UNITED STATES DEPARTMENT OF THE INTERIOR
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Water-Supply Paper 866

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

By
C. E. ERDMANN

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UNITED STATES DEPARTMENT OF THE INTERIOR
Harold L. Ickes, Secretary

GEOLOGICAL SURVEY
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Water-Supply Paper 866-A

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PART 1. KATKA, TUNNEL NO. 8, AND KOOTENAI FALLS DAM SITES, KOOTENAI RIVER IDAHO AND MONTANA

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PART 1. KATKA, TUNNEL NO. 8, AND KOOTENAI FALLS DAM SITES, KOOTENAI RIVER, IDAHO AND MONTANA

By C. E. Erdmann

ABSTRACT

Geologic conditions and cultural development in three dam-site areas on the Kootenai River between Katka, Idaho, and Kootenai Falls, Mont., are discussed. The main line of the Great Northern Railway parallels the left bank of the Kootenai River between Katka and Kootenai Falls, and for long stretches the track level is not far above the water surface. An important control on river development is exerted by the railroad, as it is the principal cultural feature in the valley. The dam sites are considered primarily, as though the railroad did not exist, and the effect of cultural control on the sites is developed secondarily. If cultural control had been given primary consideration, it would have precluded geologic examination of two of the sites.

The Katka site, in the N½ sec. 31, T. 62 N., R. 3 E., Boundary County, Idaho, appears to be the best natural location for a high dam to control the Kootenai River in the United States. The favorable features of the site are, however, nullified by the presence of the railroad at low elevations in the dam and reservoir site.

Tunnel No. 8 site, in the E½NW¼ sec. 28, T. 33 N., R. 34 W., Lincoln County, Mont., has geologic and cultural conditions that make it unsuitable as a dam site.

The Kootenai Falls sites, in secs. 13 and 14, T. 31 N., R. 33 W., Lincoln County, Mont., have favorable geologic conditions and can be developed without endangering the railroad.

Topographic and geologic investigation of the sites was made during the field season of 1934 by engineers and geologists of the conservation branch of the Geological Survey, United States Department of the Interior, through funds supplied by the Public Works Administration.

INTRODUCTION

Under a comprehensive program of surveys of western rivers for power-classification purposes, expedited greatly during 1933–37 by funds of the Public Works Administration, the survey of the Kootenai River was extended upstream from a point 1 mile below the mouth of the Moyie River[1] to a point 3 miles below Troy,[2] and from a point 3

[1] Plan of Kootenai River, Idaho, international boundary to a point 1 mile below Moyie River, scale; 1:12,000, contour interval, 2 feet, 9 sheets, U. S. Geol. Survey, Washington, 1928.

[2] Plan and profile of Kootenai River, Mont., from a point 3 miles below Troy to a point 3 miles above Libby, scale 1:48,000, contour intervals, 20 feet and 5 feet, U. S. Geol. Survey, Washington, 1932. This map has been enlarged to 1:31,680 and published as sheet B of the 1937 edition of Kootenai River maps.

miles above Libby to the international boundary at Gateway, Mont. Three dam-site areas were selected by W. C. G. Senkpiel, associate hydraulic engineer, Geological Survey, United States Department of the Interior, and mapped under his supervision by Norman B. Benson, Gilbert Griswold, and D. H. Griswold, junior topographic engineers, Public Works Administration. The writer, assisted by John S. James, of Helena, Mont., made a geologic field examination of the sites in the fall of 1934.

LOCATION OF THE DAM SITES

The location of each of the dam-site areas is shown on plate 1. The names of the four sites and a description of their respective locations by legal subdivisions follows:

Katka site—N½ sec. 31, T. 62 N., R. 3 E., Boundary County, Idaho.
Tunnel No. 8 site—E½NW¼ sec. 28, T. 33 N., R. 34 W., Lincoln County, Mont.
Kootenai Falls sites—secs. 13 and 14, T. 31 N., R. 33 W., Lincoln County, Mont.

The Katka site is about a mile upstream from the Katka station of the Great Northern Railway which is on the left bank of the river, 10 miles above Bonners Ferry; the right bank of the site is 26 miles from Bonners Ferry by way of the road to Glass ranch. This road is shown on the topographic map of the Priest Lake quadrangle.

Tunnel No. 8 site is about 1½ miles east of the Idaho-Montana boundary and 2 miles upstream from Leonia, Idaho.

The Kootenai Falls sites comprise an upper site and a lower site. The upper site is 500 feet downstream from the Kootenai Falls station of the Great Northern Railway, 11 miles by road from Libby, and 8 miles from Troy; the lower site is 4,500 feet downstream from the station.

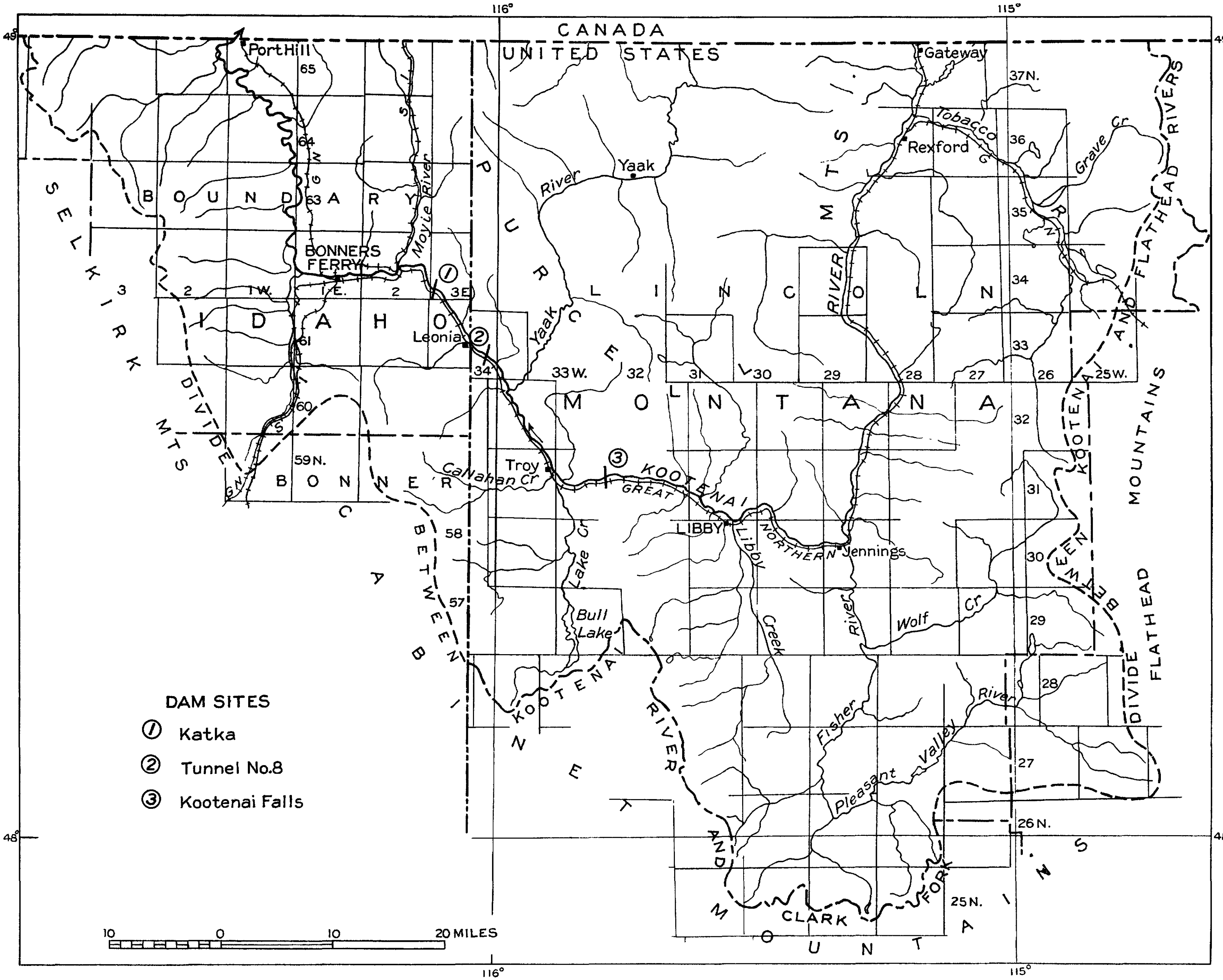
PURPOSE OF PROPOSED DAMS

Development of hydroelectric power is the principal reason for considering the construction of dams in the Kootenai River.

The highest dam that could be constructed at the Katka site would provide adequate storage capacity for irrigation or flood control, but cultural development in the area that would be affected makes such a dam impracticable. None of the other three sites would provide adequate storage capacity for such purposes.

Stream regulation throughout the Kootenai Valley would be beneficial, as it would afford protection not only to the railroad and Bonners Ferry but also to the agricultural development on the delta plain at the head of Kootenai Lake,[3] in British Columbia. The lake itself is, however, the only reservoir available that would be suit-

[3] Spelled Kootenay in Canada.



INDEX MAP OF NORTHWESTERN MONTANA AND NORTHEASTERN IDAHO, SHOWING LOCATION OF DAM SITES ON KOOTENAI RIVER.

able for stream regulation, and the benefits that could be derived therefrom would naturally obtain below the lake both in the Kootenai and the Columbia Rivers. A dam with facilities capable of storing water in Kootenai Lake was built several years ago in the Kootenai River below the lake, but authorization for regulation of the dam in a manner that would raise river levels in Idaho was not obtained until 1939.

The Kootenai River in Canada has been discussed briefly by the Army engineers [4] in their report on the Columbia River. With regard to power sites on the part of the river within the United States, the Army engineers [5] state:

761. There are but two important power sites on that portion of the Kootenai within the United States, the upper one at Kootenai Falls between Libby and Troy, Mont., and the lower one near Leonia, Idaho, at the Montana-Idaho line. E. W. Kramer estimated the power available at these sites to be 20,000 horsepower at Kootenai Falls and 11,000 horsepower at Leonia. The Kootenai Power Construction Co., under date of June 4, 1921, applied to the Federal Power Commission for a preliminary permit for power development at the Kootenai Falls site, but the application was rejected by the Commission on March 2, 1923. Mr. Kramer reported heads of 89 and 50 feet at these two sites, respectively. The mean monthly flow for the past 17 years at Libby, Mont., upstream from these sites, was 11,700 second-feet, and the Q50 flow was approximately 5,500 second-feet, the Q90 flow was approximately 3,000 second-feet, and the Q100 flow was 2,170 second-feet. To be conservative no allowance is here made for inflow below the gaging station. From these data the power duration with natural flow at 80 percent efficiency in kilowatts at these 2 sites is estimated to be as shown herewith:

Site	Percent of time		
	50	90	100
	Kilowatts	*Kilowatts*	*Kilowatts*
Kootenai Falls	33, 300	18, 200	13, 100
Leonia	18, 700	10, 200	7, 400

LITERATURE AND MAPS

The power possibilities of the Kootenai River have been made the subject of a reconnaissance report to the United States Forest Service by Kramer.[6] This report mentions briefly the Leonia and Kootenai Falls dam sites. Kramer [7] has also made a special report on the Kootenai Falls project. These reports have been summarized by the

[4] Columbia River and minor tributaries, reports of the district engineers at Seattle, Wash., and Portland, Oreg., 73d Cong., 1st sess., H. Doc. 103, vol. 2, p. 801, 1934.

[5] Idem, p. 800.

[6] Kramer, E. W., Water power in Montana, U. S. Forest Service, unpublished report, Jan. 28, 1931.

