, in many places, along the right bank. There is thus a submerged inner gorge about 50 feet wide and 25 to 30 feet deep. The total depth of Coram Canyon is therefore about 110 feet, and it is a much smaller and younger feature than the buried valley on the north side of the valley.

Apparent possible height of dam.—The controlling altitude for a dam at Coram Canyon is about 3,450 feet and occurs on the Cedar Creek-Bailey Lake divide in NW¼ sec. 10, T. 31 N., R. 20 W., the same place as that for Bad Rock Canyon dam site.

Coram Canyon dam site is analogous to Bad Rock Canyon dam site in that there are possibilities for two heights of dam—a very low structure utilizing only the postglacial gorges, or a much larger and higher one extending from the north spur of Lion Hill to Teakettle Mountain.

This latter project is largely suggestive, and it has not been studied in detail because of a lack of high-level mapping and because it can be attacked only by deep, extensive drilling and geophysical investigations—means that were not available when the fieldwork was carried out. It appears, however, to offer interesting possibilities as a partial alternative to the concept of a high dam at Bad Rock Canyon, as it would not control South Fork of Flathead River; and it is open to some of the same cultural objections that confront the high dam at Bad Rock Canyon.

It is doubtful, however, whether it would be economical to raise a dam above altitude 3,250 feet. Width of valley is about 7,100 feet at this level but increases rapidly at higher elevations, for which figures are not available. Maximum height of dam to crest at altitude 3,250 feet would be only 250 feet for a limited section in the active gorge. The total depth of fill in the preglacial channel approaches 450 or possibly 500 feet, and the height of dam over the constructional terrace that conceals it would be only about 125 feet. This part of the structure, however, would require a deep cut-off wall through the permeable fluvioglacial fill that caps the terrace. Hence, although the site requires a long dam, it would not have to be very high.

The 3,100-foot contour makes the highest possible crest for a dam in the active gorge. (See line C–C′, pl. 17.) Height above foundation at that place would be about 80 feet. By setting the dam along the axis of the ridge in the deepest part of the gorge and building a supplementary dam or dike in the cut-off channel around the north end of the ridge, an additional 20 or 30 feet of altitude can be obtained. (See line B–B[5], pl. 17.)

Character and depth of valley fill.—Fill conditions exist at three localities in the dam-site area: in the active gorge, in the cut-off channel around the rock ridge, and in the buried valley north of the ridge.

The river sweeps through the narrow, active gorge with such force that it contains very little fill downstream from the mouth of the cut-off channel in the right bank. What there is consists of loose fresh gravel from rocks of the Belt series. Just below the mouth of the canyon the stream loses velocity where the channel widens, and the gravels swept through the gorge are piled up forming an island. Upstream from the mouth of the cut-off channel, the depth of water is less. Bedrock is exposed on bottom at locality 1, at the foot of a fast riffle over gravel. This seems to indicate that the shallow condition is due to a rapid rise in stream bed rather than to an increasing amount of fill.

The fill in the cut-off channel is shallow, and consists chiefly of fine gravel and sand with minor amounts of silt. The channel is active only during flood or when the water surface stands higher than 3,045 feet. Bedrock appears in the floor at the inlet and outlet and at intervening places, and the entire fill is unconsolidated, superficial, and intermittently active.

The problem of the fill in the buried preglacial channel is more complex. At locality 2, the left bank consists of two till sheets separated by a thick layer of interglacial river gravel. This section has been described in detail in the report on the Hungry Horse dam site.[43] Resistivity work in the stream bed above this locality indicates the fill to be of considerable depth and to consist of clay or boulder clay probably related to the oldest glaciation. Presumably similar conditions occur in the buried valley, but there the upper part of the fill consists of more or less permeable masses of fluvioglacial material (late Wisconsin age). As long as the height of dam is confined to altitude 3,100 feet, there is no danger that water will rest upon this fill. Upstream from the dam site, water will rest against it along the right bank. The path of percolation around the right abutment is at least a mile, and seepage troubles are not anticipated.

For a higher dam, however, this deposit may have to serve as part of the foundation, and a cut-off wall would have to be put through it, possibly to river level. Occasional boulder trains may cause difficulty in this operation. It is also probable that boulder clay of the Kansan (?) stage has been eroded from the middle part of the buried valley. The manner in which the valley changes direction indicates that post-Kansan (?) river erosion took place against the north side of the limestone ridge in the right abutment of the active gorge, leaving a buried till terrace under the right bank of the preglacial valley. These conditions are essentially the reverse of those believed to prevail at Bad Rock Canyon (pl. 15, A–A′). Exploration of the buried Abbott Gorge leading out from Hungry Horse reservoir site has revealed a deep extensive fill of undifferentiated Illinoian(?)-Kansan(?) stratified drift. Although variably weathered, the old boulder clay is firm and compact, yielding good core recovery, and it should make a strong foundation for a wide-base flexible dam. The till itself is fairly impermeable but may contain thick highly permeable sheets of outwash gravel, or lentils of fluvioglacial material, and layers of impermeable "lake-bed" silt and clay of uncertain bearing power. The old drift occupying the preglacial gorge of Flathead River probably will be found to dip upvalley or eastward, as it does at the head of Coram Canyon, but the rate of dip is expected to decrease westward toward Bad Rock Canyon. The chief exploration problem of Coram Canyon dam site is the delineation of the buried preglacial valley and this old drift.

[43] Erdmann, C. E., Geology of the Hungry Horse dam and reservoir site, South Fork of Flathead River, Flathead County, Mont.: U. S. Geol. Survey Water-Supply Paper 866-B, pp. 64–65, 1944.

Country rock.—The rock ridge through which the dam-site gorge has been cut consists of the upper part of the Siyeh limestone. This formation also forms the foundation and abutments of the Hungry Horse dam site on South Fork of Flathead River, and it has been described at considerable length in the report on that project.

Petrologically the formation is a slightly metamorphosed, impure, siliceous, magnesium (dolomitic) limestone; well bedded and thoroughly jointed. The fresh rock is dense, strong, and rigid, and has an estimated crushing strength of about 10,000 pounds per square inch. Hardness is between 4 and 5 on the mineralogical scale, and consequently the rock yields readily to river corrasion. Chemical tests have indicated that the formation is relatively insoluble, and that the passage of water through it will not cause weakness during the useful life of a dam. Very little weathered rock is present.

Detailed measurements of about 170 feet of the formation made on the north side of the cut in which United States Highway No. 2 passes over the rock ridge has been given in the description of the Siyeh limestone in the Hungry Horse report.

The rock in the south or left abutment of section C–C′ is essentially the same as that across the river. It consists chiefly of gray to dark-gray limestone, dolomitic limestone, with minor amounts of sandy limestone, and a few thin layers of quartzitic sandstone. Most of the massive rock shows the short, thin, irregular veinlets of dark calcite which have a "crinkly" appearance. Some bedding surfaces show filled mud cracks which appear to extend into the crinkly veinlets, but they are not related. The beds vary in thickness from 0.50 inch to 2.0 feet. The dolomitic laminae are more yellowish, average 0.25 inch thick, and are harder, weathering into ridges showing 0.12 to 0.37 inches of relief.

Dips.—On the right bank, downstream from the canyon, the strata dip 38° to 47° NE. Along the axis of the rock ridge, the dip decreases to 30°, N. 50° E., and then gradually increases again. Opposite the head of the cut-off channel, it is 38°, N. 50° E. A ledge which projects into the river near locality 1 dips 52°, N. 48° E., and the exposures farthest upstream on the left bank dip 56°, N. 55° E. Throughout the dam-site area, the average dip and direction is 41°, N. 46° E. The increase in amount of dip upstream is toward the top of the Siyeh limestone and is due to a shear between the rigid, brittle limestone and the more elastic argillite.

The upstream dip is a favorable feature and adds considerable strength to the foundation and abutments since it does not favor sliding and retards percolation.

Joints.—The rock in the dam-site area is thoroughly fractured, and numerous observations were made on the joints and related structures.

From more than 50 observations, the following summary has been prepared, grouping the fractures with reference to strike. The average dip is 41°, N. 46° E.

Character	Trend	Percent
Approximately parallel to strike	N. 32°-52° W	26
Approximately parallel to dip	N. 36°-50° E	20
Diagonal to strike	N. 73°-85° E	12
	S. 22° W. to S. 4° E	20
Miscellaneous		26
Total		100

If direction of dip of the joints also is considered, the number of classes or sets is doubled, because fractures parallel to the strike may dip either northeast or southwest and so on. Thus, the rock in the abutments of dam section C–C′ shows the following fracture systems:

Right abutment C				Left abutment C′		
Strike	Dip	Spacing		Strike	Dip	Spacing variation
		Variation	Average (feet)			
N. 83° W	65° NE	1.5 in.-3.0 ft	2.5	N. 69° W	68° SW	3.0 ft.
N. 41° W	53° SW	6 in.-7.0 ft	4.0	N. 35° W	52° SW	10 in.-3.0 ft.
N. 18° W	81° SW	1-6 ft	1.5	N. 25° W	53° SW	6.0 ft.
N. 2° E	76° SE		5.0	N. 3° W	62° SW	2-7 ft.
N. 16° E	86° SE	2.5 ft		N. 14° E	70° NW	1-4 ft.
N. 23° E	85° SE	8 in.-4.0 ft	1.5			
N. 39° E	89° SE	3.0 ft		N. 35° E	82° SE	1.5-4 ft.
N. 75° E	70° NW	6 in.-8.0 ft	3.0	N. 73° E	82° NW	2.5-4 ft.
N. 82° E	86° SE	3-8 ft		N. 83° E	72° SE	8 in.-3.0 ft.

The sheet openings, bedding, and joints, of the rock in the left abutment may be summarized as follows: The impure gray limestone near the base of the outcrop shows the following openings per cubic foot of rock. The laminae vary in thickness from 0.12 to 2.0 inches, and about 16 bedding surfaces occur in each foot of rock, 11 of which show appreciable cracks on which the rock might split, the widest being 0.04 inches. The total gap per foot amounts to about 0.25 inches. Twelve cracks are parallel to the strike, spaced at intervals of 0.08 to 3.0 inches. The maximum width is about 0.05 inches, and most are tightly closed and too thin to make field measurements on. Four cracks are parallel to the direction of dip, the widest being about 0.02 inches.

The dark-gray massive limestone with the healed veinlets of dark calcite shows no fractures, and the bedding surfaces are tightly welded.

The impure dolomitic limestone is more finely laminated, the thickness of the layers varying from 0.05 to 0.50 inch. An average of 53 bedding surfaces is present in each foot of rock. The width of the widest bedding cracks is about 0.05 inch. Nearly half show widths of 0.005 to 0.025 inches, and most of the other are smaller. The strike joints are thin, 0.025 inch, and average only two per foot. Joints parallel to the dip average only three per foot. One of these is about 0.08 inches wide, and the others are 0.10 inch wide. This rock is soft, elastic, and nodular and does not fracture so thoroughly as the more brittle rock.

In the tabulation of joints at points C and C′ on the map, only four sets are common to both localities. They are the master joints of the region. Those parallel to the strike and to the dip appear to be related to the thrusting movements from the southwest. Some of the diagonal joints may also be due to these movements, but others occurred later. The joints of greatest concern with respect to percolation through the foundation are those parallel to the direction of dip, for they also control the trend of the gorge through the ridge.

Faults.—The progressive increase in amount of dip from the dam-site gorge upstream suggests the possible presence of a fault crossing the river upstream from the dam site. However, the investigation of the Hungry Horse project showed that a similar increase of dip eastward is due to a shear zone about 1,500 feet wide in the upper part of the Siyeh limestone and basal Missoula group. Its localization at this horizon is thought to result from the marked difference in physical properties of the brittle limestone and the more plastic argillite. This shear zone is related to the great Flathead thrust fault which, at its nearest point, lies about 6 miles northeast of the dam site. It is crossed by the highway and Middle Fork of Flathead River, just above Belton, 8 miles upstream. The Swan fault of similar character lies about 7½ miles southwest at its nearest point. It may be safely said that no major fault occurs within the dam-site area.

