Geology of Waterpower Sites on the Bradley River Kenai Peninsula, Alaska

GEOLOGICAL SURVEY BULLETIN 1031-C

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By KENNETH S. SOWARD

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A description of the geologic settings of dam, tunnel, and reservoir sites on the Bradley River, with recommendations for future explorations

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GEOLOGY OF WATERPOWER SITES ON THE BRADLEY RIVER, KENAI PENINSULA, ALASKA

By KENNETH S. SOWARD

ABSTRACT

Bradley River heads in the Kenai Mountains and flows into Kachemak Bay, 25 miles northeast of Homer. Bradley Lake, at an altitude of 1,090 feet, is on the river between miles 9.8 and 13.3. Power development could be accomplished by constructing a dam at the lake outlet, utilizing the lake basin as a reservoir, and diverting water from it to one of several possible powerhouse sites near tidewater in either one or two stages. For a single-stage plan, the power tunnel and penstock routes range from 3.3 to 3.8 miles in length.

Bradley Lake damsite is underlain by massive graywacke that would make a strong foundation for a concrete dam. The tunnels would penetrate massive graywacke; interbedded cherty slate and argillite; and interbedded graywacke, slate, and argillite. Two large faults cross the tunnel routes 0.75 mile and 2.1 miles west of the damsite. Tunneling conditions are excellent in the graywacke and slate. Light supports might be required in the cherty argillite and heavy supports in the fault zones. A concrete tunnel lining would be required in all rocks except possibly the massive graywacke.

Pervious glaciofluvial deposits may underlie a low divide separating Bradley River from the Nuka River drainage. If so, leakage from the reservoir could occur there.

For a two-stage development, water could be conveyed by tunnel to a powerhouse at river mile 8.2. The tunnel would be in massive graywacke except for a few short reaches in argillite. A second damsite at mile 6.7 is in interbedded argillite and graywacke. A tunnel from the mile 6.7 damsite to a prowerhouse at mile 5.0 would be in interbedded cherty argillite, slate, and graywacke.

INTRODUCTION

PURPOSE AND SCOPE

The Geological Survey, as part of its program of the classification of public lands with respect to mineral and water resources, is currently making a systematic study and evaluation of potential waterpower sites in Alaska. This report describes geologic conditions at two powersites on Bradley River, Kenai Peninsula, Alaska. The sites were examined to determine their geologic features and to outline the next steps necessary for an orderly and complete investigation of geologic conditions. The general term "powersite" is used in this report to include all elements of a power development, such as the dam, conduit, powerhouse, and reservoir.

PREVIOUS INVESTIGATIONS

Geologic investigations of the Kenai Peninsula have been regional in scope and have been confined mainly to the coastal areas that are most accessible. Some detailed investigations have been made of small mining areas. In an early report Martin, Johnson, and Grant (1915) discussed the coastal region of the peninsula and some areas around Kenai Lake. Capps (1940) summarized the geology of parts of the Kenai Peninsula related structurally and stratigraphically to the area around Bradley River. The tectonic setting of Kenai Peninsula is shown on a tectonic map by Payne (1955).

The Corps of Engineers (1955) investigated the engineering feasibility of Bradley Lake powersite and noted that the rock at the damsite and to the west is suitable as a foundation for a concrete dam and for tunnel construction along certain routes.

The Bradley River drainage basin and surrounding area are shown on the following Geological Survey maps: Seldovia quadrangle of the Alaskan Reconnaissance Topographic Series, scale 1:250,000 (1 inch=4 miles); and Seldovia quadrangle maps C–2, C–3, D–2, and D–3 of the 1:63,330 (1 inch=1 mile) topographic series, contour intervals 50 and 100 feet. Vertical aerial photographs, approximate scale 1:43,000, used in compilation of the topographic quadrangle maps are on file with the Geological Survey, Federal Center, Denver, Colo.

PRESENT INVESTIGATION

The field investigations for this report were carried on from June 3 to 18 and July 5 to August 5, 1955. Topographic and geologic mapping of the sites and related features were carried on simultaneously.

A report on the waterpower possibilities of Bradley Lake with a chapter on geologic conditions resulting from the above investigation was released to open file in 1956. The section on waterpower was subsequently revised and published (Johnson, 1961).

GEOGRAPHY

The powersites under investigation are on Bradley River, Kenai Peninsula, southern Alaska. (See fig. 8.) The peninsula has a land area of about 9,500 square miles, of which two-thirds is the rugged Kenai Mountains and the remainder is the gently rolling Kenai lowlands. The mountains rise to altitudes of 4,000 to 5,500 feet, with a