[7] Kramer, E. W., District engineers' report on application of Kootenai Power Construction Co. for a final water power permit on the Kootenai River near Libby, Mont., Kootenai National Forest, Missoula, Mont., Feb. 15, 1913 (manuscript report on file in the offices of the Forest Service in Washington, D. C., and Missoula and Libby, Mont.).

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Army engineers [8] and included in their voluminous report on the Columbia River.

The topographic map of the Kootenai National Forest (scale, 2 miles to the inch; contour interval, 200 feet) is an excellent base map of the entire region. More detail of a part of this area, which includes the Kootenai Falls dam site, is furnished by the topographic map of the Libby quadrangle (scale, 1:125,000, contour interval, 100 feet). The 1913 edition of the map of the Priest Lake quadrangle (scale, 1:250,000, contour interval, 200 feet) includes the Katka and Tunnel No. 8 dam sites. Late in 1937 the Geological Survey printed in nine sheets the plan and profile of the Kootenai River from a point 1 mile below Moyie River, Idaho, to the international boundary, Mont. The dam-site areas are shown on sheets A and B (scale, 1:31,680, contour interval, on land 20 feet, and on water 5 feet), and the detailed surveys of the dam sites (scale, 1:4,800, contour intervals, 10 and 20 feet) are shown on sheets F and G.

With the exception of the early work of Daly [9] along the international boundary and the recent survey of the Libby quadrangle, little systematic geologic work has been done in that part of the Kootenai River Valley that lies within the United States. The pioneer investigation was made by Gibbs [10] in the course of his exploration of the northwest boundary of the United States in 1857–1860. In 1905 Calkins,[11] in a reconnaissance of western Idaho and northwestern Montana, crossed the valley near Troy and Libby, Mont., and traversed it from Leonia to Port Hill, Idaho. Davis [12] passed through the valley in 1913 and 1914 and has given a vivid description of its glacial features, particularly of those in the part between Bonners Ferry, Idaho, and Kootenai Lake, in British Columbia.

Throughout the period 1920–34 Gibson [13] and his associates carried on a thorough study of the geology of the Libby quadrangle. Their comprehensive report affords an excellent basis for further study of the region. Numerous references are made to the report in the following pages.

CULTURAL DEVELOPMENT

The principal towns in the Kootenai River Valley are Bonners Ferry, Idaho, which has a population of 1,418 and whose chief indus-

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[8] 73d. Cong., 1st. sess., H. Doc. 103, vol. 2, pp. 800–801.

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

[10] Gibbs, George, Physical geography of the northwestern boundary of the United States: Jour. Am. Geog. Soc., vol. 3, pp. 147, 156, 157, 378–382, 387–388, 1873.

[11] Calkins, F. C., A geological reconnaissance in northern Idaho and northwestern Montana: U. S. Geol. Survey Bull. 384, 112 pp., 1909.

[12] Davis, W. M., Features of glacial origin in Montana and Idaho: Assoc. Am. Geographers Annals, vol. 10, pp. 97–104 [1920].

[13] Gibson, Russell, Geology and ore deposits of the Libby quadrangle, Mont., with descriptions of the glaciation by W. C. Alden and the physiography by J. T. Pardee: U. S. Geol. Survey Bull.— (in preparation).

tries are lumbering, agriculture, and railroading; Troy, Mont., a local mining center, with a population of 869; and Libby, Mont., which has a population of 2,947 and whose principal industries are mining and lumbering. Leonia, Idaho, a small mining community on the State line, is about midway between Bonners Ferry and Troy. Other than the railroad and Leonia, no development exists in the valley bottom between Bonners Ferry and Troy. North of the river, on the broad, high bench that flanks the base of the Purcell Range, are some small, partly forested farms.

Failure of a high dam at any point on the river above Bonners Ferry and Troy would probably destroy both towns. Such a disaster would also flood the railroad and its small stations. The track level is so near the surface of the river that it has been flooded twice, once in 1894 and again in 1916. In 1894 the water was so high that boats were used in the streets of Bonners Ferry, which is 1,787 feet above sea level. In the spring of 1916, 4 feet of water flowed through tunnel No. 8 for 4 days. Even in normal years spring flood waters come within a few feet of the ties at many places. The natural constrictions of the river develop high backwater during flood periods, and, as the sites under consideration are the most economical sites available for dams, improvement of flood conditions could not be expected by the construction of low movable dams, however fine and delicate their control.

A cursory examination does not reveal any feasible possibility of rerouting the railroad out of the inner gorge below Troy. The altitude of Troy is 1,889 feet above sea level, and the altitude of the river surface is about 1,870 feet at ordinary stage. An alternative route from Troy would cross the river at or near the town, ascend to the bench at the base of the Purcell Range, and then parallel United States Highway No. 2 to Moyie Falls, where connection with the Spokane International Railway into Bonners Ferry could be made, the main line of the Great Northern Railway being resumed below Bonners Ferry.

CLIMATE

The following summary of climatological data is based on records of the United States Weather Bureau at Libby, Mont.

Summary of climatological data, Libby, Mont., 1895–1936

Annual precipitation, mean	inches	19. 22
Annual snowfall	inches	50. 75
Mean temperature	°F	44. 6
Highest temperature	°F	109
Lowest temperature	°F	−46

TOPOGRAPHY AND DRAINAGE

Northwestern Montana and northern Idaho (see pl. 1) are occupied by several irregular groups of mountains and two conspicuous linear depressions. These depressed areas and the major streams form the geographic and, in some places, the geologic boundaries of the mountain ranges. The eastern depression is known, in the structural sense, as the Rocky Mountain trench.[14] It is about 800 miles long, and about 160 miles of its length is in Montana. It trends to the northwest, the axis crossing the international boundary at about 115° 10′ west longitude. The width varies, narrowing northward, and between Gateway, Mont., and Golden, British Columbia, averages about 5 miles. The floor of this trough is much aggraded and contains parts of the Columbia, Kootenai, Tobacco, Stillwater, and Flathead Rivers and Flathead Lake.

The axis of a similar depression, called the Purcell Trench,[15] crosses the international boundary at 116° 30′ west longitude, parallel to and about 60 miles west of the Rocky Mountain Trench. The floor of the Purcell trench also is aggraded and contains Lake Pend Oreille, the Kootenai River below Bonners Ferry, Idaho, and Kootenai Lake, in British Columbia. At the international boundary, the Rocky Mountain trench is flanked on the east by the Whitefish Range, known in Canada as the Galton Range, and the Purcell trench is flanked on the west by the Selkirk Range.

The Purcell Mountains extend into the United States between the trenches as far south as the transverse valley of the Kootenai River. The part in British Columbia has been described by Schofield,[16] the part along the international boundary by Daly,[17] and the part in the United States by Calkins.[18] The Cabinet Mountains are bounded on the north, downstream from Libby, by the Kootenai River; on the west by the Purcell trench; on the south, from Lake Pend Oreille to the town of Perma, by the Clark Fork River; and on the east and northeast by the Little Bitterroot and Fisher Rivers. They have been mentioned briefly by Calkins,[19] but their geologic features outside of the Libby quadrangle, which has been mapped recently by Gibson,[20] are not known in detail. Another irregular mountain mass lies east of the Purcell Range, from which it is separated by the Kootenai River. It has been known as the Flathead Mountains, although Clapp [21] in

[14] Daly, R. A., The nomenclature of the North American Cordillera between the 47th and 53d parallels of latitude: Geog. Jour., vol. 27, p. 596, London, 1906.

[15] Daly, R. A., op. cit., p. 597.

[16] Schofield, S. J., Geology of Cranbrook map area, B. C.: Canada Geol. Survey, Mem. 76, 1915.

[17] Daly, R. A., Geology of the North American Cordillera at the 49th parallel: Geol. Survey Canada, Mem. 38, vol. 1, pp. 119–137, 1912.

[18] Calkins, F. C., op cit., p. 16, 1909.

[19] Calkins, F. C., op. cit., pp. 14, 15, 16.

[20] Gibson, Russell, op. cit.

[21] Clapp, C. H., Geology of a portion of the Rocky Mountains of northwestern Montana: Montana Bur. Mines and Geol., Mem. 4, p. 14, 1932.

1932 suggested the name Selish Range,[22] which has not otherwise been used.

KOOTENAI RIVER

All the waters that rise in the mountainous areas described above form the headwaters of the Columbia River. The Kootenai River rises in the Rocky Mountain Trench, near Golden, British Columbia, where a narrow divide separates it from the headwaters of the main Columbia River. The river follows the trench southward to Rexford, Mont., which is a few miles south of the international boundary, and then leaves the trough and flows southwestward along the east flank of the Purcell Range to Jennings, at the mouth of the Fisher River, 12 miles east of Libby. From Jennings to Bonners Ferry, Idaho, where it enters the Purcell Trench, the river flows directly through the mountains. After entering the Purcell Trench, the river flows northward, crossing the international boundary at Port Hill, Idaho, and then widens out into Kootenai Lake, 16 miles north of the boundary. Thus along the international boundary the river forms a loop about 60 miles wide, which at its southernmost point, swings 43 miles into the United States. (See pl. 1.)

DISCHARGE AND DRAINAGE AREA

The size of the Kootenai River may be indicated by the following data on the mean monthly flow for 1932:[23] Rexford, Mont., 10,900 second-feet; Libby, Mont., 11,900 second-feet; and Copeland, Idaho, 15,700 second-feet. The maximum discharge between these points ranges from 61,000 to 75,000 second-feet, and the high-water months are May, June, and July. In 1932 the mean accession within the United States was about 4,800 second-feet, which was contributed chiefly by the Tobacco, Fisher, Yaak, and Moyie Rivers and numerous small streams. (See pl. 1.) The drainage area in British Columbia, above Rexford, Mont., is about 8,420 square miles; above Libby, Mont., the area is 11,000 square miles; and at Copeland, Idaho, the outgoing international gaging station, it is 13,400 square miles. Most of this area is forested, and consequently the river is free from silt, except in time of flood. The color of the water is a translucent bluish-green.

The chemical character of the water during the low-water stage is shown by the following analysis[24] of a sample taken at Kootenai Falls in October 1934.

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[22] The spelling Salish, not Selish, is used for the Indian tribe in Handbook of the American Indians: Bur. Am. Ethnology, Bull. 30, pt. 2, pp. 415–418, 1910.

[23] Surface water supply of the United States, 1932, part 12, North Pacific slope basins, A, Pacific slope basins in Washington and upper Columbia River Basin: U. S. Geol. Survey Water-Supply Paper 737, pp. 72–81, 1934.

[24] Analysis by J. G. Crawford, U. S. Geol. Survey Lab., Midwest, Wyo., Lab. No. 35–W47, Oct. 17, 1934.

Reacting values

	Parts per million	Reacting value	Value in percent
Sodium and potassium (calculated as sodium)	16	0.71	11.02
Calcium	37	1.85	28.73
Magnesium	8	.66	10.25
Sulfate	31	.65	10.10
Chloride	5	.14	2.17
Bicarbonate	148	2.43	37.73

Properties of reaction

	Percent
Primary salinity	22.04
Secondary salinity	2.50
Primary alkalinity	0
Secondary alkalinity	75.46
Chloride salinity	17.68
Sulphate salinity	82.32

Total solids

	Parts per million
By evaporation	178
After ignition	163
Calculated	170

VALLEY PROFILE

The cross-sectional profile of the Kootenai Valley between Troy and the mouth of the Moyie River is asymmetric. Within distances of 4 to 8 miles the slopes of the left, or south bank, rise from the water surface, whose altitude ranges from 1,800 to 1,860 feet, to the summit of the Cabinet Range, which stands at altitudes of about 6,400 feet. The bottom of the valley is narrow, and the river is closely confined by the lower walls, its width seldom being more than 600 feet. The right, or north bank, rises abruptly to altitudes of 2,400 to 2,600 feet and then flattens to a slope that within 2 to 4 miles rises by small steps to an altitude of about 2,800 feet, the base of the Purcell Range, and then ascends sharply to the regional summit level. This broad bench narrows upstream and seems to disappear at the mouth of Kootenai Falls gorge. The inner trench of the river, from 200 to 600 feet deep, follows closely the left wall of the old valley. (See topographic map of the Priest Lake quadrangle.)