There are, however, a number of small faults in the dam-site area, which may be classified as bedding faults, reverse faults, and normal faults.

Typical bedding faults are characterized by fault surfaces whose strike and dip are parallel to the strike and dip of the strata, but in some places the dip may steepen and the faults cut across the beds or pass from one bedding surface to another. This set of faults is the oldest, and is due to the adjustment of the competent strata by gliding during an early period of deformation. Practically all of this movement was confined to the bedding surfaces. Where determinable, the upper of any pair of beds separated by such a fault appears to have moved northeast. The amount of movement along these faults is unknown, but judging from the thickness of the gouge and breccia, the displacement must have been considerable. For this reason, in any stratigraphic section, the present superimposition of strata is not the original superimposition. Because of homogeneity of the formation, such shifting is not noticeable. Study of the section exposed where United States Highway No. 2 cuts the rock ridge (pl. 17, A–A′) shows that a fault of this character occurs approximately every 20 feet of section. The attitude of fracture cleavage, developed occasionally, suggests that the strata containing these faults have been rotated about 90° eastward by movements on the Swan and Flathead faults.

A bedding fault occurs on the left bank near locality 1; strike N. 35° W., dip 52° NE. The gouge varies in thickness from 2 to 6 inches and consists of angular fragments of limestone and dolomite in a matrix of gray to buff clay and pulverized limestone.

A similar fault strikes N. 40° W., dip 50° NE. in the left abutment of the dam section near C′. (See pl. 17.) The gouge zone varies in thickness from 8 inches to 2 feet. About half of the material is limestone breccia, and the matrix of ochre to gray calcareous clay forms the remainder.

The reverse faults are of later origin than the bedding faults and also are parallel to the strike of the strata. Their dip, however, varies from 41° to 50° SW. Thus they cut the bedding nearly at right angles. Direction of movement is from the southwest. Offset was not recognized, but the thickness of the gouge suggests that the displacement may have been considerable.

A reverse fault occurs on the left bank near locality 1. The strike is N. 45° W., and the dip is 41° SW. Gouge is about 2 inches thick and consists of buff and gray clay with minor limestone fragments. Another one is present in the left abutment of the dam section below C′. (See pl. 17.) The strike is N. 33° W., dip 42° SW. Gouge varies in width from 2 inches to 1 foot, and consists of a breccia of hackly fractured fragments of gray to cream-colored limestone with a few pieces of dark-gray limestone. The matrix is gray to ochreous calcareous clay. Still other faults of this set crop out on the left bank in the middle of the gorge near locality 3.

Technically, the fault which crops out on the left bank below B^5 (pl. 17, B–B^5) is a normal fault, as the upper or southwest block has moved downward to the southwest, and the northeast block has been thrust upward toward the northeast. Actually, however, it belongs to the same system. What happened was that the formation was sliced into narrow blocks which moved as units. The block whose lower boundary is the so-called normal fault is one that has remained relatively stationary or moved downward between blocks that moved relatively upward. The gouge on this fault is the thickest observed in the dam-site area and varies from 1 to 4 feet in width. The material consists of fragments of limestone and dolomite in a matrix of buff to gray calcarous clay.

Possibly related to faults or blocks of this character is the joint set which strikes N. 30° to 40° W. and dips 53° to 56° SW. Ordinarily these fractures occur closely spaced in groups of three; the groups being 1 to 3 feet apart. All are sharp and well defined. Approximately one-third show displacements of only a foot or so; the fractures are always upon the middle one when three are present. Downthrow is to the southwest. These small normal faults probably occur in one of the thin blocks or slices, which was relatively stationary, or they may have developed after the thrust movements by minor relaxative stress.

Typical normal faults are uncommon in the dam-site area, only two having been observed, because the region has been subjected to compression rather than tension. The faults strike normal or diagonal to the trend of the thrust and bedding faults. One, noted in the left abutment of dam section C–C′ (pl. 17), strikes N. 50° E. and dips 55° SE. The gouge zone varies in thickness from 2 inches to 1.5 feet and consists chiefly of clay. A similar fault occurs on the left bank downstream above locality 3, and it is also shown below B^5 in section B–B^5. (See pl. 17.) This fault strikes N. 72° E. and dips 66° SE. The gouge varies in thickness from 8 to 12 inches. In the thrust fault at this locality the gouge zone is only 3 to 10 inches thick. However, at the intersection of the two faults, the width of the gouge increases to 3 feet. Three faults intersect below the surface in the left abutment of section C–C′, and it is probable that a wide zone has developed there, too. These places form weak zones, which weather out as caverns.

Ground-water conditions.—The ground-water table in the north (right) bank appears to be low, because of the porous character of the glacial drift. Springs were not observed. However, on the south (left) bank at locality 2, a small waterfall cascades into the river with a 125-foot drop. The source of this stream is a series of springs, which issue from the contact of late Wisconsin till with the underlying pre-Wisconsin interglacial river gravel. This horizon terminates about 600 feet to the southwest, where the glacial deposits lap over the rock ridge, and springs were not observed along the left bank below the dam site. The altitude of the top of the zone is about 3,165 feet, and thus has ample freeboard above the pool level of a low dam. There is no possible chance of reversal of springs in this zone by flooding of the reservoir. The glacial pothole lakes in the overlying till, are one source of the water, and the lower part of Abbott Creek, which enters the Flathead about 800 feet upstream from locality 2, may also contribute a considerable volume.

Permeability.—The problem of seepage at this site involves the permeability of the Siyeh limestone in the foundation and abutments and losses through the preglacial gorge north of the dam site. Only the former will be mentioned here; discussion of the latter will be considered under leakage from the reservoir.

The considerations that were applied to the problem of permeability of the Siyeh limestone at Hungry Horse dam site [44] also may be applied here. However, the fact that direction of stream flow is opposed to that of dip greatly reduces the permeability, as percolation along bedding surfaces and strike joints is virtually eliminated. Furthermore, the presence of three intersecting sets of faults, each with a practically impermeable gouge, forms a network of thin clay seams that seals off percolation along the joints striking N. 73°–85° E., which more or less parallel the course of the stream. Assuming the cracks to be 0.0001 foot wide and that there are about 10 square feet of crack in each cubic foot of rock, one-third of which are permeable, the coefficient for the entire formation at this place is estimated to be 2×10^{-7}. This coefficient represents the quantity of water in cubic feet per second per square foot of surface exposed to percolation passing through 1 foot of rock with 1 foot of head.

Dam sections.—Two low dam sections are available at this site, B–B^5 and C–C′. (See pl. 17.) The section B–B^5 follows the axis of the rock ridge and has four deflection or angle points, B^1, B^2, B^3, and B^4. This variable course is necessary to accommodate the section to favorable topography. Its total length is 2,150 feet. For a pool level at 3,100 feet, two dams will be required. That in the gorge would have a crest length of about 240 feet and a height above foundation of 100 feet. The cross-sectional area is about 14,810 feet. The cut-off channel section has a crest length of 240 feet, a height above foundation of 60 feet, and a cross-sectional area of about 10,470 square feet. The total cross-sectional area is about 25,280 square feet.

For a pool level at 3,120 feet, the dimensions of the necessary structures in section B–B^5 are: In the gorge section, length of crest is 320 feet, height above foundation is 120 feet, and cross-sectional area is 19,900 square feet; in the cut-off section, including dike on right bank, length of crest is 280 feet, height above foundation is 80 feet, and cross-sectional area is about 16,800 square feet; in the dike section B^2–B^3, length of crest is 260 feet, height above foundation is 25 feet, and cross-sectional area is about 5,080 square feet. Total cross-sectional area is about 41,820 square feet, or an increase in cross section of about 60 percent for an increase in height of 20 feet.

[44] Erdmann, C. E., op. cit. pp. 92–95.

Section C–C′, which has a maximum possible pool level of 3,100 feet, consists only of the gorge section. Length of crest is 400 feet, height above foundation is 80 feet, and cross-sectional area is 22,875 square feet.

A section for a high dam has not been determined in detail, but it probably would adhere closely to line A–A′, plates 16 and 17. Length of crest at altitude 3,250 feet is estimated at about 7,100 feet. From the cut-off channel (B^1–B^2, pl. 17) to the left abutment, bedrock foundation would be at the surface or under light cover. All the geologic features that affect the foundation and abutments of the low dam sections are significant in the foundation of the high dam section. The fault zone at locality 3 persists southeast, and good exposures of bedding faults and a normal fault occur on the north side of the cut where United States Highway No. 2 crosses the line A–A′. This locality does not occur within the area of detailed mapping, so these faults are not shown in section A–A′, plate 17, which necessarily is much generalized.

Abutments.—Abutments for low dams in both gorge and cut-off channel sections are essentially the same in lithology, stratigraphic units, attitude of strata, joining, and fracturing. Obviously, bearing power and seepage conditions are also equal. This is so because of the homogeneity of the formation and because the river flows squarely across the strata.

The most serious problem is in the left abutment of section C–C′, where three faults intersect below the surface. Fortunately they are so situated that the intersection can be excavated.

Foundation.—Foundation conditions for low dams are simple at this locality. The massively bedded, dolomitic limestone dips upstream at an average angle of 41°. The features which appear in cross section in the abutments occur in plan in the foundation. The foundation is strong and secure, and there is no danger of sliding. There is a possibility that exposure of foundation may reveal a fault zone with gouge striking through the gorge, but if such a feature is found, it will be narrow and will not impair the footing.

The amount of alluvial material in the gorge is small, but it increases upstream. The floor is practically bare in section B^4–B^5, although the water is deep. In section C–C′, where the water is shallower, the amount of alluvium is greater and the altitude of bedrock is higher. The alluvium consists of hard, fresh, unconsolidated sand and gravel. It probably is not watertight, and it will not stand unless cribbed.

Foundation in the cut-off channel is almost bare, and only one narrow, shallow channel is occupied by silt and sand. Excavation in this channel should offer no difficulty.

Foundation for the dike section B^2–B^3 will involve the removal of some glacial drift, which may be firm and compact below the soil layer. The underlying rock is probably partially weathered and some of it may have to be removed. This also applies to the dike section between B and B′.

Reference to foundation conditions for a high dam have been made under the headings Character and depth of valley fill (p. 170) and Dam sections (p. 170).

Choice of section.—The selection of the best site for a low dam is governed by many conditions, which do not fall within the scope of this report. If maximum head is desired, the choice is limited to section B–B^5.

If less head (altitude crest 3,100 feet) is satisfactory, the choice lies between B–B^5 and C–C′. Section C–C′ has a crestline 80 feet shorter, shorter height of dam, and its cross-sectional area is about 9 percent less than the combined sections of the gorge and cut-off channel in B–B^5. For these reasons, it appears to be the most economical. An adequate spillway probably could be made over the right abutment into the cut-off channel, and this could be used also for a spillway in section B–B^5. Cofferdam construction will be necessary at C–C′, but in B–B^5 the sections B^1–B^2 and B^4–B^5 can be constructed independently.

Choice of a high dam section with crest at 3,250 feet appears to be restricted to line A–A′.

Appurtenant works.—These will consist of powerhouse, spillway, and perhaps cofferdam.

Of greatest importance in the geologic sense, is the spillway. The capacity requirement for the structure for a low dam is great since it may be called upon to handle combined floods of the main Flathead and the Middle Fork. If discharge through the gorge section or cut-off channel proves impracticable, it may be feasible to route the spillway along the north side of the rock ridge carrying section B–B^1. The limestone probably slopes sharply into the preglacial channel, and not all the structure can be built upon bedrock. Thus, some excavation of glacial deposits will be necessary, and heavy paving will be necessary to prevent scour. This plan would favor section B–B^5.