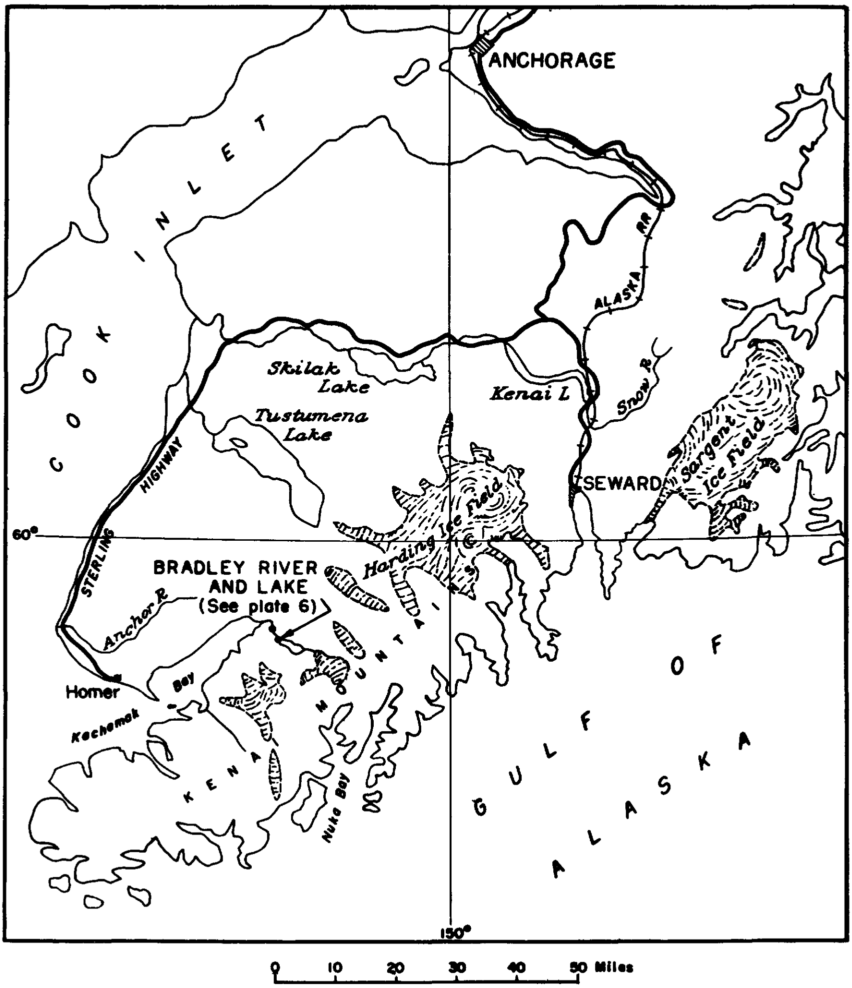

FIGURE 8.—Index map showing location of Bradley River and Bradley Lake, Kenai Peninsula, Alaska.

few peaks above 6,500 feet. They have been extensively glaciated up to about 4,000 feet by a large ice sheet that at one time covered all but the highest peaks. Deep, U-shaped glacial valleys have been and still are being carved by valley glaciers. Two large icefields, the Harding icefield west of Seward and the Sargent icefield to the east, are still in existence, as well as numerous alpine glaciers along the crestline of the range southwest of the Harding icefield.

The Kenai lowlands, which lie between the Kenai Mountains and Cook Inlet, are only 50 to 200 feet above sea level in the northern part but rise southward and are slightly above 2,300 feet in the Caribou Hills north of Kachemak Bay.

TOPOGRAPHY

The lower slopes of the Kenai Mountains in the vicinity of Bradley River rise to an altitude of 1,750 feet in a distance of 5,000 to 6,000 feet from the bay. At this height there is a break in the slope, and in the next 3 miles to the southeast the ground surface rises only 250 feet to an altitude of 2,000 feet. This area is rough and rugged and is cut by a small number of deep gorges, one of which contains the lower part of Bradley River. The main mass of the mountains starts 4 to 5 miles from the bay. Some peaks along the crest of the range reach altitudes of 5,000 to 6,000 feet. Much of the area between 1,500 and 2,000 feet has been overridden by coalescing alpine glaciers, and there are many small lakes and rounded hills with their tops between 1,700 and 2,000 feet. In the slope facing Kachemak Bay, a few small cirques are between 1,000 and 1,500 feet.

Bradley Lake is a glacial lake 3.5 miles long, 1.3 miles wide at the widest section near the east end, and 0.25 mile wide just upstream from the outlet. The water surface was at an altitude of about 1,090 feet on July 12, 1955. The outlet is 3.3 miles, airline, from the edge of the tidal flats and 2 miles from the break in slope above the flats. Steep walls on the north and south sides of the lake rise from 700 to more than 2,000 feet above the lake surface.

A flat-floored, glaciated valley 0.5 to 1 mile wide extends east to a fork 1.75 miles upstream from the lake. A branch valley extends 3 miles south-southeast to a low divide between the Bradley and Nuka River drainages. At the divide the valley is 1,500 to 2,500 feet wide, and the low point is at an altitude of 1,306 feet, about 216 feet above the lake surface. A small unnamed glacier on the west sidewall extends down to the valley floor. Melt water from this glacier flows into both the Bradley River and the Nuka River, but the major part flows south to the Nuka River. Another branch valley 3.2 miles long extends east from the fork to Kachemak Glacier.

