REPORT ON GEOLOGIC RECONNAISSANCE OF THE CLARK FORK - KOOTENAI RIVER DEVELOPMENT PLAN

LINCOLN AND SANDERS COUNTIES, MONTANA

By

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U. S. Department of the Interior
Geological Survey

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Report on geologic reconnaissance of the Clark Fork - Kootenai River development plan

Lincoln and Sanders Counties, Montana

By

Charles E. Erdmann

Summary

1. Definition of project: The Clark Fork - Kootenai River project is a plan for the joint regulation and integration of the two rivers by construction of a dam on Clark Fork River near Smead, in secs. 5 and 8, T. 26 N., R. 33 W., Sanders County, Montana, and a dam on Kootenai River at Tunnel No. 8 site, sec. 28, T. 33 N., R. 34 W., Lincoln County, Montana, or some other favorable site below the mouth of Lake Creek near Troy, to such an elevation that water can be exchanged readily between their respective reservoirs through a 40-mile transverse valley across the Cabinet Mountains that is called the Bull Lake Trench. Figure 1. This plan was proposed by John C. Beebe, Regional Administrator, Federal Power Commission, San Francisco, California.

2. Critical elevations: The maximum critical elevation for this project is pool level at 2,365 feet, the elevation of tail-water at Thompson Falls power plant on Clark Fork River. The elevation of the low point on the Clark Fork-Kootenai River divide in the Bull Lake Trench is about 2,327 feet.

3. Field work: A geologic reconnaissance was made during the period April 6 - May 2, 1945, to determine the geologic feasibility of the project. Geologic mapping was not undertaken and the geology of the reservoir areas was not examined. Special topographic surveys were made to obtain accurate profiles of dam sites on Kootenai River. Figure 11.

4. Scope of report: This report includes geologic descriptions of dam sites and related works, as follows:

Clark Fork River

Smead dam site. Location: secs. 4 and 5, T. 26 N., R. 26 N., R. 33 W.; $SW\frac{1}{4}SW\frac{1}{4}$ sec. 33, T. 27 N., R. 33 W., Sanders County, Montana. Figures 2, 3, and 4.

Chimney Rock dam site. Location: sec. 10, $NW\frac{1}{4}NW\frac{1}{4}$ sec. 11, and $N\frac{1}{2}NW\frac{1}{4}$ sec. 15, T. 26 N., R. 33 W., Sanders County, Montana. Figures 2, 5, and 6.

Appurtenant works for Chimney Rock dam site:
Smoky Creek dam site, Bull River gorge. Location: $SE\frac{1}{4}$ sec. 34, T. 27 N., R. 33 W. Figures 2 and 7.

Government Mountain tunnel route. Location: $SE\frac{1}{4}SE\frac{1}{4}$ sec. 34, T. 27 N., R. 33 W.; $W\frac{1}{2}$ sec. 2, $E\frac{1}{2}NE\frac{1}{4}$ sec. 3, $N\frac{1}{2}NW\frac{1}{4}$ sec. 11, T. 26 N., R. 33 W. Figures 2, 8, and 9.

Bull Lake Trench

Clark Fork-Kootenai River (Bull River-Lake Creek) divide. Location: sec. 9, T. 28 N., R. 33 W., Lincoln and Sanders Counties, Montana. Figures 1 and 10.

Kootenai River

Tunnel No. 8 dam site. Location: $S\frac{1}{2}$ sec. 21, $E\frac{1}{2}NW\frac{1}{4}$, $E\frac{1}{2}SW\frac{1}{4}$ sec. 28, T. 33 N., R. 34 W., Lincoln County, Montana. Figures 11 and 12.

Star Creek dam site. Location: sec. 5, T. 32 N., R. 34 W., Lincoln County, Montana. Figures 11 and 13.

Troy dam site. Location: secs. 1 and 2, T. 31 N., R. 34 W., Lincoln County, Montana. Figures 11 and 14.

5. Conclusions:

a. The overall conclusion of this report is that geologic conditions do not make the Clark Fork - Kootenai plan infeasible. They make it difficult, however, for the dam sites on Clark Fork and Kootenai Rivers are on a large scale, and certain modifications of the original plan are required. The most difficult conditions to be faced are on the Clark Fork side of the project.

b. Smead dam site has a left abutment that is badly shattered by faulting and is a potential landslide area that is weak and defective in both a geologic and engineering sense; and foundation conditions are deep and difficult. In my opinion, Smead dam site must be regarded as infeasible.

c. Chimney Rock dam site is suggested as an alternative for Smead dam site. Its location on Clark Fork River upstream from the mouth of Bull River requires an accessory dam on Bull River at Smoky Creek dam site, and the 1.6 mile Government Mountain tunnel from the forebay of Chimney Rock dam to Smoky Creek dam. All three elements of this alternative plan are geologically feasible.

Although the appurtenant works make Chimney Rock dam site a more elaborate prospect, in the long run, probably it would be safer and less expensive to construct than Smead dam site.

The presence of the Hope fault near the base of the right abutment of Chimney Rock dam site indicates a wide-base flexible dam for the site. This fault probably has not been active since late Tertiary (Miocene) time. Length of crest at elevation 2,365 would be about 6,450 feet. Height of dam above river surface will be about 225 feet. Depth to bedrock foundation is unknown, but is believed to be within 300 feet.

Smoky Creek dam site in the gorge of Bull River may be adapted to some kind of rigid dam. Length of crest at elevation 2,365 is about 1,960 feet. Height above river surface would be about 140 feet. Depth to bedrock foundation is unknown, but probably within 100 feet.

d. Tunnel No. 8 dam site is the most feasible of the three sites studied on Kootenai River. The abutments just do come up to the critical elevation of 2,365, and dikes or cutoffs may be required on either side. Length of crest is about 4,250 feet. Height of dam above river surface will be about 550 feet. Height above bedrock foundation will be at least 600 feet, but the area of deep foundation excavation will be small.

e. The Bull River-Lake Creek divide in the Bull Lake Trench can be reduced by excavation to an elevation of 2,300 feet. This will require a 14-mile canal. Deepest cuts will be on the divide itself, and will approach 50 feet for a distance of about a mile. Over the remainder of the distance, the required cut will have a depth of 25 feet or less. Most of the material can be handled by dredges.

f. All dams and works should be designed to be as earthquake-proof as possible.

6. <u>Recommendations</u>:

a. Chimney Rock dam site and appurtenant works.

1. Detailed topographic mapping of the three elements of the project, as a preliminary to

2. Detailed geologic mapping.

3. Geophysical determinations of depth to bedrock at Chimney Rock and Smoky Creek dam sites.

b. Tunnel No. 8 dam site.

1. Detailed topographic mapping, as a preliminary to

2. Detailed geologic mapping

3. Geophysical depth determinations over the upper parts of both abutments to ascertain depth of overburden, and whether or not dikes will be necessary.

c. Geophysical investigations should be carried out at Star Creek and Troy dam sites, as outlined in their individual descriptions.

d. Topographic and geologic mapping and geophysical depth determinations along the canal route over the Clark Fork-Kootenai River divide in the Bull Lake trench.

Respectfully submitted,

Charles E. Erdmann,
Regional Geologist.

Great Falls, Montana.
June 9, 1945.

Report on geologic reconnaissance of the Clark Fork -
Kootenai River development project

Introduction

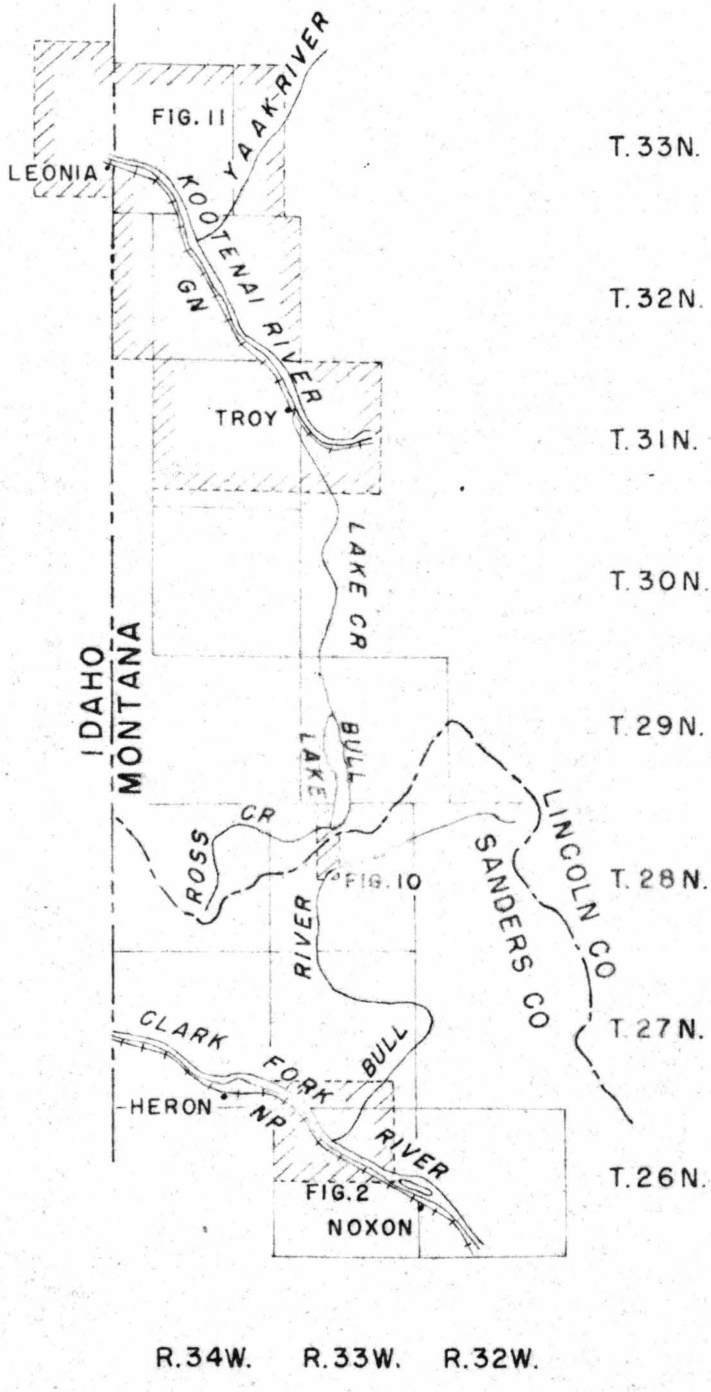
__Definition of project:__ The Clark Fork - Kootenai River development project was proposed by John C. Beebe, _/ Regional Administrator,

_/ Federal Power Commission, San Francisco Regional Office. Memorandum from John C. Beebe, Regional Administrator, to John S. Cotton, Principal Engineer, Division of Water Power. Dec. 28, 1943.

Federal Power Commission, and is a bold, comprehensive plan of great magnitude for the joint regulation and integration of the two rivers by construction of a dam on the Clark Fork near Smead, in secs. 5 and 8, T. 26 N., R. 33 W., Sanders County, Montana, and a dam on Kootenai River at the Tunnel No. 8 site, sec. 28, T. 33 N., R. 34 W., Lincoln County, Montana, or some other favorable site below the mouth of Lake Creek near the town of Troy, to such an elevation that water can be exchanged readily between their respective reservoirs through a 40-mile transverse valley, or Bull Lake Trench, across the Cabinet Range. (Figure 1).

According to preliminary studies made by R. W. Davenport, _/

_/ Memorandum re Mr. Beebe's proposed Clark Fork - Kootenai project. Washington. Jan. 1, 1945.



INDEX MAP
CLARK FORK-KOOTENAI RIVER PROJECT
LINCOLN AND SANDERS COUNTIES, MONTANA
Scale 1: 500000

Chief, Division of Water Utilization, U. S. Geological Survey, consummation of this plan "would require a dam probably a little over 200 feet high on Clark Fork and about 600 feet high on Kootenai River. The storage on Clark Fork would probably not exceed 1,500,000 acre-feet, and on Kootenai River would be about 12,000,000 -- a total of 13,500,000 acre-feet . . ." The proposed pool level of 2,365 feet is determined by the elevation of tail-water at the Thompson Falls plant of the Montana Power Company; and would create about a 50-foot depth of backwater on Kootenai River at the International Boundary between Canada and the United States.

At the time Mr. Beebe's proposal was made, the International Joint Commission was investigating the water resources of the Columbia River basin with the object of determining proper integration and coordination of flow across the International Boundary. _/ Although dam sites on Kootenai River were under consideration,

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_/ Davenport, R. W., Preliminary study of the Katka reservoir site. Unpublished paper presented at the meeting of the International Columbia River Engineering Board, Ottawa, Canada, October 1944.

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crest elevations of the contemplated works were comparatively low (Katka, 2,150 feet) and the problem of backwater across the Boundary (water surface elevation about 2,315 feet) was not raised. The introduction of Mr. Beebe's proposal into the deliberations, however, introduced International complications and necessitated reappraisal of dam site possibilities on Kootenai River from the viewpoint of much higher and larger dams than had been considered heretofore._/ For these reasons, Mr. G. L. Parker,_/ Chief

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_/ Erdmann, C. E., Geology of dam sites on the upper tributaries of the Columbia River in Idaho and Montana. Part 1. Katka, Tunnel No. 8, and Kootenai Falls dam sites, Kootenai River, Idaho and Montana. U. S. Geol. Survey, Water Supply Paper 866-A. Washington, 1941.

_/ Memorandum for Chief, Conservation Branch, from G. L. Parker, Chief Hydraulic Engineer, Washington, D.C., Feb. 5, 1945.

Hydraulic Engineer, U. S. Geol. Survey, a member of the International engineering board, invited the writer to discuss certain basic geologic questions concerning the feasibility of the Clark Fork - Kootenai plan. Based on previous familiarity with the region, a memorandum_/ was prepared that outlined the available geologic data

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_/ Memorandum for Mr. G. L. Parker, Chief Hydraulic Engineer, Washington, D.C., (Through Messrs. J. D. Northrop and H. J. Duncan) from Chas. E. Erdmann, Regional Geologist, U. S. Geological Survey, Great Falls, Montana, March 5, 1945.

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as it pertained to the three major elements of the plan, attempted to formulate the most critical geologic problems involved, and suggested some procedures for their solution. Following receipt of this memorandum, a geologic reconnaissance of the Clark Fork - Kootenai River project was authorized March 24, 1945. _/

_/ Memorandum for Mr. Erdmann, Great Falls, Montana, from J. D. Northrop, Chief, Mineral Classification Division, Washington, D.C., March 24, 1945.

<u>Field work</u>: Field reconnaissance to ascertain the limiting geologic conditions of the Clark Fork - Kootenai River plan was begun April 6, and was concluded May 2, 1945. The fundamental questions involved had been recognized by Mr. Parker, _/ who stated

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_/ Memorandum of Feb. 5, 1945.

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them as follows:

1. The feasibility of a dam to elevation 2,365 at the "Tunnel No. 8", or any other dam site on Kootenai River.

2. The feasibility of a dam to elevation 2,365 in the vicinity of Smead.

3. The character of the material through the Bull Lake Trench as it would affect the costs of excavation to lower substantially the elevation at which water could be interchanged between the Kootenai and Clark Fork parts of the proposed joint reservoir.

4. Any features affecting feasibility of the high-dam projects under consideration in which geologic conditions might be critical.

Investigation of items 1 and 4, as well as general supervision of the work, were undertaken by the writer, while items 2 and 3 were assigned to F. A. McMillin for study. Fortunately, the Smead area and the Bull Lake Trench are situated within the Libby quadrangle, and had been covered by previous regional mapping by the Geological Survey, _/ so that it was only necessary to re-examine the ground

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_/ Gibson, Russel. Geology and ore deposits of the Libby quadrangle, Montana. U. S. Geological Survey. Report in preparation.

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involved from the viewpoint of its suitability for dam sites and routes for tunnels and canals.

Except in the vicinity of Troy, the problem of recognition of a prospective site for a high dam on Kootenai River was made difficult because the existing topographic mapping above altitude 2,200 feet was so very inaccurate that apparent dam sections had to be selected in the field rather than from existing maps; and the previous geologic mapping was only of the nature of rapid reconnaissance, and restricted to the principal routes of communication. _/ Hence, after

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_/ Calkins, F. C., A geological reconnaissance in northern Idaho and northwestern Montana: U. S. Geol. Survey Bull. 384, Pl. 1, and pp. 68-70, Washington, 1909.

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apparent prospective sections had been designated, sufficient topographic mapping had to be done to obtain cross-sections of the valley and to ascertain if the requisite elevation could be secured with reasonable width. Then, of those selected, the geologic character had to be looked into. This supplementary topographic work was carried out by Mr. Arthur Johnson, Hydraulic Engineer, Water and Power Division, U. S. Geological Survey, who extended the topography of the existing Kootenai River survey [/] in

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_/ U. S. Geological Survey, Plan and profile of Kootenai River, from a point 1 mile below Moyie River, Idaho, to the International Boundary, Montana; Yaak River to Mile 9; Sheet A, Washington, 1938.

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certain critical localities to altitudes of 2,400 or 2,500 feet, and made new cross-sections of the valley at Leonia, Tunnel No. 8, and near Star Creek, below the mouth of Yaak River. Mapping on the dam site scale (1:4,800) was not attempted.

As this phase of the work was nearing completion, the Corps of Engineers, U. S. Army, Portland, Oregon District, generously made available certain advance sheets of a large scale (1:12,000) map of Kootenai River Valley prepared from air photographs. [/]

_/ Corps of Engineers, U. S. Army. Reconnaissance map, Kootenai River, Bonners Ferry, Idaho, to Gateway, Montana. Scale, 1:12,000; Contour interval, 20 feet. March, 1945.

Mr. Johnson's plane-table topography afforded an opportunity to make a rather close check of the accuracy of some parts of this aerial map, and it was found that although the planimetry is good, vertical control on the higher contours is erratic. Nevertheless, this map has been of much use, and it is to be regretted that it was not finished when our geologic reconnaissance began.

Geologic mapping on the dam site scale was not undertaken, but a rather complete structural reconnaissance was made from Troy downstream to Leonia, with the river map as a base. These details have been incorporated into a series of geologic cross-sections that are offered as an aid in making final selection of the dam site area.

Summary of regional geology

Major topographic features

The principal regional topographic features that are involved in the Clark Fork - Kootenai River project are:

1. Clark Fork River Valley between Heron and Noxon, Montana.

2. The Bull Lake Trench across the Cabinet Mountains.

3. Kootenai River Valley between Leonia, Idaho, and Troy, Montana.

The purpose of this report does not warrant any effort toward complete geomorphic description of these great features, but they are so intimately related to the three corresponding elements of the project that a brief outline of the major events of their origin and history will serve as background for the more detailed descriptions of their local features.

Clark Fork Valley: The valley of Clark Fork of Columbia River (or Clark Fork Valley, as written in this report) forms the geographic boundary between the Cabinet Mountains on the north or right bank, and the Bitterroot Mountains on the south or left bank; and it is also a geologic boundary, for the great Hope fault lies in the bed of the river and separates these ranges in a structural sense. This structural control of the river has localized its course, and accounts for the comparatively straight trend to the northwest.

At Smead dam site, about midway between Heron and Noxon, Clark Fork Valley is a magnificent broad, deep, flat-floored trench, a mile wide and more than half a mile deep, through which the thread of the stream undulates gently from side to side. Along the right bank the base of the Cabinet Mountain makes a nearly straight line with the alluvial fill, and trends about N. 55° W. Above it the mountain side rises rapidly 3,500-3,800 feet in an unbroken slope to the summit level of this part of the range. This imposing wall, breached only by the mouth of Bull River Valley, is interpreted as fault-line scarp expression of the Hope fault, whose trace is concealed by the valley fill.

The opposite wall of the trench has a more diversified appearance. An inner slope of rock rises sharply from river level about altitude 2,150 to 2,800 feet, and then flattens on to a more gentle slope about 1,000 feet wide whose inner or south margin stands at altitudes of 3,100 or 3,200 feet; and from this elevation the valley wall again rises abruptly toward the summit level of the Bitterroot Range. This comparatively gentle intermediate slope is regarded as a rear remnant of a rock-cut bench representing part of the floor and wall of an ancient high-level valley that may date back to late Tertiary or early Pleistocene. Practically nothing is known about the part the valley played during the ice epochs of early and middle Pleistocene, and deposits of these times have not been recognized. There must have been some activity, however; and, obviously, the river continued to entrench the valley floor in its endeavor to maintain grade. Later, though, toward the culmination of the Cordilleran ice sheet, it was occupied by a glacier moving downvalley that plucked and abraded its walls and doubtless deepened the bottom. With some confidence, this glaciation may be referred to the last glaciation, the Wisconsin.

About the same time, another valley glacier moved up Clark Fork Valley from the Pend Oreille lobe of the Cordilleran ice, and came to rest in the vicinity of Cabinet Gorge about 4 miles west of the Idaho-Montana boundary. Since the two glaciers met head-on, ice was piled up and blocked the valley to a considerable elevation.

Melt water from the waning ice sheets began to accumulate in Clark Fork Valley upstream from the great ice jam and formed a lake whose surface eventually stood as high as altitude 4,200 feet. This feature has been given the name of glacial Lake Missoula. One arm of the lake ran up Bull River, and over into Kootenai River Valley, which also was occupied by water ponded by the Pend Oreille ice lobe. During the maximum lake stage, there were many large interconnecting bodies of water in western Montana. Then the ice barrier was overtopped, the lowering of the lake began, and most of the flood drained through Clark Fork Valley. Although this event was progressive, it was intermittent, and there were evidently occasional periods of static level, as well as those of temporary rise. Many widespread outwash and deltaic deposits date from this time. The older land forms and deposits were successively modified and reworked as the waters were lowered, and currents were diverted by the emergence of drowned ridges, until now only remnants exist. Among those in the vicinity of Smead dam site may be mentioned the high-level (2,800-2,900 feet) fill on Smead's Bench; the corresponding outwash spur on the right bank of Bull River where it enters Clark Fork Valley; the 2,400 foot bench on the left bank of the Clark Fork between Smead and Heron; and, the delta of Bull River, that has forced the Clark Fork against its left bank.

This part of Clark Fork Valley has thus had a long, active, complex history, and in its present form it reflects the cumulative effect of all of these events. Small wonder then that this great valley is not a simple place in which to site a dam.

Bull Lake Trench: This name is given to an intermontane valley that trends north from Clark Fork River through the Cabinet Mountains to Kootenai River near Troy. Fig. 1. It includes three linear geographic elements that make a continuous topographic depression from south to north: Bull River Valley, which drains south; Bull Lake, just north of the Bull River divide; and, Lake Creek, which drains Bull Lake into Kootenai River.

Bull River probably is an old, superimposed stream, inherited from previous erosional levels on the south flank of the Cabinet Mountains. The valley is largely the result of normal stream erosion, although under structural control in certain reaches. A pre-Wisconsin glacier is believed to have moved downvalley to the Bull River School, NW$\frac{1}{4}$ sec. 18, T. 27 N., R. 32 W., and possibly farther, but its topographic effect was not profound. Perhaps the most significant characteristic of the valley is that it narrows downstream from the Bull River School into a deep, narrow gorge. This is considered to be the result of the effort of the stream to maintain grade through the relatively upthrown block northeast of the Hope fault, and is indicative of the comparative recency or rejuvenation of movement along the fault. Originally, the head divide of Bull River may have stood about 3 miles south of

Bull Lake; but now it is just south of the lake, and the stream appears to have captured some of the head-tributaries of Lake Creek. This may have been brought about in several ways, or by a combination of means. The original divide may have been breached by the ancient valley glacier; or northward tilting of the mountain block may have resulted in aggradation in the upper part of the valley, and allowed the river to extend its head tributaries across the divide. The boulder fan at the mouth of Ross Creek may also have played a recent part in this diversion.

Bull Lake has resulted from comparatively recent retardation of drainage between a low morainal dam north of the lake and the Bull River (Clark Fork - Kootenai) divide. An attractive scenic feature, it is widely known, and its name has been applied widely to associated cultural features. Insofar as this report is concerned, it may be considered jointly with Lake Creek Valley.

Lake Creek Valley is a post-glacial consequent stream upon the alluvial surface of the fill of a long, narrow down-faulted block that separates the Cabinet Mountains into an east and west mountain mass. In a structural sense, this fault valley is the Bull Lake Trench; but the structural control diminishes southward from the lake, and, in a sense, the trench can be said to be tilted northward. It has long been occupied by northward flowing streams. At least two glaciations have modified its floor, and filled it in until the bottom now stands at a comparatively high altitude. During the higher levels of Lake Missoula there was complete interchange of water through the trench, and the extensive alluvial surface at 2,500 feet unquestionably is related to that stage of the lake, and the same probably is true of the 2,300-foot level. After the lake surface fell below the Bull River divide, Bull River came under the regimen of the Clark Fork, and Lake Creek under that of the Kootenai. The most recent surface modifications have been the construction of a series of broad alluvial fans on the 2,300-foot surface at the mouths of the short, steep tributary gulches. Dependent upon their size, they force Lake Creek first to one side of the trench and then the other. Depth to bedrock is unknown, but probably is great, especially northward from the South Fork of Bull River. That part of the trench that critically affects the Clark Fork - Kootenai River project underlies the Bull River-Lake Creek divide, and is considered later in a separate section of this report.

Kootenai River Valley: The valley of Kootenai River between Leonia, Idaho, and Troy, Montana, forms the geographic boundary between the Cabinet Mountains on the south or left bank, and the Purcell Mountains on the north or right bank; it also, in part, marks the geologic boundary between these two mountain ranges. The general topographic character of this stretch of river has been described.[1] It is now known

[1] Erdmann, C. E., Op. cit. p. 8.

that the broad, high-level valley or bench on the right bank of the river is the floor of a down-faulted structural valley or trench 3 or 4 miles in width, and that the inner gorge of the stream has adjusted itself closely to the axis of a sharply compressed anticlinal fold. Fig. 11. North of the Tunnel No. 8 dam site the river cuts across the southwest flank of this fold and has entrenched itself to Katka dam site in Idaho in the trace of the Leonia fault, which makes the southwest boundary of the fault valley. This relationship of the river to the anticlinal axis illustrates an uncommon degree of adjustment to structural control in the northern Rocky Mountains, and is reminiscent of Appalachian structure where the valleys are on the anticlines and the synclines make the mountains. It is also significant in that it gives a measure of the age of the folding, for such adjustment is not attained easily or quickly. Since it is probable that the river has maintained this course for a very long time, it is equally probable that there is no ancient buried channel behind the right bank of the inner gorge.