Spillway requirements for the high dam section are less because of the greater storage capacity of the reservoir. An adequate section appears to exist over the left abutment, south of United States Highway No. 2. This structure would discharge into South Fork of Flathead River opposite Sand Creek, southwest corner sec. 8, T. 30 N., R. 19 W., and might require about a mile of paved canal to prevent excessive erosion of alluvium on the right bank of the South Fork. An overflow section might be placed in the gorge section, reserving the larger spillway to the south for emergency use. The active gorge also might be adapted to a powerhouse site.

Reservoir area.—The low-dam reservoir would be confined to the gorge of the main Flathead, and there are no large tributaries in this stretch that would afford additional storage. With pool level at 3,100 feet, back water would come to within a quarter of a mile of the junction of the main Flathead and the Middle Fork. With pool level at 3,120 feet, the junction would be inundated and water would extend up both forks for about a mile. Depth of water over the benches on either side of the river at the forks would be shallow.

Very little cultural damage would be created by flooding to this level. The bridge at the North Fork Ranger Station might be drowned out; the Geological Survey stream-gaging station, the piers and abutments of the Great Northern Railway bridge at Coram, and a few small tracts of cultivated garden land and cabins, and some coal prospects also would be affected. The existing forest is sparse second growth and has no timber value.

The area and capacity for the reservoir of a dam with pool level at altitude 3,120 feet are given in the following table computed by Arthur Johnson.

Altitude of water surface (feet)	Area (acres)	Capacity (acre-feet)
3, 043	0	0
3, 060	144	1, 220
3, 080	299	5, 650
3, 100	525	13, 890
3, 120	1, 010	29, 240

Geologic conditions are relatively simple, for the only formations exposed above the dam site are glacial deposits and Recent alluvium. Their sequence and character have been referred to in the general section of this report. This need not be reviewed here except to say that some of the deposits contain carbonized logs and beds of low-grade lignite of no commercial value. However, compensatory claims for damage or loss of these deposits probably will be made.

Ground-water conditions are variable. Along the left bank, a persistent zone of springs issues from the base of the Wisconsin till. This horizon lies above the 3,110-foot pool level, and there is no danger of drowning them out and reversing their flow. Ground-water levels in the right bank are lower and few springs were observed.

Flooding the reservoir to altitude 3,250 feet or higher develops essentially the same problems that are raised by a flood to this level in the Bad Rock Canyon reservoir (pp. 158–159). However, the fact that the lower South Fork would not be inundated reduces the amount of railway and highway location.

Leakage from the 3,110-foot reservoir may occur around the north end of the rock ridge in which the dam sites occur, and through the buried preglacial gorge. The minimum travel path for escaping water would be about 3,400 feet if a dam were placed at section C–C′, and about 1,200 feet if placed at B–B⁵. Probably only the upper part of the fill, or that which consists of fluvioglacial deposits, is permeable. With a dam at section C–C′, the maximum hydraulic gradient would be about 52 on 1; and with a 3,120-foot pool level at B–B⁵, it would be 14 on 1. A cut-off wall out into the glacial deposits might be necessary to decrease this steep gradient. The loss by seepage from a low dam at C–C′ probably would be negligible.

Little more can be said until further information is available on the character of the buried channel and its fill.

Silting of the reservoir probably will be negligible. However, floods over the Tertiary lake beds, glacial deposits, and other soft formations will periodically carry sediment into the basin.

Conclusions and recommendations.—Coram Canyon provides a good alternative site for the low (3,110-foot) dam section at Bad Rock Canyon. Head is less, discharge is less, and, therefore, power will be less. However, the dam would be very much smaller, foundation conditions are shallower and largely on bedrock, the spillway section is better, and capacity requirements are smaller. Cultural loss due to flooding the reservoir also will be less. Further study may indicate that the cost per horsepower for what power can be developed will be less than at the Bad Rock Canyon site. The chief disadvantages of the low dam section at Coram Canyon are the proximity of the buried preglacial channel of Flathead River and the small capacity of the reservoir.

Coram Canyon dam site also may be feasible for a wide-base flexible type dam with crest at altitude 3,250 feet, or even higher at the expense of length beyond 7,100 feet. Such a structure would serve as a partial alternative to the concept of a high dam in Bad Rock Canyon, as it would afford no control over South Fork of Flathead River or offer interference to the Hungry Horse project. Study of this alternative may show that a high dam at Coram Canyon might preclude construction of separate dams on the Flathead (North Fork) and Middle Fork. It is open, however, to the basic cultural objections that confront a high dam at Bad Rock Canyon, but it would require less railway and highway rerouting, for the roads could pass over the left abutment, cross the South Fork below Hungry Horse dam site, and pass through Bad Rock Canyon on the left bank of the river.

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Additional topographic mapping and further geological and geophysical exploration of the buried preglacial channel of Flathead River north of Coram Canyon are warranted for planning this project.

LOWER CANYON CREEK DAM SITE

(Also known as Miller dam site. See pls. 12, 18; fig. 11)

Location.—West of center of sec. 35, T. 32 N., R. 20 W., on (North Fork) Flathead River.

Accessibility.—An old logging road turns off from the North Fork road about 9 miles northeast of Columbia Falls and leads directly to the site. The last few hundred feet probably is impassable for automobiles. Access to the left abutment in Glacier National Park can be had by trail from the North Fork Ranger Station, 3 miles southeast. The nearest railroad point is about 4½ miles downstream, with no connecting road.

Catchment area.—The entire drainage area of Flathead River (North Fork), about 1,620 square miles.

Stream gradient through dam site.—About 14 feet per mile.

Valley profile.—This site is in the broadest part of the valley of Flathead River (North Fork) below Glacier View dam site in an embayment between Apgar Mountain on the east and the back slope of the Whitefish Range on the west. The valley width is about 2 miles. Morainal and fluvioglacial deposits bury the old floor, and the relief upon their surface usually is less than 100 feet. Locally, they show signs of reworking by the present stream, which has been superimposed upon them. Along the west side of the valley the river has trenched through these surficial deposits and cut a narrow shallow gorge into bedrock, creating the proposed dam site. The position of the preglacial gorge is not definitely known, but is believed to have been more centrally located, perhaps below the abandoned ox-bow lakes half a mile east of the proposed dam site.

Apparent possible height of dam.—Casual inspection of the valley floor indicates that the local topography might allow a dam not more than 50 feet high.

Character and depth of valley fill.—The fill in the gorge section of the active channel consists of materials in transit, and their amount is very small. Valley till and fluvioglacial material cover bedrock over the remainder of the area. In some places, Recent stream gravels several feet in thickness rest upon the glacial deposits and point to minor reworking. The floor of the buried channel probably is 250–300 feet below the surface of the bench on the east side of the river.

Country rock.—Strata in the lower part of the Missoula group make the bedrock at this site. Argillite, quartzite, and shale are present.

The argillite is predominantly red in color, and is both thinly laminated and bedded, the layers varying from ⅛-inch to 18 inches thick. Nearly every bedding surface is ripple-marked. Occasional layers of thin, soft, light-green shale are interbedded with it. Hard, fine-grained, brittle quartzite, reddish brown to brownish gray in color, occurs in beds 1 to 18 inches thick.

There can be no question about the intrinsic strength of either the argillite or the quartzite; both are extremely insoluble. The passage of water through the rock would not cause solution or enlargement of existing channels; hydration or volume changes; nor would it weaken the rock in any other way. The consideration of strength, however, is not confined to the resistance to crushing of individual specimens. In dam-site studies, it must be applied to the formation as a whole. Owing to the alternate arrangement of the tough (argillite) and brittle (quartzite) layers, slight differential movements along the bedding, produced by tilting or folding in the mountain blocks, have served to fracture the quartzite thoroughly. Thus, in a geologic sense, the formation at this locality must now be considered as relatively weak. Even so, it has sufficient strength to support a low dam.

Both argillites and quartzites are cut by conjugate sets of veins of translucent white quartz. These are usually very narrow, but at a few intersections, they widen to masses of white quartz as large as 1 by 3 feet.

Dips.—All the rocks dip to the east and northeast, the amount of dip varying from 10° to 30°, the arithmetical average being 19.6°. Direction of dip varies from N. 45° E. to N. 70° E., the average being about N. 60° E.

Jointing and cleavage.—Rock jointing at this locality is especially favored by the alternation of thin layers of brittle quartzite and tough, more elastic argillite. Slight gliding along the bedding surfaces as the formation was tilted has not affected the argillite materially, but has served to thoroughly fracture the quartzite. The fracture cleavage along the bedding dips about 74° E. and strikes N. 5° to 10° W. This direction of strike causes the cleavage to parallel a zone of stronger joints whose strike varies from due north to N. 23° W., and which dips 73° to 84° W. Occasionally the fracture cleavage passes upward into the jointing, the difference in direction of dip being accommodated by a curved fracture of short radius. The joints striking N. 10° W. contain some quartz veins ¼- to ½-inch thick. In some places they have suffered slight horizontal offsets along the bedding, and striae indicate that there have been vertical movements as well. The complementary joint direction is N. 80° E., and locally it too is occupied by the thin quartz veins, which either are vertical or dip 80° S. The joints or fractures occupied by the veins may be regarded as the master joints since they transect the entire formation. The northeast quadrant between these joints is nearly bisected by a poorly developed set of joints, which strike N. 37° E. and dip 79° N. One other set of joints was observed to strike N. 64° E., and dip very steeply (89°) to the north. These fractures probably belong to the east-striking master-joint system.

One factor in the spacing of joints is the thickness of the bed fractured, thinner beds being much more closely jointed than thick ones. Some of the quartzite layers 1 to 2 feet thick are so thoroughly jointed that they may be said to be shattered. Such zones, in conjunction with the bedding joints, offer ideal conditions for percolation through the foundations and abutments.

Faults.—Faulting has not been recognized in the vicinity of the dam site. The Flathead fault lies about 6.5 miles northeast, and a minor zone of faulting may occur about 2 miles southwest. The probability of movement along these lines of weakness, and the regional earthquake hazard, have been referred to in the general section of the report.

Ground-water conditions.—A series of springs flow from the glacial drift on the west side of the map area just above the main road. This high ground-water level is believed due to the proximity of bedrock to the surface. Water from some of these springs thoroughly saturates the unconsolidated material in the benches in the northwest quarter of the area. On the right bank of the river, half a mile downstream from the dam site, local bogs and pools stand on a bench at an altitude of about 3,160 feet. East of the dam site the ground-water level stands between 3,185 and 3,200 feet.

Permeability.—Seepage of water through bedrock at this locality will be considerable and possibly dangerous in places because the stream flows parallel to the strike of the bedding and to the direction of most intense jointing. Conditions in the right abutment are relatively good, and in line with estimates previously made, its permeability coefficient is probably about 10×10^{-7}. In the left abutment the quartzite is so thoroughly fractured that it is difficult even to guess what its permeability might be, but it is obviously many times that elsewhere. Solely for the purpose of indicating that it is great, it is arbitrarily assigned the coefficient of 100×10^{-7}.

The permeability of the glacial material also must be considered if the full head of the site is to be used. That of the boulder clay or unreworked till is low, but that of the fluvioglacial material is high. There is a dangerous possibility that water moving through openings in bedrock would wash out the contact with the unconsolidated material. This might have serious consequences if the crest of dam were raised above the level of bedrock.

Dam section.—The only section available is that along line A–A′, plate 18. The profile of this section is shown in figure 11.

Abutments.—The right (west) abutment is the highest and most massive. From the river bed up to an altitude of about 3,150 feet the argillites and quartzites are exposed, and they probably extend upward under a mantle of glacial debris to about 3,185 feet. Above that altitude the bank consists entirely of glacial material. Inasmuch as it would be impossible to erect a dam with a higher crest, the glacial material will not be involved in the abutment. The principal weakness of the west abutment is the thin-bedded character of the rock and its inclination toward the open valley. This attitude does not provide great natural security against sliding.