The gorge between Libby and Troy is about 9 miles long. Its cross section is a wide, flat U rather than the broad V of a valley formed by normal stream erosion. In the middle and upper parts of the gorge the floor is flat and narrow, and the steep walls flare outward to altitudes of about 2,400 feet. The slopes to higher altitudes are gentler. The hanging tributaries, somewhat modified by recent erosion at the mouths of Burrell, China, and Koot Creeks, once may have been accordant with their trunk stream at an altitude of about 2,500 feet, the approximate average altitude of the downstream bench. At the head of Kootenai Falls, the altitude of the valley floor is about 1,975 feet, which indicates an overdeepening of about 525 feet. Alden[25] has shown that the 2,500-foot constructional terraces on the major streams in the Libby quadrangle are related to the 2,500-foot stage of the waning glacial Lake Missoula, a comparatively recent geologic event. Pardee[26] has suggested that the silt fill at this level in the valley below Kootenai Falls may be referred to the same cause. If the hanging tributaries are related to this fill, however, erosion must have proceeded with extraordinary rapidity to reduce the valley floor to its present elevation. Valley glaciation offers an alternative explanation for the presence of these features. Below the head of Kootenai Falls, the valley floor has been incised by the stream to a depth of about 85 feet; above the falls it is intact. Upstream from Libby, the valley broadens and opens again and is different in character from the two sections just described.

GRADIENT

The profile of the part of the Kootenai River under discussion is shown on sheets H and I of the river maps,[27] adjustment being made for ordinary low water stage. Both above and below Kootenai Falls, the stream flows smoothly over alluvium for long distances. From mile 4.5, 1½ miles downstream from Katka dam site, to mile 13.5, just below Tunnel No. 8 dam site, the river surface drops 40 feet, or 4.4 feet per mile. Through Tunnel No. 8 dam site (mile 14) the gradient is about 3.5 feet per mile. From here to the foot of the Kootenai Falls section, at mile 31.75, the average gradient is 4.3 feet per mile. Upstream from Libby also the gradient is low, and a slope of 4 feet per mile may be considered as normal for the river. These stretches contrast markedly with the character of the stream in the gorge, which is entered just below the mouth of Bobtail Creek, 4 miles west of Libby. The gradient is normal, or a little less than normal, to the mouth of Dad Creek; then it increases to 11 feet per mile from here to Burrell Creek, a distance of 1 mile. Rapids also occur in the next 1½ miles. In the mile stretch just above the head of the falls, however, the river surface drops only 3 feet.

The Kootenai Falls consist of a series of short falls or rapids, that make a total drop of about 85 feet in 1.85 miles. The upper falls are the highest and drop about 30 feet in a distance of 600 feet over a series of ledges that dip upstream. A middle rapid that extends

[25] Alden, W. C., Pleistocene glaciation, in Gibson, Russell, Geology and ore deposits of the Libby quadrangle, Mont.: U. S. Geol. Survey Bull.—(in preparation).

[26] Pardee, J. T., Personal communication.

[27] Plan and profile of the Kootenai River from a point 1 mile below Moyie River, Idaho, to the international boundary, Mont., scale, 1:31,680, contour intervals, 20 feet and 5 feet, 9 sheets, U. S. Geol. Survey, Washington, 1937.

1,000 feet upstream from the mouth of Koot Creek has a drop of about 15 feet. The lower rapids begin about 500 feet below the cable bridge and continue downstream to the lower dam site, making a drop of about 15 feet over a distance of 1,200 feet. These three rapids account for 60 feet of the fall. The remainder of the stream, which is by no means quiet, drops 25 feet in a total distance of 4,200 feet. The lower end of the falls section occurs at mile 31.75, and the northward projection of the Savage Lake fault crosses the river at approximately the same place.

GEOLOGY

STRATIGRAPHY

The rock formations exposed in the Kootenai Valley between Kootenai Falls and Katka are of widely divergent ages. The old, hard rocks consist chiefly of a thick assemblage of pre-Cambrian strata that have been invaded locally by tabular masses of basic igneous rock. Soft, unconsolidated deposits of Pleistocene silt and Recent alluvium rest unconformably upon them in the valley and on the benches.

PRE-CAMBRIAN ROCKS (BELT SERIES)

The Belt series is subdivided into a number of formations or mappable units, chiefly on the basis of lithology. The lower and middle parts of the series are present along the river, and, from oldest to youngest, the formations are Prichard, Ravalli, and Wallace. The Wallace is overlain by the Striped Peak formation, which is not involved in any of the dam-site areas.

In their original state these rocks were composed of well-bedded deposits of fine-grained sandstone, clayey sandstone and siltstone, and clayey magnesian limestone. Over wide areas, toward the end of the deposition of the Wallace formation, they were invaded by basic igneous rock, and the surface of the Wallace, or its equivalent, was covered by a sheet of this material. In their present condition, the rocks of the series are now described as quartzite, argillite, meta-argillite, and siliceous dolomitic limestone. The igneous rocks approach amphibolites in character.

With the exception of argillite and meta-argillite, these terms are more or less familiar to the engineer, as they define rock types encountered frequently. An argillite may be defined as the derivative of mudstone, siltstone, or shale by incipient static metamorphism. It is less thoroughly altered than a slate, which is a product of dynamic metamorphism. A meta-argillite is more or less thoroughly recrystallized, but retains its original structures and does not show marked evidence of schistosity or slaty cleavage.

TERTIARY AND QUATERNARY DEPOSITS

The lake beds, laid down in the Kootenai Valley when ponding occurred, are not present in any of the dam or reservoir sites. Small amounts of Recent alluvium are present, but no deposits of glacial drift.

IGNEOUS ROCKS

MOYIE SILLS

The steeply inclined pre-Cambrian strata between Bonners Ferry and a point about a mile east of Leonia, Mont., have been invaded by tabular masses of basic igneous rock, which, for the most part, are accordant with the bedding. This attitude, certain internal characteristics, and the relations of veins emanating from them into the country rock, indicate that these rock masses are sills. The sedimentary rocks must have been nearly horizontal when the intrusions occurred.

Three large Moyie sills and two minor intrusives, a sill and a dike, occur in the Katka district. The sills are shown in plate 2, but the dike occurs outside of the area mapped. The most important sill is the massive one whose resistance to erosion causes a notable restriction in the width of the gorge at the Katka dam site. This sill crosses the river at right angles, 4,500 feet upstream from the Katka station. Both its width at the surface and its thickness are about 700 feet. The enclosing beds are quartzites of the Prichard formation. The beds at the base of the sill dip 52° to 56° NE., and those at the top dip locally as much as 73° NE. These variations in dip give the mass a wedge-shaped cross section and suggest that it may disappear with depth. It also seems to decrease slightly in thickness from south to north. These differences are probably local and are due to crumpling or minor variations in the dip of the quartzite.

The rock of the sill is tougher and more resistant than the quartzite and makes even more of a ridge than is indicated by the topographic map. At first sight it appears to be fairly uniform throughout, but the dull, gray-green, weathered surface conceals some important differences in texture and composition. Examination of fresh surfaces shows that the rock is a dark-green hornblendite or hornblende gabbro. The grain at both the base and the top is fine, and the texture is dense and compact. Hornblende is the most conspicuous mineral, then plagioclase feldspar. Small amounts of metallic minerals present appear to be magnetite, chalcopyrite, and, possibly, pyrrhotite. The upper part of the sill shows more feldspar than the other parts and is cut by numerous quartz veins that have altered the sill rock adjoining them to a compact, medium-grained amphibolite. At a few places where these veins persist into the quartzite they have been prospected. The quartz varies in color from nearly white to a light gray and has a translucent luster. The only mineralization noted was a sparse scattering of pyrite and some malachite stain.

The internal portion of the sill, which forms both abutments of the dam site, is a coarse-grained hornblendite containing minor amounts of feldspar. Some of the individual laths of hornblende are half an inch long. The rock is strong, tough, and insoluble, and makes an excellent foundation for a dam.

According to Daly [28] the mineralogical composition of the dominant gabbroid type of the Moyie sills is:

	Percent by weight		*Percent by weight*
Hornblende	58.7	Biotite	0.9
Labradorite	34.8	Apatite	.2
Quartz	4.0		
Titanite and magnetite	1.4		100.0

A chemical analysis of the rock follows:

	Percent		*Percent*
SiO_2	51.92	Na_2O	1.38
TiO_2	.83	K_2O	.47
Al_2O_3	14.13	H_2O at 110° C	.10
Fe_2O_3	2.97	H_2O above 110° C	1.07
FeO	6.92	P_2O_5	.04
MnO	.14	CO_2	.06
MgO	8.22		
CaO	11.53		99.78

Specific gravity of the rock, 2.99.

In the other sills in the Prichard formation the character of the rocks is essentially the same as that of the rocks in the sill at the dam site. The thinner sills are slightly more uniform in composition. The sill in the Wallace (?) rocks is, however, finer-grained and does not show marked development of hornblende, except in its upper part, where plagioclase feldspar is also more abundant.

The dike rock consists of a small, badly weathered mass, in a fault about five-eighths of a mile above Katka dam site, on the left bank of the stream. It consists of innumerable small euhedral needles of black hornblende about 0.3 inch long, embedded in a dense, gray-green groundmass. Gibson [29] also observed dikes in similar situations in the Libby quadrangle, where they are associated with stocks thought to be late Mesozoic in age and related to the Idaho batholith.

GEOLOGIC STRUCTURE

Although the Kootenai River forms the geographic boundary between the Purcell and Cabinet Mountains from Troy, Mont., northwest to the Purcell Trench, these ranges are also separated structurally

[28] Daly, R. A., Geology of the North American Cordillera at the 49th parallel: Geol. Survey Canada, Mem. 38, p. 224, 1912.

[29] Gibson, Russell, op. cit.

in this region by the Leonia fault. Between Troy and Libby the Purcell and Cabinet Mountains are an unbroken geologic unit. The dam-site areas are thus involved in two distinct types of geologic structure, the Leonia and subsidiary faults and the mountain folds at Kootenai Falls gorge.

LEONIA FAULT [30]

The Leonia fault is a high-angle overthrust fault, with downthrow to the east and dip to the west. In addition to the pioneer observation of Calkins, the fault has also been studied by Kirkham[31] and Gibson.[32] The displacement is greatest near the north end, where the fault crosses the Kootenai River east of Cranbrook, British Columbia. According to Kirkham[33]—

> The actual vertical displacement here reaches through at least 35,000 feet of Belt series alone, as well as 10,000 feet of interbedded basic sills in the Aldridge-Prichard and Creston-Ravalli formations and an unknown thickness of Purcell lavas interleaved with the Siyeh formation. As one goes southward to Moyie Lakes, the stratigraphic displacement becomes progressively less.

Gibson reports a displacement of "at least 26,000 feet" in the northwestern part of the Libby quadrangle. Thus, by interpolation, the displacement on the fault in the vicinity of Katka dam site is about 30,000 feet.