REGIONAL GEOLOGY

The Kenai Mountains are composed of thick slightly to moderately metamorphosed clastic sedimentary rocks of Mesozoic age. Capps (1940, p. 57–58) describes the rocks as follows:

> The series as a whole consists mainly of alternating bands of fine-grained mudstone, now metamorphosed to argillite or slate, and coarser impure sandstone, now indurated to graywacke. The other constituents of the series—namely, conglomerate, grit, limy argillite or argillaceous limestone, and tuff—occur in minor amount and are entirely absent over considerabe areas and through great stratigraphic thicknesses of the series. The most characteristic and perhaps the commonest phase consists of alternating layers of slate and graywacke from a fraction of an inch to a foot or so in thickness. In places

the banding is so fine as to suggest seasonal varves, but elsewhere it is much coarser, with individual beds attaining several feet in thickness and here and there are exposures of either slate or graywacke in sections 100 feet or more thick. Mud cracks and ripple marks, as well as the character of the rocks themselves, indicate deposition in shallow water, yet in order to form a series of beds many thousand feet thick but all laid down in shallow water would have required a very delicate balance of conditions in which the collecting basin sank as fast as debris accumulated, but never either much faster or much slower. * * * The materials of which the argillaceous rocks are composed are very fine and include particles of feldspar and quartz in a groundmass of sericite, chlorite, graphite, and clayey constituents * * *

The graywackes are composed of impure sand and range in coarseness from argillite at one extreme to grit and conglomerate at the other. They include materials derived from many sources, but the presence in them of grains of quartz, feldspars, hornblende, micas, and other minerals indicate that the landmass from which they were derived by erosion contained much igneous material. The graywackes also contain rock fragments, most common of which are argillite and graywacke.

The Kenai lowlands are underlain by loosely consolidated Eocene beds of the Kenai formation. The rocks include partly indurated sand, silt, clay, a few thin lenses of fine conglomerate, and many beds of subbituminous coal. The total thickness of the formation is not known, but a stratigraphic thickness of 5,000 feet or more has been suggested by Barnes and Cobb (1959, p. 225).

Quaternary deposits of till, glacial outwash, and alluvium cover most of the Kenai lowlands and the glaciated valley bottoms in the mountainous areas.

The structural setting of Kenai Peninsula is complex, as it lies in four different tectonic elements (Payne, 1955). Two of these elements are in the Kenai Mountains, and two are in the lowlands.

According to Capps (1940, p. 63), the rocks in the mountainous region of the peninsula are faulted and folded, and the structure is so complex as to have defied all attempts to work it out. The rock in any locality tends to strike parallel to the axis of the range and to dip at rather high angles. In the lowlands the structure is simple with dips generally less than 10°, broad folds, and minor faults (Barnes and Cobb, 1959, p. 227).

EARTHQUAKES

The Kenai Peninsula is active seismically, and frequent earthquakes have been noted at Seward and other points. Earthquakes with intensities of VIII to X on the modified Mercalli intensity scale have been centered within 75 miles of the sites. Hence, it appears reasonable that earthquakes of this or greater intensity with epicenters even closer to the sites may occur, and consideration should be given to this factor in the design of any structure.

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POWERSITES

LOCATION AND ACCESSIBILITY

Bradley River is on the northwest side of the Kenai Mountains, 25 miles northeast of Homer. The stream flows into the upper end of Kachemak Bay, an arm of Cook Inlet. (See pl. 6.)

Deltaic deposits at the head of the bay form wide mud flats; however, except during low tide, the river can be ascended to mile 4.5 in a small boat powered by an outboard motor. On the highest tides a lightly loaded LCV (landing craft, vehicle) can ascend the river to mile 2.8. From mile 5.0 to the outlet from Bradley Lake at mile 9.8, the river flows in a deep, narrow gorge. From mile 5.0 to 8.4 the west side of the river is accessible in most places from a rough, poor trail used occasionally by trappers and animals. From mile 8.4 to 9.4 the west bank is inaccessible, but from 9.4 to 9.8 it can be reached easily. In most places the east side of the river is accessible on foot if the climb is started from near mile 5.0 or the lake outlet. From mile 5.0 to about 2 miles above Bradley Lake, the river cannot be crossed on foot during periods of high water, usually in June, July, and August.

The damsite at mile 6.7 is accessible only on foot. Bradley Lake and the damsite at the lake outlet are easily accessible by floatplane. Light wheel planes can land on the delta at the upper end of the lake. The possible powerhouse sites near tidewater can be reached on foot from the edge of the bay.

DEVELOPMENT POSSIBILITIES

General plans for development of power on Bradley River are discussed by Johnson (1961, p. A–22 to A–25). They are summarized as follows: Bradley Lake would be utilized as a storage reservoir in order to equalize the streamflow. The requisite storage capacity could be developed by either: (a) construction of a dam of sufficient height at the lake outlet, (b) drawdown of the lake below its natural level, or (c) a combination of the two. Water would be conveyed by tunnel from the reservoir to 1 of 3 powerhouse sites which are practically at tidewater. Two of the powerhouse sites are on Bradley River at river miles 2.8 and 0.8, and the third is on Battle Creek about 1 mile above its mouth. In the above plan the entire head between the lake and tidewater would be developed in one stage.

An alternate two-stage scheme of development, also outlined by Johnson, would still use Bradley Lake as a storage site. Water would be diverted from the reservoir to a powerhouse at mile 8.2, 1.6 river miles downstream from the lake or 1.2 miles in a direct line. A dam would be built on Bradley River at mile 6.7 with a reservoir extending to the powerhouse at mile 8.2. Water would be diverted from this reservoir to a second powerhouse located near river mile 5.0.