The left (east) abutment is the weak feature of this site, it consists of a rather wide rock-cut bench upon which some glacial material has been heaped. The present superimposed course of the river includes a bend at this locality, resulting in a rather flat, thin spur through which leakage could occur. In this abutment the top of the rock-cut bench is somewhat lower than to the west, standing at about 3,180

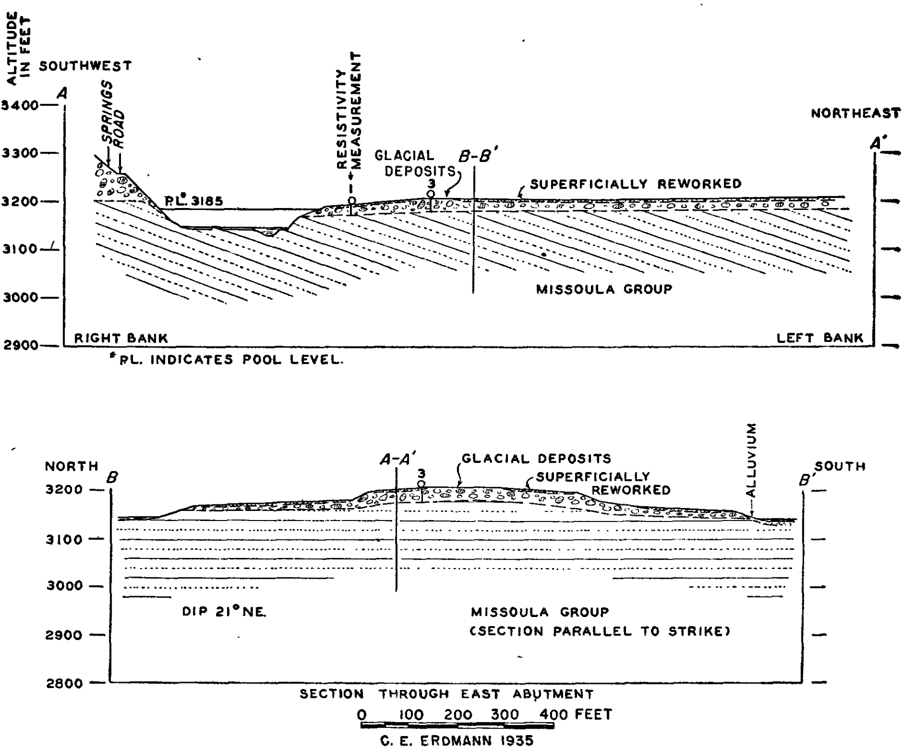

FIGURE 11.—Geologic cross sections at Lower Canyon Creek dam site, sec. 35, T. 32 N., R. 20 W., Flathead County, Mont.

feet. Glacial drift occurs above this to 3,200 feet, and a small knoll on the tip of the spur stands at 3,210 feet. The bench at 3,200 feet and at 3,160 feet extends downstream on the north side of the river for about half a mile.

Foundation.—The river bed consists of hard rock with only a small amount of gravel and alluvium. As shown in figure 11, the bedrock is just below the water surface, a narrow rock-cut bench extending out from either side toward the central channel, which is 15 to 20 feet deeper. The foundation is good and strong, but, as has been pointed out, it probably is very permeable because of the stream, which flows along the strike of the bedding, and the closely spaced joints.

Height and length of possible dam.—The rock floor of the deepest part of the channel has an altitude of about 3,135 feet. The maximum possible height of crest would be about 3,185 feet, thus making a 50-foot dam. The length of crest at this altitude would be 325 feet, and the cross-sectional area of the valley below this crest would be 11,515 square feet. The disadvantage of so high a dam at this site is that it would probably necessitate a long dike or cut-off wall down to bedrock over the east abutment. A dam could be built without such a dike if the altitude of the crest were reduced 15 feet, to an altitude of 3,170 feet. This would reduce the crest length to about 280 feet and reduce the elements of weakness in the east abutment.

Appurtenant works.—Because of the fairly large maximum discharge of the North Fork of Flathead River, and the relatively small dam possible at this locality, the chief accessory work of the project will be a spillway adequate to handle flood flows. Because of lack of storage reservoir, such a structure would have to be of maximum size, and it probably would entail works greater than the dam, which also should be designed as an overflow structure. Ample room for a large spillway exists east of the left abutment, but considerable excavation would be involved if it were properly protected against scour, and paving also probably would be necessary. The position of the buried preglacial gorge would be an important factor in the location of the spillway.

The attitude and hardness of bedrock at the dam site do not favor downstream erosion, although the many small joint blocks might quarry out under the dynamic flow of the stream. Thus, some protection would have to be given both to the toe of the dam and to the river bed for a short distance downstream.

Reservoir area.—The reservoir area above this site is confined entirely to the rather narrow valley floor. The rock formation underlying the flooded area is the lower part of the Missoula group, the beds all dipping to the east and northeast. If a 50-foot dam were built, water would be backed upstream to the Fool Hen dam site, a distance of about 3 miles. This might necessitate the rerouting of a portion of the highway near the mouth of Canyon Creek or require a longer bridge at that locality. A 30-foot dam would back water up to the Canyon Creek dam site 2 miles upstream. The flooded area includes no farm lands, meadow land, or grazing lands, and there are no homes within it. The river banks support a good stand of forest trees, but in some localities these are now being logged off. The ground-water flow is tributary to the reservoir. Silting would be negligible.

As mentioned previously, the buried channel of the preglacial river must lie east of the dam site. Probably it is neither so deep nor so well defined as at Canyon Creek dam site. Although there is small probability that water impounded behind a low-head dam would escape through it, there is a possibility that uncontrolled spillway scour might create conditions favoring such diversion.

Conclusions.—Review of the conditions at this site indicates that it would be suitable for a masonry dam of the overflow type, whose height should not exceed 30 feet. A 50-foot dam could be built, but this would involve a long cut-off wall, and the spillway requirements would be very large. Furthermore, either dam would necessitate special precautions to prevent excessive percolation through the left abutment.

UPPER CANYON CREEK DAM SITE

(See pls. 12, 19, and 20)

Location.—NE¼ sec. 27, T. 32 N., R. 20 W.

Accessibility.—The North Fork road passes high over the right (west) abutment. Columbia Falls, the nearest shipping point, is about 11 miles southwest. A nearer railroad point is some 8 miles down river near Coram with no connecting road below Lower Canyon Creek dam site. The left (east) abutment in Glacier National Park can be reached most easily by boat, if one is available, since the river is too deep to ford, or by trail from North Fork Ranger Station, 4 miles south.

Catchment area.—The drainage area of the Flathead River (North Fork) above the mouth of Canyon Creek is approximately 1,600 square miles.

Stream gradient through dam site.—About 15 feet per mile.

Purpose of dam.—Power. Storage is negligible.

Valley profile.—Flathead River (North Fork) Valley at this locality is of the intermontane type and has numerous features in common with the valley at the Lower Canyon Creek dam site. Glacial material now blankets the walls to altitudes of 800 or 900 feet above river level and once deeply buried the floor. After this material had been reworked by the stream, the surface of the fill made a flat nearly a mile wide, over which the superimposed stream meandered broadly. A change in the temporary base level of Flathead Lake caused resumption of cutting, and the meander was entrenched indiscriminately into bedrock and fill, creating the present inner gorge, the site of the proposed dam.

This excavation also yielded evidence of an older, deeper, and wider channel in bedrock. Preliminary geologic examination revealed small exposures of rock on either side of the neck of the meander loop and also just east of its head. When connected as shown in plate 19, the linear nature and direction of the area so bounded suggested a buried channel. A check by geophysical investigation confirmed the presence of the buried valley (pl. 20), which has an important bearing upon the security and efficiency of the proposed site in the active gorge section.

Apparent possible height of dam.—The Corps of Engineers,[45] citing E. W. Kramer, report:

> A dam site at a point one-half mile above the mouth of Canyon Creek and 6 miles above the confluence with the Middle Fork, where solid rock foundations and abutments are in sight. The dam would be 145 feet high above low-water level, and 525 feet long on top. Very little storage would be developed by the dam.

The present investigation shows that, on topographic grounds alone, the maximum possible height of the dam is 100 feet.

Character and depth of valley fill.—The deposits filling the preglacial gorge are chiefly of fluviolglacial origin. Excellent exposures occur in a cut back on the north side of the entrenched meander loop. Beds of buff silt, probably derived from the Tertiary formations upstream, are conspicuous. Clay in bedded deposits was not observed. Coarser material is represented by angular fragments of the Belt rocks. Stream-worn gravels and cobbles derived from older river deposits occur in small quantity. Glacial erratics of large size were not observed but may be present, although the close bedding and the jointing of the pre-Cambrian strata do not favor their occurrence. The upper parts of these glacial deposits have been reworked, and terrace gravels resting upon them to depths of from 5 to 10 feet have been cemented by lime. The depth of fill in the buried valley ranges from 20 to 30 feet on the buried rock bench west of the old channel to possibly 235 feet in the channel itself.

Judging from the results of drilling at sites both up and down stream, it is quite possible that depths of bedrock may be greater than indicated in plate 20. The geophysical boundary shown may be contact between Recent gravel and older till, as was determined at

[45] Columbia River and minor tributaries: Rept. Dist. Engineer, Seattle, Wash., pt. 2, and Portland, Oreg., pt. 3, 73d Cong., 1st sess., H. doc. 103, vol. 2, p. 802, paragraph 167.

Bad Rock Canyon. (See pl. 15, A–A′.) Interpolation from the estimated gradient of the preglacial valley suggests that the altitude of its floor at Upper Canyon Creek dam site is around 3,060 feet, or about 65 feet deeper than shown.

Both above and below the proposed dam section the present stream channel carries considerable amounts of active alluvium. These unconsolidated deposits consist chiefly of gravel and sand, the finer material having been washed out. All of it appears to have been derived from the glacial drift.

Owing to the force with which the current sweeps through the dam site, very small transitory amounts of alluvium occur, and bedrock is bare over relatively large areas.

Country rock.—Bedrock at Canyon Creek dam site consists of argillites of the Missoula group. From a distance the exposures appear as a massive reddish-tan to brown rock. Close inspection, however, shows the argillite to be predominantly maroon in color, with occasional horizons showing an alternation of light apple-green and red layers, or a mottling of red and green. Most of the rock is very thin bedded and slabby, the layers varying in thickness from ½-inch to 6 inches. Occasionally, however, there is a thick, resistant, ledge-making bed, as at the mouth of Canyon Creek. Bedding surfaces are characterized by ripple marks of small amplitude, and frequently the ripples on adjacent surfaces trend in different directions. Current markings, also present, give the layers smooth, undulating surfaces. In thin layers, the rock is fairly hard and brittle. Greenish layers are sometimes more sandy and harder than the red inclosing layers. Some of the red rock shows small, bright scales of specular hematite. All the rock is fine-grained, dense, relatively impermeable through the grain fabric, and insoluble. The passage of water along joint and bedding surfaces will do little if any harm.

Dips.—All the strata dip to the east and northeast, the amount varying from 25° to as much as 55°, which is abnormally high. Direction of dip varies from N. 45° E. to N. 70° E. The arithmetical average of 16 observations of dip and strike in the dam-site area is about 33°, N. 60° E. There are two high dips of 45° and 55° near the base of the steep west river bank, probably the result of slumping. Lack of structural irregularities in the dam site are indicated by uniform distribution of amount and direction of dip.

Joints.—Observations on the jointing of the argillite indicate that at least seven directions are present, falling naturally into three major groups, whose principal directions are as follows: (1) strike west, dip 75° N.; (2) strike N. 37° E., dip 68° N.; and (3) strike N. 33° W., dip 65° W. The joints in the first two sets are well developed, break the rock cleanly and smoothly, and show small variations from their principal direction. The last group, however, shows a dispersion of ±20° from the principal direction, and some of the joints dip to the northeast rather than to the southwest as most of them do. The joints in this group are closely spaced, in thin-bedded rock only ½-inch or 1 inch apart. Locally they contain veinlets. Insofar as percolation through the foundation and abutments is concerned, this group is the most important by reason of their direction and the shattering which accompanies them.