The Leonia fault leaves the bed of the Kootenai River about 1,500 feet upstream from the Katka dam site and passes into the north or right bank. The fault cannot be seen, owing to alluvium and slump of the Pleistocene silt from the higher benches. However, the position of the trace can probably be located within 400 feet. The strata dip toward it on either side, the dip of the Prichard formation on the west being 65° N. 60° E., and that of the younger beds on the east being 85° S. 60° W.

A fault of unknown displacement, probably directly related to the Leonia fault that lies 300 feet northeast, is exposed in a railroad cut on the left bank of the river, half a mile upstream from the dam site. The strike, as determined from the single exposure, is approximately north, which may account for its nonappearance west of the Leonia fault on the north side of the river. The beds on the east or upstream side strike N. 35° W. and dip 68° S.; those on the west side strike N. 30° W. and dip 58° N. On the west side, a short distance above the cut to the southeast, the beds strike N. 27° W. and dip 74° N. The dip of this fault could not be determined.

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[30] This fault was named by Calkins (U. S. Geol. Survey Bull. 384, p. 53) for the railway station of Leonia, Idaho, near which it passes. The spelling "Lenia," now well established, is probably due to a typographical error. It seems advisable, however, if the fault is to be named for the town, to follow the spelling of the town name.

[31] Kirkham, V. R. D., The Moyie-Lenia overthrust fault: Jour. Geol., vol. 38, No. 4, pp. 364-374, 1930, 1 map and 3 cross sections.

[32] Gibson, Russell, op. cit.

[33] Kirkham, V. R. D., op. cit., p. 371.

Another fault of unknown displacement cuts the Prichard formation about 1,700 feet west of the Katka dam axis. (See pl. 2, section C–D.) This fault, also essentially parallel to the Leonia fault, strikes about N. 15° W., but the dip could not be observed accurately. It is probably nearly vertical, as the beds on the west side at a point 350 feet east of the bench mark that indicates an altitude of 1,809 feet are vertical, whereas those on the east side strike N. 18° W. and dip 66° E. On the right bank of the river the dips along the fault are opposed; those on the west side strike N. 26° W., and dip 58° E., and those on the east side strike N. 26° W. and dip 85° W. This zone of vertical or steep west dips is about 300 feet wide, and east of the zone the normal east dips are resumed at high angles.

TUNNEL NO. 8 FAULT

The fault at Tunnel No. 8 strikes west and dips 43° S. Its strike forms an angle of about 60° with the strike of the Leonia fault, which passes 1½ miles to the south. The Wallace formation is present on both sides, so the displacement cannot be greater than its thickness, which is about 12,000 feet. This fault is characterized by a 3-foot zone of soft clayey gouge. The beds adjacent to the north side of the fault strike N. 33° W. and dip 59° W; those on the south side strike N. 31° W. and dip 65° W.

SAVAGE LAKE FAULT

The Savage Lake fault, named by Gibson,[34] crosses the Kootenai River about a mile west of the mouth of Koot Creek, which enters the river at approximately the center of the Kootenai Falls dam-site area. The fault thus does not occur within the area mapped in plate 5. The following statements have been summarized from the work of Gibson, who observed the fault at the Crater prospect, 1 mile east of Savage Lake:

> The fault zone is at least 40 feet wide and the downthrow is on the west * * * A persistent metadiorite dike, which in places is not very deeply buried in the till, probably follows the Savage Lake fault.
>
> Along the mountain front east and southeast of Savage Lake there are slight depressions and small swamps, possibly indicating recent downward movement of the depressed block near the mountains.

The Kootenai Falls have also been interpreted by Pardee [35] as evidence of a very recent upward movement of the mountain block. The falls, a scenic feature of the gorge which Kootenai River has cut between the Libby and Troy basins are at the head of an inner gorge about 3 miles long. They appear entirely unrelated to any of the glacial features and are therefore assumed to have been initiated by uplift along the fault near the entrance to the gorge. Con-

[34] Gibson, Russell, op. cit.

[35] Pardee, J. T., Physiography of the Libby quadrangle, in Gibson, Russell, Geology and ore deposits of the Libby quadrangle, Mont.: U. S. Geol. Survey Bull.—(in preparation).

sidering the vigor of the river and the fact that the rock is not particularly resistant, the upstream migration of the falls may easily have been accomplished since the Pleistocene.

MOUNTAIN FOLDS

The geologic structure in the Kootenai Falls gorge is related to the Savage Lake fault and to an anticline that plunges to the northwest just east of the fault and whose west limb is cut off by the fault. The structure in the gorge thus consists of the east limb of the anticline and the floor of the syncline adjacent to it on the east. The axis of this syncline crosses the river about 5 miles downstream from Libby.

A complete view of the left wall of the gorge below the lower dam site at Kootenai Falls shows that the east limb of the great anticline descends into the syncline to the east by a series of sharp steplike structural terraces that are characterized by short, steep "risers" and narrow "treads." An entire unit, from base to head of riser, is shown in plate 5, section A–B. Another similar unit occurs high up on the left wall of the valley, downstream from the dam-site area, and probably others exist.

Between point A, plate 5, and section E–D, structural details of the base of the riser are well exposed in the new road cut. The beds involved are the massive argillites of the lower member of the Kootenai Falls section of the Wallace formation. A series of bedding faults are present, the first fault appearing along the road 525 feet southwest of the point where a small culvert cuts through the narrow rock ridge between the highway and the railroad. This fault strikes N. 30° W. and dips 47° E. The shear zone is about 15 inches thick; the upper 6 inches consists of clay and gouge, and the basal part is a breccia. A bedding fault occurs at 553 feet, the hanging wall dipping 50° N. 62° E. The beds in the footwall dip 36° in the same direction. A fault at 558 feet strikes S. 20° E. and dips 65° W., and the gray argillite on the west side dips 27° N. 79° E. Some evidence of movement exists along this zone, the gouge being 6 inches thick. At 690 feet there is a zone similar to that at 558 feet; the strike is S. 68° E., dip 71° W. Another fault, at 990 feet, strikes S. 30° E. and dips 50° E.; the beds below the faults (west) are thin gray argillites that strike S. 30° E. and dip 51° E. Somewhat similar features appear along the road cut northeast of the culvert, and continue as far as the crumpled zone that forms the terrace or tread in the middle part of area shown on the map.

This zone begins abruptly with a small, steep fault, along which the footwall has been dragged upward by the development of two small, sharp, compressional, chevron folds. The fault strikes N. 46° W. and dips 81° W. Adjacent to the fault on the east is a 3-foot shear zone in which the thin, dense bluish-gray argillites above algal bed D are greatly mashed and squeezed, but no gouge exists. These beds strike S. 52° E. and dip 87° W. This zone is crossed diagonally by cleavage planes that strike N. 42° W. and dip 53° W., the planes being spaced a foot or so apart. Normal to them is another set of more closely spaced cleavage planes that strike N. 36° W. and dip 86° E. Striae on the surface of the fault show that the direction of movement along this fault is parallel to the dip. The throw is about 25 feet. The two small folds adjoining the fault on the east are together 200 feet across at the base. The beds just west of the axis strike N. 48°–50° W. and dip about 40° E.; about 30 feet farther west the dip increases to 55°. The fracture cleavage at the base of the massive bed near the axis strikes N. 43° W. and dips 65° E. East of the axis of this flexure the strata are nearly horizontal and extend into a rather flat-floored syncline, about 400 feet wide, that has a small saddle near its center. The east limb of the flat syncline gradually rises into an anticline, about 400 feet in width, whose flat top has been slightly crumpled. This fold breaks down by steps into a narrow syncline that forms the west limit of the major anticlinal fold on the east side of the crumpled zone. This fold has the appearance of an inverted V. It is 300 feet across at the base and about 150 feet high. One more minor open flexure occurs, and then the top of the algal zone dips below the surface of the river and does not reappear within the dam-site area. The total length of this deformed area is about 1,600 feet, and the amplitude of the folds, with the exception of the stronger folds at each end, is such as to confine them wholly to the algal zone.

The deformation of this structural terrace is probably due to the compression and shear of a relatively incompetent zone, the algal beds being the principal yielding members, between massive, rigid argillite members near the trough of a syncline. The deformed area, which shows some interesting features of structural symmetry, probably portrays in miniature the geologic structure of the Cabinet and Purcell Ranges. At the head of the structural terrace the small, sharp anticline east of the fault would have its counterpart in the mountain-forming anticline that lies to the east of the Savage Lake fault zone. The stairlike character of the limbs of the open folds and the flat-floored synclines are present on both a large and small scale.

The age of this deformation is difficult to determine, for the present attitude of the strata is the algebraic sum of all previous movements and, as has been explained, no strata later than pre-Cambrian, by which such movements could be separated, are present. The greater part of the deformation is credited commonly to the Rocky Mountain revolution in the late Mesozoic, but it is likely that some deformation accompanied the injection of the Moyie sills.

Gibson [36] determined that in the Libby quadrangle the folding preceded the major faulting, of which three periods may be distinguished. At some places the movements are continuing to the present day.

EARTHQUAKE PROBABILITY

Evaluation of the geologic stability of this region and the probability of future movement along these faults indicates that faults of the overthrust type and of the high-angle thrust or upthrust type would seem to be definitely quiescent, as the antecedent conditions that led to their development were dissipated by this same movement. Furthermore, no evidence of regeneration of stress exists.

This is not true, however, of old reverse faults on which the character of movement has changed, such as the Hope fault, or of normal faults, such as the Savage Lake fault. The post-glacial movement along the Savage Lake fault is of serious concern at the Kootenai Falls dam site, which is situated in the rising block a short distance east of the fault.

The apparent absence of activity along the old thrust faults and the lack of a historic record of seriously destructive shocks does not guarantee future immunity from earthquakes in this region. The length of the historic record for Idaho and Montana is so short, beginning in 1872 for Montana and in 1905 for Idaho, that insufficient time has elapsed to determine whether the few earthquakes that have been recorded are related to the existing faults or whether they have taken place elsewhere and are perhaps indicative of stress accumulation along new or incipient lines. Considering the geologic history and structure of northern Idaho and northwestern Montana, the earthquake activity seems small indeed.

From 1905 to 1927 only 12 earthquakes have been recorded for Idaho, and half of these took place during the years 1916 to 1918. [37] None occurred within the region under consideration and only two near it. These were of medium intensity, and the small areas affected suggest that the foci lay at shallow depths. If earthquakes occur along the Kootenai River in the United States, they will probably be of this character. The most serious danger from such shocks would probably be secondary effects, such as landslides and collapse of tunnels. Nevertheless, the design of all dams should be made as nearly earthquake-proof as possible.

The earthquake frequency of the entire Rocky Mountain region has been investigated recently by Freeman,[38] who states:

> By reason of the scant records and the rugged topography, notwithstanding the distance from the ocean, it seems only prudent for an insurance company to

[36] Gibson, Russell, op cit.

[37] Heck, H. N., Earthquake history of the United States: U. S. Coast and Geod. Survey, Special Pub. 149, p. 6, 1928.

[38] Freeman, J. R., Earthquake damage and earthquake insurance, p. 150, New York, 1932.

base its premium rates for this Rocky Mountain-Wasatch region on the basis of expecting that at one place or another there may be an average of four serious earthquakes per century within this vast area of 1,120,000 square miles.

Freeman[39] also predicts that these four earthquakes will be of intensity IX or X, the intensity of the earthquake in Montana in 1925, and that

the resulting hazard of an occurrence of a destructive earthquake at any one city or area of 25 by 100 miles in any particular year is 1 to 11,200.

Inasmuch as the Rocky Mountain region, as defined by Freeman, includes the eastern margin of the Snake River lava plain, and other fairly active seismic areas, it is probable that an apparently quiescent area, such as that along the Kootenai River, is less active than his figures for the entire region would indicate.