Kootenai River Valley has had a long and complicated history, and many of its episodes probably had parallel events in Clark Fork Valley. Much of this is preserved in its rock terraces. The old, high benches may date back to early Pleistocene; but their connection with the older ice epochs has not been established, and drift older than Wisconsin has not been found. The rock bench within the inner gorge at altitude 2,000 or thereabouts is much later, and may just antedate the Wisconsin glaciation. The river was just beginning to meander and widen this bench when some change in gradient caused it to begin the downcutting that is still in progress. Parts of the valley near the mouth of Yaak River were glaciated during the last ice age, but the effects are local and only two dam sites have been thus scoured or over-deepened. On the otherhand, all of the alluvial terraces are comparatively late geologic events, and date from the waning stages of glacial Lake Missoula. Probably all of them, down to the 2,300-foot level have their counterparts in Clark Fork Valley.

Stratigraphy

All of the dam sites and related features described in this report are involved in the geologic features of the Cabinet and Purcell Mountains. These mountains consist chiefly of great thicknesses of pre-Cambrian sedimentary rocks belonging to the Belt Series. This series has been subdivided into a number of formations or mappable units that, in order from oldest to youngest, are called: Pritchard, Ravalli, Siyeh, Striped Peak, and Libby. Gibson[/]

[/] Gibson, Russel, Op. cit.

has given a fairly complete account of the regional stratigraphy, and local details in Kootenai River Valley have been furnished by Erdmann.[/]

[/] Erdmann, C. E., Op. cit. pp. 10-12.

The dam sites described here are all situated in the Siyeh formation (or Wallace, as it is known in Idaho), and the only other rocks involved are glacial deposits such as till, outwash, and lake bed silts, and alluvium, or active stream gravel. The thickness of the Siyeh formation is about 5,000 feet, and its areal extent is great because of repetition by folding and faulting. In general, it consists of fairly hard, dense, fine-grained layers of gray to greenish-gray calcareous argillite, finely laminated argillite, dull gray dolomitic argillite, dolomitic limestone, often with typical "molar-tooth" or other intraformational structures, and reddish-gray to dull red quartzite. Pyrite is a common accessory mineral, and where present, outcrops are often stained brown by iron oxides. Bedding is usually distinct, and varies according to rock type from thin (4 inches to 2 feet) in the argillites and quartzites, to heavy, massive layers 4 or 5 feet thick in the dolomitic limestones.

Most of the formation consists of strong, durable, insoluble rock with high resistance to crushing. In the upper third, however, there are one or two zones of soft, shaly thinly bedded argillite that are comparatively weak. One of these, cropping out along the left bank of Kootenai River just upstream from Tunnel No. 8, yielded last February to the weight of an overburden of heavy massive rock and caused a local, but rather extensive landslides on to the track of the Great Northern Railway. Another weak zone, consisting of soft, light gray sericitic metargillite, was observed on Yaak River in SW$\frac{1}{4}$ sec. 30, T. 33 N., R. 33 W.; but is not involved in any dam site.

Geologic structure

__Folds:__ In contrast to the ranges farther east that consist of huge but comparatively simple tilted crustal blocks, the structure of the Cabinet and Purcell Mountains is characterized by folding as well as faulting. Some of the folds are broad and open, and this type occurs in the vicinity of Smead dam site; but on Kootenai River between Leonia, Idaho, and Troy, Montana, the folding is very tight and closely compressed with nearly vertical limbs. Folds of this sort are known technically as isoclinal. The correspondence of the course of Kootenai River to the axis of this anticline has been pointed out, and this fold is called Kootenai River anticline in this report.

The age and origin of the folding cannot be determined with any degree of accuracy because of the absence of strata younger than the Belt Series; but it may be related to the intrusion of the Idaho batholith, and thus date as far back as the Jurassic. It can be ascertained rather definitely, however, that the major period of folding antedates the major faulting. Nevertheless, in the case of the Kootenai River anticline it is possible that the folding accompanied or closely followed the faulting. The principal evidence supporting this belief is the parallelism of the fold to the Leonia thrust fault, which cuts its southwest limb; and the occasional presence of fracture cleavage in incompetent beds on that limb of the fold; the southwest limb of the fold also contains the steeper average dip.

Faults: In spite of the prevalence of folding, the larger topographic features such as the mountain ranges and the valleys of the larger rivers are under fault control. In general, there are three broad classes of faults, that also have rather distinct age relationship, as follows: (a) faults mechanically related to the folding; (b) high angle reverse faults, and related shear effects, with occasional large scale normal faulting; (c) comparatively recent landslide effects.

(a.) In all probability, the oldest faults in the region are bedding faults that originated by differential gliding movements as the strata adjusted themselves to the rather intense folding. Such faults or slips are of common occurrence, but do not detract materially from the strength of the formation in a geologic sense. Numbers of them unquestionably would appear in any foundation excavation for a dam site. Gouge along them is usually thin impermeable clay. Strong evidence of movement along bedding surfaces was observed in cuts for the Great Northern Railway along the south line of sec. 20, T. 33 N., R. 34 W. In this neighborhood these faults approximately parallel in strike the nearby Leonia fault, later to be described, and they might be subordinate features. It will be shown, however, that the probable shear effects of the Leonia fault have different attitudes. Hence, these bedding faults are considered older than the Leonia fault in spite of their apparent relationship.

Another series of old faults are the normal faults that trend approximately at right angles to the axes of the isoclinal folds, offsetting them at some places. Their general trend is N. 50° to 70° E., and the dip is northwest at angles varying from 40° to 70°. Where offset is determinable, it appears that the downthrow or northwest side was shifted relatively to the southwest. Transverse normal faults of this nature are sometimes called epi-anticlinal faults because of their relationship to the folds on which they occur. It is not known if they extend from one fold to another across the intervening syncline, but one may infer that they are rather local. Usually they are closely associated mechanically and in time to the folds that they cut. Natural exposures of the fault surfaces are rather inconspicuous and close work with particular attention to the significance of abrupt reversal of direction of dip is necessary to locate them. One was observed at the west end of a cut on U. S. Highway No. 2, high on the right abutment of the Tunnel No. 8 site; two are known rather definitely from Star Creek site; and, another has been noted at the east end of the highway bridge over Kootenai River at Troy. Still another may be in the bed of Bull River near its mouth; and the small faults cutting the abutments of Smead dam site may be of this origin. The total number and spacing of these faults is unknown, but they are believed to be of rather frequent occurrence, and to make serious flaws in the strength of the rock. Along Kootenai River at Troy and Star Creek dam sites one may occur perhaps every 1,000 or 1,500 feet; and in some localities their place may be taken by a strongly developed, closely spaced joint system that appears to have similar characteristics. This may also be the case for the fractures in the abutments of Smead and Chimney Rock dam sites. See Figs. 4 and 6. Although these faults are inactive geologically, their gouge zones may be as wide as 10 feet. They thus constitute zones of potential weakness in the foundation and abutments of prospective dam sites where the streams are situated on folded rocks.

(b.) The class of high-angle reverse or upthrust faults includes some of the major faults of northwestern Montana, such as the great Leonia fault, and possibly the Hope fault, that, respectively, have been instrumental in localizing some parts of the course of Kootenai River and Clark Fork River.

The Leonia fault occurs in the bed of Kootenai River from near Katka dam site in Idaho to the north part of sec. 29, T. 33 N., R. 34 W., Lincoln County, Montana, where it emerges and parallels the left bank, gradually diverging southeast toward the west side of the Bull Lake trench. In this part of Kootenai River Valley the stratigraphic throw of the fault has been estimated to be between 25,000 and 30,000 feet. Downthrow is to the east; and the lower part of the Pritchard quartzite has been thrown against the upper part of the Siyeh formation, all of the Ravalli being cut out. In spite of the magnitude of the throw, the crushed or brecciated zone is comparatively narrow. On land it is usually expressed as a sinuous depression, and the actual trace is concealed. Gibson saw the fault in the Liberty mine, C NW$\frac{1}{4}$ sec. 36, T. 31 N., R. 34 W., the only place where it was seen underground, and reports that the gouge zone was only 20 feet wide and the fault vertical. Calkins_/ reported an exposure of the fault

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_/ Op. cit. pp. 53-54.

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in a cut on the Great Northern Railway about $1\frac{1}{2}$ miles northwest of Leonia. There is a fault at this locality, but, in my opinion, it is a subsidiary feature to the Leonia fault in the Pritchard formation, and not the main fault, which probably lies a short distance east in the bed of the river.

The position of the trace of the Leonia fault can be determined approximately by estimating where beds of the Pritchard formation dipping steeply northeast will meet beds of the Siyeh formation dipping at equally steep angles to the southwest. By this means the fault sometimes can be localized to within 200 feet. Another criterion, not always possible to apply, is the point of truncation of metadiorite sills in the Pritchard formation. These sills are often thick, and the rock is generally strong and resistant, so they are expressed topographically as ridges. Where they extend into the river bed toward the fault trace, however, they are eroded down to the stream gradient, and there is no topographic effect, such as rapids. This condition is interpreted as evidence of the indefinite quiescence of the fault, for the sills are on the upthrow side, and if there had been recent movement, some topographic effect, or disturbance of stream gradient should be noticeable. The age of the faulting is indeterminate, except that it is somewhat later than the folding. On the basis of habit or character of the faults, in comparison to those of nearby regions, I am inclined to place it in latest Cretaceous time, and possibly continuing on into middle Tertiary time. The Leonia fault is thus very old, and probably geologically inactive.

Subordinate features of the Leonia fault. The Leonia fault is so situated that it affects directly only one of the dam sites considered in this report: the left abutment for a high dam at Tunnel No. 8. However, other parts of this site are affected by a series of minor faults that are thought to be shear effects of a component of the stress activating the main fault. One of these faults is the Tunnel No. 8 fault itself, which strikes west and dips 43° south into the Leonia fault. The complementary set is illustrated by a fault on the right bank of Kootenai River, C SE$\frac{1}{4}$SE$\frac{1}{4}$ sec. 20, T. 33 N., R. 34 W., that strikes S. 56° E., and dips 52° NE., away from the Leonia fault. These opposed dips represent intersecting planes of shear, and, theoretically, the acute angle between them faces the direction from which the stress came - an approximately horizontal component of stress from the Leonia fault. The number and spacing of these minor faults is unknown, but there are unquestionably more than have been observed. Gouge zones on those seen consist of bluish clay 3 to 4 feet thick - which are an element of weakness of considerable extent, and this condition may be aggravated at their intersection.

The thickness of the gouge suggests considerable movement, although this is not always a valid criterion. Certainly, the displacement was not sufficient to offset the Siyeh formation in which these faults occur. As one moves northeast from the master fault they seem to diminish in frequency. None were observed at the Star Creek or Troy sites.

Two large faults, believed to be normal, but which may be high-angle thrust faults, are also involved in the geology of the Clark Fork - Kootenai project. Beginning just north of Savage Lake, secs. 25 and 26, T. 31 N., R. 33 W., Gibson _/

_/ Gibson, Russel, Op. cit.

mapped a normal fault to Kootenai River; and from the river northward to the margin of the Libby quadrangle its trace has been extended under alluvium along the base of the high, west-facing mountain excarpment that makes the left bank of O'Brien Creek Valley, for which the fault has been named. Protraction of the general trend of this fault intersects Yaak River in SW$\frac{1}{4}$ sec. 30, T. 33 N., R. 34 W. (Fig. 11). In this vicinity, along the right bank of the river, there is a shear zone 500 feet or more in width in soft, gray, flaky sericitic metargillite. For this region, the beds have the unusually low dip of 23°, S. 58° W. At intervals of 30 feet or more they are cut by fractures that strike N. 10° W., and dip 80° SW., that are filled with clay gouge 6 inches to 1 foot thick. No single fracture could be selected as the principal fault. Throughout the entire zone the soft, incompetent layers show well developed fracture cleavage that has about the same strike as the beds, but dips 50° southwest.

Deformation of this extent represents a major structural feature, and, on the basis of present information, it seems reasonable to associate it with the O'Brien Creek fault. In all probability, Pine Creek Valley, southwest of Tepee Mountain, makes a further northwest extension of this zone. Thus, the O'Brien Creek fault becomes the bounding fault on the northwest side of Kootenai River Valley over a distance of about 20 miles. It is also evident that the river valley occupies a downfaulted linear block or structural trench that is the northwest extension of the Bull Lake Trench. This feature is not a graben, or trough, between opposing normal faults, because the Leonia fault on the southwest side is a thrust fault. Regionally, it is probably similar, although on a smaller scale, to the Purcell trench farther west.

The Hope fault, which locally controls the course of Clark Fork River, is another large scale normal fault.

Exposures do not occur within the area of Smead dam site (Fig. 2). Regional studies by Anderson,[1] Calkins,[2] and Gibson,[3] however, show that the dip and downthrow are toward

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[1] Anderson, A. L., Geology and ore deposits of the Clark Fork district, Idaho: Idaho Bur. of Mines and Geology, Bull. 12, pp. 44-47, 1930.

[2] Calkins, F. C., Op. cit. p. 55.

[3] Gibson, Russel, Op. cit.

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the southwest. Anderson's suggestion that the fault is complex, with probably many fractures distributed through a wide zone, is especially pertinent to foundation conditions at Smead and Chimney Rock dam sites. In this respect the Hope fault appears to be similar to the O'Brien Creek fault where it crosses Yaak River. Reference has been made to the fact that the topography of the lower part of Bull River gorge suggests that there has been relatively late movement on the Hope fault. However, the unbroken condition of the 2,900-foot outwash spur on the right bank of Bull River where it enters Clark Fork Valley indicates that this movement antedates glacial Lake Missoula. The dimensions of the gorge, with respect to the size of Bull River, suggest that this fault movement may date back to the Miocene epoch of the Tertiary.

(c.) Recent landslide faults. Following the glacial scour of Clark Fork Valley, and before the major period of aggradation, the valley evidently was in an over-deepened condition, with inadequate support for those parts of the walls that were weakened by numerous fractures, as well as by more or less complete saturation. These places slumped valleyward on small, surficial step-faults. Two of them have been recognized at Smead dam site, and doubtless there are others that are concealed. These landslide faults are not mechanically related to the regional tectonics, and geologically are insignificant. Nevertheless, their presence in an abutment of a prospective dam site is a matter of serious concern, for they are more likely to be potentially active, and to contribute greater elements of weakness than larger tectonic faults.

Earthquake probability

The probability of earthquakes in the Kootenai River Valley has been considered in the previous report on the region._/ There is no reason to alter the conclusions reached

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_/ Erdmann, C. E., Op. cit. pp. 17-18.

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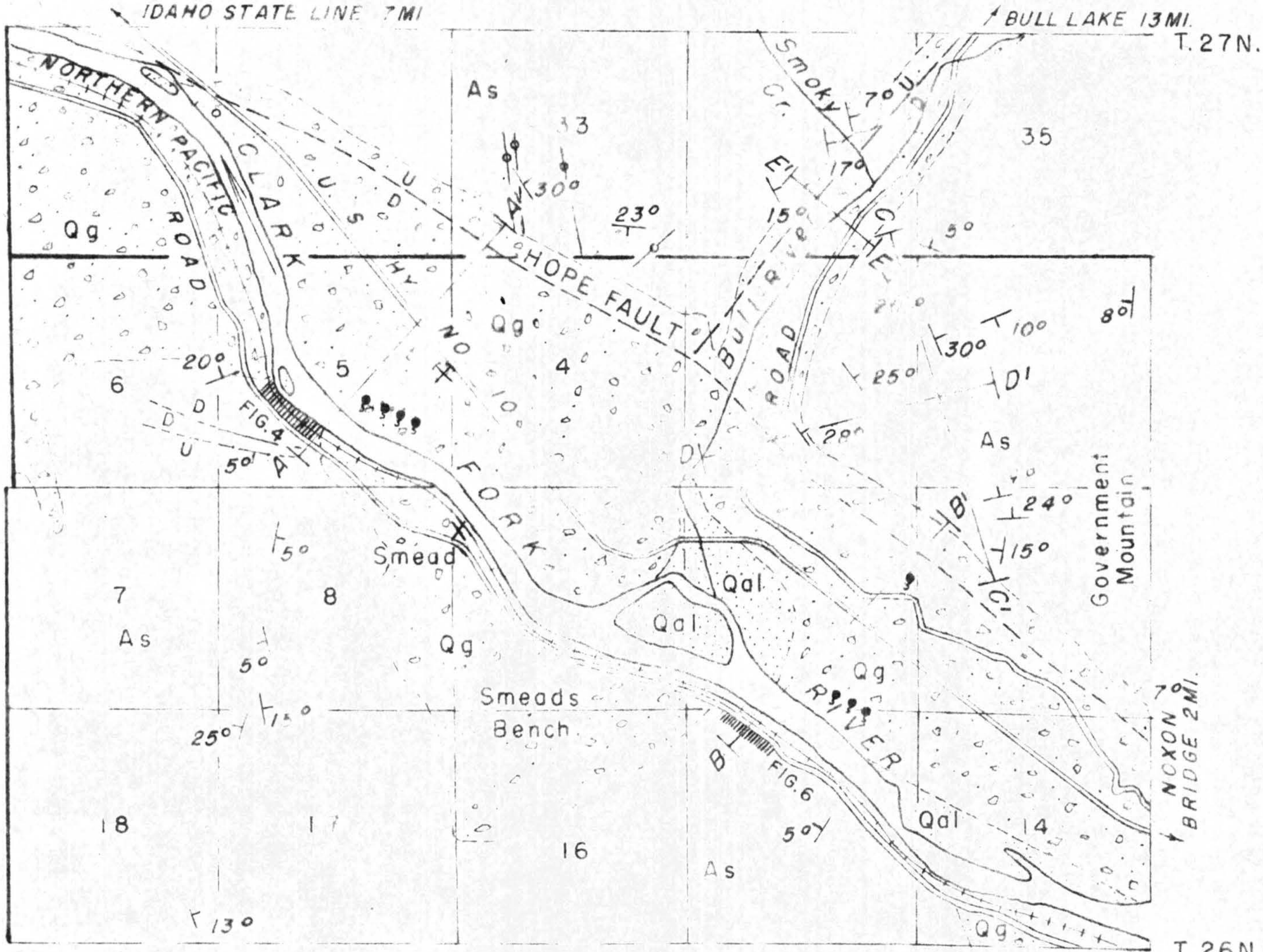
therein. The design of all dams should be made as nearly earthquake proof as possible.

Geologic descriptions of dam sites and appurtenant works

CLARK FORK RIVER



GEOLOGY BY RUSSEL GIBSON, 1934
WITH ADDITIONS BY F.A. McMillin, 1945.

EXPLANATION

Springs

Qal — Alluvium

Qg — Glacial Deposits Undifferentiated

As — Siyeh Limestone Formation

Gravel Pit

A — A' Line of Cross Section

Area of Detailed Map

20° Strike and Dip

X 2166 Smead Benchmark

U / D Fault

Fault with Vertical Dip

0 — 5000 FEET

GEOLOGIC MAP OF SMEAD DAM SITE AREA
SANDERS COUNTY, MONTANA

F.A.M.

FIG. 2

Smead dam site

(Figs. 2, 3, and 4)

By

F. A. McMillin

Location: Smead dam site is located on Clark Fork of Columbia River in secs. 4 and 5, T. 26 N., R. 33 W., and SW$\frac{1}{4}$SW$\frac{1}{4}$ sec. 33, T. 27 N., R. 33 W., Sanders County, Montana.

Accessibility: U. S. Highway No. 10A passes through the valley bottom on the north side of the river, and a county road crosses the middle part of the left abutment. The county road is open during the dry season. The nearest bridge is about 5 miles upstream, at Noxon; and there is another bridge about 18 miles downstream at Clark Fork, Idaho. The main passenger line of the Northern Pacific Railway follows the southside of the river through the dam site area.

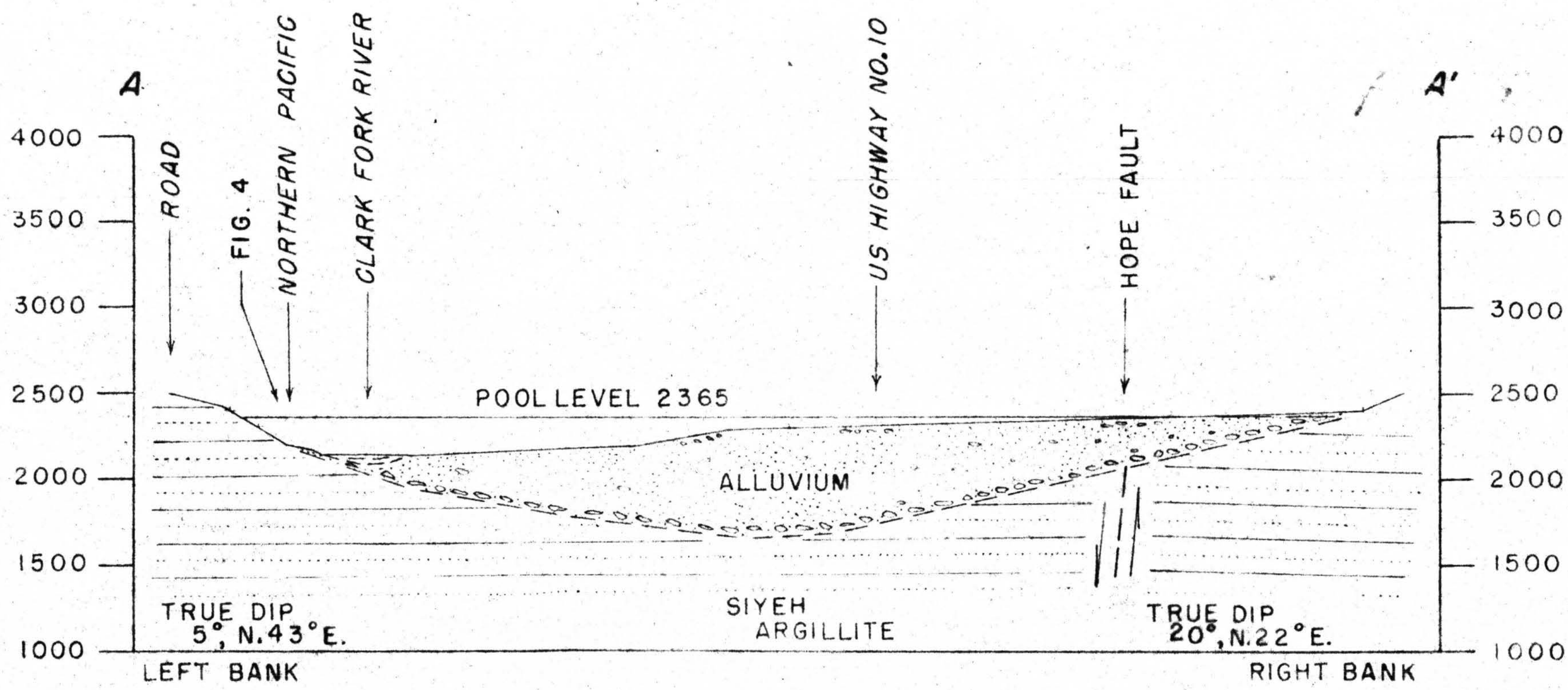
Purpose: In order to utilize the Bull Lake trench as an integral part of the Clark Fork - Kootenai River project, it appears essential that a dam be situated on Clark Fork River just below the mouth of Bull River. Smead dam site fulfills that requirement. The chief function of any dam on Clark Fork River related to this project would be diversion of water into the Kootenai River reservoir area. Storage on the Clark Fork above this site would be comparatively small, about 1,500,000 acre-feet. Some power would be generated, but would be secondary to that developed on the Kootenai side of the project.

Stream gradient: The current of Clark Fork River is swift, but no appreciable rapids occur within the dam site area. Stream gradient is about 4 feet per mile.

Valley profile: A general description of Clark Fork valley at Smead dam site has been given in the introductory section of this report. A cross-section at low elevations is given in Figure 3, and a certain amount of symmetry is evident. Rock is present in the right bank at elevations above 2,400 feet, and in the left bank from river level at 2,135 to 2,500 feet and higher. The intervening valley floor is more than a mile in width, and exhibits a smooth low relief on alluvial deposits. The chief constructional feature appears to be a broad fan or delta that has been built at the mouth of Bull River. Recent terraces have been cut on this deposit, which has forced the river against bedrock in the south (left) abutment. Glacial striae have been observed near the northwest end of the rock exposure along the railway in sec. 5. Hence, the left wall of the valley probably maintains its steep, scoured face below the alluvial fill.

Apparent possible height of dam: Insofar as local topography is concerned, it seems possible to carry a dam up to altitude 2,500 feet.

Character and depth of valley fill: Information on this topic is not available. However, from the general history of the valley, one may conclude that a number of types of deposits are present, and that the fill is deep. It is quite possible that the bottom of the valley is occupied by till. Boulder trains that make small riffles suggest that the upper part of this deposit has been reworked by the stream. Following the till came lacustrine silts and sands, during the existence of glacial Lake Missoula, and then, during the waning stages of the lake, the fluvio-glacial outwash deposits. Only those at altitude 2,500 feet or lower may be considered as indigenous to the prospective dam site. Sorting is poor in some facies of the Bull River delta, and at the State gravel pit in NW$\frac{1}{4}$SW$\frac{1}{4}$ sec. 4, T. 26 N., R. 33 W., there is no marked segregation of the material by size, although most of the pebbles are less than an inch in diameter. Occasional lenses of clay are interbedded in the gravel, and some water wells have reported "quicksand". Topographic conditions suggest that the delta may make the upper 200-250 feet of the valley fill. The total thickness of fill indicated in Fig. 3, is about 600 feet.