Faults.—Faulting has not been observed within the dam-site area. However, transverse faults of some magnitude have been noted at Fool Hen dam site 1½ miles upstream, and the great Flathead thrust fault lies 5 miles northeast at the east base of Apgar Mountain. Minor faulting may be present in the eastern part of the Whitefish Range. The probability of movement along the major lines of weakness and the regional earthquake hazard have been considered in the general section of this report.

Ground-water conditions.—Discharge from a series of springs enters the river about 300 feet due north of the west (right) abutment. Their source is probably in the glacial drift north and west of the dam site. No other springs were noted. The ground-water level of the bench within the entrenched meander loop probably is low, because of favorable drainage conditions.

Permeability.—The coefficient of permeability of bedrock at this site is roughly estimated to be 8×10^{-7}.

Permeability of the glacial deposits in the buried gorge also must be considered; that of the fluvioglacial or water-laid deposits will be greater than that of the boulder clay or till. Accurate estimates of the quantity and position of the various kinds of material cannot be made. If water were raised 100 feet against the north side of the spur in the meander loop, the entire buried gorge could be considered as an earthen dam. The path of percolation through it would be about 1,200 feet long. As long as water did not enter the fluvioglacial beds, the gorge would be relatively watertight, otherwise there would be seepage.

The most dangerous possibility is that water moving through the openings in bedrock may wash out material at the contact between the argillite and the unconsolidated deposits in the vicinity of the plane-table bench mark at an altitude of 3,267 feet and southward over the buried rock bench separating the buried gorge from the active channel. Some water may also seep along the left (east) wall of the old channel at the base of this loop.

Dam section.—Only one section is available. The axis lies in the postglacial gorge 1,440 feet upstream from the mouth of Canyon Creek. (See pl. 20, A–A′.)

Abutments.—The right (west) abutment is the highest and most massive. From the river surface up to altitude 3,250 feet, the argillite is well exposed. Above is a heavy cover of glacial drift. Practically no water could seep into the creek through the spur between McGinnis Creek and the river. The only structural disadvantage is that the strata dip into the open valley at a rather steep angle (30°).

The left (east) abutment is neither so high nor so massive. Rock is exposed to altitude 3,200 feet, and glacial drift caps the bench to 3,265 feet. Bedrock rises gradually under the drift to an altitude of about 3,235 feet. The strata dip into the bank, and there is good security against sliding. Owing to the relatively narrow width of the buried ridge separating the buried channel from the active gorge, the east abutment should be regarded as more permeable than that on the right bank.

Below altitude 3,235 feet, both abutments are essentially equal in bearing power. Obviously, if the full height of the west abutment were to be used, the bearing power would become very unequal, because the east abutment rests upon unconsolidated material. Aside from this, the additional height would raise water over the boundary between the bedrock and the drift, and the unconsolidated material would probably wash out.

Foundation.—The foundation is essentially free of sand and gravel. During the later part of July 1934, the depth of water was about 15 feet on the axis of the dam and 15 to 20 feet in the pool 100 to 200 feet upstream. A narrow rock-cut bench extended out from the west bank for 10 to 15 feet, just below the water surface. The east abutment is probably almost vertical with respect to the stream bed. Bedrock, which dips upstream, is hard and strong and offers a secure foundation.

Height and length of possible dam.—The character of the east abutment limits the safest height of dam to about 75 feet. The altitude of the crest would be about 3,235 feet and its length about 240 feet. This is intermediate between the heights shown on plate 20. A 100-foot dam, in addition to the disadvantages mentioned, would require an impractically long and deep cut-off wall in the upper part of the east abutment.

Appurtenant works.—Lack of reservoir storage capacity creates a maximum spillway requirement. The west bank provides little room for a large spillway section. One solution would be to design the dam as an overflow structure. Another would be to tunnel through the spur between McGinnis Creek and the river. Although more expensive, this suggestion has some merit in that the powerhouse also could be placed up the creek, away from view, and the problem of downstream erosion would be minimized. There probably would be a small loss of head for power.

Reservoir area.—The reservoir area of this site would be confined to the deep and narrow river gorge, half of which lies within Glacier National Park. A 50-foot dam would create backwater for 4.5 miles, a 100-foot dam for about 6.5 miles. The area subject to flood contains no bottom or meadowlands or habitations of any kind. Timber within it is scrubby, burned over or logged over, and has little value. Except at Fool Hen dam site, where the Siyeh limestone and Grinnell (?) argillite appear, it is underlain by rocks of the Missoula group, all dipping east and northeast. None carry deposits of economic value. Any dam 75 feet or more in height may necessitate rerouting some sectors of the North Fork road.

The only locality where leakage might be serious is the buried channel east of the left abutment of the dam site, and the probabilities there have been discussed under several preceding headings. If the height of dam were kept down to 50 or 75 feet, the water loss would unquestionably be small.

Conclusions.—A review of conditions at upper Canyon Creek dam site shows that it would be suitable for a masonry dam whose crest should not exceed altitude 3,235 feet. This limits the height of dam to 75 feet. Storage capacity is negligible. Spillway requirements are large and difficult. Since even a 50-foot dam would drown out a more favorable site upstream, Upper Canyon Creek dam site must be regarded as of secondary or lesser importance.

FOOL HEN DAM SITE

(See pls. 12, 21, and 22)

Location.—North center sec. 23, T. 32 N., R. 20 W., Flathead County.

Accessibility.—The North Fork road closely parallels the right (west) bank of the river in the dam-site area, about 13 miles north of Columbia Falls, the nearest shipping point. Another near railroad point is in the bend of the river west of Lake Five, but connection with it would require a new bridge. Coram bridge is about 10 miles south of the dam site. The left (east) abutment in Glacier National Park can be reached most easily by boat, as the river is too deep to ford. Trail distance to North Fork Ranger Station at the mouth of the Middle Fork of the Flathead is about 5 miles.

Catchment area.—The drainage area of the North Fork of the Flathead River is about 1,550 square miles.

Stream gradient through dam site.—Fifteen feet per mile.

Purpose of dam.—Power. Storage capacity is minor.

Valley profile.—Fool Hen dam site on the North Fork of Flathead River lies at the head of the embayment between Apgar Mountain and the Whitefish Range. In consequence, the river valley is much narrower and deeper than at the dam sites downstream. Local peaks on Apgar Mountain rise about 2,800 feet from river bed (3,200 feet) to altitudes around 6,000 feet, while those on the back slope of the Whitefish Range stand roughly 1,500 feet lower. Valley width at the 4,000-foot contour is about 1.25 miles. Morainal material extends up to this altitude; below it the valley profile exhibits the characteristic U-shape of alpine glaciation. The bottom, however, has been modified by stream action, and several rock-cut benches are evident below altitude 3,400. (See pl. 22.)

Because buried gorges exist on a rather large scale on one side or the other at several dam sites downstream, notably the upper and lower Canyon Creek and Coram Canyon sites, search for evidence of similar features constituted an important part of the geologic investigation at Fool Hen dam site. The narrow confines of the valley seem to preclude the possibility of such a channel being elsewhere than in its central portion. Preliminary geophysical investigation in 1934 (test lines 1 to 6) suggested a possible course for a buried gorge of dimensions corresponding to those of the present active channel, but further work in 1935 (test lines 7 to 13) failed to establish its presence. Even so, the spacing between the centers of the resistivity lines is so great that deep narrow channels may occur between them.

In 1944 the Corps of Engineers put down drill hole No. 1 to test the possibility that the gap in continuity of bedrock at resistivity station 10 (see pl. 21) might indicate the presence of a buried channel under the right bank. The depth to bedrock (see pl. 22, D–D′) suggests the existence of such a channel, but it is difficult to interpret on the basis of a single bore hole. Thus, it is not as deep as might be inferred by interpolation from estimates of the bedrock gradient of the preglacial valley between Bad Rock Canyon and Glacier View dam site, and its upstream course through Fool Hen dam site has not been determined. Further exploration on centers not less than 50 feet apart across the bench on the left bank is needed to test its presence there. As will be shown later, the shallow depth to bedrock at this site may be an effect of comparatively recent movement on the cross-valley faults.

Apparent possible height of dam.—On the basis of topographic features alone, the maximum possible height of dam is about 200 feet.

Character and depth of valley fill.—Alluvial fill in the active river channel is insignificant, because of the force with which the stream sweeps through the site. This is especially true at the localities selected for dam sections. Elsewhere, however, there is shallow to moderate fill. Resistivity determinations were made at several places where topography and character of ground indicated fill. Depths to bedrock and the character of overburden are indicated in the following table:

Results of resistivity depth determinations at Fool Hen dam site

Line No.	Depth to bedrock (feet)	Overburden	Determination by
1	91	Gravels	B. E. Jones.
1[1]	42	do	C. E. Erdmann.
1, A	29	do	B. E. Jones.
2	73	Fluvioglacial	Do.
3	20	do	Do.
4	25	do	Do.
5	19	Gravels	Do.
6		do	
7	30	Fluvioglacial	R. K. Thies.
	28.5	do	C. E. Erdmann.
8	9	do	R. K. Thies.
	7.5	do	C. E. Erdmann.
9	23	do	R. K. Thies.
	27, 37	do	C. E. Erdmann.
10	13	Gravels	R. K. Thies.
	12	do	C. E. Erdmann.
11, 12	60	Glacial drift	R. K. Thies.
	63	do	C. E. Erdmann.
13	22	Fluvioglacial	R. K. Thies.
	24	do	C. E. Erdmann.

[1] Rerun in 1935.

Country rock.—Geologic conditions are more complex at Fool Hen dam site than elsewhere along the river, chiefly because of faulting and the presence of diabase. From oldest to youngest, the exposed rock formations are Grinnell (?) argillite (see pp. 129–130), Siyeh limestone, Missoula group, and diabase.

The belt of sedimentary rock 2,400 to 2,600 feet thick between the two faults that bound the dam-site area to the north and south has been referred tentatively to the Grinnell argillite. The rock is predominantly dull maroon and purplish red and is hard and dense, the thinly laminated beds aggregating into strong massive layers. Smaller amounts of dull gray-green argillite are interbedded, their thickness usually not exceeding 25 feet. A bed of this argillite is adjacent to the lower fault, and thinner layers crop out in the river bank below the bench mark at an altitude of 3,390 feet and on top of the ridge 1,000 feet north of the bench mark. This rock forms the foundations and abutments in one of the dam sections. Except that it is prevailingly thin-bedded, it is eminently suitable for such duty.

Limestone, identified as the Siyeh limestone, crops out in the river bed downstream from the north Fool Hen fault over a distance of about 1,600 feet. Approximately 850 feet of strata are present. Upstream from the fault, fine-grained, thinly-laminated, light-gray dolomitic limestone is transitional into greenish-gray argillite similar in lithologic character to the Missoula (?) group. This horizon is regarded as the top of the Siyeh limestone, although the exact boundary has not been determined. The stratigraphic displacement of the fault is thus about 3,600 feet.

Contact with the underlying Grinnell (?) argillite is blanketed with glacial deposits and cannot be observed. However, the strike and dip of both formations are nearly accordant, and the boundary is believed to be normal. This accordance of dip is interrupted in the north part of the dam-site area by a mass of basic igneous rock. Owing to the drift cover, intrusive contacts were not observed. Locally, though, the limestone south of the fault and east of the intrusive is cut by fairly thick calcite veins, which probably originate in the contact zone.

Lithologically, the lower Siyeh limestone is a hard, dense, dark-gray dolomitic limestone in beds 1 to 4 feet thick with partings of softer, thinly-laminated, light-gray shaly limestone. Effects of movement are observable in the massive layers, and in some places cleavage can be separated from bedding only with difficulty. The character of the Siyeh limestone and its suitability for dam foundations are discussed in detail in the report on Hungry Horse dam site [46] and will not be reviewed here. The only essential difference is the presence of the calcite veins in the north part of the map area, upstream from any possible dam section, and the more intense development of fracture cleavage.