In his report Johnson points out that the area normally draining into Bradley Lake could be increased appreciably by diversion of the headwaters of Nuka River into Bradley Lake reservoir and by diversion of a tributary to Bradley River at a point 2.5 miles east and 1 mile north of the lake outlet. The diversion point is at an altitude of 2,190 feet, or 1,100 feet above the lake.

BRADLEY LAKE POWERSITE

GEOLOGY

A detailed geologic examination was made of Bradley Lake damsite and of the most likely tunnel routes in the area extending generally 2.25 miles west and 1.25 miles north of the lake outlet. The geology of the areas examined is shown in plate 6.

SEDIMENTARY ROCKS

The sedimentary rocks in Kenai Mountains in the vicinity of Bradley Lake and Bradley River are of the Mesozoic era, Cretaceous system, upper and middle part (Dutro and Payne, 1957).

The rocks between the lake outlet and the end of tunnel line *C–C′* 14,600 feet to the west can be divided into three units. (See pl. 6, Bradley Lake tunnel routes.)

One unit, a massive graywacke interbedded with a few thin lenses of argillite or slate, is exposed from about 2,000 feet east to 3,000 feet west of the lake outlet. The graywacke is fresh, massive, strong, slightly metamorphosed, dark greenish gray and dark gray, and very fine to medium grained. From a megascopic examination the rock appears to be composed mainly of feldspar, clay, and a few (generally less than 1 percent) very fine grained to grit-sized subangular to subround particles of dark-gray slate. The rock is slightly calcareous and is cut by a few thin quartz-calcite veinlets. Nodules of chert that range from sand to cobble size are present in some of the argillaceous layers. In a few places, graywacke layers in the argillite have been squeezed into a boudinage structure.

To the west, the graywacke grades into a second unit composed of dark-gray slate and argillite, with a few thin interbedded layers of graywacke. Chert pebbles make up about 5 percent of the slate and argillite but locally can be as much as 90 percent. A tongue of graywacke 300 to 500 feet wide is present 200 feet west of the contact with unit 1. The tongue pinches out about 400 feet north of where tunnel line *C–C′* crosses unit 2.

Farther west, a third unit composed of interbedded graywacke, slate, argillite, and chert conglomerate is exposed over a distance of more than 10,000 feet. Graywacke, in thin to massive beds similar to that exposed at the lake outlet, makes up slightly more than 50 percent of the rock. The conglomerate beds contain as much as 80 to 90 percent chert particles in a sandy matrix. Some chert is present in the argillaceous beds. This unit was mapped to the west end of line *C–C′* and to the north as far as the midpoint on the northwest leg of *D–D′*. From a study of vertical aerial photographs, distant visual observations of the outcrops, and projection of the strike of the beds, it is inferred that these beds extend to the northwest end of line *D–D′*.

IGNEOUS ROCKS

Two dikes of post-Cretaceous age are exposed near line *D–D′* about 3,500 and 5,500 feet from the lake. From a megascopic examination, the rock is classed as a fine- to medium-grained greenish-gray quartz diorite. The dike 3,500 feet from the damsite is 22 to 25 feet wide, strikes N. 68° E. and dips almost vertically. The dike 5,500 feet from the damsite is 35 feet wide, strikes from N. 75° W. to N. 60° W. and dips almost vertically.

UNCONSOLIDATED DEPOSITS

At Bradley Lake damsite and to the west, surfical deposits overlie much of the bedrock. Overburden, consisting of soil, sand, gravel, and some talus, makes up the greater part of these deposits. It generally is overgrown by a heavy stand of grass or alders. Talus deposits have accumulated at two places within the damsite map area. Deposits of gravel and of gravel mixed with talus are present near lake level at the damsite.

Reworked glacial outwash is in the reservoir area upstream from the lake. Outwash glacial deposits are present at the Bradley-Nuka divide. Moraines in the vicinity of the divide are largely till. A small gravel deposit is in the North Fork of Battle Creek about 3,500 feet south of the damsite.

STRUCTURAL FEATURES

In Bradley Lake basin the regional strike is a few degrees east of north, and the dip is to the west. From the east end of Bradley Lake to the west end of tunnel line *C–C′*, the dip increases from 40° W. to almost vertical. West of the lake outlet the dip ranges from 70° W. to vertical, and in some outcrops the beds are overturned slightly.

Two faults are present between Bradley Lake and the powerhouse sites at tidewater. (See pl. 6, Bradley Lake tunnel routes.) A large fault three-fourths of a mile west of the damsite trends N. 10° E. and can be traced for about 6 miles on the ground, on topographic maps, and on aerial photographs. Its trace is expressed by a connected series of topographic lows that include short alined segments of valleys separated by low divides north of river mile 7.0, the deep, narrow Bradley River canyon from river miles 7.0 to 8.3, a conspicous draw south of mile 8.3, and topographic lows south of the draw. Aerial photographs show that half a mile south of river mile 8.3 the fault splits. Two trend lines are expressed by shallow depressions that can be traced about 2 miles to the south where they apparently die out in the Battle Creek drainage. About 2,500 feet northeast of the Mile 6.7 damsite, crushed, broken rock is exposed over a distance of 18 feet in the bank of a tributary to Bradley River. The exposure appears to lie a short distance east of the main trace of the fault as indicated by the topographic map, and it may be a small branch fault. If the two dikes mentioned above are displaced segments, the fault has a strike-slip movement of about 1,500 feet.