KATKA DAM SITE

(See pls. 1 and 2)

Location.—N½ sec. 31, T. 62 N., R. 3 E., Boundary County, Idaho, about a mile upstream from Katka station on the Great Northern Railway.

Stream gradient.—The gradient above the dam site is about 4 feet to the mile, but it is steeper between the axis of the proposed dam and Katka station.

Catchment area.—The drainage area above the Geological Survey stream-gaging station at Katka covers 11,860 square miles. No upstream diversion is made.

Purpose of dam.—Power and flood control.

Valley profile.—The width of the ancient high-level valley is near its maximum. The character of the inner gorge, in which the site is located, is shown in plate 2, section A–B.

Apparent possible height of dam.—The general topographic character of the site is such that it would be suitable for a 430-foot dam.

Character and depth of valley fill.—Owing to the force with which the river sweeps through the narrow gorge, only a small amount of alluvium is present in the channel at the axis of the dam. Above and below the axis of the dam there are considerable deposits of alluvium that consist chiefly of unconsolidated sand and gravel.

Country rock.—The rocks in the dam-site area are the Prichard formation and some younger rocks, which are thought to be Wallace but which may be Ravalli. Both the Prichard and the Wallace (?) formations have been invaded by a series of sills of basic igneous rock. These are the famous Moyie sills described briefly in a preceding section.

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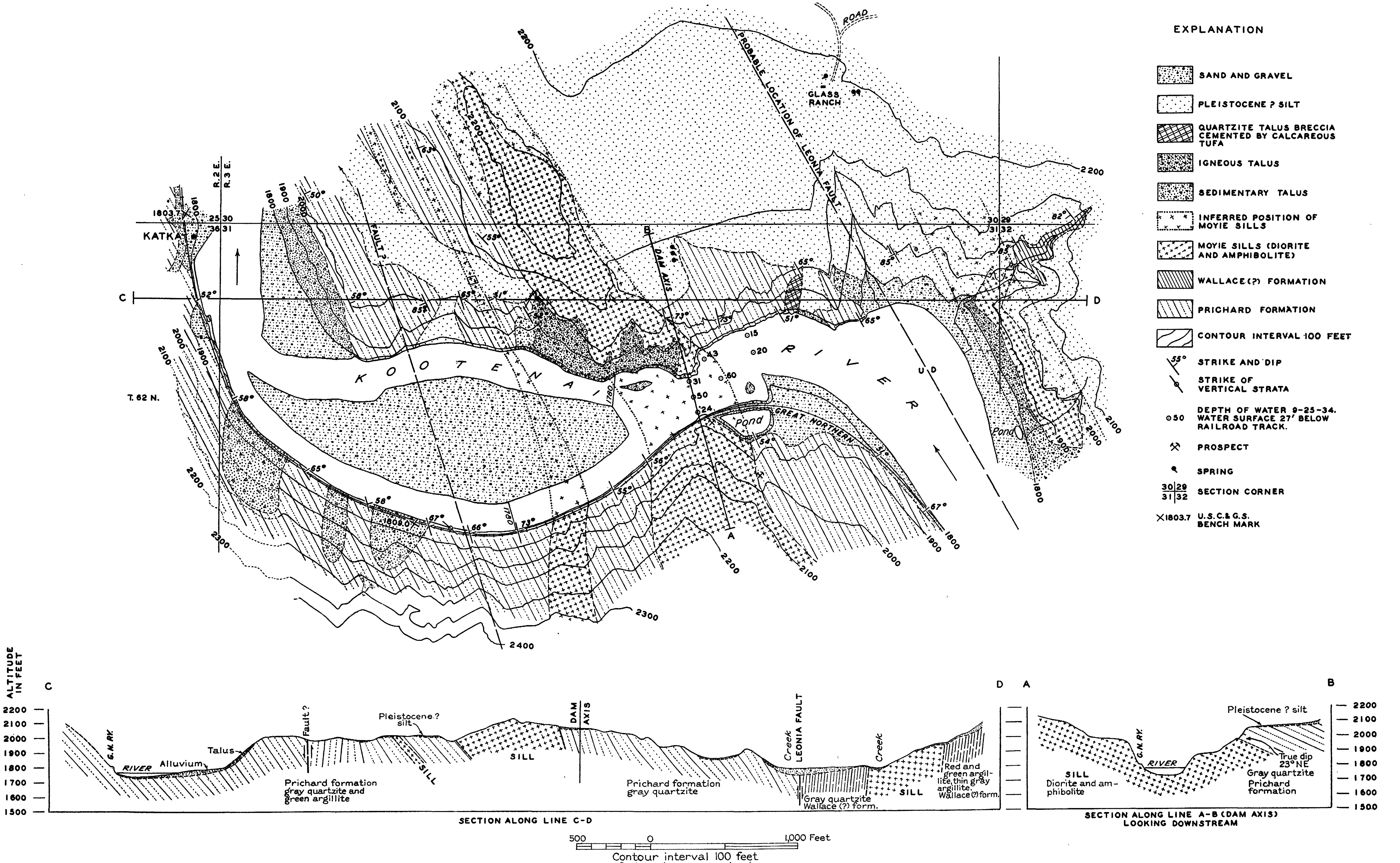
[39] Freeman, J. R., op. cit., p. 630.



GEOLOGIC MAP OF KATKA DAM SITE, N½ SEC. 31, T. 62 N., R. 3 E., BOUNDARY COUNTY, IDAHO.

The dam site itself is situated in one of these thick sills, which is now in a nearly vertical position. This sill is about 700 feet thick and is included in gray quartzite of the Prichard formation. The top of the sill dips about 73° E., and the beds at the base dip 52° to 57° E. The general strike is N. 25°–30° W. The rock is a fine- to coarse-grained, dark-green hornblendite or hornblende gabbro. The top is cut by thin quartz veins. Subsequent to cooling some recrystallization occurred, with alteration of the character of the hornblende from the magmatic type to a more fibrous type.

The rock is strong, tough, and more elastic than the quartzite. Tests of the ultimate crushing strength are not available, but flawless fresh specimens would probably resist pressures of 25,000 pounds to the square inch. The specific gravity of the fresh rock is close to 3. Permeability, porosity, and absorption through the fresh rock are probably negligible. The rock minerals are difficultly soluble under under present climatic conditions. Under prolonged exposure some of the accessory sulphide minerals would break down, but they are present in such relatively small amounts that the quantity of acid radicles developed would not be important or affect normal weathering. These processes would remove some iron from the hornblende and break down the plagioclase. However, as a whole, the rock of the sill is very fresh.

Dips.—The attitude of the country rock is indicated in plate 2, and that of the beds enclosing the dam-site sill has just been described. Insofar as the dam site is concerned, the sill is so thick and massive that the question of dip does not enter, in a practical manner, into the considerations of the structure at this site. Any dam that may ever be built at this locality will probably have both abutments and foundation wholly within the limits of the upturned sill.

Joints.—The following joints were observed in the right (north) abutment:

Strike	Dip	Character
N. 68° W.	62° W.	
N. 28° W.	62° E.	
N. 64° E.	88°–90° S.	Major
N. 80° E.	64° S.	
N. 47° E.	67° N.	

Other joints were also observed, including some that are nearly horizontal now but that were probably nearly vertical when the sill was in its initial position. All of the joints are spaced closely, being 1 to 4 feet apart.

The joints in the left (south) abutment are as follows:

Strike	Dip	Character
N. 42° W.	48° W.	Strong; spaced at 20-foot intervals.
N. 65° E.	Vertical	
N. 58° E.	69° N.	

The intervening areas are thoroughly jointed by fractures that dip principally to the northwest and west at low angles; these are probably the older joints.

Examination of the joints in both abutments indicates that there are two sets of master points, one striking about N. 42° W. and dipping 48° W. The strike of this set is normal to the direction of stream flow and unfavorable to percolation, but the direction of dip favors leakage. These joints are not closely spaced, and percolation through them would probably not be as effective as it would along the joints of the other set, which are more closely spaced and are approximately parallel to the direction of stream flow. This sill and the latter set of joints are probably responsible for the abrupt bend of the river just above the sill.

Faults.—Several faults are present in the Katka district. The principal one, the Leonia fault, is about 1,500 feet east of the dam site and strikes to the northwest. It is probably of the high-angle thrust or upthrust type. Another fault that may be of some significance cuts the Prichard formation about 1,700 feet west of the axis of the dam.

Ground-water conditions.—The ground-water table on each side of the river in the Katka district is high, particularly upstream from the dam site. Many springs issue from the silt overlying the pre-Cambrian rocks, which apparently have their sources in lakes and ponds on the broad high-level bench. Several large perennial springs occur at the Glass ranch, and another series appears on top of the bench, 800 feet north of the dam site. The ground is boggy and gives forth a resonant sound when struck, suggesting the presence of small open pockets or channels close to the surface. Travertine from these springs has cemented some of the talus in the river gorge to a breccia, and the surface of the deposit was wet with seepage water where observed. A rather large stream flows into the river from the northeast, where it has exposed the Wallace (?) strata. The gorge is steep and rocky and contains several falls. Dry ponds were noted on top of the bench on the left bank upstream from the axis of the dam.

Permeability.—The question of permeability at the Katka dam site involves only the dam-site sill. Percolation through the rock is probably negligible. Tests on this particular type of crystalline rock do not seem to be available, but tests on granites have yielded a permeability coefficient as low as 2 to 10 $\times 10^{-12}$. Any percolation that takes place probably occurs along the joints, particularly along those that parallel the course of the river and those that are normal to the course but that dip downstream. Assuming one crack to be 0.001 foot wide per unit cubic foot of rock and to have a head of 300 feet and a path of percolation of 700 feet, or a crack to be 0.001 foot wide, 1 foot high, and 700 feet long under a 300-foot head, the permeability coefficient per unit area of the foundations and lower abutments would be about 250 $\times 10^{-7}$, which is probably about 10 times too high, owing to the excessive width of crack selected. On the same basis as the flawless granite specimen cited above, this would be 25,000,000 $\times 10^{-12}$.

As has been mentioned, the passage of water through the rock would not result in solution or other weakness. Furthermore, the cracks in the sill are probably amenable to pressure grouting. Permeability should not cause any difficulty at this site.

Dam section.—Only one section is available. (See pl. 2, A–B, and pl. 3, *A*.) The width of the gorge at the water surface in September 1934 was 280 feet, and the maximum depth of the water in the axis of the dam was 50 feet. A short distance upstream, where the bottom was probably of bedrock, the depth was 60 feet. The altitude of the bottom of the valley is about 1,720 feet. If a masonry dam were built, the foundation would thus have to be about 60 feet deep. If a dam were raised to 1,800 feet, the crest would be about 20 feet above the water surface and only 7 feet below the level of the railroad track. The length of crest would be 300 feet. Data on other heights of dam are presented in the following table:

Height above foundation	Altitude of crest	Length of crest
Feet	*Feet*	*Feet*
130	1,850	385
180	1,900	590
250	1,970	760

Abutments and foundation.—The abutments at this site are strong and rugged, equal in bearing power, give good security against sliding, and the rock is relatively impermeable and insoluble. The same is true of the foundation.

Height and length of possible dam.—Although the site is admirably suited for a dam, the railroad grade is the factor that controls the height of any possible structure under present conditions. In 1934 the high-water mark was only 18 feet below the track level, and in years of high water the approach is much closer. In times of flood the track is submerged. No spillway section is available (except tunnels, which would have to be of considerable diameter) for dams less than 250 feet in height, and any dam below track level obviously would render the situation of the railroad even more precarious than it is now. Furthermore, the depth of the foundation is such that, to obtain a 10- or 15-foot head, it would be necessary to build 70 to 75 feet above the foundation, which would not be economical.