Rocks of the Missoula group flank the narrow belt of Grinnell (?) argillite and Siyeh limestone in the horst at Fool Hen dam site. Those on the north side of the area have been mentioned briefly in connection with the top of the Siyeh limestone. Although thin-bedded, they are fairly hard, durable, and insoluble, and are unaffected by solutions. The argillite of the Missoula group on the downthrown side of the south Fool Hen fault consists, as far as the exposures extend, of greenish-gray argillite in both massive and thinly laminated beds. The massive rock can be scratched easily with a knife, and breaks irregularly with a subconchoidal fracture. Its color, grain, size, and dense, compact texture are very uniform. The rocks are mashed and brecciated a few feet from the fault, and more or less fractured in the hanging wall for 50 to 100 feet. Within this zone, the rock is neutral gray and soft, with a soapy feel due to the development of sericite. These changes have been brought about by solutions. Where so altered, the rock is not sufficiently strong or impermeable to serve as a dam foundation.

Dips.—Away from the faults, which have produced a certain amount of drag, the strata within the horst or upthrown fault ridge have a prevailing dip to the northeast. Amount of dip varies from 29° to 64°,

[46] Erdmann, C. E., Geology of the Hungry Horse dam and reservoir site, South Fork of Flathead River, Flathead County, Mont: U. S. Geol. Survey Water-Supply Paper 866–B, pp. 48–55, 1944.

the arithmetical average being 41°. Direction of dip varies from N. 17° W. to N. 59° E., the average being N. 25° E. The northwest dips are north of the north Fool Hen fault, and outside the area of the dam site. Dips immediately below the south or lower Fool Hen fault are to the south. The locality where reversal into the regional northeast dip takes place cannot be determined along the river because of the heavy overburden.

Joints.—Observations on joints are very incomplete in comparison to those at other dam sites. This is due partly to lack of exposures suitable for their determination, and partly to less thorough jointing. An observation at the southeast end of section C–C′, plate 22, where green argillite dips 32°, N. 31° E., revealed a set of master joints that strike S. 32° E. and dip 57° SW. Spacing is about 5 feet and the surfaces are clean and smooth. Another set less perfectly developed strikes S. 56° W. and dips 78° E. Spacing is about 4 feet. Joints probably belonging to this set were observed on the west bank of the river; strike S. 64° W., and dip 76° S. Surfaces are smooth and clean. A second set at this locality strikes S. 67° E. and dips 60° S. The large calcite vein in the north part of the map area strikes N. 37° E. and dips 79° E. It is considered to occupy one of the local master joints.

Faults.—Two faults of considerable displacement are present in the dam-site area, and the great Flathead fault passes along the eastern toe of Apgar Mountain some 3 miles northeast. Several minor faults also may be present in the eastern part of the Whitefish Range.

In this report the faults in the dam-site area are called the north (upper) Fool Hen fault and south (lower) Fool Hen fault. Together they bound a horst or an upthrown block between two downthrown blocks. This structure is responsible for the dam site, for the upthrown rocks are older and harder, and the river gorge across them is narrower than it is either up or downstream. Along the line of section A–A′, plate 22, the faults are 3,760 feet apart and converge eastward. If each be projected along its strike from the most easterly locality where observations on it were made, the point of intersection falls 6,120 feet southeast on the north fault and 6,500 feet northeast on the south fault.

The south fault is well exposed at the mouth of the rock gorge 800 feet downstream from the lower Fool Hen rapids. Red Grinnell (?) argillite forms the footwall on the right bank, and its smooth hard surface shows numerous closely spaced striae. The argillite strikes N. 70° E., and dips 79° S. The striae pitch 74°, S. 58° W. Rock in the footwall adjacent to the fault dips 34°, N. 54° E., and 100 feet to the north it dips 40° to 45° in the same direction. Light-greenish gray argillite of the Missoula group makes the hanging wall, and at the fault, dips 50°, S. 71° E.; a slight decrease in dip is observable 50 feet to the south, and there is some brecciation and drag in this interval. Owing to the mantle of glacial deposits, it is impossible to say how far downstream this south or reverse dip persists, but it obviously does not extend as far as upper Canyon Creek dam site. On the left (east) bank, the fault surface strikes N. 74° E. Beds in the footwall dip 37°, N. 44° E., and those in the hanging wall dip 53°, S. 60° E. A zone of soft gouge 1.6 inches thick separates the two surfaces. Where fresh, the clay is bluish; where weathered, it is rusty. Sericitization has been observed in the hanging wall to distances of 100 feet from the fault.

South Fool Hen fault has considerable stratigraphic displacement. The rock in the downthrown block represents a horizon in the Missoula group not observed elsewhere in the general area but evidently above the basal quartzitic members. All the Siyeh limestone has been cut out, and the footwall in the Grinnell (?) argillite is fairly near the base of that formation. Hence, the stratigraphic throw cannot be less than 7,000 feet, and may be a few thousand feet greater.

North Fool Hen fault strikes S. 82° E., and dips 88° N. The crush zone on the north side extends to the first Fool Hen bridge, and may have a thickness of about 150 feet. On the right (west) bank of the river, Siyeh limestone is present on both sides. The thickness and character of the rock have been mentioned above. If these stratigraphic assignments are correct, this fault has a stratigraphic throw of about 3,600 feet, or approximately half that of the south fault. The horst or upthrown block between the faults is thus tilted to the northeast, and the dip of the rocks within the dam-site area is evidently an effect of the fault movements. North Fool Hen fault also cuts the north side of the igneous rocks, indicating that they are older than the faulting.

Rapids, which indicate bedrock at shallow depths, are absent where the faults cross the river, and the high terrace gravels (late Wisconsin (?) age) show no displacement or change of grade. These facts indicate that the faults have been inactive for a very long time. Consideration of local geologic history suggests that one might expect to discover a buried valley to one side of the active channel at Fool Hen dam site, or a considerable depth to bedrock below it. These conditions, however, appear not to prevail. Bedrock crops out or occurs at shallow depth, and even the deepest levels are higher than that estimated from interpolation of the bedrock gradient between Bad Rock Canyon and Glacier View dam site. This ungraded character of the valley floor could be produced in either of two ways—

through vagaries of glacial scour or by faulting. The physiography of the valley favors deep scour; and the fact that shallow bedrock is confined to the area bounded by the faults sustains the concept of faulting. The lack of continuity of the deep valley, with its bottom packed with old drift, therefore, may be evidence of the post-Illinoian (?) age of the Fool Hen horst. The magnitude of the faulting, however, argues against all of it being accomplished within Pleistocene time, and the most probable explanation is that the faults were reactivated after the Illinoian (?) glacial stage. Transverse faults of this character are probably related to the master faults that bound the larger mountain ranges, and movement upon them is evidently conditional upon the stability of the major thrust faults. Probability of future movement upon these faults has been considered elsewhere. Finally, it may be said that the probability of earthquake shocks originating in Fool Hen dam site is no greater than for any other equal area on the Flathead River.

Ground-water conditions.—No springs or other signs of ground water were noticed in the dam-site area, other than the small pothole lake at the south end of the map. This is because the thin overburden allows surface water to seep into the hard rocks, whence it finds its way into the river quickly.

Although the pothole lake was observed from several directions, a careful study was not made. It is of interest in that it retains water when other deep potholes above Fool Hen Hill are dry for part of each year. Either it is fed by springs arising in the high morainal slopes above it, or the bottom is especially impervious. During September 1934, seepage was not observed in the bank below it, although the hydraulic gradient to river level from lake surface is about 1 on 4.5. This lake gives an index of the impermeability of the unreworked valley moraine.

Permeability.—Estimates of permeability factors for all rock formations along the Flathead River have been given in this series of dam-site descriptions. At Fool Hen dam site only the Grinnell (?) argillite and Siyeh limestone will be involved in the possible dam sections. The Grinnell (?) argillite is probably a little more insoluble and impermeable than the Siyeh limestone, and because of greater degree of dynamic metamorphism, the limestone is probably less soluble and permeable than it is at Hungry Horse dam site. There the permeability factor was estimated to be: $K=6\times10^{-7}$ for cracks 0.0001 foot wide, percolation through the fabric of the rock being dismissed as negligible. That for the argillite (Ravalli group) at Bad Rock Canyon was estimated to be $K=2.5\times10^{-7}$. Although only by a guess, a factor of $K=4\times10^{-7}$ is assigned to the Grinnell (?) argillite at Fool Hen dam site, and $K=5\times10^{-7}$ to the Siyeh limestone.

Reference to the permeability of the glacial drift has been made under the heading "Ground Water."

Dam sections.—Two possible dam sections are available at Fool Hen site, as shown by B–B′ and C–C′, plates 21 and 22. A section for a low dam at bench mark 3255 also was studied in the original investigation, but has been eliminated from consideration because of the probability of a buried channel (see pl. 22, D–D′) behind the right abutment and proximity to the south Fool Hen fault.

Data on the comparison of sections B–B′ and C–C′ is given in the table on plate 22. Insofar as surface appearance goes, section B–B′ is smaller and more economical. Interpretation of subsurface information shows that for any dam standing 50 to 215 feet above stream bed the amount of fill in section B–B′ is greater than in C–C′, and that when the total cross-sectional areas are compared that for C–C′ is somewhat the smaller. Both sections are deficient in that bedrock in the right abutment is covered deeply by a constructional terrace of fluvioglacial drift.

Section B–B′ somewhat resembles C–C′ in profile, but the symmetry is reversed, the midvalley benches being on the right bank and the high steep valley wall on the left bank. Glacial drift mantles the valley bottom so completely that the trace of the boundary between the Grinnell (?) argillite and Siyeh limestone cannot be located with precision. Presumably it strikes about N. 60° W. from a point on the left bank just downstream from the southern most exposure of Siyeh limestone and crosses the line of section in the vicinity of resistivity station 13, then swinging north into the basic igneous rock. Hence, argillite forms the upper part of the right (west) abutment, probably above altitude 3,300 feet, and limestone must occur in the lower part and in the entire left abutment. The Siyeh thus occupies the greater part of the section. As pointed out elsewhere, the rock of this formation is somewhat softer and more permeable than the argillite. The boundary between the two is believed to be transitional and no more permeable than any normal bedding surface in the limestone. The bearing power of the abutments and the foundation conditions are essentially uniform throughout. The section is well situated with respect to both faults. However, there may be some shattering and brecciation south of the igneous rock (see sec. A–A′) that may affect the stability or permeability of the upper part of the right abutment. This danger, if real, can be overcome by shifting the section downstream about 200 feet.

Depth to bedrock in the active stream channel is shallow. Distribution of rock exposures in the valley upstream and indications from resistivity work suggest that in this section the river occupies its old (pre-Wisconsin) gorge. Distance between exposures and depth determinations is such, however, that deep narrow gorges may exist. The spillway section might be placed on the right bank, west of the road.

The lower section, C–C′, is wholly in the Grinnell (?) argillite, which appears to dip upstream throughout. Depth to bedrock in the gorge section is shallow, and it also may be shallow on the left bank. One disadvantage of this section is that for a dam 150 to 200 feet high, the east end of the crest would fall dangerously near the extension of the south Fool Hen fault; and another is that bedrock may swing west under a cover of drift a short distance southwest of the right end of the section, placing the abutment too near the end of a spur.

Choice of section.—Taking both geology and topography into consideration, first choice goes to section B–B′ because of greater security in the right abutment.

Reservoir area.—The reservoir area above Fool Hen dam site is confined to the valley bottom throughout its length. Backwater from a 100-foot dam would extend about 7 miles upstream. Storage capacity would be increased by inundation of Great Northern Flats, a low wide terrace about 4 miles above the dam site. Certain portions of the North Fork road would have to be changed. Backwater from a 150-foot dam would extend upstream for about 11 miles or just to Glacier View dam site. The Big Creek Ranger Station would be drowned out. A 200-foot dam, the maximum possible, would back water up for about 16 miles, or to a point just below the mouth of Logging Creek. Some additional storage would be developed in the lower part of Big Creek Valley and in the broad valley above Glacier View dam site, which would be flooded.