RECONNAISSANCE GEOLOGIC CROSS SECTION

SMEAD DAM SITE

Scale 1: 12000

FIG. 3

F.A.M.

Country rock: Bedrock at Smead dam site consists of the Siyeh formation, an assemblage of dolomitic, siliceous argillite, quartzite, and limestone with occasional development of gnarly "molar tooth" structure. Bedding is comparatively thin in the more argillaceous rocks, and ripple marks and sun cracks are of common occurrence. Fresh rock is gray-green or greenish-gray in color. Pyrite is a common accessory mineral, and much of the brown weathered surfaces are the result of its oxidation. Igneous rocks were not observed.

All of the rock of the Siyeh formation in this locality is of sufficient strength to support any type of dam that may be placed upon it. Nevertheless, certain masses of the rock are weak in both a geologic and engineering sense because they are so thoroughly fractured.

Geologic structure: Dip of beds. The dips shown on Fig. 2 are those observed by Gibson, and they indicate considerable variation in regional structure due to folding and subsequent faulting. Locally, on the dam axis, the dip is comparatively simple. The beds in the right abutment dip 22° N. 22° E., with a tendency to steepen to the northeast. A little farther east, however, a reversal takes place, and it appears that the right abutment terminates in an asymmetric syncline with the steep limb on the west. The strike of this feature is to the southeast, and presumably it is cut off by the Hope fault some 1,500 to 2,000 feet southeast of the right abutment. The resultant close compression of this fold makes a strong, secure abutment relatively free from tensional fractures.

The beds in the left abutment are nearly horizontal, dipping 5°, N. 43° E., or thereabouts. This is an abnormally low dip for this region; and, as will be shown later, this area may be underlain by a fault. Hence, the beds in the deeper part of this abutment may have some other attitude.

Jointing: Jointing in the right abutment is infrequent. Most of the fractures there parallel the small faults that in turn parallel the synclinal axis.

Jointing is common in the south abutment. Most of the fractures show signs of movement, and are described at greater length in the section on Faulting that follows. The following joint sets were observed in the south abutment:

Type	Strike	Dip	Character
Bedding	N. 30° W.	4° NE.	Major
Tectonic	N. 15° W.	74° NE.	Major
Tectonic	N. 24° E.	79° NW.	Major

Numerous incipient joints are present but are recognizable only where emphasized by weathering.

Faults: Faults are of common occurrence at Smead dam site, and range in size from the great Hope fault to small surficial landslide faults. Both types may create equally serious foundation defects.

The Hope fault controls the course of Clark Fork valley at this locality and is perhaps the dominant structural feature of the region. It does not crop out within the area of Fig. 2, and the exact position of its trace under the alluvial fill is not known. Field evidence suggests that the fault is not far out from the north (right) wall of the valley, which is believed to be a fault line scarp. Figure 3.

Farther west, near Hope, Idaho, from which the name is taken, field data show that the fault is normal, with both dip and downthrow to the southwest. There, too, the stratigraphic displacement is comparatively great, but in the area of Fig. 2, it is not great enough to offset the Siyeh formation. Its displacement may, therefore, be less than 5,000 feet, possibly a third of the maximum. There is also some difference of opinion whether or not the fault is a simple shear or of the distributive or step type. Some very large faults in this region have surprisingly thin gouge zones, but if the displacement is of the distributive type, the zone of deformation may be wide. The Hope fault may thus constitute a very serious foundation defect.

Numerous small faults are present in both abutments of Smead dam site, and the mechanics of most of them are obscure. Some may be related to the folding, and thus be of the epi-anticlinal type, older than the Hope fault. Others are rather definitely of the landslide type, and not related to the tectonics of the region.

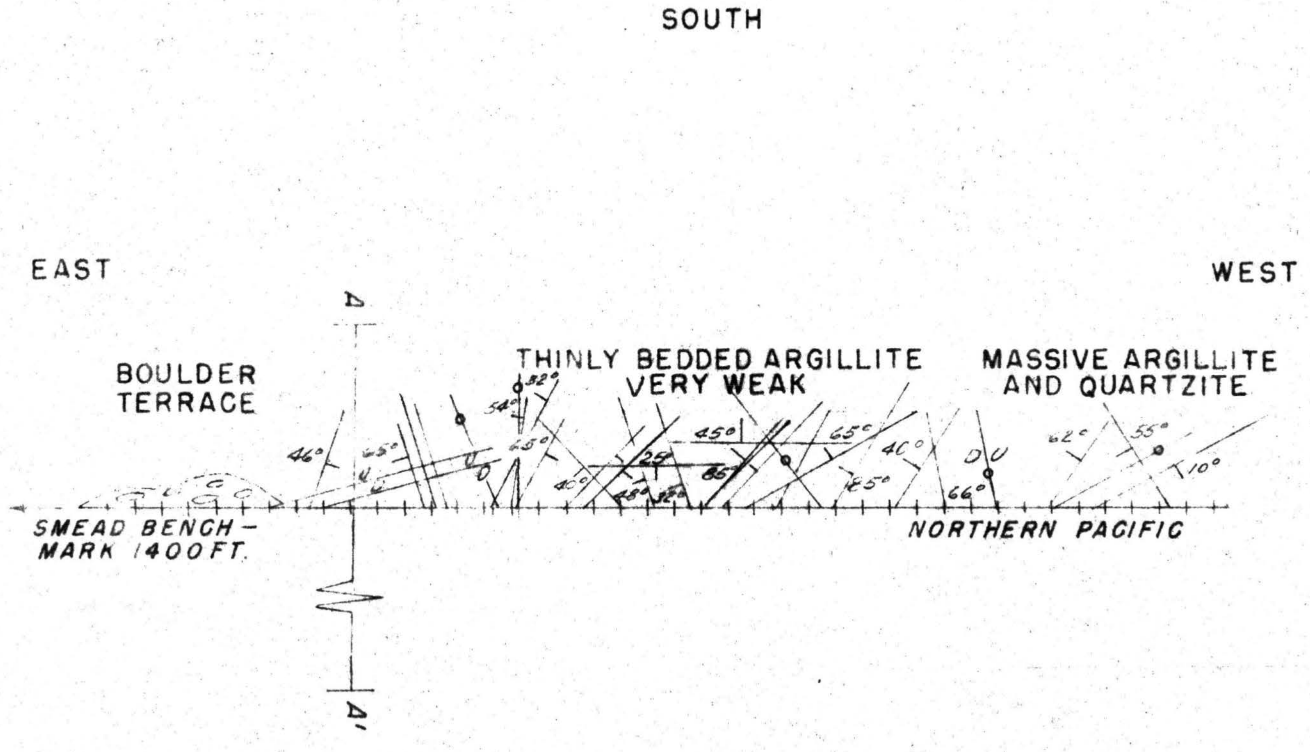
The north or right abutment of Smead dam site is cut by three minor faults. Figure 2. They cannot be shown in Fig. 3, since their projection into the line of the section falls northeast of the end of the profile. Two of them, parallel at a distance of about 170 feet, strike N. 06° W., and are approximately vertical in attitude. The westerly one of the pair would have to have the valleyward block removed before the abutment can be considered secure. Some 1,000 or 1,200 feet east, the third fault strikes N. 10° W. Although it appears to be more strongly developed, dip is indeterminate, but a few small drag folds suggest that the west side has moved down. The beds in the downthrow side dip 6° W., while those in the upthrown side dip 21° W.

The attitude of the strata indicates that the synclinal axis lies between these faults, and they are parallel to it.

They are a type of epi-anticlinal fault that makes a mechanical couple with those that strike normal to the axis of a fold. Some thrusting or shearing may be involved.

The fault pattern of the lower part of the left abutment is illustrated diagrammatically in Figure 4. Their mechanics are unknown, but the probability is that they are of tectonic origin. Farther up the slope to the southwest are several faults (Fig. 2) of probable landslide origin. The minor stress involved in such surficial movements seems inadequate to originate such a complex fracture pattern, but no doubt it has emphasized the fractures by loosening and opening them up as the slumped mass tended to rotate.

The position of the dam section across the shatter zone of the left abutment is shown in Fig. 4 by the line A-A'. The general character of the tectonic faults may be illustrated by a description of the attitude of a small group that cut the wall of the railway cut 700 to 850 feet west of line A-A'. Seven hundred feet west of the line of section, there are two faults. The stronger strikes S. 28° W., and dips 32° SE. The crush zone accompanying this fault consists of 10 to 12 inches of breccia; if gouge clay was ever present, it has been washed out. The second fault strikes S. 22° E., and is vertical. Gouge along it is only 2 or 3 inches thick.



SMEAD DAM SITE AREA

PLAN VIEW OF SOUTH ABUTMENT SHOWING MINOR FAULTS

TRAVERSE ALONG RAILWAY

Scale 1:12000

FIG. 4

F. A. M.

Forty-eight feet farther west another fault strikes S. 10° W., and dips 54° E. Gouge on this fault is 10 inches thick. A fourth fault, 75 feet farther west, strikes south and has a vertical dip. This fault has 5 feet of gouge. Shattering of this sort extends westward for another 1,400-1,500 feet, where massive unfractured rock begins to appear again.

Returning again to the line of the prospective dam section, A-A', in Fig. 4: the abutment zone is cut by two closely spaced parallel faults that strike S. 75° W., and dip northwest. These fractures are later than the sequence just described, and are part of a frequent series of normal or gravity faults that extend at least 1,000 feet back (southwest) from the left bank of the river. They are believed, on the basis of topographic evidence, to be of landslide origin; and probably the sliding took place shortly after the deglaciation of the valley, when the beds were thoroughly saturated with water and the slope of the valley wall greatly oversteepened. Two of the upper members of this set are shown on Figure 2. The most southerly fault in sec. 5 may be the sole fault or basal fault of the slumped zone. Its strike is N. 75° W., and dips northeast, but the amount of dip could not be observed. The vertical displacement of this fault is about 165 feet. Another step in this series lies 500 feet north. On this fault, the strike is S. 75° W., with dip to the northwest. Displacement appears to become less with each successive downward step until the one nearest the river has a throw of about 50 feet.

The net result has been to translate a mass of highly fractured, thin argillaceous rocks forward and downward over more dense massive strata. The combination of thin beds, with a closely spaced fracture pattern, and thin fault slices cutting the older faults in the slumped blocks nearly at right angles, has been most effective in reducing the strength and continuity of the rock in the left abutment. The sole fault probably completely severs the shattered ground from the unfaulted terrane in the north part of sec. 8. The entire area is highly permeable and weak in both a geologic and engineering sense, and must be regarded as a potential landslide mass.

Ground water conditions: The ground water table on either side of Clark Fork River at Smead dam site was high at the time this reconnaissance was made, because of heavy rains and melting snow. A few small rivulets, possibly with a discharge of 1 or 2 second-feet, descend the higher slopes, but are soon absorbed in the alluvium. No run-off was noted from the shattered ground in the left abutment.

North of Highway 10A, on the right bank, farm wells find water at depths of 21 to 24 feet; and along the river bank at elevation 2,155 feet, there is a spring zone whose flow is again absorbed before it can reach the river. The water wells bottom in what is locally called "quicksand". These wells seem adequate for domestic and stock use, except in the very dry years, and the inference is that the Bull River delta gravels are well saturated with water.

Permeability: Permeability of the rock formations at Smead dam site must be considered from the viewpoints of that of the alluvial fill and of bedrock.

Field evidence, such as the absorption of small streams and the discharge of springs, shows that the gravel facies of the fill have a very high permeability. That of the sandy facies of the lake beds is also effective, but probably not dangerous.

Permeability of the Siyeh formation is a function of the sheet openings. That of the massive rock is probably of the same order as that on Kootenai River. However, in thoroughly shattered areas, such as the left abutment, it is much greater. Tests on broken ground of this type are not available, but the factor, obviously, would be very high and possibly dangerous.

Dam section: Only one dam section is available at this locality. This prospective axis has a bearing of about N. 41° E., through a point about 600 feet south of the northeast corner of sec. 5, T. 26 N., R. 33 W. Line A-A', Fig. 2, and Fig. 3. Structural conditions in the left bank limit the breadth of this section to about 250 feet either side of the axis. Width of open valley at the critical elevation of 2,365 feet is about 5,650 feet, but a length of about 850 feet will be required for a dike or cutoff to obtain a secure right abutment. The total length of crest will thus be about 6,500 feet. Excess elevation above 2,365 is available in both abutments.

Abutments: Smead dam site is characterized by low abutments and a very broad foundation. This is because the height of dam from river surface to the critical elevation is comparatively low. Actually, at elevation 2,365 the right abutment rests on alluvium, and an 850-foot dike or cutoff is necessary to carry it over to rock in the valley wall.

The base of this slope is concealed by a thin mantle of talus, obviously post-glacial, which has an angle of rest of about 32°, and rises 100 to 160 feet above the upper margin of the alluvium. Bedrock behind the talus dips 16°, N. 70° W., and consists of an assemblage of argillite interbedded with limy quartzite. Bedding is well developed and some of the massive layers are 10 feet thick. The argillite is blue-gray, weathering buff. Freshly broken surfaces of the quartzite are creamy-white, with accessory pyrite, and weather gray. This rock is sound and secure, and relatively free from jointing and faulting. The highly compressed synclinal structure of this part of the valley wall adds a considerable element of strength to the formation.

Bedrock in the left (south) abutment rises from river surface to elevations well above 2,500 feet. Over a distance of about three quarters of a mile, somewhat less than 500 feet of rock is of sufficient strength and free from fractures to warrant consideration as a dam abutment. Fig. 4. Even this narrow zone is comparatively thin, and is separated from the main wall of the valley by a series of landslide faults.

Taken as a whole, the entire left abutment spur is a thoroughly shattered, structurally weak, highly permeable, potential landslide mass that is geologically unsound and wholly unsuited to serve as the abutment of a dam. No doubt local remedial measures could be taken to reduce the permeability where the formation appears to be unbroken, but there is no continuity of strength within the area, and immunity from future sliding cannot be guaranteed. Hence, if movement did occur, the old fractures would be reopened and new ones might form, with likely disastrous effects to any structure abutting against the south side of the section.

Obviously, the bearing power of the abutments at Smead dam site is unequal, the right being stronger than the left. Practically, however, they are so far apart that the matter of equality or lack of equality of bearing power does not enter into consideration, since they are beyond mutually supporting distance.

Foundation: The foundation area of Smead dam site occupies most of the valley floor, whose material consists of various facies of alluvium, fluvio-glacial outwash, and lake beds. Brief descriptions of the general character of these deposits have been given. Except for minor lentils of clay, all of it is highly permeable, and all of it is unconsolidated. The geologic history of the valley suggests that soft, fine-grained sands and silts of lake bed origin underlie some of the less compactible fluvio-glacial deposits and beds of reworked gravels. If this interpretation is correct, the arrangement constitutes a dangerously unbalanced distribution of materials of widely different bearing power. Loading the surface of the fill with a heavy dam might cause readjustment of the more compactible material, with consequent sliding or sub-surface flow of the finer parts of the foundation. Much deep drilling and exploration will be required to ascertain the character and arrangement of this fill. Without the results of such tests, any statement as to the unfeasibility of the alluvial foundation must be regarded as unduly pessimistic; but, it is in order to point out that conditions are difficult, and that a deep cutoff and extensive grouting will be required under any circumstances.

The depth and volume of the alluvial fill is so enormous that excavation to bedrock foundation seems out of the question. For this reason, discussion of its nature becomes academic. Without doubt, the Hope fault is the most serious defect in this element of the site, particularly if the throw of the fault is of the distributive type. The width of this fault zone is unknown, but even if it is 1,000 feet wide, it would occupy a relatively small part of the foundation area. The sound rock and favorable geologic structure of the right wall of the valley probably carry up to the Hope fault, but make only a very small part of the foundation area. There is a possibility that depth to bedrock northeast of the fault is less than that on the river side. Bedrock southwest of the fault does not appear until exposed in the disturbed left abutment. Conditions there cannot be applied to all of the rock floor of the valley southwest of the Hope fault. Nevertheless, since the geologic history of the valley suggests that the sliding in the left abutment took place after deglaciation, leaving the valley deep, with unsupported walls, it is conceivable that landslide blocks or debris may rest on the floor under the left bank, deeply buried by lake beds and river gravels. Thus, even if the bedrock foundation were attainable, its character from bank to bank might change rapidly from place to place, with accordant variation in bearing power.

In summary: foundation conditions in both the alluvial fill and on bedrock must be regarded as unfavorable until proved sound and secure.

Height and length of possible dam: Assuming that the unsound character of the foundation and left abutment can be overcome, in order to fulfill requirements of the Clark Fork - Kootenai project, a dam at Smead site would have a minimum height above river surface of about 226 feet, and a crest length of at least 6,500 feet. However, height above foundation would add considerable footage to the elevation of the structure, and if a cutoff were carried into sound rock in the left abutment, an additional 1,000 feet might be added to the length. Obviously, a very large dam is required for Smead site, and more specific dimensions cannot be given until additional information is available. Furthermore, the nature of the defects indicate a broad base flexible dam.

Appurtenant works: The great volume of the river and the size and character of the flood stages makes the problem of a spillway the most critical of the appurtenant works. It is quite possible that an adequate spillway can be provided over or around the south (left) abutment, especially if the bank requires extensive excavation for a cutoff. The spillway would probably have to be lined heavily with concrete, and also to pass over a potential landslide area. The spillway would discharge onto the Heron flats, where it would excavate vast quantities of alluvium to be re-deposited farther downstream. Serious problems of delta building might develop at the mouth of the river in Pend Oreille Lake.

Other appurtenant works would include a powerhouse site and cofferdams for river diversion. Siting these works should not be difficult and need not be considered until construction is contemplated.

Conclusions and recommendations: Smead dam site is affected by the following adverse geologic conditions:

1. A deep and difficult permeable foundation in alluvium, with uncertain and variable bearing power.
2. A bedrock foundation that is practically unattainable due to depth of overburden; with

additional defects occasioned by the presence of the Hope fault near the base of the right bank, and the probable presence of landslide debris on the floor at the base of the left bank.

3. A very wide river valley, requiring a dam section of at least 6,500 feet, and possibly 7,000 or 7,500 feet.
4. Extensive shattering of the left abutment by very closely spaced faults that have cut off by a series of closely spaced landslide faults that extend back into the abutment for at least 1,000 feet, rendering it weak in both a geologic and engineering sense. The entire left bank of the river at Smead dam site is considered to be a potential landslide mass.
5. The only available spillway section is over this potential landslide.
6. Discharge from the spillway onto Heron Flats would cause excessive scour of the alluvial fill, followed by extensive aggradation of the river bed downstream, and possibly delta building in Pend Oreille Lake.

7. These unfavorable features and consequences are of such magnitude that they will be very difficult and expensive to overcome by engineering skill.

8. It is recommended that further consideration of Smead dam site be postponed until the possibilities of an alternative upstream site can be investigated.

Chimney Rock dam site

(Figs. 2, 5 and 6)

By

F. A. McMillin

Location: Chimney Rock dam site is located on Clark Fork of Columbia River in sec. 10, NW$\frac{1}{4}$NW$\frac{1}{4}$ sec. 11, and N$\frac{1}{2}$ NW$\frac{1}{4}$ sec. 15, T. 26 N., R. 33 W., Sanders County, Montana. The suggested dam section is about a mile upstream from the mouth of Bull River gorge in the east wall of Clark Fork valley. Reference points on the left bank are: 1.5 miles east of B.M. 2,166 at Smead; and 0.15 miles east of the Smead Bench Road. The name is taken from a high pinnacle rock, elevation 4,329, on the axis of the spur in SW$\frac{1}{4}$SW$\frac{1}{4}$ sec. 15.

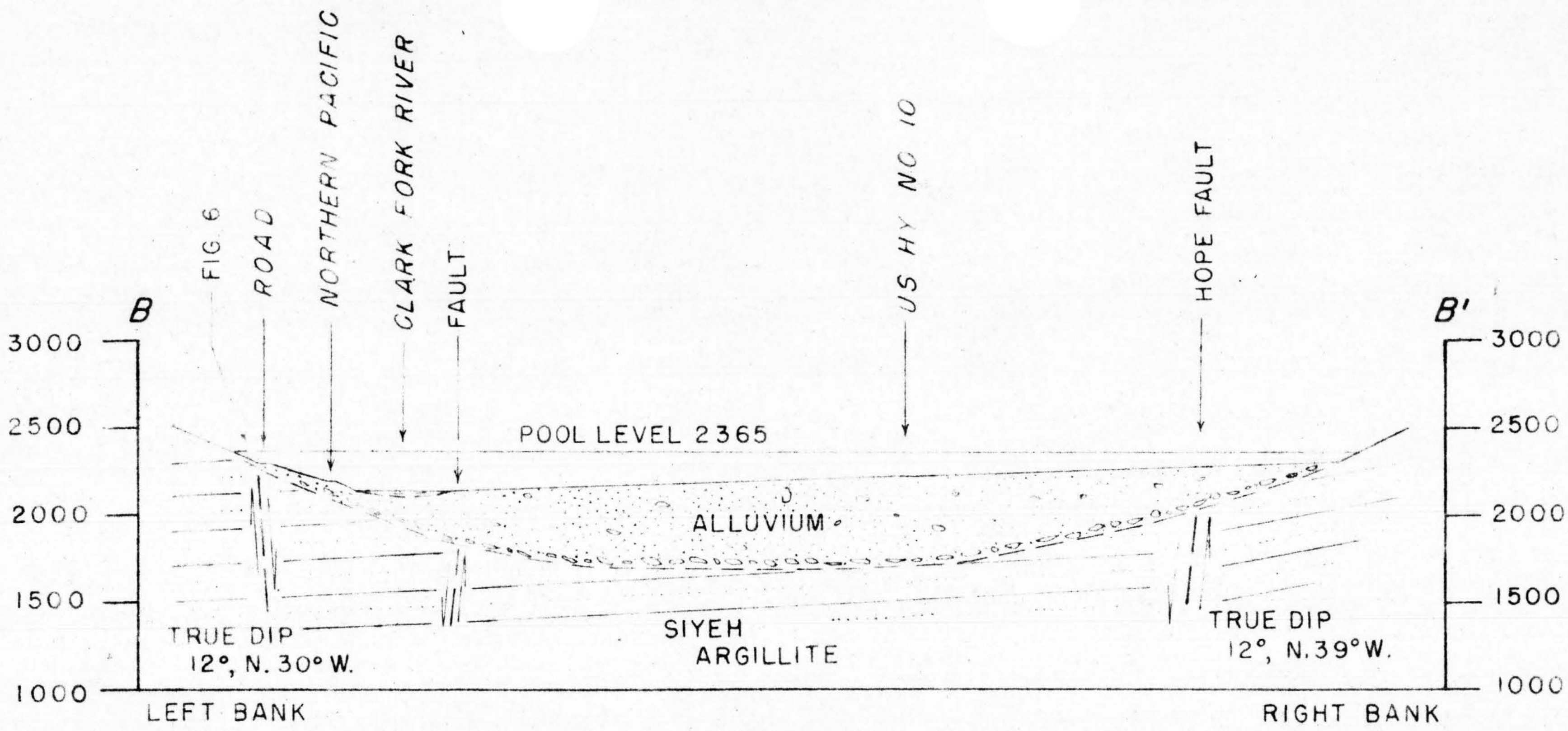
Accessibility: Accessibility is essentially the same as for the Smead site, which is 2.25 miles downstream.

Purpose: Chimney Rock dam site is an alternative for Smead dam site which has serious geologic defects in its left abutment and foundation.

The essential element of the Clark Fork - Kootenai River project furnished by Smead dam site is its location down-valley from the mouth of Bull River, thus making it possible to divert water through the Bull Lake Trench into Kootenai River 40 miles north. The location of Chimney Rock dam site upstream from Bull River violates this condition. However, the same end can be achieved by a small additional dam across the lower end of Bull River gorge, and a short tunnel under Government Mountain from the forebay of Chimney Rock dam site to the forebay of the dam in Bull River gorge. With these appurtenant works, Chimney Rock dam site will serve exactly the same purposes of diversion, minor storage and power as Smead dam site.

<u>Stream gradient</u>: Clark Fork River has a gradient of about 2.5 feet per mile through Chimney Rock dam site.

<u>Valley profile</u>: A general description of Clark Fork Valley has been given in the introduction of this report. A cross-section at low elevations is given in Fig. 5. Comparison with the profile at Smead dam site shows two significant differences: (1) the left abutment consists of the glaciated wall of the younger, inner valley of the river, and is a much higher and more massive feature than the left abutment at Smead dam site. (2) the northeast end of the axis crosses the valley upstream from the Bull River delta. Hence, although the width of the valley floor is about the same as at Smead dam site, it is lower, flatter, and does not contain so much alluvial fill.



RECONNAISSANCE GEOLOGIC CROSS SECTION
CHIMNEY ROCK DAM SITE
Scale 1 : 12000

FIG. 5

F. A. M.

Apparent possible height of dam: Topographic conditions will allow a dam to be carried considerably above the critical elevation of the Clark Fork - Kootenai River project (2,365 feet) without materially lengthening the section.

Character and arrangement of valley fill: Present information on this topic is obtainable only from surface observation and deductions from the geologic history of the valley. The general condition is considered to be somewhat more simple than at Smead dam site. This is due to the position of the site upstream from the mouth of Bull River, where there would be less tendency for gravel spits and bars to develop, and to the absence of the top-set and fore-set beds of Bull River delta. From the bottom upward, the general sequence is probably till (valley moraine), lake beds (sand and silt), and miscellaneous terrace gravels resulting from the reworking of the older deposits. It is believed that there is relatively much more finer material than at Smead dam site, and more suited to the driving of a cutoff wall.