Appurtenant works.—The great volume of the river makes the spillway the most important accessory work. A natural spillway section does not exist below an altitude of 1,970 feet. Up to that altitude tunnels or an overflow type of dam would have to be used. A bench 250 feet wide occurs in the left abutment at an altitude of 1,970. This is hardly an adequate width for the flood requirement, but it might be adapted to the design. The peculiarity of this site is that the higher and longer the dam the better the spillway section, the section over the right abutment being best for the maximum possible height. As the height of the dam is increased the storage capacity of the reservoir increases. At its best, however, the reservoir would probably not contain enough reserve storage capacity to remove the crest from a large Kootenai flood. Consequently, the spillway requirement remains a maximum and cannot be reduced greatly by raising the dam to provide for flood storage.

Reservoir area.—The reservoir of the Katka dam site is the inner gorge of the Kootenai River. (See pl. 3, *B*.) A dam 100 feet above bedrock (altitude crest 1,820 feet) would back up water beyond Leonia. A 180-foot dam (altitude crest 1,900 feet) would back up water to within a few miles of the base of Kootenai Falls (altitude 1,885 feet), and a 280-foot dam (altitude crest 2,000 feet) would back up water a little beyond the head of Kootenai Falls (altitude 1,975 feet). To preserve the Kootenai Falls site, the water should not be raised higher than an altitude of 1,885 feet, although the maximum possibilities of the site are greater.

The geology of the valley floor is relatively simple. A few small mines and prospects are present in the vicinity of Leonia and Troy. They have been described in the reports by Calkins and Gibson, to which reference has been made. The bottom lands are timbered, but the stands are small and generally of second growth. Most of the good timber has been logged off. Ground water moves toward the reservoir, from which no leakage is possible, except a negligable amount at the dam site. Little or no silting would occur.

Conclusions and recommendations.—The Katka site is suitable for a masonry or concrete dam up to an altitude of 2,150 feet. This would require a structure having a maximum height above foundation of 430 feet and a maximum crest length of 1,820 feet. Such a dam would provide the maximum possible attainment in power and flood control on the Kootenai River in the United States.

A 430-foot dam would, however, back up water beyond Libby, which is 37 miles upstream, and inundate the town site. The river surface at Libby has a normal altitude of 2,050 feet at the bridge, and the altitude of the town ranges from 2,060 to 2,100 feet. A dam of this height would also deeply flood the town of Troy and would effectively block the passage of the Great Northern Railway between Libby and Bonners Ferry.

The crest of a dam 180 feet above foundation would stand at an altitude of 1,900 feet. Water at this level would flood the lower end of Kootenai Falls, and the level is the maximum possible if that power site is to be preserved. It would cause considerable flooding in the vicinity of Troy, which is at an altitude of 1,889 feet, and force the Great Northern Railway to reroute its trucks over the bench along the south flank of the Purcell Mountains. As has been pointed out, such a dam would have an available head of only 100 feet, and the spillway section would be inadequate.

The contingencies of a dam with a crest below the track level at the dam site have been examined, and the conclusions have been reached that the proportion of available head to depth of foundation is far from economical, that the spillway requirement increases with reduction of head, and that the peril to the present track level will be much increased by floods and ice if any obstruction is placed across the stream.

The ultimate conclusion is that although the Katka dam site is topographically and geologically the most attractive of any in the southern loop of the Kootenai River, the cultural development in the valley indefinitely precludes consideration of the site for actual construction.

TUNNEL NO. 8 DAM SITE

(See pl. 1 and fig. 1)

Location.—E½ NW¼ sec. 28. T. 33 N., R. 34 W., Lincoln County, Mont., about 1½ miles east of the Montana-Idaho boundary and 2 miles upstream from Leonia, Idaho.

Stream gradient.—The gradient through the dam site is about 3½ feet to the mile.

Catchment area.—The entire drainage area of the Kootenai River above Leonia covers 11,740 square miles, and the catchment area at the dam site is slightly less.

Purpose of dam.—Power.

Valley profile.—The width of the ancient high-level valley is less in the vicinity of tunnel No. 8 than at Katka. The lower slopes of the inner gorge show a series of minor rock-cut benches, and a steplike group is especially well defined above the north abutment of the dam site. (See pl. 4, *A*.)

Apparent possible height of dam.—The rail elevation at Tunnel No. 8 is about 1,831 feet. During normal water stages the altitude of the river surface is about 1,815 feet, which allows the railroad a freeboard of 15 feet.

The width of the stream along the axis of the dam is 360 feet, owing to the projection of the spur through which the tunnel passes into the river. This is about half of the normal width of the river, and the constriction causes the stream to rise rapidly during flood periods. In the ordinary year high water comes in June, and the water rises to within 2 feet of the ties, or to about 1,828 feet. The local trackwalker reports that during the flood of 1916 the depth of the water in the tunnel was about 4 feet and that this depth was maintained for 4 or 5 days. Even a movable dam with a 10-foot head would aggravate this condition to a considerable degree. Another difficulty is that the proportion of available head to foundation depth is about 1 to 4.

Character and depth of valley fill.—Owing to the force with which the river sweeps through the narrow gorge, only small amounts of alluvium are present in the active channel. The cutting is now against the north bank, and the depth of the water there on October 1, 1934, was about 30 feet. The depth to bedrock is probably not much more than 40 feet, which would make the altitude of the bottom of the channel about 1,780 feet. From this point the floor probably shelves gradually toward the left bank.

The fill is chiefly gravel and silt, with the silt particularly abundant at the mouth of McCormick Creek and on the left bank below the tunnel and the gravel confined to the stream bed. The alluvium is probably reworked during each flood period and is too unstable to support a dam. If any structure is contemplated at this locality, it should be founded upon the bedrock, in spite of the added difficulty and expense.

Country rock.—The country rock is the Wallace formation. It consists of thin-bedded, platy bluish-gray argillaceous limestone and contains a good deal more clay material than the same formation in the Swan Range and other ranges farther east. The bedding surfaces are smooth and regular and open easily upon weathering. As a whole the rock is not very strong. The east end of the tunnel requires a timber support, and the west portal was being prepared for timbering in the fall of 1934, a large crack having developed above this entrance. A trackwalker reported that the rock in the tunnel tended to slake down when exposed to the air.

Crushing tests of the rock are not available, but its ultimate crushing strength is estimated to be 8,000 to 10,000 pounds to the square inch. An individual specimen containing no joints or bedding surfaces would probably be more resistant. The hardness of the rock is about 4 or 5, and the specific gravity is about 2.7. Owing to incipient metamorphism, the absorption and porosity are probably small.

Dips.—The strata dip steeply downstream. Although the downstream dip is unfavorable, it is compensated by the steepness of the dip, which in some places is nearly vertical. North of the fault the dip ranges from 69° to 79°. The strike ranges from N. 15° W. to N. 27° W. South of the fault, on the spur about 300 feet above the tunnel, the dip is 52° W., and the strike N. 35° W.

Joints.—The thin beds are well-jointed. The following observations were made on joints cutting the massive beds in the tunnel:

Strike	Dip	Character
S. 88° W.	66° S.	Good
S. 70° W.	28° N.	------
S. 72° E.	75° S.	Fair
S. 80° W.	63° N.	------

These joints, at least those that strike strongly to the west, are probably related to the fault just south of the tunnel.

Faults.—The fault just south of the tunnel strikes west and dips 43° S. The gouge zone is 3 feet thick. Adjacent to the fault the beds on the north side strike N. 33° W. and dip 59° W., and those on the south side strike N. 31° W. and dip 65° W. This fault, with its thick zone of soft clayey gouge, is an element of weakness in the spur through which the tunnel passes and makes the spur unsuitable for the abutment of a high dam.

Ground-water conditions.—The general attitude of the strata favors the quick return of ground water to the river and does not favor the reversal of the flow of any springs that may be present. McCormick Creek, which enters the river just above the axis of the dam, has built up a rather large deposit of calcareous tufa, which indicates that the flow is chiefly from springs. These springs are, however, probably near the top of the bench on the right bank, above the limits of any possible pool level.

Permeability.—Movement of water through the bedrock is favored by the many smooth, even-bedding surfaces, but the attitude of the beds is against the direction of such flow; so the joints that cut across the beds principally affect the permeability of the formation. These joints would probably cause some leakage. In the north abutment, however, they are not closely spaced, and the path of percolation is about 300 feet long; so leakage would be small. In the south abutment some of the joints are closely spaced and are parallel to the fault. The path of percolation through the spur of the abutment is 200 feet or less, and that along the fault is 600 feet. The south abutment would probably leak more than the north, and, if the gouge zone should become saturated, the abutment might have a tendency to move toward the stream, though the direction of the dip is unfavorable to a complete slide.

The estimation of a permeability coefficient for this formation is difficult. A rough estimate would be that $K=10\times10^{-7}$.

Dam section.—Only one section is available. (See A–B, fig. 1.) The profile at the level of the lowest bench (1,900 feet) is suitable for a dam 100 feet high, with a crest length of 640 feet. The details for other economical sections are as follows:

Height above foundation	Altitude of crest	Length of crest
Feet	*Feet*	*Feet*
50	1,850	420
100	1,900	640
200	2,000	1,000
300	2,100	1,260

The profile of the lower part of the valley is obviously suitable for dams up to a height of about 300 feet.

Abutments.—Both abutments are in the steeply dipping Wallace formation. The north abutment is more massive and stronger. Conditions in the south abutment are almost identical with those in the north, except that the base of the south abutment is cut off by a fault having a wide zone of weak gouge. The bearing power of the two abutments cannot, therefore, be considered equal.

Foundation.—The character of the rock in the foundation is the same as that in the north abutment. It is sufficiently strong to resist crushing, and its attitude gives good security against sliding.

Appurtenant works.—The spillway requirement at this site is large for a low dam, and the present channel of the river is inadequate to take care of the flood flow of the river without danger to the railroad. A dam high enough to provide storage capacity adequate to reduce the flood head would submerge the railroad for many miles upstream.

Reservoir area.—The reservoir area consists of the Kootenai River trench (see pl. 4, *B*), which is probably underlain entirely by the Wallace formation. The trench contains only a small amount of alluvium, the banks are steep and forested, and it contains a minor amount of bottom land. The ground-water table on each side of the trench is high. Leakage from the reservoir is possible only in the vicinity of the dam site. Silting in any reservoir on the river would be negligible. The railroad is the principal cultural development within the reservoir area.

A. VIEW UPSTREAM FROM A POINT 400 FEET EAST OF THE BENCH MARK THAT INDICATES AN ALTITUDE OF 1,809 FEET.

This view shows particularly well the profile of the left abutment of the Katka dam site; the right abutment is somewhat less distinct. The bench at the base of the Purcell Range is also visible, and in the distance are the mountains of the Purcell Range.

B. VIEW UP THE KOOTENAI RIVER FROM THE RIGHT BANK SOUTH OF THE GLASS RANCH

Shows the character of the inner gorge, which would form the reservoir area for the Katka Dam, and the route of the Great Northern Railway along the left bank. The Cabinet Range appears in the extreme distance.

A. VIEW DOWNSTREAM AT TUNNEL NO. 8 DAM SITE, SHOWING THE PROFILE OF THE VALLEY.

The east portal of the tunnel appears at the left center.

B. VIEW UPSTREAM FROM ABOVE THE EAST END OF TUNNEL NO. 8.

Shows the grade of the Great Northern Railway and the character of the reservoir area of the proposed dam site.