The area and capacity for the reservoir of a dam with pool level at altitude 3,400 feet are given in the following table computed by Arthur Johnson.

Altitude of water surface (feet)	Area (acres)	Capacity (acre-feet)
3, 200	0	0
3, 220	27	270
3, 240	77	1, 310
3, 260	166	3, 740
3, 280	405	9, 450
3, 300	832	21, 820
3, 320	1, 060	40, 740
3, 340	1, 400	65, 340
3, 360	1, 910	98, 440
3, 380	2, 910	146, 640
3, 400	4, 270	218, 440

Geological conditions in the reservoir area are simple. From North Fool Hen fault to the head of Glacier View Canyon, the river flows over northeastward-dipping argillites of the Missoula group, which are of no economic value. Above Glacier View Canyon, Tertiary "lake beds" containing deposits of lignite coal crop out in the valley bottom. If water were raised to the 3,400-foot level, it would come dangerously near flooding the workings of the North Fork coal mine.

Ground-water flow is everywhere tributary to the reservoir area, and there is no possibility of leakage except in the vicinity of the dam site.

Silting in the reservoir would be negligible.

Clearing the reservoir site of brush would be a major problem in construction of any dam the height of which exceeds 100 feet.

Conclusions.—Review of conditions at Fool Hen dam site indicates that sections are available for dams up to a maximum height of 200 feet. Since this height of dam would drown out the Glacier View site 11 miles upstream, studies should be made to determine whether a 150-foot dam at the Fool Hen site would satisfy all requirements of river control and thus be a smaller and less expensive alternative to the Glacier View dam site.

GLACIER VIEW DAM SITE

(See pls. 12, 23, 24, 25, and 26)

Introduction.—Glacier View dam site merits serious consideration in any scheme of river development because, if a feasible project can be established there, it would afford complete control of North Fork of Flathead River. In this respect, it is analogous to Hungry Horse dam site on South Fork of Flathead River and the Kootenai Creek dam sites on the Middle Fork. Hence, all other dam sites downstream on the North Fork must be regarded as alternates, not to be considered until the possibilities of Glacier View have been explored carefully and found wanting. The site is also noteworthy for the gigantic scale of its physical features. Reservoir capacity at the highest possible flow line has been estimated to closely approach 11 million acre-feet, or a little more than half the capacity of the Fork Peck dam reservoir on Missouri River. Such a reservoir would have to be controlled by a dam standing 525 feet above low water with a crest length of about 2,500 feet and containing a volume of concrete for a full gravity section roughly equal to that of Shasta dam in California. Water supply, however, is comparatively small. Recent runoff records obtained at the Geological Survey gage just above the confluence of the North Fork with the Middle Fork indicate that the mean annual flow is about 1,600,000 acre-feet. Making allowance for the discharge of Big Creek, the principal tributary below the dam site, the probable mean annual flow there is 1,500,000 acre-feet. Thus, so great a dam is not needed. Preliminary studies, to be described later, indicate that a dam raising water to 3,600 feet would probably provide all control necessary. A dam with crest at this altitude would stand about 275 feet above low water, and have a volume of about 1,500,000 cubic yards.

Geological investigation of the project involved two distinct but supplementary studies: the dam site, and inquiries into the possibility of leakage from the storage reservoir at Langford Creek saddle and the McGee Meadows Divide. (See pl. 23.) Their scope is sufficiently broad to provide an adequate picture of geologic conditions limiting any type of project.

Location.—Vicinity of southwest corner unsurveyed sec. 14, T. 33 N., R. 20 W., Flathead County. (See pl. 12.) For purposes of dam-site investigation, an area of about 475 acres was mapped on a scale of 1:4,800 or 1 inch to 400 feet. That area is approximately 7,200 feet long and 2,800 feet wide, and the course of the river through it is nearly 2 miles.

Accessibility.—An automobile road from Columbia Falls, 20 miles south on the Great Northern Railway, follows the west (right) bank of the river through the dam site, and extends upstream through the reservoir area 32 miles to the International Boundary. The left bank in Glacier National Park is not so conveniently accessible. During low-water stage, the river can be waded just below the south end of the map area. Access overland may be had from the new Camas Creek road in sec. 12, T. 33 N., R. 20 W., about 1.5 miles north of the north end of the site. There is no trail, and much of the ground is rough and swampy.

Living accommodations are available at Polebridge, 14 miles upstream, where are also the nearest store, post office, and bridge. A National Park Service ranger station is established there on the east bank of the river. A nearer habitation, occupied seasonally, is the Big Creek Ranger Station, United States Forest Service, about a mile downstream at the mouth of Big Creek.

Travel throughout the reservoir area is facilitated by the road along the west bank of the river. Upstream from Polebridge Ranger Station the Kintla Lake road gives access to the east bank; downstream the road leads to Belton. Much of this road, particularly the older part, is far back from the river. South of Logging Creek Ranger Station, the Polebridge-Belton road forks, the new portion extending south to Camas Creek, thence upstream to McGee Creek and southeast to the old road again. This route makes the McGee Meadows country, the controlling divide of Glacier View reservoir, easily accessible. Langford Creek Divide, the other locality where seepage from the reservoir may occur, is crossed by the new Coal Creek road. All roads, with the possible exception of that from Polebridge to Belton, are usually closed to traffic from late in December to early in May because of snow.

Stream gradient through dam site.—Gradient is 9 feet per mile.

Purpose of dam.—Primarily storage for flood control and river regulation. Power and irrigation are secondary objectives but justification of the project would probably involve every possible use of water.

Valley profile.—North Fork Valley at Glacier View dam site is superimposed upon the low divide from Apgar Mountain to Demers Ridge, which forms the east side of the Whitefish Mountain structural block. Owing to the hardness of the rock in the mountain ridge, the stream must have been considerably constricted after its new course was established across it. Subsequently this narrow gorge was modified by the action of valley or alpine glaciers to its present deep, flaring U-shaped profile. From the northeast spur of Glacier View Mountain at the head to the southwest spur of Huckleberry Mountain at the foot, the length of the gorge is about 1.5 miles. Maximum relief is on the east side where the ground rises rapidly from the alluvial bottoms at 3,330 feet to the summit of Huckleberry Mountain at 6,580 feet, a difference of 3,250 feet. Total relief on the west bank is 2,670 feet. Plate 25 shows the character of only the lower slopes.

Bedrock is not everywhere exposed in the valley walls. Cover consists of talus, glacial drift, and alluvial cone material. Owing to recent destructive forest fires, the slopes of Huckleberry Mountain are quite barren, and avalanches have swept down them at several localities. That shown on the map (pl. 24) took place in the spring of 1934, and the debris dammed the river temporarily. Glacier View Mountain still retains its forest cover and evidence of snow slides is not visible.

The floor of the valley is a nearly flat, featureless alluvial plain, with minor distributary channels and low terraces, both constructional and erosional in origin. Near the head of the gorge the valley walls are characterized by narrow rock-cut benches mantled by aqueoglacial deposits and standing 60 to 70 feet above low water. Remnants of higher benches were seen on the west flank of Huckleberry Mountain at altitudes of 3,670 and 4,000 feet.

Apparent possible height of dam.—Insofar as the dam site is concerned, a structure could be raised as high as necessity requires or safety in design allows.

The maximum possible height of dam is controlled, however, by the altitude of the McGee Meadows Divide, sec. 27, T. 33 N., R. 19 W., Glacier National Park. (See pl. 23.) This divide, which is considered in greater detail in the discussion of the reservoir, stands at altitude 3,865 feet and separates the heads of Fish and McGee Creeks, east of the north end of Apgar Mountain. Allowing 15 feet of freeboard, a flow line at 3,850 feet would require a dam 525 feet above low water. The demands of such a structure have been referred to briefly in a preceding section.

Character and depth of valley fill.—Resistivity investigation in the central part of the dam-site area (pl. 24, lines 1 to 17), with a few borings put down by the Corps of Engineers in 1944, shows that the buried portion of the valley is a wide flat-bottomed trough (pl. 25), with rock-cut benches on one side or the other, and a deeper gorge section, more or less modified by glacial scour. Upstream from section E–E′, ice movement of the North Fork glacier was directly from the northeast, producing a deep symmetrical bottom, with minor terracing or plucking effect on the east (left) bank. This direction of flow was diverted southward diagonally across the valley by the massive southeast spur of Glacier View Mountain, which probably marks the approximate position of the ancient stream divide on Apgar Mountain and Demers Ridge. If the interpretations shown in section G–G′ are correct, the result was to shift the overdeepened channel toward the left bank, leaving a rock bench in midvalley and along the right bank. As an alternative hypothesis, it may be argued that the diagonal gorge was developed by river erosion during the long Yarmouth interglacial stage; but whatever its origin, it must be admitted that all earlier topographic features were profoundly affected by the last (Wisconsin stage) glaciation.

The composition and arrangement of the material filling the buried gorge is unknown, but it is believed to be complex. Exposed deposits on the valley floor are active stream gravels and finer alluvium. Fluvioglacial wash, valley moraine, alluvial cone deposits, and active talus have been recognized on the higher slopes. Their counterparts may be buried along the valley walls. Resistivity investigations suggest that a layer of lime-cemented stream gravel may be present below the present active gravels. The pebbles in this recent conglomerate are hard and fresh, and the conglomerate offers good bearing power locally; but its distribution is probably erratic, and the lime cement is susceptible to leaching. Elsewhere, layers of low resistivity are indicated, and these are interpreted as deposits of silt or clay produced by local ponding of the stream. Such materials are probably unconsolidated, soft and plastic, and of low strength and bearing power. Remnants of the older glacial deposits also may be present locally, where they have been protected from later erosion and scour.

In all probability, a competent foundation can be obtained here only by complete excavation to bedrock. Maximum depth ranges up to 225 feet in the valley bottom and to 160 feet over the buried rock benches. Approximate depths to foundation are estimated in plate 25, but no attempt has been made to classify the fill.

Excavation of the left abutment probably would be a serious problem, and it might develop that a greater depth to foundation in one section would be a lesser evil than a deeply buried abutment in another. Materials most dangerous to remove would be talus and alluvial cone. Active talus of argillite and greenstone has an angle of rest of 36° and will slide if slopes are oversteepened. The alluvial cones are of very recent, postglacial origin, and have been built of loose unconsolidated material by small streams, which issue from springs high on the mountain wall. The depth of the lower part of the cones is unknown, but may be considerable. As the material is probably saturated with water, it may slide if disturbed.

Country rock.—Bedrock at Glacier View dam site consists of the upper part of a very thick series of undifferentiated argillite referred to the Missoula group, with which are intercalated two tabular bodies of Purcell basalt. Olive to grayish green are the predominant colors of the argillite, but minor amounts of red and maroon rock are interbedded. Occasional zones of buff-weathering dolomitic argillite also are present, as in the vicinity of the old Scoville cabin below the road at the north end of the map. Irregular bands and, in a few places, beds several feet thick of brown and buff quartzite and quartzitic sandstone were seen. Massive individual layers of extremely dense argillite have thicknesses of as much as 4 feet. The thinly bedded rock shows layers from a quarter of an inch to 6 inches thick. Usually it is finely banded, the laminae ranging from microscopic dimensions to a thickness of 0.05 inch. Grain diameters are commonly those of silt, with a matrix of clay, now recrystallized to sericite, but there also is a sprinkling of sand. Aggregates of such rock frequently total 40 to 50 feet and form conspicuous lithologic units. Both green and red rock show ripple marks and mud cracks, and the red argillite is usually dusted with white clastic mica. Hardness is variable layer by layer, some beds being scratched easily with a knife blade, others scarcely at all. On Moh's scale, the hardness of the formation as a whole probably ranks around five. Crushing strength is considered to be essentially that of a normal clay slate or about 400 tons per square foot. Bedding surfaces are smooth, but undulate gently. The dolomitic layers are locally contorted and gnarly. Fractures transverse to bedding and joint surfaces are rough and hackly. All this rock is strong, tough, elastic, and insoluble and would afford secure foundations and abutments for any dam.