The amount of fill is unknown; Figure 5 indicates 500 feet. Whatever the thickness, over the middle and north (right) margin of the valley floor it is at least 150-200 feet less than at Smead dam site.

Country rock: Bedrock at Chimney Rock dam site consists of the Siyeh formation, a very thick assemblage of more less calcareous argillites, interbedded with impure magnesian limestone and calcareous sandstone. Metamorphism has just been sufficient to initiate recrystallization in some of the more calcareous members. Some of the quartzitic sandstone contains metacrysts of pyrite as an accessory mineral. Calcite is present in sufficient amount to yield a feeble effervescence when treated with dilute hydrochloric acid. Weathering develops a buff or gray surface that penetrates deeply into the rock along the joints.

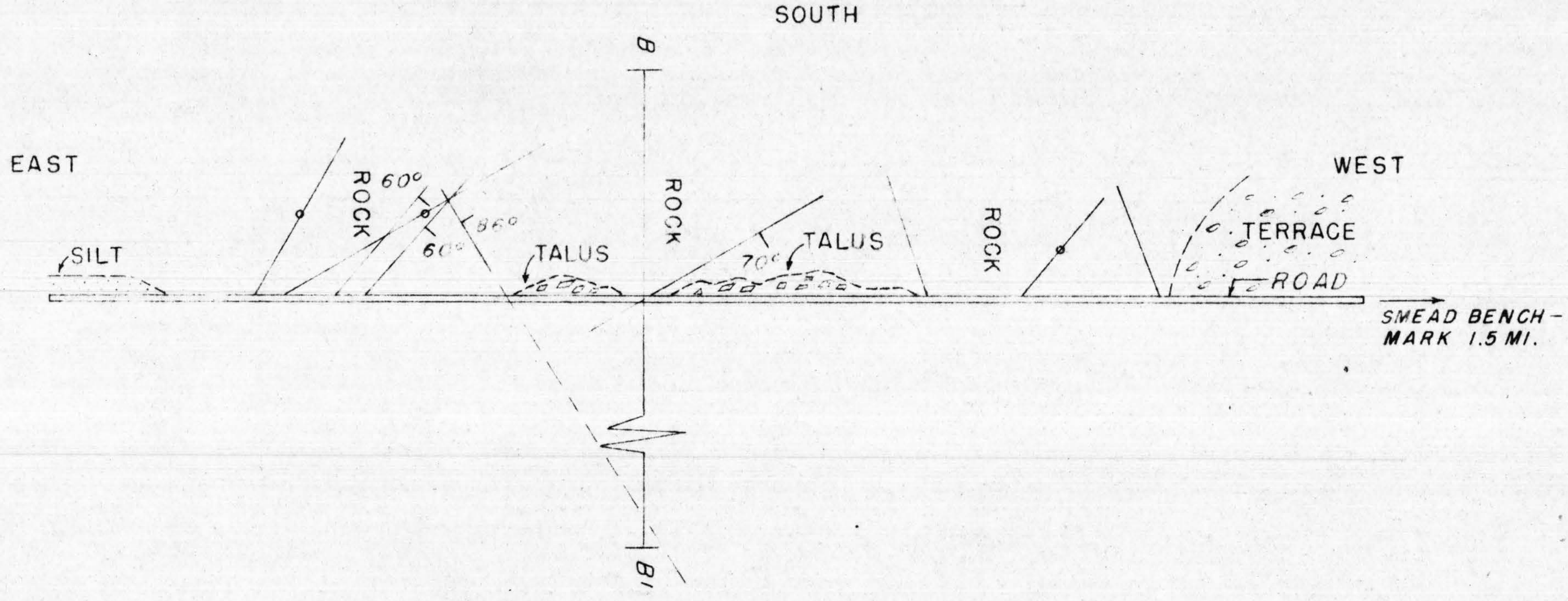
The rock in the abutment areas is strong. There is no available data on the crushing strength of rocks of this type, but it seems reasonable to assume that sound sections free from minor joints and flaws will have a crushing strength comparable to good limestone, 10,000 pounds per square inch, or well cemented sandstone, about 9,000 pounds per square inch.

Solution appears not to have affected these rocks, and even the more calcareous members show very little evidence of pitting or loss of material.

Geologic structure: Dip of beds. In spite of the lack of structural continuity across the valley, the beds on either side appear to share a common westerly dip. In the vicinity of the right (north) abutment the amount of dip varies from 4° to 24°, but some of this difference is the result of minor faulting. Half a mile northwest, the beds dip strongly northeast into Government Mountain at angles of 25° to 30°. A mile northeast of the right abutment, on the west spur of Government Mountain, the beds are flexed gently into an anticline whose limbs dip 8° to 10°.

In the south (left) bank the prevailing dip is westerly in amounts varying from 5° to 23°. In general, structural conditions are more simple in the left bank than in the right.

Joints. Joints in this area are of two general types: bedding and tectonic. In the cliffs of the left bank the rock has a marked tendency to cleave into rough prismatic blocks 3 to 10 feet on a side. Occasionally a major joint has been etched out by differential erosion into deep, narrow gashes. Viewed from the valley floor, they appear as minor faults, but their true character is evident when they are seen from the top of the cliffs. A plan view of these major joints is given in Fig. 6. This illustration should be compared with Fig. 4, which shows a plan view



CHIMNEY ROCK DAM SITE

PLAN VIEW OF MAJOR JOINTS IN SOUTH ABUTMENT

TRAVERSE ALONG COUNTY ROAD

Scale 1:12000

F.A.M.

FIG. 6

of the fractures in the south abutment of Smead dam site.

In the right abutment, closely spaced joints parallel the cliff-face, and may reflect the attitude of the Hope fault.

The Corps of Engineers, U. S. Army, have drilled a dam site 12 miles west of Chimney Rock in the same general type of rock and report_/ that the joints tighten or dis-

_/ Informal communication.

appear altogether 10 to 20 feet below the surface.

Faults. The great Hope fault that parallels the north (right) bank of the river strikes through Chimney Rock dam site and gives prominent fault-line scarp expression to the valley wall. It has been described in the general section of this report and again in connection with the description of Smead dam site. The exact position of the trace is concealed by alluvium, but it is believed to be fairly close to the valley wall. The cliff-face is oversteepened, and apparently carries a series of step faults, but close observation fails to indicate offsetting of the strata.

Minor faults. Two parallel faults, probably of the epi-anticlinal type, cut the right wall of the valley 800 and 900 feet, respectively, east and west of the north end of the abutment. Both are expressed topographically as gulches. The fault to the east strikes N. 30° E., and dips 64° NW., and appears to be on the west limb of an anticline whose axis strikes north along the east line of sec. 2. Presumably, it is normal, and there is some variation in dip from side to side, but no appreciable change in strike.

The left bank in the vicinity of the abutment is affected by eight small faults, but only one cuts the abutment itself, and one other fault cuts the foundation at river level. Fig. 5.

Ground water conditions: The ground-water level in the rock walls of the valley is low, for they are dense and impermeable, and much of the runoff reaches the valley floor through fractures. Springs or rivulets were not observed on the left bank. On the right bank, however, two small streams discharging 1 or 2 second feet, come down the south face of Government Mountain and are absorbed by porous fill on the valley floor. A few intermittent springs were noted at irregular intervals along the line B-B', Fig. 2, north of the river. Near the southeast corner of sec. 10, a line of springs at altitude 2,181 feet feed a swampy tract about 1,200 feet long. The amount of water flowing into the swamp seems much less than the discharge of either of the mountain brooks absorbed near the margin of the fill. Discharge from the swamp into the river was not observed.

West of the suggested dam section, between the roads just north of the center of section 10, there is an old lake bed about half a mile long and 1,000 feet wide. During a wet year water may stand in it for the entire year, but during the past 10 years it has usually been dry during the summer.

Water wells were not observed in the area as the residents obtain their supply from the mountain brooks. In general, the spring zones and the character of the vegetation indicate a high ground-water level for the valley bottom at Chimney Rock dam site.

Permeability: Permeability of bedrock at this site is generally low, and a function of the effectiveness of sheet openings rather than the texture or fabric of the rock. The character of the rock is much like that at Kootenai River dam sites, for which rough estimates of coefficients have been given. In general, the rock in the right bank is a little tighter than that on the left.

Permeability of the alluvium is high, but variable, and, on the whole, less than that for the fill at Smead dam site.

Dam section: Casual inspection of the valley profile at Chimney Rock dam site suggests that almost any section across the valley between the NW cor. sec. 15 and the left bank just south of the E$\frac{1}{4}$ cor. sec. 15, a distance of about 6,000 feet, might serve as a prospective dam axis. Geologic conditions appear to be much the same throughout this area, and detailed geologic and topographic surveys will have to be undertaken to ascertain the most economical section. However, an axis near the northwest (downstream) end of this stretch will have a shorter tunnel route to the forebay of the accessory dam on Bull River just below Smoky Creek; and a tentative axis has been drawn, as shown on Figure 2, B-B'. This line bears N. 45° E. through a point about 1,600 feet south of NE cor. sec. 10. Width of open valley at the critical elevation of 2,365 feet is about 6,425 feet. This distance is a maximum and cutoffs will not be required in either abutment. Excess elevation above 2,365 feet is available in both abutments.

Abutments: Like Smead dam site, Chimney Rock dam site is characterized by low abutments and a very broad foundation.

The upper part of both abutments are in bedrock, or ground mantled lightly with talus or slope wash. Roughly, 60 feet of rock is available below pool level in the right abutment, and about 225 feet in the left abutment. Fig. 5.

The rock in both is sound and durable and fully capable of supporting any type of dam that may be placed against them. Bearing power in each is essentially equal, although they are too far apart to be mutually supporting.

Foundation: The foundation of Chimney Rock dam site occupies most of the width of the valley floor. This part of the valley has been glaciated by ice moving downvalley, and bedrock foundation is likely to be deep. The character and arrangement of the fill is believed to be about as at Smead dam site, except that the Bull River delta beds are missing - that is most of the fill probably will be lake beds over till. The absence of overlying top-set and fore-set gravels removes the condition of unbalanced bearing power that is believed to exist at Smead dam site. Bottom-set beds of the Bull Lake delta may be present, but this material would be fine-grained and very difficult to distinguish from the lacustrine deposits. Occasional beds of gravel or an ice-rafted boulder may occur in the fill, but, in general, the composition of the deposits is believed to favor the driving of cutoff sheeting to the till. The geologic history of the valley suggests that if till bottoms the valley, it will not have been reworked to any extent by the river, for ponding followed deglaciation so quickly that extensive deposits of outwash or fluvio-glacial beds did not have time to develop. The lower part of the fill may thus be expected to be impermeable and well compacted. If it can be reached by piling or sheeting, it should make a good tight seat.

The character of the bedrock foundation at Chimney Rock dam site is probably much like that at the Smead site. The Hope fault, with its adverse condtions, will be present on the north side of the valley. However, landslide debris probably will not occur on the floor under the left abutment; and the attitude of the beds in the foundation southwest of the Hope fault will be essentially the same as in the left abutment.

Comparison of dam sections: Chimney Rock dam site appears to be definitely superior to Smead dam site in several essential respects:

1. The left abutment is stronger, more massive, unshattered, and not subject to potential landslides.
2. The amount of fill is less over the middle and north side of the valley by 150 to 200 feet. Hence, considerably less excavation will be entailed.
3. The fill is less permeable, and is not believed to contain elements of unbalanced bearing power. The material is finer-grained and more amenable

to driving a deep cutoff. Seating conditions for piling are considered good.

4. Landslide debris probably is not present on the bedrock floor.

The sites appear to be equal in:

1. Size, Length of crest, and Height of dam above river surface. However, the Chimney Rock site will not require dikes or cutoffs in the abutments.
2. Strength of right abutment.
3. Presence of Hope fault in bedrock foundation.

Smead site is superior only, in that it requires less elaborate appurtenant works.

Choice of section: In view of these superior elements, there can be no hesitancy in indicating that the dam section at Chimney Rock is better than that at the Smead site.

Height and length of possible dam: A dam at Chimney Rock site would have a minimum height above river surface of about 225 feet, and a crest length of about 6,425 feet. Height above foundation will add considerable footage to the elevation of the structure. Obviously, a very large dam will be required, but more specific dimensions cannot be given until more accurate surveys and knowledge of foundation conditions are available. The character of the foundation and the presence of the Hope fault indicates a broad-base flexible dam for this site.

Appurtenant works: The position of Chimney Rock dam site above the mouth of Bull River necessitates two accessory works to compensate for the upstream location: an accessory dam in Bull River gorge, and a tunnel from the forebay of Chimney Rock dam site to the forebay of the accessory dam. Both of these accessories are easily feasible, and are minor undertakings in comparison to the construction of a dam at Chimney Rock site. Geologic conditions affecting them are described briefly in separate chapters of this report.

The usual accessory works for any dam include a spillway, a powerhouse, and some means of diverting the flow of the river during the construction of the dam.

Under the circumstances at Chimney Rock site, it seems possible that the diversion tunnel and dam could also be assigned the role of a spillway. If the discharge were over the accessory dam onto rock in the floor of Bull River valley, much aggradation by alluvium in the Clark Fork river between Bull River and Lake Pend Oreille might be avoided. Several alternative rock sites for a powerhouse would be available. Diversion of Clark Fork River during construction would have to be by cofferdam because of the breadth of the valley.

Reservoir area: The geology of Chimney Rock reservoir area has not been studied. With a properly constructed dam, and a deep cutoff to an impermeable foundation, leakage from the reservoir would be improbable. Seepage through the rock abutments would be negligible.

Construction materials: Ample natural materials for construction are available. Rock is abundant in accessible quarry sites in either wall of the valley and in Bull River gorge. Coarse gravels are available in the Bull River delta deposits; finer gravels and sand are available on the lower parts of the valley floor. All of the sand and gravel will have to be washed. Some of the gravel is coated with opalite and some with secondary lime deposits (calcite). Unless there is careful selection, the opaline silica may react with the alkali content of the cement, causing internal swelling and disintegration of the concrete. Electric power is available from the plant at Thompson Falls 40 miles up Clark Fork valley.

Conclusions and recommendations: Although on a large scale, Chimney Rock dam site and accessory works are feasible projects, and the probability is that the Clark Fork - Kootenai River project cannot be accomplished without them, for a good alternative site is not available.

It is recommended that detailed topographic surveys of the various elements of the project be undertaken to provide an adequate base for a more comprehensive geologic and geophysical investigation of the project.

APPURTENANT WORKS FOR CHIMNEY ROCK DAM SITE

Smoky Creek dam site

(Figs. 2 and 7)

By

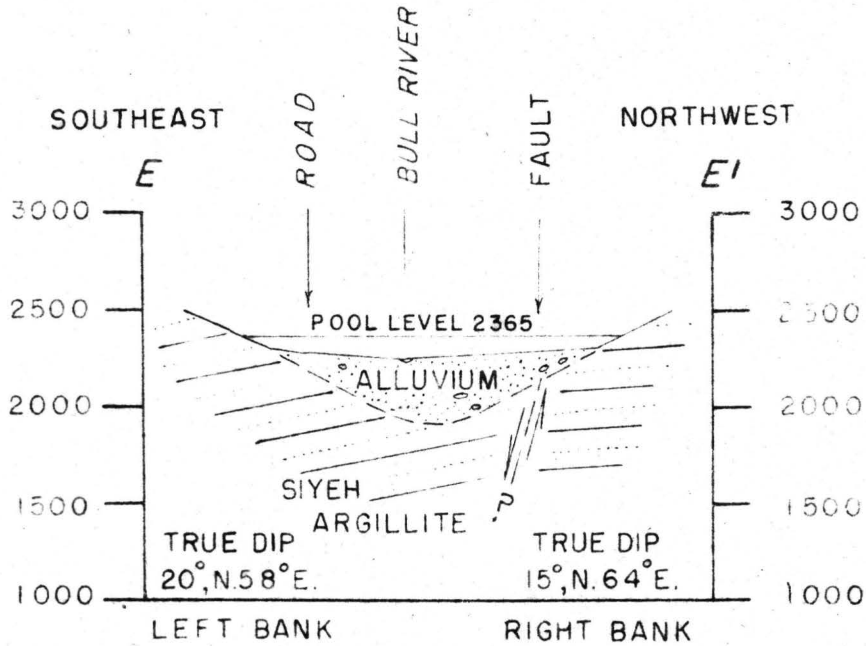
F. A. McMillin

Location: Smoky Creek dam site is situated on Bull River in SE$\frac{1}{4}$ sec. 34, T. 27 N., R. 33 W., Sanders County, Montana. The name is taken from Smoky Creek, a small tributary on the right bank of Bull River, about 1,150 feet north of the west abutment.

Accessibility: An improved county road, connecting U. S. Highways No. 2 and No. 10A through the Bull Lake trench, passes over the left (east) abutment of the site.

Purpose: Smoky Creek dam site is an accessory work to Chimney Rock dam site, and is necessary to close the mouth of Bull River valley, in order that water may be diverted through the trench into Kootenai River. The forebay of Chimney Rock dam site will be connected with the forebay of Smoky Creek dam site by a tunnel through the west spur of Government Mountain.

Valley profile: Bull River valley in its lower part is a deep, narrow V-shaped gorge. This topography results



RECONNAISSANCE GEOLOGIC CROSS SECTION

SMOKY CREEK DAM SITE

Scale 1:12000

F.A.M.

from active cutting of the river in an antecedent course across the relatively upthrown block on the northeast side of the Hope fault, and is considered as evidence of comparatively late movement on that fault.

The valley floor is alluvial and slopes gently toward the river. Width at the base of the rock cliffs is about 1,650 feet. Near the middle, the rapidly flowing stream occupies a shallow inner trench 10 to 15 feet deep and 25 to 50 feet wide. Elevation of river surface is about 2,225. During the latter part of April 1945, depth of water was about 2 feet.

Apparent possible height of dam: The valley walls have considerable excess elevation above altitude 2,365 feet, the maximum allowable for the project. Aside from the Clark Fork - Kootenai project, the controlling elevation for this site is about 2,326 feet, the elevation of the Bull River-Lake Creek divide. Dams higher than altitude 2,365 need not be contemplated.

Character and depth of valley fill: The alluvial deposits consist largely of fluvio-glacial outwash that have been reworked by stream in the valley. Most of the material is well-sorted gravel in a matrix of silt. Few, if any, large boulders are present. Till was not observed. Depth of fill may not exceed 50 feet, but probably is deeper, with a maximum of about 300 feet.

Country rock: Bedrock at this site is the Siyeh formation, and consists of dense, massive, heavy-bedded calcareous argillite, weathering a brownish-gray. All of the rock is strong and durable, with high crushing strength, and capable of supporting any type of dam that may be placed upon it.

Structural geology: Dip of beds. The rock on the west (right) side of the valley dips 19° northeast, while that on the left bank opposite dips 15° northeast.

Joints. The usual pattern is rectangular to cubic. Some of the larger joint blocks are more than 50 by 75 feet on a side, but their thickness is controlled by the bedding, which is much thinner.

Faults. The valley may be under fault control, and there is some evidence that a fault parallels the right bank. If present, it is probably one of the epi-anticlinal group that are associated with the folding. These faults are much older than the Hope fault, and are geologically inactive. Since the site appears to be adapted to a rigid type dam, it is advisable to investigate the position and character of this fault more fully.

Ground water conditions: Ground water level in the valley walls is low for the attitude of the beds and the character of the slopes facilitate its rapid return to the valley floor.

The alluvial fill is highly porous and absorbent. Local rivulets on the mountain walls are absorbed as soon as they reach the valley floor, and do not reappear above river surface.

Permeability: Essentially the same as at Chimney Rock dam site. That in bedrock is low; that in the alluvium is high.

Dam section: Almost any profile in the lower part of Bull River gorge from just below Gin Creek, S$\frac{1}{4}$ cor. sec. 26, T. 27 N., R. 33 W., down-valley to S$\frac{1}{4}$ corn. sec. 33, T. 27 N., R. 33 W., is a potential dam section. The Smoky Creek section has been designated because it embodies the prevailing geologic conditions, and because a section toward the mouth of the gorge makes possible a shorter tunnel section.

The Smoky Creek section, line E-E', Fig. 2, and Fig. 7, bears N. 49^{o} W., and almost parallel the strike of the beds, which dip upstream. Width of valley at elevation 2,365 is about 1,950 feet. Height of dam above river surface would be about 140 feet; height above foundation may be 350 feet.

Abutments: Both abutments at this site are in good sound rock and are equal in bearing power.

Foundation: This site appears to be adapted to a rigid type dam, and foundations should be carried to bedrock. With the exception of the probable presence of the fault in the river bed, conditions in the rock foundation are essentially as in the abutments. The beds dip upstream, the most favorable attitude for the prevention of sliding; permeability is low; their crushing strength high.

Appurtenant works: A dam of the overflow type might possibly be incorporated in the spillway system of Chimney Rock dam site.

Reservoir area: Leakage from the reservoir area will be negligible.

Construction materials: Same as for Chimney Rock dam site.

Conclusions and recommendations: There are no known geologic reasons why a dam at Smoky Creek site is not feasible.

The topography of the site should be mapped on the dam site scale, and following its completion, a geologic map and geophysical depth determinations should be made.

Government Mountain tunnel route

(Figs. 2, 8, and 9)

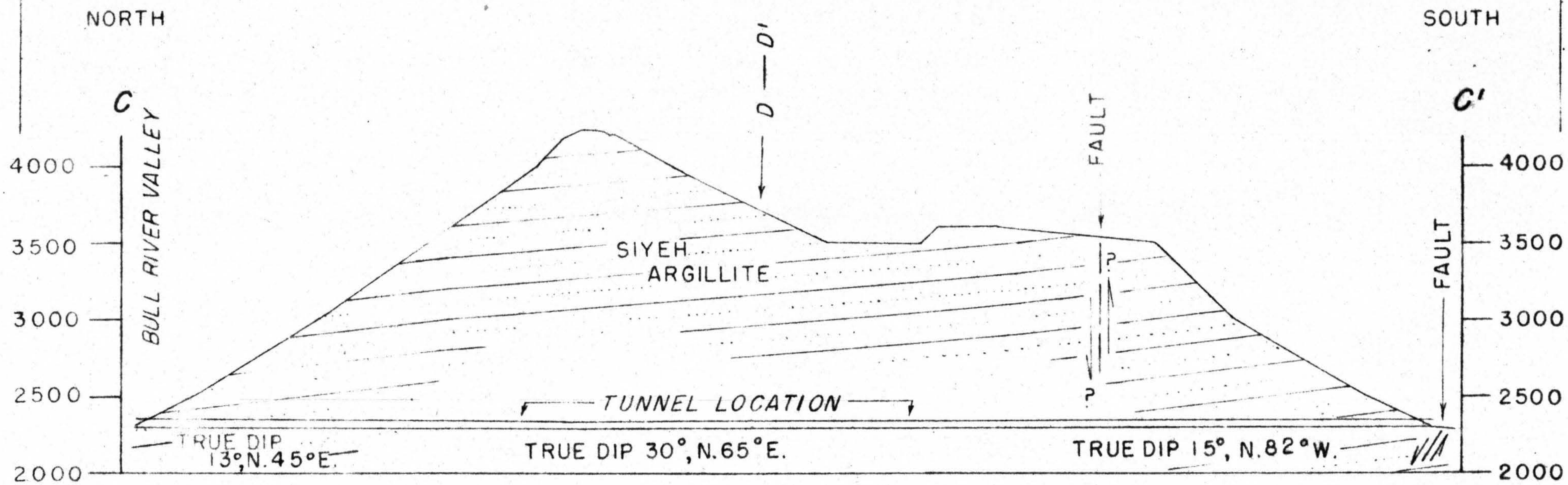
By

F. A. McMillin

Government Mountain tunnel is an accessory work to Chimney Rock dam site, and is necessary to carry water from the forebay of Chimney Rock dam to the forebay of Smoky Creek dam on Bull River. The tunnel will penetrate the west spur of Government Mountain, a 6,330-foot peak of Siyeh formation, whose summit stands in NE$\frac{1}{4}$ sec. 1, T. 26 N., R. 33 W., and from which the name is taken. Its length at the 2,300-foot contour will be about 8,400 feet (1.6 miles).

The bearing of the suggested axis is about N. 17° W. The south portal has been placed tentatively in a small gulch 1,600 feet south and 1,400 west of the northwest corner of sec. 11. A small fault strikes N. 30° E., dip 64° NW., through this gulch, but the portal probably can be placed west of the fault. The north portal will enter Bull River gorge approximately 600 feet north and 600 feet west of the southeast corner of sec. 33, T. 27 N., R. 33 W.

A geologic cross-section along the axis is shown in Fig. 8. The dip of the beds in the diagram is low because



GOVERNMENT MOUNTAIN TUNNEL PROFILE

Scale 1 : 12000

FIG. 8

F.A.M.

the bore will be almost parallel to the strike. True dip is shown in Fig. 9, which also shows the maximum amount of cover over the bore, about 1,500-1,600 feet.

Rock conditions are believed to be good, and the roof and walls should stand without support. The finished tunnel, however, should have a concrete lining. Minor water may be present where the cover is light, moving down dip on the bedding, or possibly in an occasional fault zone. One small fault, striking about N. 30° E., through a small gulch about 700 feet west of the right abutment of Chimney Rock dam site, should be encountered in the bore about 2,150 feet northwest of the south portal. Ventilation will be needed, but gas should not be encountered.

Naturally, the elevation and gradient of the tunnel, as well as the size of bore, or bores, if it is to be incorporated in spillway design, will be determined after analysis of the amount of water to be handled. Insofar as geologic conditions are concerned, construction of this tunnel should offer no difficulty.

The topography of the tunnel route should be mapped on a scale of about 1:24,000, in order that a detailed geologic survey may be made along the axis. Mapping should include the ground for half a mile either side of the tunnel.