A second fault, 1.4 miles west of the one described above, can be traced for about 3.5 miles. Its surface expression includes a high-gradient, steep-walled stream valley and a series of alined draws and notches to the south. At two places in the valley southeast of the proposed powerhouse at river mile 2.8, crushed broken rock and a small amount of clay gouge are exposed over a width of 12 feet. Near altitude 225 feet, the strike of the fault is N. 10° E., or parallel to the general surface trace, and the dip is 75° SE. At an altitude of 310 feet, the strike is N. 25° E., and the dip is 67° SE. Slickensides in the broken rock have a bearing of N. 50° E. and a pitch of 47°. Many short lineaments can be seen on the aerial photographs, but on the ground these features generally are covered by overburden. They may reflect fractures, small faults, or shear zones.

DAMSITE

TOPOGRAPHY

The most favorable location for a dam is in the first 200 feet downstream from the lake outlet, where the channel is 140 to 170 feet wide. (See figs. 9 and 10.) A small rock island 22 feet high is near the center of the river 100 feet downstream from the outlet. The right (northeast) abutment is formed by a rounded knob that rises to an altitude of 1,229 feet. A small saddle, with a low at 1,150 feet, is between the knob and the main valley wall. Northeast of the saddle a steep cliff rises to 1,550 feet, where the slope flattens but continues to

FIGURE 9.—View, looking southeast, of the damsite at the outlet from Bradley Lake. July 1955.

FIGURE 10.—Panorama of the west end of Bradley Lake. The lake outlet and damsite are at the center, and the main stream channel is to the right (northeast) of the small rock island. For geologic and topographic features, the right two-thirds of the view is comparable to the right two-thirds of section A–A', plate 6. July 11, 1955.

rise to above 2,000 feet. The left (southwest) abutment is near the east end of an elongated rock hill that trends eastward and rises to 1,279 feet. Northwest of the high point the ground surface descends to 1,175 feet in a low saddle and then rises to above altitude 1,500 feet. The rounded rock knob that forms the right abutment is north of the east end of the elongated hill that forms the left abutment. The configuration is such that, to 30 feet above the river surface or to 1,120 feet, the valley is narrowest near the lake outlet but widens downstream. Above 1,120 feet, the valley is narrowest 100 to 150 feet downstream from the outlet.

HEIGHT OF DAM

Johnson (1961, p. A–19) states that complete control of the estimated yearly runoff would be provided by a dam that would raise the lake level 150 feet to an alititude of 1,240 feet and 90 percent control by a dam that would raise the lake level 90 feet to an altitude of 1,180 feet. The total height of a dam for either flow line would be about 25 feet more than the increase in the altitude of the lake level because of freeboard, depth of water in the river, and excavation in the foundation.

The maximum altitude to which Bradley Lake could be raised would be controlled by the character of the fill in the Bradley-Nuka divide or by the bottom altitude of the cut diverting Nuka River into the Bradley River drainage. The bottom of the cut probably would be near an altitude of 1,280 feet.

A dam with a crest near an altitude of 1,185 feet would require three structures to block the canyon completely (sec. *A–A′*, pl. 6). At a possible axis only a short distance upstream from section *A–A′*, the canyon is 320 feet wide at an altitude of 1,185 feet, 260 feet at 1,150, 220 feet at 1,100, and 160 feet at the river surface. At the lake outlet about 100 feet upstream from the section, the canyon is only 180 feet wide at an altitude of 1,100 feet and 130 feet at the river surface. The saddle east of the right abutment is 200 feet wide at 1,185 feet but narrows to 80 feet at 1,160, a few feet above its lowest point. The fill in the saddle may be as much as 50 feet deep, and the height of a dam required here could be as much as 75 feet. In the saddle about 700 feet west of the left abutment, the low point is at altitude 1,175 feet, and at altitude 1,185 feet the saddle is 50 feet wide. The fill is estimated to be 10 to 15 feet deep, and a dam here would have to be 20 to 25 feet in height.

A dam with a flow line at 1,240 feet would be highter than the knob that forms the right abutment for the lower dam. Two structures would be required. One, with a crest length of about 1,000 feet, would extend from the left abutment to the right valley wall. A second, in the saddle 700 feet west of the left abutment, would have a crest about 330 feet long and would be 85 to 90 feet high.

BEDROCK

Massive graywacke forms about 96 percent of the exposed rock in the abutments and foundation. The remainder of the rock consists of a few thin lenses or beds of argillite or slate that in a few places contain chert, graywacke conglomerate, or alined pillow-shaped pieces of graywacke in a boudinage structure. The entire right (northeast) abutment is massive graywacke. The greater part of the left (southwest) abutment is massive slightly more argillaceous graywacke, with a few lentils of argillite or slate. Massive graywacke makes up the cliffs south of the small stream in the southwest part of the damsite map. Boudinage structure is well exposed on the south side at the east end of the elongated hill that forms the left abutment.