Exposures of the Purcell basalt are rather restricted. One prominent mass crops out well up on the left bank in the vicinity of letters F′ and G′, plate 24, and what is believed to be the same flow is exposed in a small area on the right bank near the plane-table bench mark at an altitude of 3,577 feet. The thicker upper flow appears as shown on plate 24, near the letter D and again on the north slope of Huckleberry Mountain near B′.

The upper flow, with a thickness of about 160 feet, is not involved in any dam section. However, the lower flow passes under the river near a possible dam section, E–E′, and also is present at the location of the abutments of section F–F′ and the right abutments of sections G–G′ and H–H′. (See pl. 24.) It has a thickness of about 100 feet, and consists chiefly of massive amygdaloidal rock. Although perhaps less hard than the argillite, the altered lava is strong, massive, tough, and elastic and is very suitable for the foundation or abutments of a dam. Its crushing strength probably equals or exceeds that of the argillite.

Dip of rock.—Amount of dip varies from 14° to 40°. Steeply dipping beds are exposed at the north end of the map area in the east spur of Glacier View Mountain. This steep dip does not persist northward along Demers Ridge, and may be due to slump. The average dip of strata in the central part of the dam site is 20°. Direction of dip varies from due north to N. 38° E., the arithmetical average being N. 14° E.

Joints.—Careful observations have been made on the character of about 40 joints in both argillite and Purcell basalt. First impression is of the apparent lack of system. However, further analysis of direction of strike and direction and amount of dip shows some regularity. The following sets have been recognized as average characteristics of the master joints:

Strike	Dip	Spacing	Remarks
N. 8° E	79° W	8 in. to 3.0 ft	Parallel to direction of stream flow.
N. 41° E	68° S	3 in. to 2.5 ft	Control cliff face.
N. 74° E	74° S	10 in. to 3.0 ft	
N. 43° W	83° E	4 in. to 1.5 ft	Control cliff face.
N. 69° W	70° S	1.0 ft	

These five systems account for nearly 80 percent of the observed joints. As many as nine joint systems have been noted in a single outcrop. Joints not included in the above classification may fall into one of the same strike groups but show either very low dips or dips in the opposite direction.

On the road 100 feet south of section E–E′, a small shear zone, which cuts across the argillite, strikes N. 10° E. and dips 12° W. The upper block appears to have moved west with respect to the lower block. A crushed zone 2 to 6 inches thick marks the fracture. No evidence of movement was observed along any of the other fractures, nor was any noted with corresponding dip and strike. Details of jointing for each cross section are shown in plate 25.

Faults.—Other than the small shear zone previously mentioned, no faults have been observed in the dam-site area. However, a number of large faults are present nearby. Apgar Mountain is flanked on the east by the great Flathead fault, which probably underlies the McGee Meadows district. Its course through the Glacier View Reservoir area is not definitely known, but it may pass into a fault mapped just west of the Whale Buttes in the south part of T. 36 N., R. 22 W. If this correlation is correct, it must pass under Camas Creek about a mile or a mile and a half northeast of the dam site. Recent movement along this fault has resulted in deformation of the Tertiary "lake beds" (Kishenehn (?) formation) east of Demers and Winona Ridges.

Eight or nine miles northeast, the Roosevelt or North Fork fault strikes along the west face of the Livingston Range. North Fork Valley above the dam site thus occupies a structural depression or graben. East of the Roosevelt fault, the low angle Lewis overthrust fault underlies the Lewis and Livingston Ranges. Some geologic evidence suggests that this fault has its root in the east flank of the Whitefish Range. If this is correct, it must underlie the valley floor of Flathead River (North Fork). Possibility of future movement on any of these faults is small. Flathead fault appears to have been active most recently. The probability of movement upon it, and the regional earthquake hazard have been evaluated in the report on Hungry Horse dam site.[47]

Ground-water conditions.—Locally on the left bank of the river the ground-water level is high. Springs appear at 3,660 feet on the south side of the large alluvial cone cut by section F–F′. Probably the water is stored in the upper part of the cone. However, the geologic structure of Huckleberry Mountain is such that water falling on its top or east flank might be carried through on a permeable bed.

Springs were not observed along the right bank within the dam-site area.

Permeability.—The permeability of the argillite of the Missoula group is affected most strongly by the set of master joints striking a little east of north, which parallel the direction of river flow through the dam site. For cracks 0.0001 foot wide, the constant *K* is roughly

[47] Erdmann, C. E., op. cit., pp. 80–84.

estimated to be 4×10^{-7}. Permeability of the submarine lava flows is probably much less, because of the lack of bedding and the wider joint spacing. A useful factor for this formation is approximately $K = 2 \times 10^{-7}$. Permeability of the alluvium and glacial deposits in the buried gorge is about the same as that of related deposits downstream, but these formations would not be involved, for they would be removed by foundation excavation. They are, however, present in the McGee Meadows and Langford Creek Divides and must be considered in evaluating possibilities of leakage from the reservoir.

Dam section.—Careful studies have been made to determine the most economical dam section. Nine profiles were examined, eight of which are shown in plates 24 and 25. The profile not shown parallels line H–H′ about 950 feet downstream. As a result of preliminary analysis, chiefly on the basis of size of open valley, sections E–E′, F–F′, and G–G′ were selected for further study, and resistivity work was done at each of them. If the interpretations at G–G′ are correct, it is evident that geophysical work should have been undertaken at H–H′, but time did not permit. In the following table, using the data from the table on plate 25, total width of valley, area of open valley, area of buried valley, and total cross-sectional area of valley are compared for various heights of dams or pool levels. On topographic grounds, it appears that section F–F′ is the most economical up to a height of 375 feet above channel bottom, and that G–G′ is the best for the higher dams. Section E–E′ is a poor second or third in nearly every case. However, when the cross-sectional areas of the buried valley are considered, section E–E′ consistently places first, G–G′ second, and F–F′ third choice, and the same holds for the total cross-sectional area.

Comparison of sections at Glacier View dam site indicating relative economy of construction

Height of dam above channel bottom (feet)	Altitude of pool level (feet)	Choice of section with reference to—											
		Width of valley			Area of open valley			Area of buried valley			Total cross-sectional area of valley		
		1	2	3	1	2	3	1	2	3	1	2	3
175	3,500	G–G′	E–E′	F–F′	F–F′	E–E′	G–G′	E–E′	G–G′	F–F′	E–E′	F–F′	G–G′
275	3,600	G–G′	E–E′	F–F′	F–F′	G–G′	E–E′	E–E′	G–G′	F–F′	E–E′	G–G′	F–F′
375	3,700	G–G′	E–E′	F–F′	F–F′	G–G′	E–E′	E–E′	G–G′	F–F′	E–E′	G–G′	F–F′
475	3,800	E–E′	G–G′	F–F′	G–G′	F–F′	E–E′	E–E′	G–G′	F–F′	E–E′	G–G′	F–F′
525	3,900	E–E′	G–G′	F–F′	G–G′	E–E′	F–F′	E–E′	G–G′	F–F′	E–E′	G–G′	F–F′

Abutments.—Only those portions of the valley walls above river surface will be considered as abutments; those below that level are included with the valley floor as the foundation. The abutments are shown in plan and profile, respectively, in plates 24 and 25.

All the abutment is characterized by its massive form, which assures adequate bearing surface for any kind of dam. With the exceptions noted below, the composition and attitude of the rock in the three favored sections, E–E′, F–F′ and G–G′, is approximately equal, and the bearing power and resistance to sliding is essentially the same. In the two lower sections, the amount of dip is 8° to 10° greater than in E–E′, and they are thus considered somewhat more secure against sliding.

Except below E, the slope of the right or west abutment is fairly steep. (See pl. 25, F–F′, G–G′.) Exposures are more or less complete, and only a relatively small amount of loose or active talus is lodged at the foot of the slope. The soundest rock in any section is exposed in the right bank just above water surface. Higher slopes are usually cliffy, and because of thorough jointing, carry much loose rock which will require scaling down. Exposures on the left bank are not so complete. The best are probably in the cliffs below E′. Elsewhere, talus and alluvial-cone deposits are extensive and deep, particularly below F′. An important factor in selecting the dam site will be the amount of excavation required to expose the left abutment.

The lower greenstone flow is involved in all three sections considered here. In plate 25, E–E′, it is so situated as to form the lower part of both abutments, and possibly some of the upstream part of the foundation. Wherever present in full thickness, it will contribute much in the way of strength and impermeability. Owing to the direction and amount of dip, this flow rises in altitude downstream, but continues to be present in the lower right abutment at F–F′ and G–G′, its top not exceeding an altitude of 3,400 feet. On the east bank, however, it is much higher and would not be involved in any dam necessary to fulfill the requirements of this site. The inequalities of occurrence of the flow in the various sections is counterbalanced by the uniformity in hardness and strength of the argillite and greenstone, so the variations in distribution make little difference. There is a possibility, however, that the left abutments at F–F′ and G–G′ may be slightly more impermeable than the corresponding right abutments, but this differential will decrease in proportion to the height of the dam.

Foundations.—Geophysical measurements and borings indicate considerable depth to bedrock foundation at Glacier View dam site. Unfortunately, drilling was not carried to bedrock in the deeper part of the valley, but interpretation of resistivity data taken at station 2 (pl. 25, F–F′) suggests that it may lie about 225 feet below river surface. The surface of the rock floor is probably fairly smooth, with shallow flutings. However, deep, narrow till-packed gorges with overhanging walls are ever possibilities. Such features are too narrow, usually, to be detected by the resistivity method operating on overburdens of more than 100 feet. Hence, greater depths may exist. Depth of fill over the rock benches averages about 150 feet. These conditions make excavation to foundation difficult and expensive, and it may be unattainable.

The rock in the valley floor apparently is the same as that exposed in the abutments. The upper greenstone flow crosses the river at the head of Glacier View Canyon and is not involved in any possible dam section. The lower flow underlies the valley just upstream from section D–D′. Elsewhere the argillite of the Missoula group is present. It is all very strong and can support the highest possible dam without crushing. Dolomitic facies, which might be somewhat soluble, are not involved in any possible section.

If a foundation suitable for a rigid dam is unattainable, the natural alternative would appear to be a rock-fill structure. Such a concept involves the valley fill as a foundation. In this respect, Glacier View dam site is analogous to the Bad Rock Canyon and Coram Canyon sites where very similar conditions exist, but on a larger scale. Some of the resistivity curves suggest a layer of low resistivity, which, in geologic terms, probably is a layer of clay or silt laid down by ponding of a glacial stream. Although such material is relatively impermeable, its bearing power is not great, and its presence in a dam foundation probably would result in differential settlement. The possibility of the occurrence of remnants of glacial drift of pre-Wisconsin age has been mentioned. If Illinoian(?) or older till is present, its distribution may be expected to be erratic, contributing to the complexity of the fill. Only the most thorough exploration by boring will determine whether the foundation at this site is safe for a flexible dam.

Choice of section.—Of those most fully investigated, section E–E′, plate 25, on the basis of economy of section, is first choice for any height of dam, section G–G′ ranks second, and F–F′ third, although the presence of the alluvial cone in the left abutment is a weak element. It is probable, however, that section H–H′ is more economical than F–F′, and it may be equal to or a little smaller than E–E′. Further exploration of Glacier View dam site is warranted to test the possibilities of section H–H′.

Height and length of possible dam.—The maximum reservoir elevation at this site would be 3,865 feet. This could be attained by a dam 540 feet above stream bed. In this report, the maximum height considered is 525 feet above stream bed, or 690 to 765 feet above foundation, which would place the pool level at 3,850 feet and allow 15 feet of freeboard at McGee Meadows Divide in Glacier National Park. Width of valley at this level in section E–E′ is 2,315 feet. In order to obtain good anchorage to the abutments, the length of dam would have to be somewhat greater, probably 2,365 feet.