BULL LAKE TRENCH

Bull Lake Trench

Bull River - Lake Creek divide

(Figs. 1 and 10)

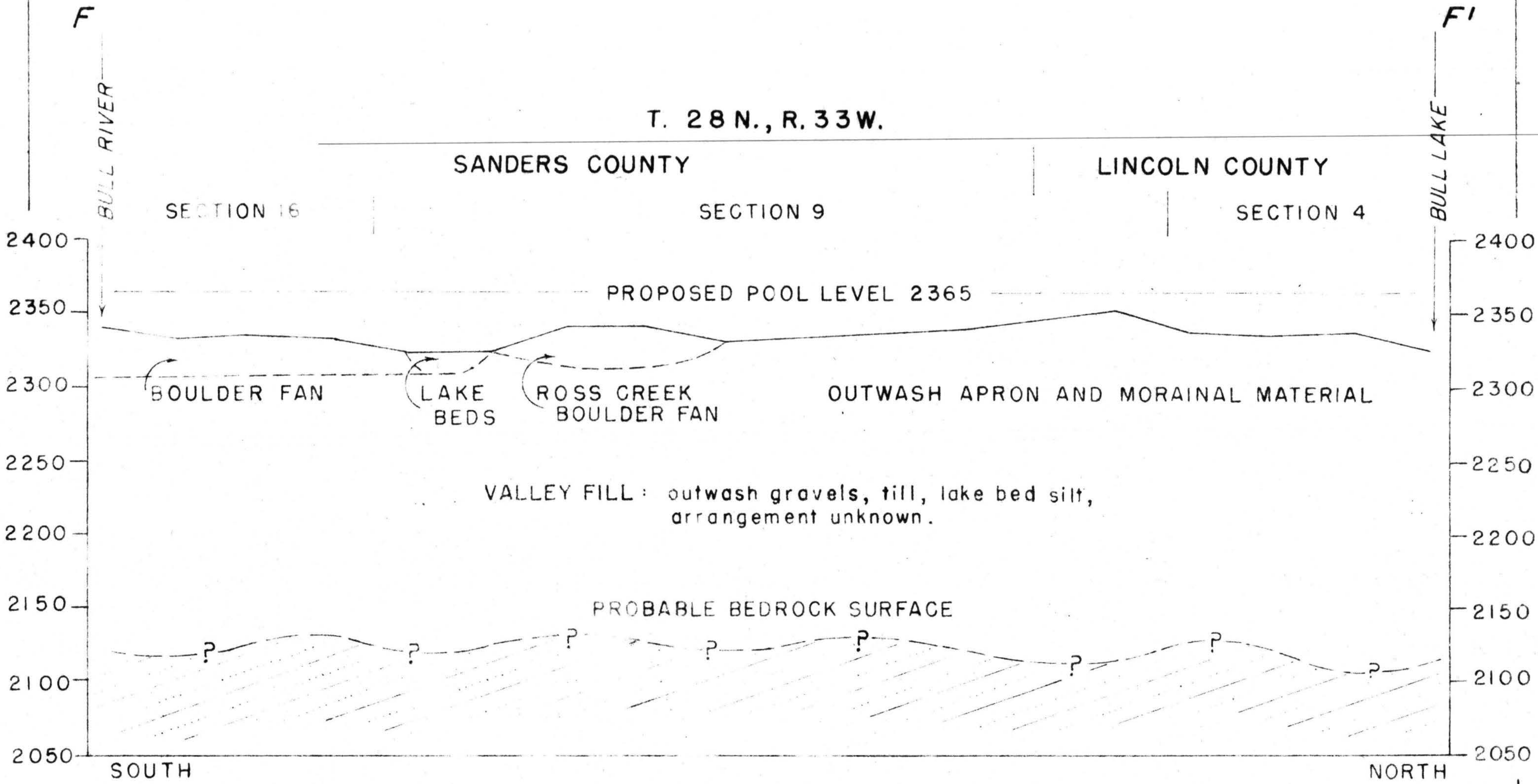
The scheme of the Clark Fork - Kootenai River project is to interchange water between reservoirs on these rivers through the transverse mountain valley called the Bull Lake Trench. This feature has been described briefly in the general section of this report; and the critical area is the Bull River-Lake Creek (Clark Fork-Kootenai) divide in sec. 9, T. 28 N., R. 33 W., about 18 miles up Bull River valley.

Present information is that the high point on this divide stands at altitude 2,350 feet, and the low point about altitude 2,327. This is a local relief of about 23 feet. Since the pool level of the project has been set tentatively at elevation 2,365, minimum depth of water over the divide would be only 15 feet, and maximum depth only about 38 feet. These conditions seriously restrict the draw-down of the reservoir, and prohibit interchange of water below altitude 2,326 or 2,327. Higher efficiency could be obtained, if a greater draw-down were possible. This could be obtained by dredging a canal across the divide.

The geologic problem is whether or not the character of the material through the Bull Lake trench would affect the cost of excavation to lower substantially the elevation at which water could be interchanged.

Time did not allow, and sufficiently large-scale base maps were not available, for a detailed study of the fill in the trench. The divide area was selected as offering the deepest and most difficult excavation problem. An interpretation of the character and arrangement of the fill is shown in Fig. 10. All of the shallow fill is believed to be unconsolidated, and much of it, such as the lake beds, is soft and saturated with water. The boulder fans present the most difficult material to handle, as individual boulders may be as large as 4 by 5 by 6 feet. Away from the divide, where the canal section should be straight, the boulder fans can be avoided by changes in the course of the canal, and the streams have already made this adjustment.

A canal with bottom at altitude 2,300 feet would have a length of about 14 miles. Through the divide, maximum depth of cut would be about 50 feet, but most of the excavation would be to depths of 25 feet or less. This should not be an expensive project. Probably deeper cuts can be made, with proportionate lengthening of the canal. However, shallower depth to bedrock may occur near the pre-glacial divide of



BULL LAKE TRENCH
BULL RIVER TO BULL LAKE PROFILE

Scale Vert. 1:1200
Hor. 1:12000

F.A.M.

FIG. 10

Bull River. This locality is believed to occur about 3 miles south of Bull Lake, near $W\frac{1}{4}$ cor. sec. 28, T. 28 N., R. 33 W.

An important factor in the determination of the depth and length of canal will be the altitude selected for the level of dead storage in the reservoir areas, and whether or not it is desirable to have interchange of water down to this elevation. Considerable economy in dam sections and improvement in feasibility, especially on Kootenai River, could be obtained by reduction of pool level to altitude 2,300 feet.

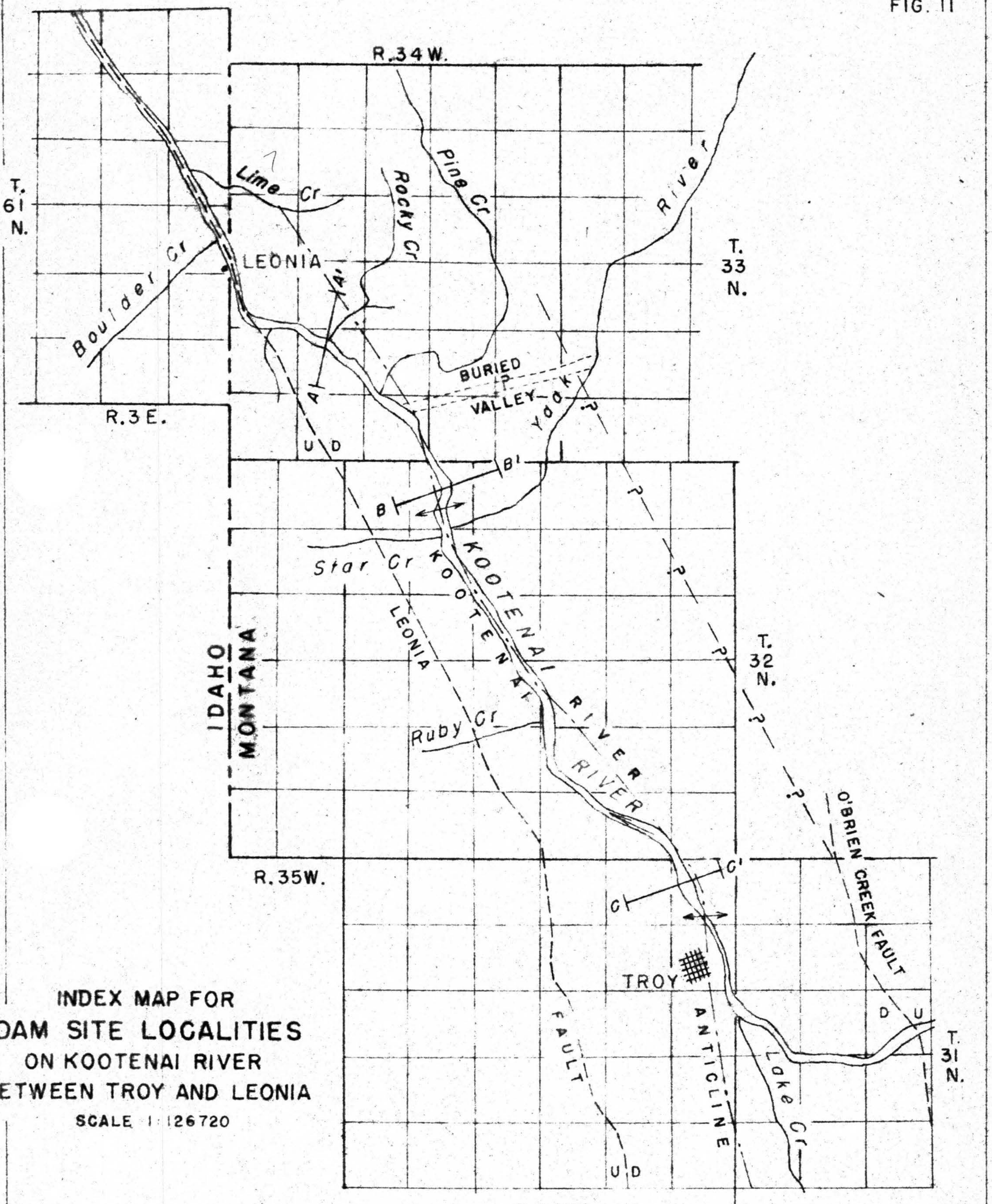
Operation of the Clark Fork - Kootenai plan, unquestionably, will result in more water moving from the Clark Fork to the Kootenai than in the reverse direction. This north-flowing current may be expected to wash large amounts of alluvium from the floor of the Lake Creek valley segment of Bull Lake trench into the trough of Kootenai River just above Troy, with consequent aggradation or silting of the downstream section of the Kootenai reservoir. The probability is that this deposition will not affect the operation of any dam on Kootenai River, but, if the Troy site were to be built, eventually there might be some overlap of the bottom-set beds on the upstream toe of the dam. In the course of time, equilibrium of channel gradient would be established and conditions would become more or less static.

Water moving into Clark Fork reservoir would aggrade the upper (north) end of Smoky Creek reservoir in Bull River valley and would have no effect on Chimney Rock dam.

More accurate large-scale surveys through the Bull Lake trench are essential for study of the geology of the canal route, and as a base for geophysical depth determinations in the divide areas south of Bull Lake. In view of the difficulty of the terrain, and that interpretation of the composition of the fill must usually be based upon recognition of land forms of indistinct relief, it is in order to suggest that the topography of Bull Lake trench be mapped by aerial photography on a scale of 1:12,000 with a 10-foot contour interval, as a preliminary to more detailed surveys by conventional methods. Horizontal and vertical control is available from the Libby Quadrangle, U. S. Geological Survey.

KOOTENAI RIVER

FIG. 11



INDEX MAP FOR
DAM SITE LOCALITIES
ON KOOTENAI RIVER
BETWEEN TROY AND LEONIA
SCALE 1:126720

Tunnel No. 8 dam site

(Restudied from the viewpoint of a high dam)

(Figs. 11 and 12)

<u>Location</u>: Tunnel No. 8 is situated on the left bank of Kootenai River in E½ NW¼ sec. 28, T. 33 N., R. 34 W., Lincoln County, Montana. The area occupied by the enlarged dam site includes the E½ SW¼ of sec. 28, and extends northward into the S½ sec. 21. From the viewpoint of a high dam, all of secs. 21 and 28 should be regarded as dam site area.

<u>Accessibility</u>: Tunnel No. 8 is about 1½ miles east of the Idaho-Montana boundary, and 2 miles upstream from Leonia, Idaho. The right abutment is crossed by U. S. Highway No. 2 at an altitude of about 2,240 feet. Numerous trails and logging roads turn-off from the highway into sec. 21, and the gorge section of the dam site is about ¼ mile south of the road. Easiest access to the lower part of the site is along the Great Northern Railway. The walk requires about 45 minutes. The upper part of the left abutment can be reached from the Star Creek road to Leonia and Bonners Ferry, but there are no convenient trails on the left bank. This road is of secondary character, and is hardly more than a truck trail. During the winter and spring, certain parts of it may be impassable for passenger automobiles.

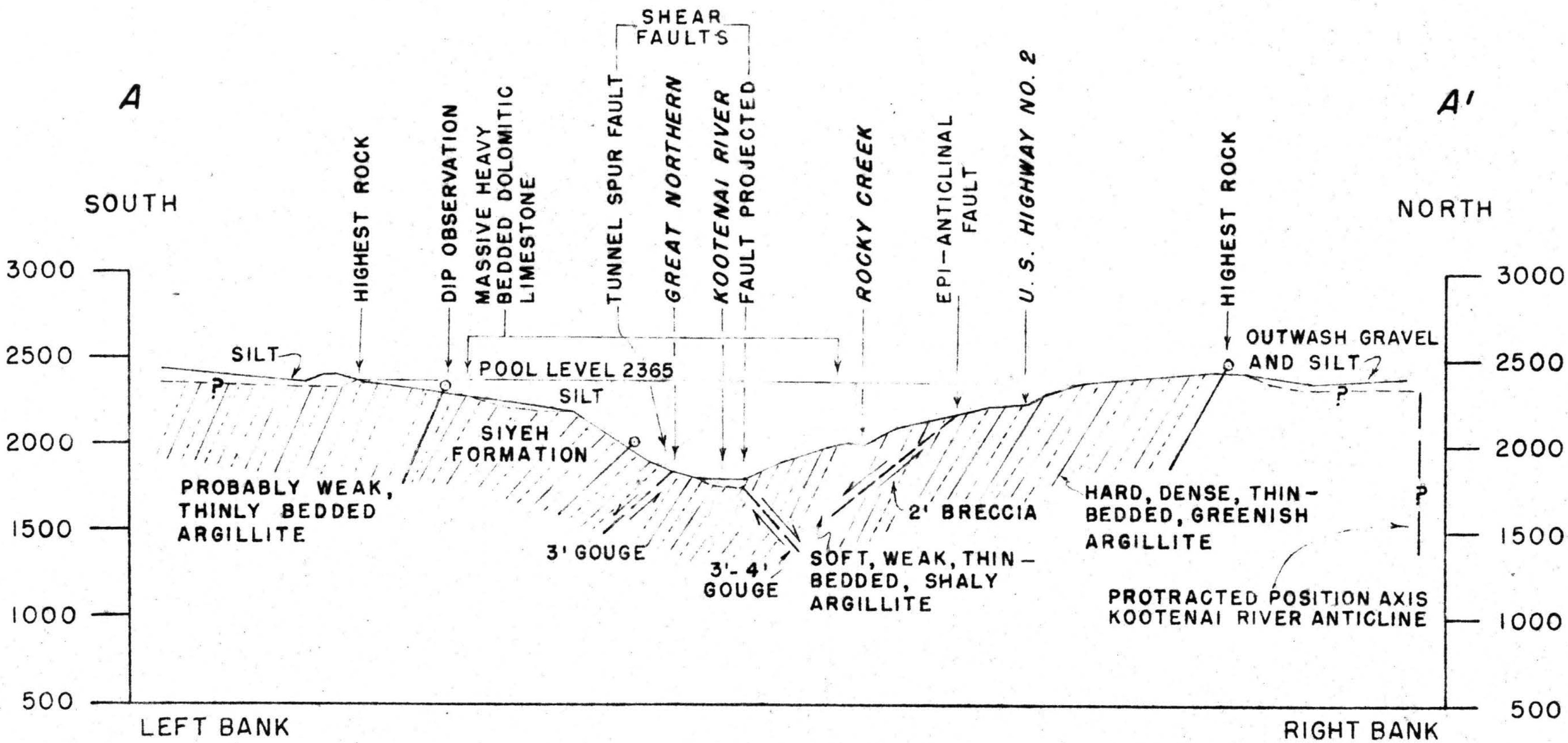
Previous work: This site was investigated by the writer from the river surface to elevation 2,200 in the Fall of 1934, and it has been reported on in U. S. Geol. Survey, Water Supply Paper 866-A. pp. 23-28. Although the topography of the inner gorge of Kootenai River is attractive for a dam site, Tunnel No. 8 site was looked upon unfavorably, largely because of the presence of a fault in the tunnel spur, and because it was excelled in strength and elevation by the alternative Katka site a few miles downstream in Idaho.

Present investigation: The present preliminary plan of the Clark Fork - Kootenai project has a controlling pool-level altitude of 2,365 feet. Since it is doubtful if this elevation can be obtained at the Katka site, and since the project demands a dam downriver from the north entrance to the Bull Lake Trench, it becomes necessary to re-examine Tunnel No. 8 site to determine if the requisite elevation can be secured there, and to use it as a standard of comparison for prospective alternative sites in the stretch of river upstream to Troy. Obviously, reappraisal cannot remove the existing geologic defects, but to some extent there is a tendency for their significance to diminish as the magnitude of the contemplated structure is enlarged. At the same time, however, if new difficulties are introduced, the sum total of their proportional effect may remain unchanged.

Purpose of dam: This site is the farthest downstream locality in Montana at which a dam could be incorporated in the Clark Fork - Kootenai project. Thus, its primary purpose would be storage and river regulation, with power development as a secondary function.

Stream gradient: The gradient through the dam site is about $3\frac{1}{2}$ feet to the mile.

Valley profile: The inner gorge of Kootenai River at Tunnel No. 8 has been described in Water Supply Paper 866-A, and a profile (Fig. 1-B) from river surface (1,817 feet) to altitude 2,200 feet is given on page 27 of that report. In the present study, topography was carried up to altitude 2,440 feet on the right bank, and to altitude 2,500 feet on the left bank. In order to secure the narrowest width of profile above altitude 2,300 feet the bearing of the new high profile (Fig. 11, this report) has been changed somewhat from that given in Fig. 1-B (W.S.P. 866-A). Hence, there is some variation in the character of the two profiles below elevation 2,200. The apparent bench at elevation 2,000 on the right bank in Fig. 12 results from the line of section paralleling a contour in the small re-entrant valley of Rocky Creek. Width of valley at elevation 2,200 in Fig. 1-B is about 1,480 feet, whereas in Fig. 12 it is about 2,300 feet.



RECONNAISSANCE GEOLOGIC CROSS SECTION

TUNNEL NO. 8 DAM SITE

SEC. 21 & 28, T. 33N., R. 34W.

LINCOLN COUNTY, MONTANA

Scale 1:12000

FIG. 12

Above altitude 2,200 valley width increases rapidly. This results from a broad terrace on either side between the elevations of 2,200 and 2,300 feet. From the rear of this terrace the ground rises gently on to the old, broad, high-level valley of Kootenai River. This feature is especially well developed on the right bank, where it extends back at elevations close to 2,400 feet for a mile or a mile and a half. Its surface is covered with fluvio-glacial outwash and glacial lake silt, and it rises gradually on to a constructional surface at altitude 2,500 that is also of considerable local extent.

At the critical elevation of 2,365 feet, width of valley is about 4,250 feet.

Apparent possible height of dam: From the work done thus far at this site, it appears that a dam could just be raised to the critical elevation of the project, 2,365 feet, but no higher; and further work is needed to determine this definitely. Rock was not observed in the left abutment above altitude 2,300 feet, but the topography indicates that it may be under shallow cover between 2,300 and 2,400 feet. On the right bank, rock has been observed as high as 2,420 feet, but there is a possibility that there may be a buried valley, with bedrock lower than 2,365, under the drift covered ridge northeast of Highway No. 2.

Character and depth of valley fill: Insofar as the inner gorge is concerned, the valley fill is essentially as described in W.S.P. 866-A. page 24. There is less fill in the valley bottom at Tunnel No. 8 than at the two alternative sites upstream.

The principal fill problem is on the upper parts of the right and left abutments. On the right abutment, depth to bedrock should be determined along the axis of the section northeast from the rock knob in south center sec. 21 for such a distance that the possibility of a buried valley cannot escape detection. If such a valley exists, it is likely to be broad and shallow, or to consist of an undulating series of strike ridges with small intervening valleys, rather than a single narrow deep valley.

On the left abutment, depth to bedrock should be determined between elevations 2,300 and 2,600 feet, or until there is assurance that its surface does not fall below elevation 2,365 feet.

Most of the high valley fill is of glacial origin - outwash or lake bed silt. Till is probably not present. The base of the fill is probably saturated with water, and the contact between the overburden and bedrock should show a sharp drop in resistivity. All of the material is unconsolidated, and its excavation should be easy. An occasional large ice-rafted, erratic boulder may be present.

Country rock: Bedrock at Tunnel No. 8 consists of the middle and upper parts of the Siyeh formation (Wallace formation of Idaho). About 150 feet of thin-bedded reddish-gray quartzite, with thin films of maroon argillite and mud-pellet conglomerate marking their bedding snfaces, crop out on the right bank of the river about 4,000 feet downstream from Tunnel No. 8, and mark the upper third of the Siyeh. If projected along their strike, they appear to intersect the axis of the proposed dam high on the left bank, near the southwest corner of sec. 28.

Immediately below these reddish quartzites are about 700 to 750 feet of dense, thin-bedded, gray to greenish-gray dolomitic argillites with minor layers of quartzite that are structurally weak. Excellent exposures of this horizon occur along the Great Northern Railway beginning about 1,400 feet northwest of Tunnel No. 8 and continuing downstream for about half a mile. The lower part of this zone, possibly the lower 200 feet, are softer than the upper part, somewhat shaly and more calcareous. Ripple and current markings are common, and the bedding surfaces are wavy and slightly irregular. These layers appear to be particularly weak. In part, this is the result of rather complete weathering of closely jointed thin-bedded rock, and no doubt they are stronger where fresh. All of these beds project into the upper part of the left abutment, where they are concealed by a cover of silt. In section A-A' they occur at the extreme southwest end of the diagram.

Next underlying is a thick zone of about 2,000 feet of dull gray rock that consists of dense, massive, heavy bedded, finely laminated, dolomitic limestone. Lentils of dolomite predominate and interfinger with limestone or calcareous argillite. Individual layers may be 4 or 5 feet thick, and sometimes their surfaces are ripple-marked. Some beds show secondary "gnarly" masses of light-gray limestone apparently mechanically mixed with the darker, buff-to brown-weathering dolomite. Some sericite is present, and pyrite may be an accessory mineral. At intervals among these thick layers are groups of platy, thin-bedded (2 inches to 1-foot) bluish-gray argillaceous limestones. This type of rock was described in more detail in W.S.P. 866-A. page 24.

Below this heavy-bedded zone, there is about 250 feet of very finely laminated, light-gray, thin-bedded (¼-inch to 1-inch), soft, shaly, sericitic, calcareous argillite, with minor accessory pyrite. Originally this rock must have been a calcareous shale, with occasional layers of mud-pellet conglomerate. Bedding is slightly irregular. Weathered surfaces are littered with thin chips and splinters. Dips in this horizon are consistently low due to the tendency of the thin layers to creep valleyward. The top of this zone is exposed in a railway cut about 1,700 feet upstream from the south portal of Tunnel No. 8, and the width in diagonal section along the track is about 400 feet. It crosses the river just upstream from the axis described in W.S.P. 866-A, and has been eroded into a rather deep re-entrant on the right bank at the mouth of Rocky Creek. The structurally weak position of this zone in the left bank of the valley, and the lack of strength and incompetency of the soft, thin beds was responsible last February for a small landslide onto the track of the Great Northern Railway. The presence of this zone in a dam foundation is a definite element of weakness as it lacks bearing power, is crushed and squeezed between heavier, more competent members, and is probably highly permeable. An effort has been made to emphasize its presence in section A-A', Fig. 12.

Below this shaly zone there are some 850 feet of beds within the area examined that are also included within the Siyeh. For the most part they consist of hard, massive, fine-grained, non-calcareous argillite in beds 4 inches to 3 feet thick. Color is predominantly a dull gray-green, and closer inspection shows a fine interlamination of gray-green and dark-gray rock. Mud cracks and ripple marks are common features on the slightly irregular bedding surfaces. These beds are well exposed in a new cut on U. S. Highway No. 2 in

$S\frac{1}{2}$ $SW\frac{1}{4}SE\frac{1}{4}$ sec. 21, near where they form the upper right abutment of the dam site.

The total thickness of these estimated sections is about 4,000 feet.

<u>Dip of rocks</u>: Tunnel No. 8 dam site is on the southwest limb of the Kootenai River anticline, and all of the rocks dip to the southwest at comparatively high angles. The amount of dip varies from 65 to 77 degrees, with an average of about 71 degrees. Occasionally in the thin-bedded zones dips as low as 43 degrees were found, but these are believed due to slump or creep and are not included in the above average. Strike varies from N. 08° W. to N. 36° W., with an average direction of N. 26½° W. At Tunnel No. 8 this direction is across river, but both above and below the dam site the river parallels the strike for long distances.

<u>Joints</u>: Jointing in the rock in the tunnel has been described in W.S.P. 866-A, page 25. Jointing is conspicuous in the argillites exposed in the new road cut in the $SE\frac{1}{4}$ sec. 21. The two most prominent or master sets are as follows:

Strike N. 40° E. Dip 30° SE. Surfaces are smooth and clean, and have an average spacing of about 18 inches.

Strike N. 65° E. Dip 70° SE. Surfaces smooth, but wavy, with an average spacing of about 3 feet. They cut the bedding at right angles, and show evidences of fluid movement.