UNCONSOLIDATED DEPOSITS

Unconsolidated deposits at the damsite include talus, gravel, and overburden. Till may be present at depth in some of the deeper draws and ravines. On the small hills the cover is generally less than 10 feet thick, but in the draws and ravines it may be considerably more.

In the saddle on the right abutment, talus, gravel, and sand are exposed at the ground surface. Bedrock may be at a depth of as much as 50 to 60 feet or about at an altitude of 1,100 feet. This narrow notch is believed to be due to glacial abrasion on the broken rock in the fault that probably strikes through the saddle. It is possible that Bradley River may have flowed through the notch for a short time.

Water in the river channel between the island and the right abutment may be as much as 25 feet deep. This estimate is based on a measured depth of water of 19 feet in a considerably wider part of the river a short distance upstream from the island. Between the left abutment and the rock island, the channel is almost completely filled with talus, gravel, and some silt. Depth to bedrock in this channel probably is almost as much as on the northeast side of the island; so the thickness of fill is about 25 feet.

The saddle 700 feet west of the left abutment is underlain by an estimated 10 to 15 feet of talus, soil, gravel, and sand. This shallow depth is based on the projection of the side slopes into the draw and the lack of any structural features striking through the draw.

STRUCTURAL FEATURES

At the damsite the average strike of the beds varies somewhat from the regional strike. However, accurate determinations were very difficult to obtain. In the massive graywacke, bedding is obscure, and no determinations could be made. In the argillaceous layers a general indication of the attitude of the beds could be gained from the alinement of pieces of conglomerate. The strike of the beds ranges from N. 25° W. to N. 3° E., averaging N. 10° W. The dip ranges from 63° W. to 81° E., averaging 75° W. The beds that dip at high angles to the east are overturned slightly.

A small number of minor faults occur within the damsite map area. The largest one is exposed about 150 feet southwest of the downstream end of the small island on the north side of the knob that forms the left abutment. (See pl. 6, Bradley Lake damsite.) The strike is N. 4° E., and the dip is vertical. The fault ranges from 1 to 15 inches in width and has crushed rock and a small amount of clayey silt gouge along it. A narrow crevice 15 to 36 inches wide has been eroded to a depth of 5 to 6 feet back from the face of the rock cliff at the outcrop. Although the zone appears to be fairly impermeable, freezing and thawing of water along the edge of the zone probably has caused mechanical breakdown of the rock. To the south the extension of the fault is indicated by a small notch on the crest of the knob and a shallow debris-filled depression on the south slope. To the north there are no definite topographic indications of the fault, but on the right abutment 900 feet from the exposed fault, a saddle separating a rock outcrop from the hillside to the east may be an expression of the fault. A second fault may be in a draw about 90 feet west of the first one. No outcrops were found, and the fault is indicated by debris-filled depressions on the knob.

A fault may be concealed in the saddle on the right abutment. No exposures were found, but the saddle itself, the deep notch that may have been eroded at the low point, and the steep cliff to the east may be topographic evidences of a fault. At the north end of the right abutment, there are two covered areas through which the fault could pass. On the damsite map, plate 6, the fault is shown as going through the area to the west, giving it a strike of N. 32° W. If it goes through the covered area to the east, the strike would be N. 20° W.

Eight small faults with ½ to 2 inches of crushed rock and gouge along them were found in the damsite map area and many more probably are concealed by the overburden. Of these, one may be detrimental. It is a wavy irregular fault that crops out in the left abutment opposite (southwest) of the upstream end of the island. At the place where the fault is exposed, the approximate attitude is

N. 35° W., 65° NE. This strike is about parallel to the river, and the fault surface forms the face of the rock cliff and abutment for a short distance. Upstream (southeast) from its trace the fault is at a shallow depth, and in combination with joints allows large blocks to break loose from the cliff.

The rock is moderately jointed, and the greatest concentration of joints is in the more argillaceous rock on the west side of the river (fig. 11). Most of the joints are tight, and those with narrow

FIGURE 11.—Closeup of the joints and fractures in the left (southwest) abutment. The photograph covers a distance of about 150 feet from a point 60 to 70 feet upstream from the island to about opposite the downstream end. The almost vertical joints, striking parallel to the line of sight, are in a set that strikes N. 65° W. to W. and dips 81° SW. to 83° NE. August 3, 1955.

openings bound loosened blocks. It appears that the openings will be tight within a few feet below the ground surface. Most of the joints fall into five sets, with the following attitudes: (a) Strike N. 65° W. to W., dip 81° SW. to 83° NE.; (b) N. 35°–57° W., 63° NE. to 87° SW.; (c) N. 31°–50° E., 72°–89° SE.; (d) N. 60°–74° E., 57°–84° SE.; and (e) N. 10°–15° E., 56°–80° SE.

FEASIBILITY

The site is feasible for a concrete dam. The right abutment appears capable of taking the thrust of an arch dam, but the left abutment may be deficient in strength and size. In the left abutment the rock is more closely jointed and breaks into smaller blocks. The minor fault discussed above underlies much of the left abutment southeast (upstream) of the upper end of the island. Similar faults may be present at shallow depth in the hillside. Immediately opposite the downstream end of the island, the rock knob that forms the left abutment swings away from the river and the canyon widens. Unless an arch dam were keyed a considerable distance into the rock sidewall upstream from where the canyon widens, there might not be a sufficient mass of rock to take the thrust.