Construction materials.—None available except those required for a rock-fill dam. The limestone of the Wallace formation is probably not suitable for the production of cement.

Conclusions and recommendations.—The gorge of the Kootenai River at tunnel No. 8 is so narrow that it is inadequate to pass the

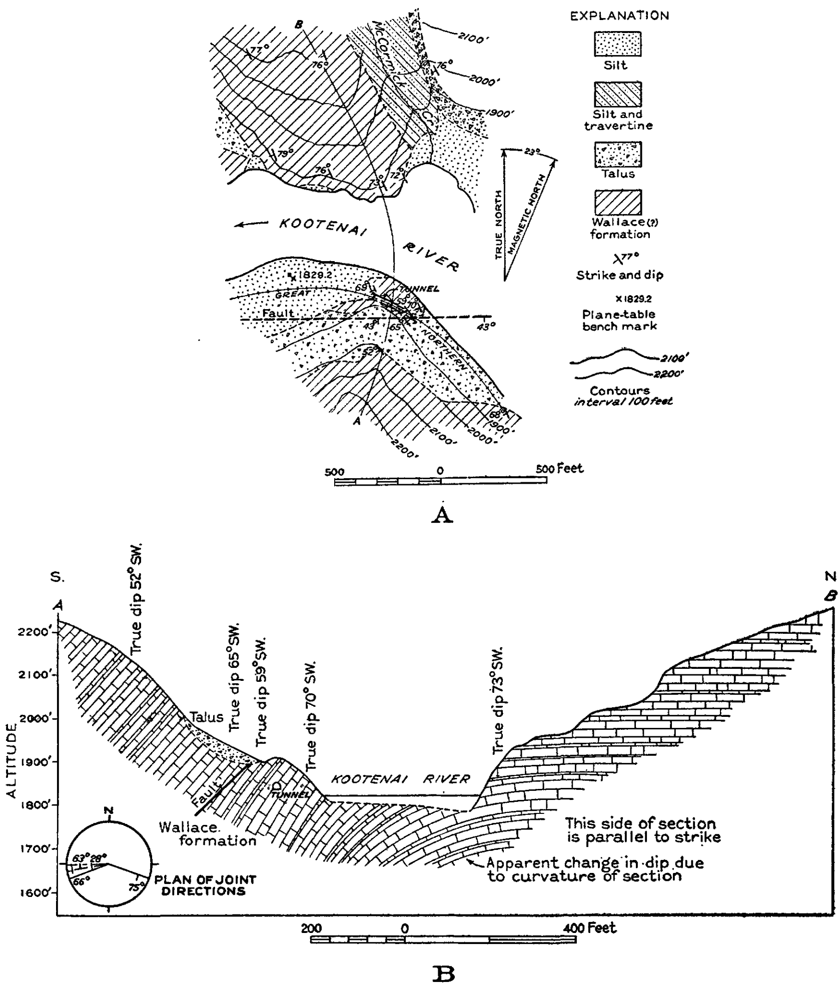


FIGURE 1.—Geologic map and cross section of Tunnel No. 8 dam site, center N½ sec. 28, T. 33 N., R. 34 W., Lincoln County, Mont.

flood crest of the river without inundating the main line of the Great Northern Railway. The construction of even a low dam would aggravate this condition and unquestionably cause much damage. The geologic study shows that the left abutment rests against a fault having a thick zone of gouge that precludes the possibility of building a dam higher than 20 feet. If a high dam were considered, the spur through which the tunnel passes should be removed, and the left end of the dam should be rested in the rock south of the fault; but even this procedure would be questionable, because the fault would still be present. The existence of a fault in the abutment of a dam warrants consideration of some flexible type of design; however, the large spillway requirement operates against such a design. Tunnel No. 8 site is, therefore, unsuitable for a dam from both economic and geologic points of view; the recommendation is made that it be given no further consideration.

KOOTENAI FALLS DAM SITES

(See pls. 1 and 5)

Location.—In secs. 13 and 14, T. 31 N., R. 33 W., Lincoln County Mont. The upper site is about 500 feet and the lower site about 4,500 feet downstream from the Kootenai Falls station.

Stream gradient.—In the area of the sites the stream falls about 85 feet in 1.85 miles.

Catchment area.—The drainage area of the river at Libby, 12 miles upstream, is about 11,000 square miles, and the total area at the sites is slightly more than 11,200 square miles.

Purpose of dam.—Power. The Kootenai Power Construction Co. once proposed to erect a dam at the lower site and core drilled the foundation of the section then selected. (See pl. 5, F–G.) The A-frames that suspended the drilling equipment still stand and are landmarks in the vicinity of the lower site. The company proposed to build a masonry dam 110 feet high and 2,110 feet long that would have occupied about 1.7 acres. The reservoir area at maximum flood level was to be 183.7 acres and 160 acres at spillway level, about 112 acres of which would have lain in the Kootenai National Forest.

Application for a final permit from the United States Department of Agriculture was made on January 20, 1913. The permit was granted by the Secretary of Agriculture on May 4, 1914, but was revoked on October 1, 1919, because the company failed to pay rental charges or begin construction.

During the period the permit was pending the feasibility of the project was investigated by E. W. Kramer, district engineer, United States Forest Service, Missoula, Mont. The following summary has been taken from Mr. Kramer's report.[40]

[40] Kramer, E. W., District engineers' report on application of Kootenai Power Construction Company for a final water power permit on the Kootenai River near Libby, Mont., Kootenai National Forest, Missoula, Mont., Feb. 15, 1913 (manuscript report on file in the offices of the Forest Service in Washington, D. C., and Missoula and Libby, Mont.).

Estimate of power capacity

	Stream flow (second-feet)	Head (feet)	
		Total	Effective
Flood	80, 000	55	50
Maximum station capacity	8, 000	87	85
Minimum (primary) flow	2, 000	90	88
Average flow utilized	2, 950	89	87

Amount of water appropriated, 22,500 second-feet.

Theoretical horsepower at generator switchboard

	Horsepower
Maximum	58, 000
Minimum	15, 000
Average	22, 000

It was proposed to transmit this power to Moscow, Idaho, 100 miles distant.

Valley profile.—The profile of the valley at Kootenai Falls has the form of a wide flat U. (See pl. 6, *A*.) The floor is flat and narrow in the middle and upper parts, but the lower part has been trenched by the stream to a depth of about 85 feet.

Apparent possible height of dam.—The general character of the lower site, section D–E, is such that it seems to be suitable for an 85-foot dam. The upper site, section H–I, might allow a 10-foot dam, but probably none higher.

Character and depth of valley fill.—Owing to the force of the current through the falls, little alluvium is present in the channel. Small gravel bars occur in protected areas. The bedrock floors at both sites are practically bare. Beginning about 500 feet below the area mapped the channel contains considerable amounts of gravel.

Country rock.—The bedrock formation at Kootenai Falls is the Wallace. Three members have been recognized and are shown in columnar section in plate 5. The lowermost member consists of dense massive gray argillite, and occasional zones of purplish material in beds ranging from 18 inches to 20 feet in thickness. This member is not involved in either of the sites. The middle member consists of about 255 feet of siliceous algal beds separated by massive layers of purplish and greenish-gray argillite. The lower part of this member is involved in the lower site. The uppermost member consists of thin-bedded, hard, dense, brittle, gray-green argillite. Ripple marks, mud cracks, and casts of salt crystals are common on the bedding surfaces. This member is involved in the upper site.

The argillites and meta-argillites have a hardness of 4 or 5, and, although not as hard as quartzite, are tougher and less brittle. They fracture only when folded closely; the algal beds, as far as known, always yield by folding. The rock is strong and durable in both an engineering and a geologic sense. Crushing tests are not available, but flawless specimens would probably withstand pressures of 15,000 to 20,000 pounds to the square inch. The average specific gravity is about 2.7. Owing to incipient recrystallization, the absorption and porosity are probably low, and all of the rock is fresh. Practically all of the rock material is insoluble, and passage of water through it will not cause hydration or volume changes, nor enlargement of existing channels, nor weaken it in any other way. Pyrite is an uncommon accessory, and its oxidation will probably have no effect.

Dips.—Structurally the Kootenai Falls area lies in a syncline, the axis of which is a short distance upstream from the upper site. All of the beds thus dip upstream. Those at the upper site range from 11° N. 65° E. in the right abutment to 28° N. 64° E. in the left abutment. The dips at the lower site are much steeper and range from about 21° N. 15° E. to 59° N. 44° E. The altitude of the beds in the intervening area is rather complicated, as shown in plate 5, section *A–B*. The folding and faulting are probably due to the crumpling of the incompetent algal zone between the massive, resistant argillite members as the area was compressed in the trough of the syncline.

Joints.—The thin-bedded argillites are thoroughly jointed. At the upper site one set of joints strikes N. 4° W. and dips 80° W., the joints being spaced 8 to 10 inches apart. The associated set strikes N. 64° W. and dips 74° W., with the joints spaced 2 to 4 inches apart. The north-striking joints are earlier than those that strike to the northwest. Indications of movement on one joint striking N. 58° W. suggest that, with respect to the north side, the south side has moved to the northwest. The rock at the lower site is also jointed, and in addition fracture cleavage has developed in some of the sharper flexures. Just below the upstream A-frame on the left bank, the important closely spaced directions of jointing are strike, N. 41° W., dip, 66° W.; strike, N. 25° E., dip 84° S.

Faults and folds.—Several small faults are present in the area of the sites, but their nature is such that they do not affect the stability of the region. They consist of bedding faults and shear zones developed in the argillite by gliding along the beds and of small vertical faults associated with the chevron folds in the algal zone. None of these features occur at the sites, and none are active.

Ground-water conditions.—The ground-water level throughout the valley floor is low, owing to the thorough fracturing of the hard, dense rock. A few hillside seeps and springs wet the rock above the highway in the southwest end of the map area. A small stream flowing from the north enters the elbow a few hundred feet above the lower site. Koot Creek, the principal tributary to the river within the area of the sites, heads on the right bank, a little to the east of the summit of King Mountain. No danger of reversal of flow of any of the tributary springs exists.

Permeability.—The country rock is as hard and as dense as slate, and danger of percolation through the texture of the rock is negligible. The important seepage from any dam that may be built will be by way of the sheet openings, which consist of numerous bedding and jointing planes. This is particularly true of the rock at the upper site. A rough estimate of the permeability coefficient of the rock at the upper site would be: $K=20\times10^{-8}$. On account of the thicker beds at the lower site and the less intense jointing, the permeability coefficient of the rock in these beds would probably be: $K=15\times10^{-8}$.

Original section at lower dam site.—Three dam sections are available, one at the head of the falls and two at the foot. The location of the original section at the lower site, F–G, is shown in plate 5.

The gorge section at F–G is 230 feet wide, from rim to rim, at the surface of the rock-cut bench. The banks are steep, nearly vertical in places, and have an average slope of about 60°. The width of the water surface is about 150 feet. A rock-cut bench, the top of which is just below the water surface, extends 50 feet outward from the base of the right bank. A narrower bench, about 10 feet wide, extends from the left bank. The surfaces of these benches are slightly more than 70 feet below the rim of the gorge. The midchannel, from the edge of one submerged bench to the other, is about 90 feet wide and probably 20 or 30 feet deep.

When the area was mapped, the altitude of the water surface at the axis of the dam was about 1,903 feet. Narrowness of the gorge causes the surface to fluctuate considerably with variations in river discharge. Just below the dam site a high watermark was found at 1,920 feet. A few hundred feet upstream, just above the fault, the high watermark was 1,940 feet, or 30 feet above the river surface.