Jointing is a very important structural element in these thin-bedded rocks, and contributes to their structural weakness as well as to their permeability.

<u>Folds</u>; The Kootenai River anticline can be traced down river from Troy through the Star Creek site near the mouth of Yaak River. Projecting the axis to the northwest, it strikes into the right bank of the river and is believed to intersect the dam section at Tunnel No. 8 just north of the center of section 21. Hence, although this area is covered by glacial outwash and silt, there is some reason for predicting that the rocks at the north end of the dam site might show a northeast dip. Due to the presence of the epi-anticlinal faults, whose northwest side has moved relatively to the northeast, it is difficult to make an accurate projection of the anticlinal axis, for over a distance of several miles the cumulative shift may amount to a good many feet.

Inasmuch as this fold is exposed more fully at the Troy and Star Creek sites, no further description will be given here.

Faults: Several faults have been observed at this site. A bedding fault was observed on the fresh exposures in the road cut in SE$\frac{1}{4}$ sec. 21. Considering the altitude of the beds, such features are uncommon, or it may be that they cannot be observed except on fresh exposures. This particular fault has about 2-inches of blue clay gouge. It is impossible to estimate the amount of movement that has taken place, but it is obvious that the beds are not in their true stratigraphic position.

Another good example of the epi-anticlinal faults is exposed near the northwest end of this road cut. It strikes N. 70° E., and dips 44° NW. The crush zone is 1$\frac{1}{2}$ to 2 feet thick and is predominantly a breccia rather than clayey gouge. What clay there is occurs on the upper side of the breccia, and fracture cleavage within it indicates that the northwest side of the fault has moved down. There is very little change in altitude of the beds on either side of the fault. Such a zone would appear to be highly permeable under a high head of water.

The Tunnel spur fault, described in W.S.P. 866-A, is believed to be a shear joint related to stress activating the Leonia fault, and it is thought that it makes a mechanical couple with another shearing fault that is exposed on the right bank of the river near the SE corner of sec. 20.

This latter fault has been projected into the dam section A-A', in order to show their probable relationships. The Tunnel spur fault strikes west and dips 43° south at the only place where it can be observed, but more complete exposures might show that its general trend was approximately parallel to the strike of the beds, about N. 26° W. The thickness of the gouge at the tunnel is about 3 feet.

The fault in the SE corner of sec. 20 strikes S. 56° E., and dips 52° NE. The beds on either side show little change in attitude. The gouge zone is about 4 feet thick and consists of blue clay, weathering to a limonite brown. Just above the fault, the beds in the hanging wall show some alteration to chlorite.

Exposures are too incomplete to determine if these are the only faults present, but it seems probable that in a site of this size there would be many more. If each has a gouge zone of equivalent thickness, a considerable element of weakness is introduced.

The Leonia fault, the master fault of the region, passes near the south end of the left abutment, but its exact position is indeterminate because of a cover of silt. The fault can be traced out of the bed of Kootenai River to a point in the valley of a small creek about 1,000 feet south of the N¼ corner sec. 29. At this place the fault can be localized to within about 200 feet. The beds in the Siyeh on the northeast side of the fault strike S. 46° E., and dip 60° SW.; those in the Pritchard quartzite on the southwest side strike S. 50° E., and dip 60° NE. Protraction of the average strike to the southeast carries the fault into the prospective dam section approximately 2,700 feet S. 13° W. of Tunnel No. 8. This position is only 1,000 feet SW of the highest rock exposure in the left abutment at elevation 2,365, and, if the bedrock surface does not rise to the southwest, it is conceivable that the fault might become involved in the foundation of a cutoff wall or spillway.

Another method of determining the approximate position of the fault gives a more favorable picture in that it appears to pass a greater distance south of the left abutment. This method is simply to make a straight line interpolation between the position of the fault in the creek in the north part of sec. 29 and the most northwesterly point to which it was traced by Gibson in the Libby quadrangle, N$\frac{1}{4}$ cor. sec. 33, T. 32 N., R. 34 W. The distance through which it is concealed is approximately 8 miles. However, enough of its course is known to the northwest and southeast to give good control, and its position, as determined by this means, is probably more accurate than that based on the protraction of only a single local strike observation. This place is about 5,600 feet SW of Tunnel No. 8, or about 3,700 feet southwest of the point of high rock in the left abutment. Here, presumably, the fault would not affect the contemplated works.

I recommend, however, that some effort be made to determine the exact position of this fault. It would be helpful to know if it can be observed where it crosses Ruby Creek and Star Creek, and further details on the dam axis could be added by resistivity traverses with equi-electrode spacing.

<u>Ground-water conditions</u>: The general attitude of the strata favors the quick return of ground-water to the river. This return is so efficient that there appears to be no concentration of flow into springs, although elsewhere they have been observed issuing from the base of the alluvial or glacial cover. Rocky Creek (called McCormick Creek in W.S.P. 866-A) is a small perennial stream that drains all of section 21. A rather large deposit of calcareous tufa has been built up near the mouth of the creek, which suggests that it is spring fed. These tufa beds conceal the thin-bedded shaly argillite in the lower part of the right abutment.

Construction of a high dam on this axis would divide the lower drainage area of this creek. The east fork, which is the main stream, would contribute to the reservoir area. However, the small tributary in the strike valley in SW$\frac{1}{4}$ sec. 21 would be dammed. After its pool level had raised to elevation 2,200 or 2,230 probably it would reverse its flow and return to the river through Lime Creek, SE$\frac{1}{4}$NW$\frac{1}{4}$ sec. 15, T. 61 N., R. 3 E., Idaho.

Permeability: Conditions favoring permeability are more acute for a high dam than for a low. This is because the innumerable bedding surfaces are generally parallel to the direction of stream flow. The weak thin-bedded shaly argillite in the right abutment may have a higher permeability than the more resistant members of the formation, and there may also be contributions to permeability through the fault zones, especially where brecciated. The coefficient of permeability for the Siyeh formation as a whole is difficult to estimate as it may range from $6x10^{-8}$, or less to $10x10^{-7}$, or more. Probably the higher value would prevail at this site.

Dam section: The topography of the dam site is such that only one economical section is available for a high dam. In order to obtain the shortest crest length at 2,365, favorable sections for lower dams have to be ignored. The matter, however, is largely one of orientation of the axis. That selected, A-A'., Figs. 11 and Fig. 12, strikes about N. 13° E. through a point about 225 feet west of the N¼ corner sec. 28, T. 33 N., R. 34 W., Lincoln County, Montana. This axis is diagonal to that shown in W.S.P. 866-A. Fig. 1-B. South of the river it passes about 100 feet west of the west portal of Tunnel No. 8, and then passes up the west flank of the tunnel spur. North of the river it passes east of the low dam axis. A line taking in favorable topography at both low and high elevations would be sinuous, but the cross-sectional area below it would be smaller.

Abutments: In view of the lack of bottom land along this stretch of river, most of the features portrayed in section A-A' can be described in terms of the abutments or banks rather than the foundation.

The right abutment is about 2,000 feet wide, and consists of a cliffy and terraced slope rising from mean water level to pool level at altitude 2,365. In plan view this abutment area is somewhat irregular, consisting of a lower spur, the intermediate re-entrant valley at the mouth of Rocky Creek, and a high, irregularly lobate spur that makes the divide between Lime Creek and Rocky Creek. It is well shown on the Corps of Engineers multiplex map of Kootenai River. The entire slope is under the control of the bedding, which dips riverward at an average inclination of 71°. Owing to this high dip there appears to be small possibility of sliding into the river along the bedding. Although comparatively thin-bedded, most of the rock is strong, durable, and insoluble, and capable of supporting any type of structure that may be placed upon it. There is, however, a zone of 250-300 feet of soft, finely-bedded, shaly calcareous argillite in the lower part of the abutment, 400 or 500 feet northeast of the river that is evidently geologically weak or incompetent, and it must also be regarded as of low strength in an engineering sense. These beds underlie a strike valley, tributary to Rocky Creek on its right bank near its mouth, that trends northwest into the right bank of Kootenai River in SW$\frac{1}{4}$ sec. 21, and it may be deeper than indicated. Siting a rigid narrow-base dam on this zone might be attended with difficulty, but where it is confined by the more resistant beds above and below it probably has sufficient strength to support a flexible broad-base dam with ease. Heavy loading might cause some flowage of the material along the strike into the open valley, or the comparatively thin spur of hard rock that supports it on the river side might shear. The presence of this zone is the most serious rock defect at the dam site.

Two lesser elements of weakness are the faults, one projected into the section at the base of the right abutment, the other near the top, and no doubt there are others that were not seen. Their gouge zones are from 2 to 4 feet thick. The effectiveness of the lower fault as a potential "slip" is mitigated by its attitude, but the upper fault is dynamically situated to contribute to a slide. This particular fault, however, probably will not slide since the deeper part is under a heavy supporting load.

The left abutment is more massive in plan, especially above elevation 2,240, the summit of the tunnel spur. This feature is a strike ridge of fairly massive rock that causes the constriction or bend in the river and continues on into the lower spur of the right abutment. This is considered good evidence of the structural continuity of the Siyeh formation, and illustrates the comparatively minor character of the shear faults - that is their effect probably is not great. All of the beds in the left abutment dip into the left bank of the river, which contributes much to its strength. The observed fault dips in this direction also. Along the axis of the tunnel spur there are a few sub-normal dips that result from creep toward the river, but there is no evidence of large scale sliding. A short distance upstream, however, the weak shaly calcareous argillite strikes into the left bank, and some slides have taken place where it is unsupported on the riverward side.

All things considered, the bearing power of the abutments is essentially the same, but the left is considered somewhat the stronger because of the southwest dip of the rocks and the presence of only one fault. As explained in a preceding section, it is believed that the Leonia fault is not involved in this prospective dam section.

Foundation: If the foundation of this site be defined as that part of the section underlying the bed of Kootenai River, it is evident that its length and area is negligible as compared with that of the abutments.

The foundation is in a block bounded by the shear faults, which are believed to be inactive. The beds dip steeply to the southwest, and their attitude is good security against sliding. Most of the rock is thin-bedded platy dolomitic limestone. However, the upstream face of a dam on this axis would come very near, or possibly overlap the soft, weak zone of shaly calcareous argillite, which crosses the middle of the river only 200 or 300 feet upstream from the dam section. Foundation conditions may thus be difficult over a comparatively small area.

Depth to foundation probably is not great, probably not more than 50 or 60 feet. Foundation excavation is at a minimum at this site. This part of the river valley has never been glaciated, and the fill is believed to consist chiefly of stream gravel.

<u>Height and length of possible dam</u>: At the proposed flow line elevations of 2,365 crest length for a high dam at the Tunnel No. 8 site is about 4,250 feet. This appears to be the narrowest width of Kootenai River Valley at this elevation in the stretch between the Idaho-Montana line and the town of Troy. Cross-sectional area of the open-valley below this elevation is about 1,060,000 square feet, also a minimum. Maximum height of dam above mean water surface would be about 548 feet, the highest at the three Kootenai River sites under investigation, because of its farthest downstream location.

It should be noted, however, that this site just does attain the critical elevation of 2,365 feet, and, unless bedrock continues undercover to rise away from the river in each abutment, extensive dikes may be required on either side to prevent escape of water around the end of the dam.

Appurtenant works: The principal accessory works for the Tunnel No. 8 site will include a spillway section, tunnels for river diversion, a powerhouse site, and possibly dikes.

The spillway requirement for any Kootenai River site is large, without additional discharge from Clark Fork River. However, there appears to be an adequate section for any requirement high on the left abutment, discharging into the small unnamed creek that empties into Kootenai River near $N\frac{1}{4}$ corner sec. 29 (Mile 13) over a distance of about 0.75 mile. This water would re-enter the river about a mile downstream from the suggested axis. A longer, less attractive alternative section probably could be found over the right abutment, eventually discharging into Kootenai River in Idaho through Lime Creek. This route would require a fairly deep cut 0.75 mile long through the 2,400-foot ridge in the north-central part of sec. 21, and then possibly a 2.5 mile canal.

Final location of the tunnel section may require some rock exploration. On the right bank a short route might utilize the embayment at the mouth of Rocky Creek, and then strike west through the hard rock ridge between the zone of weak calcareous argillite and the river. If the shear fault dipping northeast were to be penetrated, the angle of intersection would be large and the footage of difficult excavation reduced to a minimum. Siting a tunnel on the left bank also might be possible, but perhaps it would have to be a little longer. If it were started a few hundred feet upstream from the east portal of the tunnel, the tunnel spur fault could be avoided.

Location of a powerhouse site on rock should offer no difficulty.

Reference to the possibility of dikes has been made in the section on height of dam. Present information is insufficient to determine whether or not they will be required, and their length and height.

Reservoir conditions: The reservoir area of a high dam has been examined in a general way only from the viewpoint of the possibility of leakage.

There appears to be no possibility of low-level seepage around either abutment. There are possibilities, however, that high-level seepage may occur over or around bedrock in either divide if it levels off at elevation 2,365 or drops somewhat below this altitude. These contingencies are not believed to be serious, although the extent of the conditions cannot be determined from surface geology. These are the areas where it has been suggested that dikes may be needed.

Materials for construction: Rock occurs in abundance at Tunnel No. 8 dam site. Test pitting will have to be done to determine if the high-level glacial outwash can be washed for sand. Limited amounts of gravel are immediately available only in the river bed. Timber is abundant locally, although the best stands have been logged off. Electric power will have to be conveyed in from Troy.

Conclusions and recommendations: Tunnel No. 8 dam site appears just to satisfy the height requirement for the high Kootenai River dam of the Clark Fork - Kootenai River project. Width of valley, or length of crest is about 4,250 feet at the proposed flow line elevation of 2,365 feet. This distance appears to be the narrowest width of Kootenai River Valley at this elevation between Leonia, Idaho, on the State line, and Troy, Montana. Additional elevation cannot be obtained without an undue increase in length of crest; and dikes may be required over each abutment to sustain the crestelevation. Cross-sectional area of the open valley below elevation 2,365 is about 1,060,000 square feet. This is also a minimum for the valley. Foundation excavation will be very small in comparison with the size of the site, but some excavation of overburden will be required above elevation 2,200 feet on each abutment, especially if dikes prove necessary. Height of dam above river surface will be 550 feet, and height above foundation will be at least 600 feet.

The rock formation at this site is roughly the middle part of the Siyeh formation, which consists chiefly of argillite, dolomitic argillaceous limestone, and minor quartzite. With the exception of a zone of weak rock in the lower part of the right abutment and the upstream part of the foundation, bedrock is strong, durable, and insoluble, and fully capable of supporting any type of dam that may be selected.

Bearing power of the abutments is essentially equal, but the left probably is somewhat the better of the two because of the inward dip of the rock and the stronger character of the rock throughout.

Structural conditions are comparatively simple. The site is situated on the west flank of the Kootenai River anticline, whose axis is believed to lie about 4,300 feet northeast of the river. Average strike is N. 26° W.; and dip averages 71° southwest. Several small faults were noted, one at the base of the left abutment, and two in the right abutment. Others probably are present, but are concealed. While they may be regarded as flaws in the rock, they do not endanger the security of the site as a whole. The master fault of the region, the Leonia fault, is believed to lie south of the left abutment, and does not directly endanger the site.

An adequate spillway can be routed high over the left abutment, to discharge into the small un-named creek in sec. 29. The spillway might cross the Leonia fault.

Possibilities for leakage from the reservoir are negligible except near the critical elevation of 2,365 feet.

Geophysical work should be carried out on the upper part of both abutments to determine depth of overburden, and whether or not dikes are necessary.

Star Creek dam site

(Figs. 11 & 13)

<u>Location</u>: Star Creek dam site is situated on Kootenai River at Mile 17.1 in section 5, T. 32 N., R. 34 W., Lincoln County, Montana. The selected axis crosses the river about 0.5 mile below the mouth of Yaak River, which enters Kootenai River from the east, and about 0.7 mile below the mouth of Star Creek, tributary to the Kootenai from the west. The name Star Creek has been used advisedly in order not to preoccupy the name of Yaak River.

<u>Accessibility</u>: The right bank of the Star Creek site is traversed by both the new low-level route of U. S. Highway No. 2 and the old abandoned high-level grade of the same road. The left bank is accessible by car to Yakt siding, and then a 2.0 mile walk down the track of the Great Northern Railway. The Troy-Leonia road crosses Star Creek southeast of the site, and the upper part of the left abutment is poorly accessible by abandoned logging trails from this road.

<u>Purpose of site</u>: This site is an alternative to the Tunnel No. 8 and Troy sites at Mile 14 and Mile 25, respectively. The purpose of the dam would be chiefly storage and river regulation, with power development secondary.

<u>Stream gradient</u>: Below Mile 17.1 the gradient of the river surface is about 5 feet per mile; upstream it is about 4 feet per mile. The difference may be accounted for by aggradation or fan-building at the mouths of Star Creek and Yaak River.

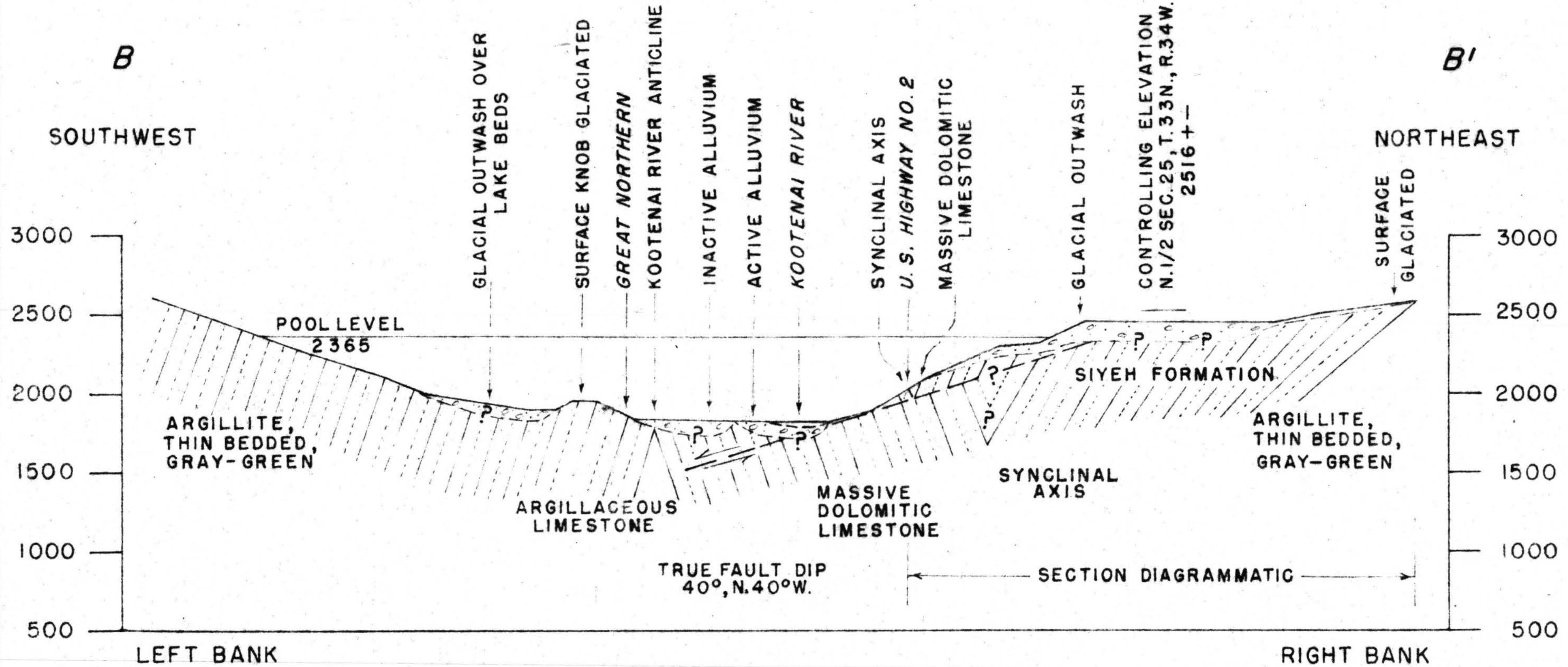
<u>Valley profile</u>: This section of Kootenai River Valley has a broad shallow profile characterized by a series of terraces on either bank. This part of the valley has also been glaciated, but the effects are not severe - that is, obstructions within the valley were overridden rather than removed. Evidently the ice load was light, and consisted of a downstream diversion of a part of the Yaak River glacier. A good deal of the mass of this glacier passed through the Tepee Springs saddle, N$\frac{1}{2}$ sec. 25, T. 33 N., R. 34 W., north of the dam site, and moraines and pot hole topography occur in SE$\frac{1}{4}$ sec. 27 and NW$\frac{1}{4}$ sec. 35. No effect of low level valley glaciation has been observed on Kootenai River downstream from the mouth of Pine Creek.

The terraces at Star Creek dam site are developed on both sides of the river, and across-valley correlations appear possible for some of them. Those on the left bank, just below the mouth of Star Creek are cut chiefly on rock, whereas those on the right bank, just below the mouth of Yaak River, are constructional. It seems probable that the rock-cut terraces are older than the constructional terraces, and some of the higher benches may date from late Tertiary or early Pleistocene. The constructional terraces, however, are all probably of late glacial age.

The following sequences have been observed:

Left bank		Right bank	
Altitude	Kind	Altitude	Kind
2,720-40	Rock	2,740	Constructional
		2,580	Constructional(minor)
		2,475-2,500	Constructional
2,450	Rock		
		2,300	Constructional
2,250	Rock	2,250	Constructional
2,150	Rock		
2,000-1,980	Constructional; rock.		
1,840	Present flood plain.		
1,830	River surface.		

Only those from elevation 2,500 to river level are shown on Fig. 13, and the scale of the topography is inadequate to portray most of the narrow rock cut benches. The highest level of filling is marked by glacial outwash on the right bank at



RECONNAISSANCE GEOLOGIC CROSS SECTION

STAR CREEK DAM SITE

SEC. 4 & 5, T. 32 N., R. 34 W.
LINCOLN COUNTY, MONTANA

Scale 1:12000

FIG. 13

elevations of 2,740 to 2,800 feet. There may be considerable valley till at this level in the form of reshaped lateral moraines. On the bare rock hill in SE$\frac{1}{4}$NW$\frac{1}{4}$ sec. 36, T. 33 N., R. 34 W., there is some evidence of drift and glaciation as high as altitude 3,150-3,200 feet. The level of fill at altitude 2,500 is of regional extent, and is thought to mark the 2,500-foot stage of the waning glacial Lake Missoula - a late Pleistocene event. This terrace is well-developed on the right abutment of Star Creek dam site, and is a rather critical feature, as it may cause considerable extension of length of crest. The 2,500-foot terrace also marks the approximate level of fill in the Tepee Springs saddle, and there may block an early or preglacial channel of Yaak River into Kootenai River. The 2,300-foot terrace is also probably related to that level of Lake Missoula, and is extensively developed along Kootenai River. Because of its comparatively low altitude it is restricted to the inner valley of the river, or occurs just above it, and is thus rather narrow. The other constructional terraces, such as those at 2,250, 1,980-2,000, are also late glacial features; but the alluvial plain at 1,840 is post-glacial. The wealth of terrace detail, and the character and arrangement of some of the deposits make the Star Creek area a valuable locality in which to study the late-Wisconsin history of Kootenai River Valley.

Apparent possible height of dam: Insofar as topography alone is concerned there appears to be sufficient elevation in the valley walls to carry a dam section up to an elevation of about 2,700 feet. However, the controlling elevation for this site is in the Tepee Springs saddle, N$\frac{1}{2}$ sec. 25, T. 33 N., R. 34 W., and is about 2,516 feet. More detailed surveys will have to be run to determine the precise elevation. This saddle is a fluvio-glacial fill occupying a broad valley between the southeast spur of Tepee Mountain and the 3,200-foot rock hill in sec. 36, T. 33 N., R. 34 W. Star Creek dam site thus has about 150 feet of excess elevation over the critical level of 2,365 feet of the Clark Fork - Kootenai River project.

Character and depth of valley fill: The greater part of the fill in Kootenai River Valley at Star Creek dam site is high on the right abutment. All of it at these levels consists of fluvio-glacial outwash - a till or boulder clay that has been rehandled by water and most of the clay-size material washed out. The thickness of this deposit is unknown, but it may be as much as 200 feet near the rear of the terrace. On the otherhand, on the opposite bank there is a rock-cut bench at altitude 2,450, and if its counterpart is present on the right bank, the overburden supporting the 2,500-foot terrace may only be 25 to 100 feet thick. This is a matter for geophysical determination.

Minor amounts of fill occur on the left bank 1,500 to 2,200 feet southwest of the river, and between elevations 1,900 and 2,000. The upper part of this deposit consists of boulder gravels, and is underlain by lake beds. The following section is typical, and was measured in a cut for the Great Northern Railway in sec. 5, 2,000 feet north (downstream) from the mouth of Star Creek.

Description	Thickness (Feet)
Top of bank.	
Gravels, cobbles and pebbles in a matrix of unconsolidated sand. Material has been rehandled by a powerful stream. An occasional thin lentil of sand.	20
Sand, medium-grained, soft, unconsolidated.	2
Gravels, boulder, in matrix of unconsolidated sand. Boulders consist of well-rounded, fresh argillite, metadiorite, and other Beltian rocks. Unusually heavy concentration of boulders at base, comparatively free from sand. This bed rests upon a bevelled silt surface that dips northwest. The form of the deposit suggests that it might be a fan glomerate issuing from Star Creek valley; but the character of the boulders is fluviatile - their source is not local and they are more rounded than present day Star Creek gravels.	15
Glacial lake beds. Fine-grained sand and silt. Micaceous. Buff in color.	35+
Track level.	
	72

There is good evidence that the valley was relatively open and occupied by a ponded lake when deposition of the silt began. The silt deposit built up at least to elevation 2,100, and possibly higher, more than 200 feet above the top of the silt in the above section. With the cutting down of the ice barrier, much of the silt must have been washed out by the released water, but some bodies have been preserved by being overlapped by resistant gravels. The thickness of the silt beneath the gravels is unknown, but it could easily be 75 or 100 feet. With the exception of the gravels, the silt is easily excavated.