Water losses through the pores of the rock will be negligible, but some loss will occur along the joints and fractures. Cement grouting should reduce this to a minor amount.

RESERVOIR SITE

GEOLOGIC CONDITIONS

Interbedded graywacke, slate, argillite, and some cherty argillite crop out on the north and south sides of the lake and in the valley walls upstream from the lake. The percentage of slate increases, and the percentage of argillite decreases toward the eastern end of the reservoir.

The valley floor from the lake to the Bradley-Nuka divide and beyond is covered by outwash consisting of boulders, gravel, sand, and silt. Till is exposed in a small moraine 6,000 feet north of the divide. Remnants of two small morainal ridges are in the upper end of the Nuka River valley, one about 1,500 feet and the other about 3,000 feet south of the divide. Till is exposed at four places in the northernmost of these moraines, but the bulk of the material in front of the glacier and downvalley is outwash. A reconnaissance geologic map of the Bradley-Nuka divide is shown on plate 6.

No large faults were noted in the lake basin or upvalley from it. Some minor faults occur on the north shore about 2 miles east of the lake outlet near the mouth of a small stream.

LEAKAGE

The Bradley-Nuka divide may be underlain by permeable material through which water could escape from a reservoir into the Nuka River drainage. The valley floor at the divide is about 1,500 feet wide. A short distance south of the divide, rock outcrops near an altitude of 1,310 feet on opposite sides of the valley are 1,700 feet apart. To the north the valley widens to a maximum of 3,000 feet except for two low rock spurs that extend out from the west valley wall. At these spurs the valley bottom is 1,300 and 2,600 feet wide.

For a reservoir with flow line at an altitude of 1,180 feet, the possibility of excessive or even large water losses seems remote because of two factors. First, the length of the percolation path between the 1,180–foot contours on either side of the divide is over 4 miles. Even for fairly permeable material the percolation distance would be long. Secondly, there is the possibility that impervious material or a bedrock high underlies the divide. Although most of the material exposed at the divide is gravel and sand, till occurs at a few places in the moraines. The heterogeneous distribution of sand, gravel, and till in the glacial deposits probably would reduce the permeability of the material to a moderate value.

There appears to be an excellent possibility that bedrock extends to 1,180 feet or higher at some place near the divide. The shoreline of a reservoir with a flow line at 1,180 feet would extend only a short distance beyond a point, 1.8 miles north of the divide, where rock spurs are only 1,300 feet apart. Possibly a buried bedrock ridge may extend across the valley and may act as a partial dam to prevent water losses to the south. In the Nuka River valley, bedrock outcrops were noted near the east wall about 3,500 feet south of the divide and near the center of the valley 5,500 feet from the divide. The topographic map of the area indicates that the outcrops are near altitude 1,240 feet. It seems possible that there may be a bedrock high in Nuka River valley a short distance south of the divide.

For a reservoir with a flow line at altitude 1,240 feet, the possibility of large water losses at the divide is much greater. The reservoir would extend to within 0.8 mile of the divide, and the 1,240-foot contour crossing on the Nuka River is 0.7 mile south of the divide. This short percolation distance in permeable material would be a very unfavorable factor, and the divide should be investigated thoroughly before a high-level reservoir is considered for Bradley Lake powersite.

A narrow notch, 2,000 feet south of the lake outlet, forms a saddle between Bradley Lake and the north fork of Battle Creek. The low is at 1,243 feet, but permeable material probably is concealed by topsoil and grass. Drilling is necessary to determine the thickness of the overburden and if an auxiliary dam would be necessary to prevent leakage.

DIVERSIONS INTO RESERVOIR

Diversion damsite and canal site at Bradley-Nuka divide.—The glacier at the divide has deposited low gravel-covered ridges that trend parallel to the valley. Most of the exposed material is fairly clean gravel, but below the ground surface considerable sand and silt are intermixed. Till is exposed at three places in the moraine 1,000 to 1,500 feet south of the divide and at a point in the left (east) bank 400 feet downstream from the diversion damsite (fig 12).

FIGURE 12.—Panorama of the diversion damsite and canal site south of Bradley-Nuka divide. The diversion damsite is in the lower left at the near end of the moraine. The canal site extends from the sharp bend in the river to the right (north) along the low in the foreground. August 1, 1955.

At the proposed site of the diversion dam, till is exposed in the right (west) abutment, and silt, sand, and gravel are in the river bottom and on the left (east) abutment. The till probably is tight, but the alluvium in the left abutment may be quite permeable. Graywacke and graywacke conglomerate in a slate matrix crop out 200 to 250 feet east of the left abutment near altitude 1,310, or 25 to 30 feet above the river surface at the damsite.

If the bottom of the diversion channel is excavated to about 1,280 feet, or to 5 to 7 feet below the stream level at the sharp bend where the river swings to the south, the maximum depth of the cut will be 26 feet. Surface indications are that the major part of the cut will be in gravel, sand, and silt, but the lower part might be in till or even rock.

Bradley River tributary.—At this diversion area, moderately hard interbedded slate, graywacke, and graywacke conglomerate with an argillite matrix crop out at many places along the stream and to the southwest (pl. 6). The strike of the beds is between N. 3° W. and N. 20° E., and the dip is 55° to 74° W. The rocks are of very good quality for the foundation for a low dam.