The current is swift through this section, and rapids occur 100 feet upstream and 150 feet downstream. The water is a light apple-green color, owing to the presence of innumerable bubbles of escaping air. Near the water surface the sharp hiss of the air is audible above the roar of the rapids.

The right abutment of section F–G consists of the lower part of the algal zone, bed A cropping out 25 feet south of the downstream A-frame. The strata dip upstream 55° N. 42° E. The rock is hard, strong, tough, and durable. Owing to slight differences in thickness and composition, some layers are more resistant than others and impart a serrate character to the wall of the gorge. A considerable amount of jointing exists, especially in the thinner beds.

The left abutment is somewhat similar to the right in character, the strata included forming the middle part of the algal zone. The upstream A-frame rests on bed D, and the downstream A-frame rests on bed C. At the water surface, just below the upstream A-frame, the dip is about 21° N. 15° E. Just below bed C is a 4-foot layer of dense, light reddish-brown argillite, which in turn is underlain by beds of dense, greenish-gray argillite that range in thickness from 6 inches to 2 feet. Separating the algal beds is 10 to 15 feet of thin-bedded, gray-green argillite, the lower 3 feet being considerably fractured.

The intense fracturing at this locality results from a sharp, asymmetric flexure, the axis of which strikes to the northwest through the upstream A-frame. It flattens rapidly down dip to 15°, the beds abutting against the fault. To the southwest, or up dip, the beds steepen rapidly to a maximum of 67°. The brittle argillites have been particularly affected, and their shattered condition is the unfavorable feature of this abutment. The important directions are strike N. 41° W. dip 66° W and strike N. 25° E. dip 84° S. They are closely spaced, and the removal of small blocks has resulted in the formation of a small cavern that extends into the bank toward the downstream A-frame and has the general form of a triangular pyramid, the mouth of the cavern forming the base of the pyramid. The length of the cavern is about 25 feet, and the width of the mouth is about 15 feet. The beds at the west corner of the mouth dip 54° N. 22° E.

If this abutment were used to support a dam, all of the shattered rock that surrounds the cavern should be removed; the abutment would then be essentially equal to the right abutment in bearing power, resistance to sliding, and permeability.

The rock foundation stands at an altitude of about 1,880 feet and is covered with little or no gravel. Structurally and stratigraphically its character is much like that of the right abutment, and any concern as to its strength is unwarranted.

Complete development of section F–G requires a dike from each abutment of the gorge section to the base of the main valley walls. The 110-foot dam that the Kootenai Power Construction Co. proposed to erect, assuming that height to have been above the foundation bottom, would have placed the crest of the structure at an altitude of about 1,990 feet and given the railroad track 5 feet of freeboard, the minimum allowable. A greater measure of safety would be afforded the railroad by allowing it 15 feet of freeboard. This would place the crest of the dam at 1,980 feet. At this altitude the crest length of the dike over the left abutment would be 310 feet and would follow the strike of the beds (S. 51° E.) from the A-frames. Half of this distance would be over bare rock and half over undifferentiated alluvium resting upon the rock. Unconsolidated material would have to be removed. The height of this dike at the A-frames would be about 20 feet, and no difficulty should be encountered in its construction.

The dike over the right abutment would have to extend only 110 feet northwest before it encountered crest altitude. However, the gravel-covered embankment against which it abuts is a remnant of an alluvial fan. This fan was built out upon the rock floor of the valley by the small stream, which now divides it, before the river had attained its present course. At the time of fan building, the river was probably flowing along the center of the valley; directly across the salient projecting into the elbow, as is witnessed by the narrow, abandoned channel at its base and the abandoned falls on the right bank below the dam site. The strike of the steeply dipping beds in the vicinity of the fault would, however, tend to deflect the river to the northwest, where it probably met the fan-building stream and was again deflected sharply to the southwest, establishing its present course. As the river cut downward, the fan was dissected by its own stream, owing to its increased gradient and its inability to supply material as fast as it was removed by the undercutting river. The effect of this erosion is beautifully shown by the 10-foot contours on the topographic map, and the form of the remnants, as well as their composition, leaves no doubt as to their origin.

To obtain a rigid abutment for the right dike would probably necessitate trenching back into this fan for at least 200 feet, the rock wall of the valley probably lying about 250 feet north of the A-frames. The total length of the crest would be about 850 feet.

The spillway requirement for any dam in this valley is large, and the lack of room for a suitable section suggests that an overflow type of dam might be desirable. The shortest section would be over the left dike into the river, which would create a considerable fall and might necessitate paving part of the way to prevent quarrying out of joint blocks by the dynamic flow of the water. Other than this, probably little downstream erosion would occur. Another possible section is over the right dike and onto the old rock floor, the water returning to the river through one of the abandoned falls. This procedure would probably necessitate the removal of the entire southwest lobe of the dissected fan.

Relocated section at lower dam site.—The location of this section, D–E, is shown on plate 5. The right abutment is about the same as that in section F–G, plate 6, *B*, the difference being that the axis of the dam of section D–E is more nearly parallel to the strike of the beds.

The left abutment (see pl. 7, *A*) has been shifted 150 feet downstream from the A-frames on the left bank. The axis of the dam thus crosses the river just above the head of the lower rapids. From rim to rim the gorge section is 245 feet wide. The top of the right bank has an altitude of 1,970 feet, and the top of the left bank an altitude of 1,950 feet. The width of the stream is 135 feet. The length of the right dike section to crest altitude of 1,980 feet is 125 feet, about

50 feet of which length is covered with an alluvial fan deposit. The length of this fan, from the outer margin to the base of the main valley wall, is about 210 feet. The total length of the right dike must thus be not less than 290 feet. The left dike section is about 225 feet long, the upper 100 feet resting on a superficial cover of undifferentiated alluvium and talus that must be removed. The total length of the section is thus about 760 feet. On account of the shallowness of the water at the head of the rapids, the height of the dam from foundation will probably not exceed 90 or 95 feet.

The strata included in the relocated abutment fall between algal beds A and B, which consist chiefly of dense, massive layers of gray-green and purplish argillite, ranging in thickness from a few inches to 3 or 4 feet.

The rapids are formed by an exceptionally hard, massive bed that occurs just above algal bed A. All of the beds dip steeply upstream, 59° N. 44° E. (See pl. 7, *A*.) This new location avoids the shattered zone in the flexure at the old site, and the steeper dip is also a more favorable feature, equalizing the bearing power of the two abutments and reducing the permeability factor. Another advantage of the relocation is that the axis of the dam is essentially normal to the course of the main valley. The spillway conditions are the same as for section F–G.

Section at upper dam site.—The location of this section, H–I, suggested as an alternative by W. C. G. Senkpiel, associate hydraulic engineer, Geological Survey, is also shown in plate 5. The section is at the head of Kootenai Falls, the axis crossing the river 650 feet downstream from Kootenai Falls station. (See pl. 7, *B*.) The altitude of the railroad grade just south of the left abutment is about 1,990 feet, and the crest of the dam should, therefore, not exceed 1,980 feet in altitude. The length of crest for this altitude is about 1,775 feet, except for a slightly deeper channel against the right bank. (See pl. 6, *A*.) The height of the dam is thus limited to about 5 feet. It would probably be of the diversion type, either an overflow masonry dam or a roller dam. These designs would permit passage of large floods without creating a high and dangerous backwater and would also allow the passage of occasional log drives and ice. The diverted stream would be carried through pipes to the powerhouse at the foot of the falls, and the total available head would be the same as for the sections at the lower dam site.

The rock in the foundation and abutments consists of the hard, dense, thin-bedded, much-jointed, greenish-gray argillites of the member above the algal zone. In the right abutment the beds dip 11° N. 65° E., and those in the left abutment, 28° N. 64° E. The low dip and the thorough jointing would necessitate excavation to sound rock to secure the foundation against sliding and to serve as a safeguard

A. UPSTREAM VIEW OF THE UPPER HALF OF KOOTENAI FALLS FROM THE RIGHT WALL OF THE GORGE AT AN ALTITUDE OF ABOUT 2,260 FEET.

Kootenai Falls station is the small shed at the right of the upper line of riffles. The mountain to the right is Wm. Grambauer Mountain (altitude 7,385 feet) of the Cabinet Range, and the slope to the left is the south face of Flagstaff Mountain (altitude 6,078 feet) of the Purcell Range.

B. VIEW OF THE RIGHT (NORTH) ABUTMENT OF THE KOOTENAI FALLS DAM SITE, WHICH IS JUST BELOW THE TWO A-FRAMES IN THE RIGHT CENTER.

Note the sharp flexure in the argillite in the wall of the gorge.

A. VIEW OF THE LEFT ABUTMENT OF THE KOOTENAI FALLS DAM SITE AS RELOCATED TO AVOID THE SHATTERED ZONE AT THE CREST OF THE FOLD DOWNSTREAM.

The new axis of the dam passes just above the head of the rapid in the foreground.

B. VIEW FROM THE RIGHT BANK SOUTHEAST ALONG THE STRIKE OF THE BEDS AT THE HEAD OF KOOTENAI FALLS.

The axis of the upper dam section strikes along the upper riffle.

against percolation. The local head would be so low, however, that probably little leakage would occur through the rock.

Comparison of sections.—The only sections that are strictly comparable are the two at the lower site, D–E and F–G. These have equal advantages as to head, spillway conditions, and reservoir capacity. Section D–E has the following advantages over F–G:

It is normal to the strike of the main valley.

It is shorter by about 90 feet, because it is straight.

The foundation is probably a little shallower, which reduces the height to about 90 feet.

It is parallel to the strike of the beds.

It has steeper upstream dips throughout, thus reducing permeability through the rock, affording more security against sliding, and equalizing the bearing power of the abutments.

It has a better left abutment.

Comparison of sections D–E and H–I is necessarily not so direct. The two sections have equal advantages as to length and storage capacity. The advantages of section H–I as compared with section D–E are:

A low height of 5 feet.

Shallow foundation.

Lack of gorge section.

Less excavation of rock and of unconsolidated material.

Less difficult stream diversion during construction.

Easier spillway conditions.

Less leakage and percolation as a result of small local head.

Section H–I is inferior to section D–E in the following respects:

A long pipe line will be required from the dam to the powerhouse at the foot of the falls.

The left abutment is low and may require a dike extending downstream parallel to the railroad to prevent the grade from washing.

The dip of the strata in the foundation is low, and greater danger from ice and sliding would exist than at the lower sites.

Choice of section.—The upper and the two lower sections are safe for the construction of a dam. The upper section would be the most economical to build, but this saving would be partly offset by the cost and maintenance of the pipe line. The factors governing the final choice fall outside the domain of the geologist, and this decision must be made by the designing engineer.

Appurtenant works.—The appurtenant works for the lower sections are the dikes, powerhouse, spillway, and tunnels for stream diversion. Those for the upper section comprise the powerhouse, the dike for railroad protection, and the pipe line.

Reservoir area.—The reservoir area for each of the sections is small, the water being backed up for approximately a mile in each instance.

The reservoir area for the lower sections will extend from the axis of the dam to the head of the falls. The geologic conditions of this area are shown in plate 5. The area is characterized chiefly by the crumpled exposures of the algal zone. Economic deposits and cultural development are nonexistent in the area. Ground-water conditions are tributary to the reservoir, in which a little silting will occur. Some leakage will probably develop through the rock of the dissected bench into the gorge downstream, but this can probably be controlled without difficulty inasmuch as both intake and outlet areas are accessible.

Conditions in the upper reservoir are even more simple. Less opportunity for leakage exists, and if silt or gravel should ever accumulate it can be swept downstream through the gates.

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