Valley bottom at Star Creek dam site is occupied by a broad bench of inactive alluvium on the left bank. This material probably consists chiefly of sand and gravel, and may be part of a rather broad alluvial fan or delta at the mouth of Yaak River that is constantly being attacked and reworked by Kootenai River. Hence, below the silt surface most of it is believed to be a boulder bar similar to that on the right bank of the Yaak at its mouth. There has been some ice scour in the valley here, and it is difficult to make an accurate prediction of the depth of the fill. Some parts of it are certainly 50 feet deep, and there may be gorges on either side of the mid-valley rock ridge that are 100 feet or more in depth.

All things considered, the amount of fill in the valley bottom at this site is not formidable, and depth to foundation is not great. The outwash material in the 2,500-foot terrace on the right bank is so situated as to be excavated easily.

Country rock: Bedrock at Star Creek dam site belongs to the Siyeh formation, probably the middle part. The oldest rock crops out near the middle of the valley on the crest of the Kootenai River anticline. The buried hill, 200 feet southwest of the river, crops out a few hundred feet southeast of the section and consists of dark-gray, heavy-bedded, massive layers of finely laminated dolomitic limestone. These beds extend northeast to the right bank of the river. The rock in the 1,950-foot hill, 1,200 feet southwest of the river, is thin-bedded (2 in. to 12 in.), finely laminated, dense, gray-green calcareous argillite (called argillaceous limestone in Fig. 13 for sake of brevity). The bedding surfaces are distinct, but somewhat irregular and show mud-cracks, ripple marks, and other markings. The laminae are brought out by weathering, there being an alternation of buff (dolomite) and greenish rock. The massive dark-gray limestones that crop out in the river bed probably are present in the middle part of the left abutment, but the upper part (above altitude 2,400) consists of thin-bedded finely laminated gray-green argillite. On the right bank, cuts along U. S. Highway No. 2 expose layers of massive, dark-gray, finely-laminated, dolomitic argillite. The upper part of this consists of thin-bedded gray-green argillite, with mud cracks and associated markings on the bedding surfaces.

On the whole, the rock at this site is more homogeneous than at Tunnel No. 8 or Troy dam sites. All of it is strong and insoluble and fully capable of supporting any type of structure that may be placed upon it.

Geologic structure: Structural conditions are somewhat more complicated at Star Creek dam site than at the alternative upstream and downstream sites. In general, the river is situated on the crest of the Kootenai River anticline, a highly compressed isoclinal fold. In addition, however, there is a sharply compressed minor syncline, with parallel strike, about 1,500 feet northeast of the anticlinal axis. Northeast of this syncline, over a distance of about 5 miles, the beds dip uniformly to the southwest. A further complication is added by the presence of an epi-anticlinal fault that offsets the synclinal axis about 500 feet. These conditions are shown diagrammatically in Fig. 13.

Dips: On the southwest flank of Kootenai River anticline the strike of the beds varies from N. 26° W. to N. 46° W., and the amount of dip varies from 57° to 78° southwest. Average conditions are about: strike N. 30° W., dip 71° SW.

On the northeast flank of the anticline, above the fault (or in its hanging wall), average conditions approximate: strike N. 32° W., dip 82° NE; below the fault, strike varies from N. 15° W. to N. 45° W., and dip from 70° to 80° northeast, with average altitude: strike N. 31° W., dip 76° NE.

Northeast of the synclinal axis, above the fault, the average altitude of the beds is: strike N. 32° W., dip 83° SW; below the fault, strike varies from N. 25° W. to N. 60° W., and dip from 50° to 74° SW., with average conditions: strike N. 46° W., dip 60° SW.

Joints: The rocks of the Siyeh formation at Star Creek dam site are thoroughly jointed or fractured because they are involved in an anticline that has suffered considerable tensional stress over the rest of the fold. Rocks in different beds, or in different parts of the fold, have yielded in various ways, and a critical analysis of the mechanics of the jointing becomes a rather difficult matter. Because of the complexity of the problem, joints from only two localities on the suggested dam axis will be described.

On the right bank of the river at the waters edge, and on the northeast limb of the anticline, below the fault, massive dolomitic, argillaceous limestone strikes N. 45° W., and dips about 75° NE. The beds are thinly laminated, but bedding surfaces or joints occur only every 10 or 15 feet. These rocks are cut by two sets of joints, as follows: strike N. 33° - 37° E., dip 73° NW. Fracture surfaces are smooth and persistent. Spacing varies from 18 inches, with an average of about 3 feet. On joints every 15 to 20 feet apart there is evidence of movement, or thin selvages of clay. The second set strikes N. 55° E., and dips 26° SE. These fractures are not especially well developed, and occur at intervals of 3 to 4 feet. A third set is occasional or infrequent, and strikes N. 38° E., dip 41° NW. Now and then it makes a rather prominent surface. This locality probably represents the minimum development of jointing, and the rock is as sound and as free from fractures as any in the dam site.

On the left bank of the river in the 1,950-foot hill, on the southwest limb of the anticline, thin-bedded, gray-green calcareous argillite strikes N. 26° W., dip 73° SW. These beds are cut by three sets of joints, as follows: strike N. 83° W., dip 62° N. Fracture surfaces are sharp, clean and persistent; spacing varies from 4 inches to 4 feet. The second set strikes N. 30° W., and dips 39° NE., and is less well-developed, with rough, irregular surfaces. The third set, less common, but well-developed where found, strikes N. 45° E., and dips 26° SE. In an occasional shaly layer closely spaced fracture cleavage strikes N. 67° E., and dips 80° SE. These joints, in conjunction with the bedding, which has acted as a joint set, thoroughly fracture the rock into rhombohedrons varying in size from a few inches to 1 or 2 feet on a side.

Most of the joints are tightly closed under cover, and there probably are no conditions that cannot be remedied by grouting.

Faults: Only one fault was found at Star Creek dam site, and observations on it are not conclusive because of incomplete exposures. Much more information could be obtained by detailed mapping. This fault is believed to be of the epi-anticlinal type, closely associated with the folding. It was noted first in a cut for U. S. Highway No. 2, about 250 feet SE. of line B-B', Fig. 13. At this place, only one observation of a very small part of the fault was possible, but the strike appeared to be N. 68° E., dip 48° NW. The footwall showed about a foot of gouge and breccia mixed, and then about 4 feet of rock shattered by closely spaced (2 in.-3 in.) joints parallel to the fault. The downthrow side appears to be to the northwest. This fault causes a change in direction of dip. The beds to the southeast strike N. 15° W., and dip 70° E., and those on the northwest side strike N. 40° W., and dip 78° SW.

What is believed to be the same fault was observed on the dam axis on the right bank about 75 feet above water surface. At this place the fault strikes N. 50° E., and dips 40° NW., but again it was difficult to obtain a satisfactory observation. The beds southeast of the fault strike N. 45° W., and dip 75° NE., and those on the northwest strike N. 33° W., and dip 86° SW.

Projection of the synclinal axis on the northwest side of the fault back into the plane of the cross-section causes it to intersect just below where line B-B' crosses U. S. Highway No. 2. Lack of exposures make it difficult to protract the synclinal axis southeast of the fault up to the fault, but it is believed to lie about 500 feet northeast of the road. This distance is the approximate minimum amount of shift along the fault, and it appears that the movement has been diagonal, the northwest side moving down and southwest with respect to the southeast side.

Some license has been taken with Fig. 13 in order to show this offset, and the illustration, insofar as structural conditions in the right abutment are concerned, is diagrammatic northeast of Highway No. 2. If this part of the figure were true, there should be only a simple southwest dip into that part of the syncline northwest of the fault; the fault and the lower part of the truncated syncline should not appear. They exist; but lie several hundred feet southeast of this part of the plane of the section.

Field work was insufficient to demonstrate offset of the anticlinal axis, and it may not exist.

There is some reason to believe that there may be more than one epi-anticlinal fault, or that, where not expressed as faulting, the stress developed a series of joints parallel to the strike of the faults. Thus, in a cut on the Great Northern Railway near the SW cor. sec. 35, T. 33 N., R. 34 W., there is a set of joints that strike S. 56° W., and dip 65° NW. The walls of the fractures are sharp and clean, and separated by 1 to 2 inches of clay gouge or small rock "horses". Those that show signs of movement are spaced at intervals of 3 to 10 feet, but fractures without movement may be as close as 1 foot. Movement has been down 2 or 3 inches on the NE side, and the down side appears to have moved southwest 2 to 3 inches. Sometimes a simple fracture diverges into a "V" with gouge on both sides. The maximum width of such zones may be about 1 foot. Somewhat similar conditions were noted in a cut on the railway about 1,500 feet N. of Star Creek in the north part of SE$\frac{1}{4}$SW$\frac{1}{4}$ sec. 5, T. 32 N., R. 34 W.

The Leonia fault, the master fault of the region, passes about 1.3 miles southwest of the river, and does not directly affect the site. On the northeast, the protraction of the O'Brien Creek fault, crosses Yaak River about 2.5 miles from the dam site.

Ground water conditions: In general, groundwater conditions throughout the site are low. The highly inclined strata, and the rather complete jointing favor quick return of rainfall to the valley bottom.

Where section B-B' intersects U. S. Highway No. 2, there is a small spring, piped for use, flowing from the contact of till on bedrock. Two hundred fifty feet north, the road passes over a small creek that appears to have its catchment area in a re-entrant valley in the 2,300-foot constructional terrace in the NE corner of sec. 5. It is quite possible that the discharge of the spring is related to the flow of the creek.

Permeability: The permeability of the overburden of fluxio-glacial outwash probably is high. Water has not been observed to be retained on this material.

Permeability of the Siyeh formation as a whole is also high and comparable to that at the Tunnel No. 8 site. Most of the permeability of the formation is through sheet openings, and the most numerous and those that would control seepage through the abutments are the bedding surfaces.

Dam section: Topographic conditions allow only one section for a high dam at this site. This section line B-B', Fig. 11 and Fig. 13, has a bearing of about N. 71° E. through a point 400 feet north of the center of sec. 5, T. 32 N., R. 34 W., Lincoln County, Montana.

Abutments: At this site, abutments and foundation can be differentiated easily on the basis of topography, especially if the foundation area is defined arbitrarily as lying below altitude 1,900 or 1,950 feet. Then, about two-thirds of the length of the section may be referred to the abutments, and the middle third to the foundation.

The right abutment is a critical feature of this site. From 1,900 to altitude 2,100, it is in solid rock, and is massive in plan, with only minor spurs and re-entrants; from 2,100 to 2,300, the rock is more or less under light cover of silt or outwash gravel; but from 2,300 to the surface of the 2,500-foot terrace, rock appears to be under a fairly heavy cover of outwash. Furthermore, it narrows in width to 2,000 feet, due to a large re-entrant in NE$\frac{1}{4}$NE$\frac{1}{4}$ sec. 5, and another near E$\frac{1}{4}$ corner sec. 5. The character of the bedrock surface below this terrace is unknown, but the depth of fill should be determined by geophysical methods, because if the rock surface is as low as indicated in Fig. 13, a substantial extension to the length of crest will be required. On the otherhand, it is possible that this terrace could be incorporated into a spillway section. Bedrock conditions are indicated diagrammatically in Fig. 13. The attitude of the fault is actually not as threatening as it seems, for the dip shown is but a component of the steeper true dip to the northwest. It thus appears that the right abutment is strong and massive in the lower part, but becomes progressively weaker with increase in elevation.

The left abutment is strong and massive throughout, and consists of rock from base to top. Its bearing power is considered to be somewhat superior to the right abutment because the entire slope is in rock dipping into the valley wall, and there are no structural complications.

Foundation: If the foundation be considered as comprising that part of the site below elevation 1,950, it is evident that that part on the left bank is under comparatively light cover. The rock ridge rising to 1,950 feet is part of a strike ridge that trends through the entire site, and the same is true of the lightly buried hill just within the left bank. The latter ridge rises above the fill both up and downstream from the axis. They add considerable strength to the foundation, and it may be that the mid-valley ridge could be incorporated in a coffer dam for use in river diversion. The axis of the Kootenai River anticline lies in the center of the foundation area, and its close compression contributes a considerable element of strength to the foundation. The foundation, as a whole, is in good strong rock, and it will not crush or slide under any load that may be brought to bear upon it.

Height and length of possible dam: At the proposed flow line elevation of 2,365 feet, crest length for a dam at Star Creek site is about 5,020 feet. Unfortunately, at this elevation, the right abutment consists of glacial outwash, and is highly permeable and of low strength, and will probably require a dike or cut-off that will extend its length materially. The amount of required extension is unknown, but it could be 1,000 feet. However, the foundation under the extended length will be shallow. Cross-sectional area of the open valley below the flow line is about 1,770,000 square feet. Maximum height of dam above mean water surface will be about 535 feet, and probable height above foundation will be around 635 feet. However, it must be recalled that the valley bottom has been subject to glacial scour, and there may be deep, narrow buried gorges that cannot be predicted from surface geology.

Appurtenant works: The chief appurtenat works for this site will consist of a spillway section, provision for river diversion during construction, and a powerhouse site. The latter should give no concern. A natural spillway route does not exist. As suggested above, it may be possible to utilize the locality of the 2,500-foot terrace, especially if it be supported by rock at shallow depth; or it may be possible to spill over the left abutment and canalize the discharge in the shallow valley on the 1,900-foot terrace. Natural tunnel routes for river diversion, also, do not occur, and at this site, it may be more simple to divert the stream with a coffer-dam, utilizing the mid-valley strike ridge as a foundation.

Reservoir conditions: Star Creek reservoir site has been examined only from the viewpoint of the possibility of leakage. Reference has been made to the liability of the right abutment to leak at high levels. There is also a possibility that leakage may occur from the reservoir at elevations as low as 2,060.

The general arrangement of the topography north of Star Creek dam site suggests that the pre-glacial valley of Yaak River may have entered Kootenai River valley farther downstream than the present confluence near the southeast corner sec. 4, T. 32 N., R. 34 W., (Fig. 11), and that a buried valley lies somewhere between the southeast end of Tepee Mountain, sec. 24, T. 33 N., R. 34 W., and the 3,200-foot rock hill in sec. 36, T. 33 N., R. 34 W. This area is now a broad, flat in N½ sec. 25, and makes the divide between Pine Creek and Yaak River. It has been referred to previously in this report as the Tepee Springs saddle, the locality of the 2,516-foot controlling elevation of Star Creek dam site.

The chief points of the argument supporting this hypothesis are:

1. The gorge of Yaak River just upstream from its mouth, across the northwest spur of Yaak Mountain, is narrow and deep, and has the characteristics of a youthful,

superimposed valley rather than an older, mature pre-glacial (Tertiary) valley. Hence, Yaak River probably had some other earlier outlet.

2. The southwest protraction of that part of Yaak River valley upstream from sec. 19, T. 33 N., R. 33 W., meets the present thread of Kootenai River near the mouth of Pine Creek, SW$\frac{1}{4}$ sec. 27, T. 33 N., R. 34 W. This protracted course passes through the Tepee Springs saddle.

3. The fill below this saddle consists of drift, indicating the passage of a glacier through this saddle. Deep pot-hole topography near the southeast corner of sec. 27 and northwest corner of sec. 35, T. 33 N., R. 34 W; and a spring zone at elevation 2,100 on the right bank of Kootenai River, center NE$\frac{1}{4}$ sec. 34, suggest a low level for bedrock along the projected valley, and a possible outlet into Kootenai River valley.

4. Geologic reconnaissance along the right bank of Yaak River from the SW$\frac{1}{4}$ sec. 17 to NW$\frac{1}{4}$ sec. 31, T. 33 N., R. 33 W., reveals two localities where bedrock either has a low altitude or does not occur in the valley wall. One locality occurs near the center of sec. 19, and may possibly

represent the pre-glacial mouth of Pine Creek on Yaak River. The other lies near the center of sec. 30, is wider and deeper, and could represent the upstream end of the buried pre-glacial valley of Yaak River.

If this valley exists as postulated, its length may be about 3 miles. With a head of about 300 feet of water over its upper end, a permeable bed along it might serve as an important conduit for the escape of water from Star Creek reservoir. Furthermore, the distance between the 2,360-foot contour on Pine Creek, sec. 26, T. 33 N., R. 34 W., and on the right bank of Yaak River in secs. 19 and 30, T. 33 N., R. 33 W., is only about 2 miles. If the fill is as permeable as it seems to be, in the course of time, seepage might even pass through the upper part of the divide. Because of the length of the filled sections, these contingencies would not be immediately dangerous. Nevertheless, it seems prudent to suggest that the Tepee Springs saddle be investigated to determine whether or not it is underlain by a buried valley; and, if one is found, to test the permeability of the fill.

Materials for construction: Rock resources are abundant, and with some selection, several different types might be made available. Test pitting will have to be done to determine if the high-level glacial outwash can be washed for sand. Considerable amounts of gravel of various sizes are available from the extensive alluvial flats in the vicinity of the mouth of Yaak River. Some of the lake bed silt may be useful for fine sand, but the amount may be limited. Timber is abundant locally, but the best stands have been logged off. Electric power will have to be brought in from Troy.

Conclusions and recommendations: Star Creek dam site has a valuable feature in that it has about 150 feet excess elevation over that required for the Clark Fork - Kootenai project. Width of valley at the proposed flow line elevation of 2,365 feet is about 5,020 feet, but a comparatively long dike or cut-off may be required over the right abutment. Cross-sectional area of the open valley below the flow line is about 1,770,000 square feet. Height of dam above river surface will be about 535 feet, and height above foundation may be about 635 feet.

Bedrock consists of the Siyeh formation, which here is predominantly dense, thin-bedded argillite, with minor argillaceous dolomitic limestone. All of it is strong and insoluble, and fully capable of supporting any type of dam that may be placed upon it.

Structural conditions are more complicated than at the Troy or Tunnel No. 8 sites, but do not constitute an element of weakness. The Kootenai River anticline is present, the axis being in mid-valley, and there is a minor syncline on its northeast flank. The axis of this syncline has been offset by an epi-anticlinal fault that has a horizontal shift of about 500 feet. The Leonia fault does not directly affect this site, and the O'Brien Creek fault lies 2.5 miles northeast.

The foundation consists of good strong rock, and is under shallow to moderate cover. However, it is well to bear in mind that the valley bottom has been glaciated, and that some unpredictable conditions as to depth and arrangement may be anticipated. The two rock ridges in the foundation add to its strength, and that in mid-vally probably can be adapted for a coffer-dam for stream diversion. There is little danger of sliding or crushing.

The left abutment is massive in plan, and is in strong rock from base to top. Very little excavation will be required to expose it. The right abutment is strong and sound at the base, but it narrows with elevation, and the altitude of bedrock within it becomes a critical question above elevation 2,300. This part of the abutment may require extension of the crest length by a dike or a cut-off wall. In general, the right abutment is somewhat weaker of the two, but insofar as rock is concerned, the bearing power of the two is about equal.

A natural spillway section does not exist; but it may be possible to utilize the section of low rock under the upper part of the right abutment.

Possibilities exist for leakage from the reservoir.

Geophysical exploration should be carried out at this site to determine:

1. Depth of fill in the foundation.
2. Depth of fill in the constructional terrace on the upper right abutment.
3. Whether or not a buried valley underlies the Tepee Springs saddle, sec. 25, T. 33 N., R. 34 W., and provides opportunity for leakage from the reservoir.

Troy dam site

(Figs. 11 & 14)

Location: Troy dam site is situated on Kootenai River in secs. 1 and 2, T. 31 N., R. 34 W. The lower part of the site may extend northwest into secs. 35 and 36, T. 32 N., R. 34 W., Lincoln County, Montana. Mileage on the river map is about 24.9.

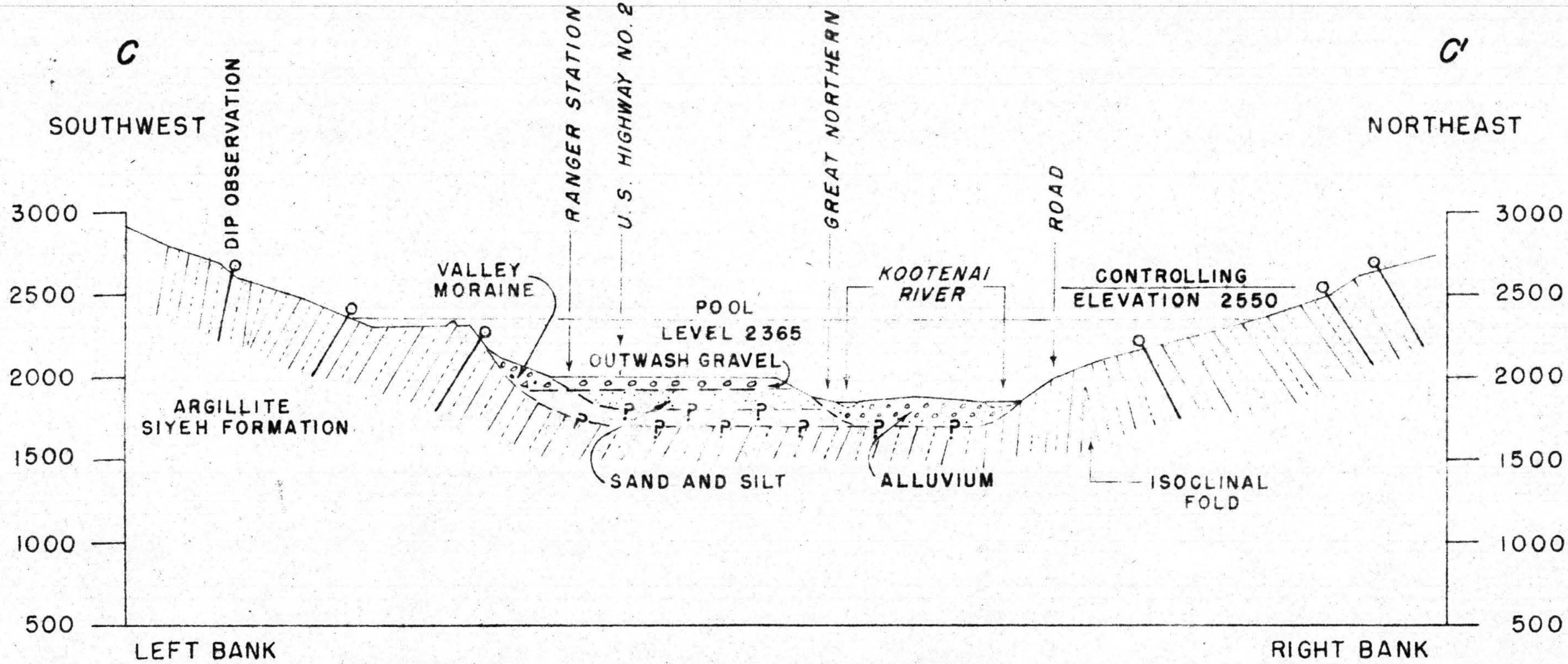
Accessibility: All parts of this site are easily accessible. The most favorable section lies about 1.2 miles northwest of the railway station in the town of Troy. The right bank of the river is traversed by the old route of U. S. Highway No. 2, and, at higher elevations, the roads to Kilbrennan Lake and Slee Lake and Alvords Lake. The left bank is traversed just above river level by the route of the Great Northern Railway; and the new route of U. S. Highway No. 2 passes over the 2,000-foot terrace about 1,300 feet southwest of the river. The river is bridged at Troy, and the new highway bridge crosses from the left to the right bank 2.6 miles northwest of Troy.

Stream gradient: Through the dam site, and for a few miles downstream, stream gradient averages about 6.0 feet per mile, being a little greater from Mile 24.5 to 25.

Above Mile 25, it is about 5 feet per mile for 5 miles.

Purpose of site: This site is an alternative to the Star Creek and Tunnel No. 8 sites at Mile 17 and Mile 14, respectively, and is the locality farthest upstream on Kootenai River at which a dam could be incorporated in the Clark Fork - Kootenai plan. The purpose of the dam would be chiefly storage and river regulation, with power development secondary.

Valley profile: This part of Kootenai River Valley is broad and open, the general profile being so shallow that it has the general form of a catenary curve. This is hardly the accepted form for a dam site, as there is no gorge section. Nevertheless, the valley walls here attain greater elevations nearer the river than at any other place. The mean water surface is between 1,860 and 1,865 feet. After rising sharply to elevation 2,000 on a 1 on 1 slope, the right bank ascends more gradually to an altitude of about 2,750 feet in a distance of about 2,400 feet. The entire bank is in rock, and only a few minor terraces are developed. The left bank rises with equal abruptness to a broad constructional terrace at altitude 2,000. Its surface is very flat, and its width may be 1,400 feet or more. The new Troy Ranger Station, U. S. Forest Service, stands near the head of this terrace.



TOPOGRAPHY FROM U.S.E.D. KOOTENAI RIVER RECONNAISSANCE MAP WITH MODIFICATIONS BY C.E. ERDMANN

RECONNAISSANCE GEOLOGIC CROSS SECTION

TROY DAM SITE

SEC. 1&2, T 31N., R 34W.

LINCOLN COUNTY, MONTANA

Scale 1:12000

FIG. 14

The slope again becomes abrupt and rises rapidly to an elevation of about 2,300 feet where there is a rather flat terrace 300 to 400 feet wide. Rock knobs project 15 to 20 feet above the alluvial surface; and the inner margin stands at about altitude 2,325. From this point the valley wall rises in a rather uniform, cliffy slope to altitude 2,900 in a distance of only 1,500 feet. Rock exposures are abundant in this slope, but are less common on the slope between the 2,000 and 2,300 foot terraces.

At the critical elevation of 2,365 feet, the width of valley is about 5,500 feet. Valley width at elevation 2,300 is about 4,500 feet. This rather important difference of about 1,000 feet of width in a vertical distance of about 60 feet is occasioned by the development of the 2,300-foot terrace. This is a regional feature and is also present at the other sites. If the crest of dam can be kept below its top, considerable economy might be gained, and it might be possible to do this by deeper excavation across the Bull River-Lake Creek divide in the Bull Lake Trench.

Apparent possible height of dam: The controlling elevation for a dam at this locality is a narrow saddle at altitude 2,550 in the rock ridge that separates the valley of Kootenai River from the basin of Alvord Lake. The saddle is located about 1,000 feet southwest of the southeast end of Alvord Lake, and lies about 600 feet west of the northwest corner of sec. 1, T. 31 N., R. 34 W., Lincoln County, Montana. Bedrock is probably at shallow depth in this saddle, and a cut-off wall could probably be placed across it without difficulty. However, there is another saddle in the east center of sec. 1, a few hundred feet southwest of the northwest end of the lake that is wider and deeper. According to the multiplex map of the Corps of Engineers, the elevation of this saddle is about 2,580 feet. Assuming a cut-off in the first saddle, this would be the maximum possible elevation for a dam at Troy site.

Since the critical elevation for the crest of the proposed dam is 2,365 feet, the 2,550-foot altitude of the Alvord Lake saddle furnishes an excess elevation of about 185 feet.

The controlling elevation of the left abutment is the Gordon Creek-Brush Creek saddle in the SE corner sec. 6, T. 31 N., R. 34 W. The elevation of this marshy divide is about 3,300 feet.

Character and depth of valley fill: There is probably more fill at Troy dam site than at any other in this reach of Kootenai River. Except the active stream gravels and the island in the river, all of it is in the left bank under the 2,000-foot constructional terrace. The following section of this fill was measured in a railway cut on the face of the terrace 2,000 feet southeast of the northwest corner of sec. 1, T. 31 N., R. 34 W. This locality is about 900 feet downstream from the axis of the site.

Unit	Top of bank	Thick (feet)
A.	Cobble gravels, sandy matrix; fluvio-glacial outwash apron	10-15
	Gravels, pebble size	5-8
	Sand, coarse, poorly sorted	2-3
	Boulder gravels	6-7
B.	Gravels, pebble size in matrix of sand and silt. Exposed section shows well-developed fore-set attitude, dipping $15^{\circ} - 20^{\circ}$ downstream (northwest)	35-40
C.	Sand and silt, with occasional stream pebbles. Dry surface has light tan color. Half a mile southeast, at the switch point into the Troy railway yards, the upper surface of this deposit has been deformed by the drag or push of glacial ice into a series of small folds that are overturned upstream.	50
D.	Track level	
	Riprap	20
	Water surface, April 4, 1945	
	Approx. total...	128-143

Units A. and B. make a nearly vertical cliffy slope, about 70 feet high, that supports the terrace. Most of the supporting strength, however, is furnished by the close-packing of the boulders and cobbles in unit A. All of the gravels are dry, and are probably highly permeable. The boulders and cobbles are largely derived from Beltian argillites, quartzites, and metadiorites, especially the larger ones, and will offer a considerable obstacle to excavation. The entire deposit is probably of fluvio-glacial origin; and, near the rear of the terrace there are morainal ridges at the base of the valley wall. Some transition from the outwash materials to the valley till may be expected, and it is possible that the till may increase in thickness toward the rear of the terrace.

The sand and silt of unit C. is entirely unconsolidated, and lumps crumble easily in the fingers. Since this material has evidently been disturbed by glacial ice moving up valley - probably a divergent component of the Yaak glacier, one may assume that the valley till near the Ranger Station to the southwest was deposited by this glacier. Hence, it is possible that the sand and silt, which were laid down in a ponded glacial lake, underlies the entire terrace. It has no particular strength and appears to be highly permeable. Hence, if it were to be incorporated in the foundation of some type of flexible dam, a cut-off wall would have to be carried through it. A small but representative sample was selected for mechanical analysis, with results as follows:

Mesh	Percent
+10	8.22
-10 +20	7.20
-20 +32	7.95
-32 +48	12.08
-48 +65	8.74
-65 +80	6.00
-80 +100	4.75
-100 +200	23.26
-200	21.23
Loss	0.57
	100.00

The character of the deeper fill presents a more difficult problem. The probabilities are that the sand and gravel in the river bed has a thickness of at least 100 feet, or even more. It has been indicated as about 150 feet in the accompanying cross-section, but these gravels may rest upon silt. The thickness of the silt under the terrace on the left bank is at least 70 feet, and it may be more than 200. Presumably, it rests upon an older series of river or glacial deposits. Bedrock has been indicated diagrammatically as at elevation 1,700, but it may be even deeper, and the surface much more irregular than shown. In a valley of this size, many features may occur, and there could be a buried rock-cut terrace under the gravel terrace, and a deeper inner gorge. The depths shown, however, indicate the approximate scale of whatever conditions may be encountered. These will have to be determined by geophysical investigations, and checked by test drilling.

Country rock: The Siyeh argillite is the only formation present at Troy dam site, and at least three phases can be recognized. Probably only the upper part of the Siyeh is exposed. Along the axis of an anticline presently to be described, which parallels the road from the NE end of Troy bridge to the turn-off to Kilbrennan Lake, there are exposures of reddish-gray argillite, brownish-gray quartzites in massive layers 4 feet thick, with partings of thinly laminated shaly maroon argillite. Other quartzites are reddish-gray, and their bedding surfaces glisten with a fine-grained white mica (sericite). Overlying these reddish rocks are several hundred feet of thin (2-inch) irregularly bedded gray and greenish-gray argillites. Most of the rock is moderately hard, dense, finely-laminated. Occasional layers are calcareous, but dolomite, to judge from weathering characteristics, is more common. Pyrite is an accessory mineral. Ripple marks occur on almost every bedding surface. Near the top of the right abutment the rock changes to a dull gray, gnarly dolomitic limestone.

Rock in the left wall of the valley is predominantly thin-bedded gray-green dolomitic argillite. These beds are stratigraphically higher than the reddish argillites and quartzites, that are evidently concealed in the river bed. Most of the rock exhibits wavy, irregular bedding, but some layers are platy and fairly smooth.

All of the exposed rock is strong and durable, and of sufficient strength to support any kind of structure adaptable to the site. There is no reason to believe that the rock concealed by the river bed or terrace is different from that exposed.

Dip: The dip of the beds at Troy dam site indicates that the river is situated on or near the crest of a large, sharply compressed anticlinal fold. The axis of this feature is exposed in a cut on the county road near the center of sec. 1, and it appears to trend about N. 35° W., with some minor variations that may be due to off-setting by epi-anticlinal faults. The fold also appears to be slightly asymmetric, with lower dips on the northeast flank. These range from 43° to 76°, with an average of about 60°. The strike of the beds varies from North to N. 30° W., with an average direction of about N. 20° W.

On the southwest flank, there is a steep southwest dip of 86° at the waters edge on the right bank. Whether or not this continues under the concealed part of the valley is unknown. It has been so indicated in the cross-section because where rock first crops out at the base of the left wall of the valley, the dip is also to the southwest. There is room, however, for another isoclinal fold under the covered area. The beds in the left wall vary in dip from 60° southwest at the base to 80° southwest at altitude 2,630, the average being about 66°; and the strike varies from N. 16° W. to N. 27° W., with an average of N. 22° W.

The two limbs of the fold are thus essentially parallel, and the average dip of the southwest flank is about 6° steeper than the northeast flank.

It may be worthwhile to note that Gibson's map shows the axis of this anticline in mid-valley, more than 2,000 feet southwest of the position indicated in Fig. 14. Near the NW cor. sec. 1, however, it swings back to its mid-valley position.

__Joints:__ Jointing is not well developed in the thin irregularly bedded argillites. Occasionally, however, in localities of heavier bedded, more homogeneous rock, strong and persistent joints may be observed. At one such place south of the center of sec. 36, T. 32 N., R. 34 W., the attitude of the master joints is:

Strike S. 60° E., dip 60° SW.

Strike N. 56° E., dip 75° NW.

Joints could not be observed well enough in the natural exposures of the upper part of the left bank to determine the master sets. It is probable, however, that they are about the same as in beds of similar attitude farther downstream (Star Creek site). Inasmuch as the site is situated upon the crest of a rather sharp anticline, it is probable that there is a considerable amount of tensional jointing, and since most of the folded beds are thin, it must be particularly effective in fracturing the rock.

__Faults:__ Faulting was not observed in the rocks at Troy dam site, but probably it is present. No doubt there are bedding faults in the steeply dipping argillites, and epi-anticlinal faults may cut the axis of the fold, but the exposures are too incomplete for them to be recognized.

A probable epi-anticlinal fault was observed near the northeast end of the Troy bridge. It appears in a road cut 75 feet northwest of the bridge abutment. This fault strikes N. 50° E., and dips 70° northwest. The crush zone varies in width from 10 to 15 feet, and obviously is a zone of weakness. Drag effects persist northwest of the fault for about 75 feet. The fault may be responsible for the northeast shift of the axis of the Troy anticline into the valley wall. This particular fault was overlooked by Gibson, or was possibly considered too insignificant to place on his map. If such faults occur in the dam site area, they may prove to be serious defects. The thought occurs that the saddles in the Alvord Lake ridge may be the result of erosion along such zones of weakness. If so, then at least one such fault may be expected in the right abutment.

The Leonia fault lies about 2.2 miles southwest of the river at Troy dam site. With respect to distance from this fault and freedom from possible harmful effects if activity on it should ever be renewed, Troy dam site is more favorably situated than any other site described in this report.

The O'Brien Creek fault lies about 3 miles northeast, and although lacking the regional significance of the Leonia fault, the same considerations apply.

From the viewpoint of regional structure, Troy dam site is situated on a broad, sharply compressed anticline in a down-faulted block that is about 5 miles wide.

Ground water conditions: Ground water appears to stand at a rather low level under the 2,000-foot terrace on the left bank. Springs or seeps were not observed to flow from these deposits. One small spring was noted at the rear of this terrace, about 2,000 feet south of Troy Ranger Station, and is piped in for domestic use. It emerges from bedrock at the base of the left wall of the valley. Springs or seeps were not observed on the right bank.

East of the right abutment there is a chain of small lakes that stand at rather high levels above the floor of the river valley. Alvord Lake, the largest, and the head of the chain, has a surface level of about 2,570 feet; Slee Lake stands at about 2,470 feet; and a small unnamed pond half a mile south has nearly the same elevation. The valley occupied by these lakes drains southward into Kootenai River through a small creek whose mouth is opposite Troy. A low morainal dam prevents Alvord Lake from draining through the 2,550 saddle that controls the elevation of the highest possible dam. Drainage from Alvord Lake is evidently subsurface, and some water may escape below the 2,880-foot saddle west of the head of the lake, but evidence of such seepage was not noticed on the right bank of Kootenai River opposite the lake.

<u>Permeability</u>: Ground-water conditions indicate a rather high degree of permeability for the glacial outwash gravels and lake beds in the main valley, for they appear unable to retain water. On the other hand, the filling in Alvord Lake valley is sufficiently impermeable to retain several lakes. This fill is probably of glacial origin, and must have been laid down at the highest levels of glaciation. Good exposures were not seen, but it is thought to consist of a clayey silt or sand.

Permeability of the bedrock formations must also be rather high. The bedding surfaces parallel the river, and eventually lead into the valley. The tensional jointing is also rather complete, and contributes to permeability through the sheet openings. It is impractical to set a figure for the coefficient of permeability, but in general, bedrock at this site is probably more permeable than that at Tunnel No. 8.

<u>Dam section</u>: Only one section is available, and its axis has an approximate strike of N. 74° E. through Troy Ranger Station. Fig. 11, Line C-C'.

Abutments: The right abutment of Troy dam site is well exposed and consists of bedrock from river surface to elevations of more than 2,700 feet. Along the river, bedrock crops out over a distance of about 1,500 feet. The axis of an isoclinal fold crosses the middle part of the abutment at right angles. All beds thus strike parallel to the river. To the southwest, they dip toward it, but in most of the abutment, especially the upper part, they dip northeast. Although there is tensional jointing on this fold, and probably some shear along the axial plane, due to its close compression, it cannot be considered an element of weakness. The right abutment is capable of sustaining any type of dam that may be placed against it.

If the active valley of the river may be called the gorge section, the lower part of the left bank between elevations 1,862 (water surface) and 2,000 (top of terrace) must be considered as the lower part of the left abutment. The lower half consists of poorly sorted, unconsolidated sand and silt. This material is without strength, and is probably highly permeable. The upper half consists of glacial outwash gravels, and, although it has greater strength than the sand and silt (lake beds), it is also comparatively weak and highly permeable. Hence, there is great difference in the bearing power of the lower parts of the right and left abutments.

With proper remedial measures it could probably be adapted to some type of flexible dam, but a cut-off would have to be carried across the terrace for about 1,800 feet. Above elevation 2,050, or thereabouts, the left abutment is in sound rock much like that in the right bank except that the dip is to the southwest.

Foundation: Foundation conditions at this site are virtually unknown because of the great amount of cover. In the river bed the material is probably largely gravel; under the terrace it is boulder and cobble gravel, sand, and silt. The bedrock beneath is presumed to have about the same characteristics as the rock in the left bank above elevation 2,000.

The foundation is the principal problem at this site. Until depth to bedrock is known, it is almost futile to conjecture. The amount of overburden appears to be so great that excavation to bedrock seems out of question. On the other hand, if the outwash gravels could be trenched to the lake beds, a cut-off wall might be emplaced without great difficulty, and some type of flexible dam placed on the foundation. Indeed, if the 2,000-foot constructional terrace is supported at comparatively shallow depth by a rock-cut terrace, it might even be possible to place a rigid dam on the site.

Height and length of possible dam: At the proposed flow line elevation of 2,365 feet the length of crest would be about 5,450 feet. Maximum height of dam above water surface would be about 500 feet. Cross-sectional area of open valley is about 1,700,000 square feet. No attempt has been made to estimate the area of buried valley because of the many uncertainties involved.

Appurtenant works: The principal appurtenant works for this site will include a spillway section, cofferdams for stream diversion (or possibly a rock tunnel in the right bank), and a powerhouse site.

Adequate spillway sections are difficult to obtain, but it may be possible to utilize the 2,300-foot rock bench on the left bank for this purpose.

Reservoir conditions: A possible avenue of leakage from the reservoir is through the Alvord Lake valley, which appears to by-pass the main valley of the river. Alvord Lake valley, however, is filled to comparatively high levels with a fill sufficiently impermeable to retain three small lakes, so seepage through it seems improbable. The shortest possible route for seepage to escape would be under the 2,580-foot saddle just west of the head of Alvord Lake. The total length of this route would be about 3 miles. Hence, this contingency is not regarded as dangerous. The route along the axis of Alvord Lake valley is even greater - if it exists.

Materials for construction: Sand, gravel, and rock occur in abundance at Troy dam site. Timber is abundant. Electric power is available.

Conclusions and recommendations: Troy dam site has one valuable feature in that it has a considerable excess of elevation over that required for the Clark Fork - Kootenai River project. Width of valley at the proposed flow line elevation of 2,365 feet is about 5,450 feet. However, if the pool level could be reduced to altitude 2,300, the length of crest could be reduced to about 4,500 feet. Cross-sectional area of the open valley below elevation 2,365 is about 1,700,000 square feet. Foundation excavation is a major problem, and larger than at the Tunnel No. 8 or Star Creek sites. Height of dam above river surface is 500 feet. Height above bedrock foundation is unknown, but is expected to be at least 600 feet.

The rock formation at this site is the upper third of the Siyeh formation, and consists predominantly of argillite, with minor argillaceous limestone and quartzite. All of the rock is strong, durable, and insoluble, and fully capable of supporting any type of dam that may be placed upon it.

Structural conditions are complicated somewhat by the presence of a closely folded anticline in the right abutment.

The axis of this fold is approximately parallel to the strike of the beds. Northeast of the axis the beds strike N. 20° W., and dip 60° NE; on the southwest side they strike N. 22° W., and dip 66° SW. Local minor faulting was not observed, but is expected to be present. The master fault of the region, the Leonia fault lies about 2 miles southwest, and the O'Brien Creek fault about 3 miles northeast.

The right abutment is in good strong rock from water surface to the controlling elevations for the site, altitude 2,550. Rock is exposed in the left abutment from altitude 2,000 to the controlling elevation, and higher. However, between river surface, elevation 1,862, and altitude 2,000, the lower part of the left bank consists of a broad constructional terrace. The upper 70 feet of this feature consists of outwash gravels, and the lower 70 feet consists of sand and silt. Conditions in and below this terrace are unknown, and they pose the principal problem of this site.

A fair spillway section is available on a terrace on the left bank at altitude 2,300 feet.

Possibilities of leakage from the reservoir are negligible.

Comparison of dam sections on Kootenai River

Inasmuch as the Tunnel No. 8, Star Creek, and Troy dam sites are all on the same river within relatively short distances of one another, and since each has the same ultimate purpose, as well as being an alternative choice, it is obvious that they should share many features of the valley in common and be essentially equal in others. These elements, which include Location, Accessibility, Purpose of dam, Apparent possible height of dam, Catchment area, Stream gradient, Country rock, Jointing, Ground water conditions, Permeability, Situation with respect to major fault lines, Earthquake hazard, Reservoir silting, and Construction materials, tend to cancel out and need not be considered in the selection of the most feasible site. The basic factors on which the selection thus depends resolve into: Economy of dam section at altitude 2,365 feet - Height of section above river surface, Length of section, Cross-sectional area of open valley, Excess abutment elevation above altitude 2,365, Height above foundation, Necessity for dikes on abutments; Character and depth of valley fill; Structural conditions; Strength of foundation; Strength of abutments; Adequacy of spillway section; and, Possibilities for leakage from the reservoir.

None of these localities is a perfect site for a dam - far from it; but they are the best available on that stretch of Kootenai River that is adaptable to the Clark Fork - Kootenai plan. A choice between them is rather difficult, because the points on which they differ are so dissimilar, and hence is solely a matter of opinion. On the basis of the 12 factors listed above, each site has been ranked first, second, or third choice, with the exception that when an equality occurs, they were assigned whatever rank conditions warranted. The ranking of the various elements as given in the following tables represents the writer's personal opinion of their strong and weak points.

TABLE 1

Economy of dam section at elevation 2,365 feet

Dam site	Height of section above river surface, feet	Rank	Length of section, feet	Rank	Cross-sectional area open valley, square feet	Rank	Excess abutment elevation above altitude 2,365, feet	Rank	Estimated height dam above foundation, feet	Rank	Necessity for dikes on abutments		Rank
											R	L	
Tunnel No. 8	548	3	4,250	1	1,060,000	1	0	3	608	1	Yes	Yes	3
Star Creek	535	2	5,020	2	1,770,000	3	150	2	635	2	Yes	No	2
Troy	500	1	5,450	3	1,700,000	2	185	1	650⁄	3	No	No	1

TABLE 2

Character and depth of valley fill

Dam site	Rank	Remarks
Tunnel No. 8	1	Very little on foundation; some on upper parts both abutments. No glaciation.
Star Creek	2	Moderate on foundation; possibly considerable on upper right abutment. Glaciated.
Troy	3	Very great in foundation; none on abutments. Glaciated.

TABLE 3

Structural Conditions

Dam site	Rank	Remarks
Tunnel No. 8	1	Simple. Uniform steep dip to southwest; some faulting.
Star Creek	3	Complex. Anticlinal and synclinal axes in section. Steep dips, opposed. Minor faulting.
Troy	2	Moderately complex. Anticlinal axis in section. Faulting not recognized, but may be present.

TABLE 4

Strength of foundation

Dam site	Rank	Remarks
Tunnel No. 8	2	Fair.
Star Creek	1	Good.
Troy	3	Poor on alluvium. Bedrock foundation probably good but comparatively deep.

TABLE 5

Strength of abutments

Dam site	Rank	Remarks	
Tunnel No. 8	2	Right:	Fair, zone weak rock in lower part, and minor faults.
		Left:	Fair, one fault at base. Stronger than right.
Star Creek	3	Right:	Weak above altitude 2,300 feet.
		Left:	Good. Stronger than right.
Troy	2	Right:	Good. Better than left.
		Left:	Good above altitude 2,000; poor below.

TABLE 6

Spillway section

Dam site	Rank	Remarks
Tunnel No. 8	1	Adequate. High, over left abutment.
Star Creek	3	Poor. Possibility over right abutment.
Troy	2	Fair. 2,300-foot bench on left bank.

TABLE 7

Possibilities of reservoir leakage

Dam site	Rank	Remarks
Tunnel No. 8	1	Possible over tops of abutments unless dikes are used. Low-level possibility poor.
Star Creek	2	Possible high on right abutment unless dike is used, and through buried valley below Tepee Springs saddle to north. Low-level possibility poor.
Troy	3	Poor possibility around right abutment. Good through alluvial foundation, unless deep cut-off is used.

The ranking of these elements is summarized in Table 8:

TABLE 8

Preliminary summary of ranking of critical elements

Dam site	Economy of dam section at altitude 2,365 feet						Character and depth of valley fill	Structural conditions	Strength of foundation	Strength of abutments	Adequacy of spillway section	Possibilities of reservoir leakage
	Height of section above river surface	Length of section	Cross-sectional section open valley	Excess abutment elev. above 2,365	Height above foundation, estimated	Necessity for dikes on abutments						
Tunnel No. 8	3	1	1	3	1	3	1	1	2	2	1	1
Star Creek	2	2	3	2	2	2	2	3	1	3	3	2
Troy	1	3	2	1	3	1	3	2	3	2	2	3

These data may be summarized further, as follows:

TABLE 9

Dam site	First	Second	Third
Tunnel No. 8	7	2	3
Star Creek	1	8	3
Troy	3	4	5

If 5 points are allowed for a first, 3 for second, and 1 for third, the numerical ranking is as follows:

TABLE 10

Tentative numerical ranking of dam sites

Dam site	Points	Place
Tunnel No. 8	44	First
Star Creek	32	Second
Troy	32	Third

Further comparison may be invidious. However, it is worthwhile to emphasize that the most advantageous features of the Tunnel No. 8 site are the smaller sectional area, and what appears to be an adequate spillway route. The width of open valley is about 770 feet (18 percent) shorter than at

Star Creek dam site, and about 1,200 feet (28 percent) shorter than at Troy dam site. The cross-sectional area of open valley is about 1,060,000 square feet, and the total cross-sectional area of the valley is considered to be about 1,200,000 square feet. This latter figure is about 570,000 square feet (47.5 percent) less than the open valley area at Star Creek dam site, which may be increased by about 360,000 square feet, if the probable cross-sectional area of the fill be included; and 500,000 square feet (41.5 percent) smaller than the open valley area at Troy dam site, which may be increased by about 650,000 square feet when the probable cross-sectional area of the fill is included. Hence, the total cross-sectional area of the valley below altitude 2,365 feet at Tunnel No. 8 dam site may be about 77 percent less than the total area at Star Creek dam site, and 96 percent less than the total at Troy dam site.

The disadvantageous features of the Tunnel No. 8 site are the lack of excess elevation above altitude 2,365 feet in the abutments, and the presence of the zone of weak rock in the lower right abutment and the upstream part of the foundation.

Star Creek dam site has a width of open valley of about 5,020 feet. This is 770 feet more than at Tunnel No. 8, and 430 feet less than at Troy dam site. However, it might have to be increased by 1,000 or 1,200 feet to obtain a rock abutment in the right bank; but the depth to foundation over this length probably would not be great. The cross-sectional area of open valley at Star Creek site is about 1,770,000 square feet, the greatest section at any of the three sites, and it may have to be increased by about 360,000 square feet, if the cross-sectional area of the fill is included. This makes the total cross-sectional area of the site about 2,130,000 square feet. This area is about 77 percent larger than the total cross-sectional valley area below altitude 2,365 feet at Tunnel No. 8 site, and about 4 percent greater than the open valley area at Troy dam site. Approximately 200,000 square feet of the additional fill section is in the upper right abutment. This is the weak point of the site; but further investigation may show that conditions are not as serious as conjectured, and that this abutment can be adapted for a spillway.

Troy dam site has a width of open valley of about 5,450 feet, the maximum of the three sites. Since both abutments are in sound rock it is not likely that it will be exceeded greatly. This length is 1,200 feet greater than at Tunnel No. 8 site, and 430 feet greater than at

Star Creek site, but the crest lengths at both of these sites may have to be increased so the ultimate difference will be less. The cross-sectional area of open valley at Troy dam site is about 1,700,000 square feet, but inclusion of the cross-sectional area of the fill will increase it by about 650,000 square feet, making a total area of 2,350,000 square feet. This is 96 percent more than the total area at Tunnel No. 8 site, and about 10 percent more than the total area at Star Creek site. Hence, all things considered, Star Creek and Troy dam sites are about equal in size of section. Troy dam site, however, is ranked below Star Creek dam site in feasibility because of its 45 percent greater amount of fill, and the more difficult conditions under which excavation would have to be carried out.

Recommendations

Before any final choice of section is made, it would be advisable to carry out preliminary depth determinations on the amount of fill on the abutments and foundations at these three prospective dam sites.

In view of the much greater economy of section at the Tunnel No. 8 dam site, it is suggested that the work begin there. Exploration should be extended away from the river over the top of each abutment until there is positive assurance that the bedrock surface on the line of the dam section remains above altitude 2,365 feet. Determination of depth of fill should also be carried out on the valley bottom.

If expected conditions fail to materialize at Tunnel No. 8 site, the upper right abutment at Star Creek site should be investigated; and, if it proves favorable, the work should be extended to the foundation.

Depth of fill should be determined over the 2,000-foot constructional terrace at Troy dam site. If this terrace should prove to be underlain at shallow depth by a rock bench, it is likely that Troy dam site will prove to have a more economical section than the Star Creek site.

Detailed geologic mapping of these sites should precede geophysical investigation of drilling to serve as a guide for the location and interpretation of the subsurface data.