Gravel, boulders, and sand are in the stream channel between the rock outcrops. Most of the ground surface away from the rock outcrops is grass covered. Many boulders are scattered about, and an estimated 1 to 20 feet of glacial outwash and possibly some till overlies rock. At the diversion point at an altitude of 2,190 feet, rock crops out to about 2,195 feet in both banks of the stream. The cut for the diversion canal would be in gravel and sand, with the possibility of some rock in the bottom.

CONDUIT ROUTES

For a one-stage development, 3 all-tunnel routes have been suggested to carry water to 3 different powerhouse sites at tidewater. (See pl. 6 and fig. 13.) Line *C–C′*, which was proposed by the Corps of Engineers, bears about N. 75° W. from the lake. Lines *D–D′* and *E–E′* bear N. 37° W. and N. 60° W., respectively. The topography in the vicinity of lines *C–C′* and *D–D′* would allow pipelines to be substituted for parts of the tunnels. The tunnel lines would penetrate all three geologic formations previously described. Because of the high-angle dip of the beds, the relative amount of the various rock types that would be traversed along any tunnel line is approximately that shown on the geologic map of the tunnel sites.

For construction purposes the quality of the rock along the tunnel routes ranges from fair to excellent. In the massive graywacke a tunnel will not require support while being driven; in fact, the strength of the rock may be high enough that a concrete lining may

FIGURE 13.—View of Bradley River looking upstream from river mile 8.9 to Bradley Lake. The three lines extending from the lake to the right show the approximate location of possible tunnel routes leading to powerhouse sites at tidewater. The line in the lower right shows the location of part of a possible tunnel route leading to a powerhouse site at river mile 8.2. About 0.9 of a mile of the river channel can be seen, and in that distance the river descends 250 feet. The river is in flood, and the flow is 1,300 cubic feet per second. July 13, 1955.

not be required even during operation. The only structural defect noted in this rock is the jointing; however, lineaments on the aerial photographs may indicate shear zones or small faults. Possibly some lenses of argillite or cherty slate may be present. If so, short sections of the tunnel might have to be lined. In the interbedded cherty slate and argillite, a tunnel probably will require support over 75 percent of its length during excavation. The entire section in this rock will require a concrete lining for operation. In the interbedded graywacke, cherty slate, and argillite, only short reaches of the tunnel will require light support during excavation. However, the tunnel probably would have to be lined for operation, although some sections in the thicker graywacke beds could stand without lining. Extremely difficult tunneling conditions will be found where the tunnel line intersects faults.

All the proposed conduit routes for a one-stage development intersect the bedding at favorable angles. Line C–C' is almost at right angles to the bedding and has the best alinement relative to it. Line *D–D′*, from the bend in the line to the penstock, intersects the bedding at an angle of 50° and has the poorest alinement.

Ground-water inflow into a tunnel constructed along line *C–C′* probably would be greater than on any other, because this line is only a short distance north of a topographic low containing a number of small lakes. Ground-water inflow should be very low along *D–D′* except possibly 3,000 to 5,000 feet northwest of the bend in the section.

Line *D–D′* is a favorable route from a construction viewpoint, because more than two headings could be utilized during the excavation and lining of the tunnel. Additional headings could be started from a short adit located in the steep draw near the bend in the route.

For a two-stage development either line *F–F′* or *G–G′* (pl. 6) could be used to carry water to an upper powerhouse at river mile 8.2. Line *F–F′*, mostly on the west side of the river, could be either an all tunnel or a combination pipeline and tunnel route. The latter possibility is shown on plate 6, but a tunnel could be substituted for the pipeline. In order for the tunnel to pass beneath Bradley River, it would have to descend to about altitude 625 feet at a point 2,000 feet from the powerhouse. This last section would be a high-pressure tunnel. Tunnel line *G–G′* was suggested by Johnson (1961, A–23 to A–24).

Line *F–F′* would be mostly in massive graywacke. At the lower end two short reaches, with a total length of 500 to 800 feet, would be in cherty slate or argillite. Rock and construction conditions along the line are similar to those described for the routes to the south. The most critical area for investigation is beneath the gorge of the river, where there may be a possible fault or a deep narrow gravel-filled crevice.

Line *G–G′* was not investigated in the field, but it should be mainly in massive graywacke.

EXPLORATION

The next exploratory work undertaken should be the investigation of the depth and permeability of the valley fill at the Bradley-Nuka divide. Seismic methods probably would be the cheapest and best means of determining the thickness of the fill or of locating a bedrock high. Test pits or possibly drill holes are necessary to check the seismic findings and to investigate the permeability of the fill. The morainal ridge 1,000 to 1.500 feet south of the divide should be investigated by the test pits or drill holes.

The second step should be exploration of the damsite and the proposed tunnel lines. The graywacke, argillite, and slate can be tested adequately by core holes, but wherever chert is present core recovery probably will be poor, especially if the rock is fractured. At the damsite the left abutment and the notch in the right abutment warrant first consideration if a limited program of drilling is undertaken. The most critical areas along the tunnel lines are at the proposed intake and outlet portals and at the intersections with the large faults.

The rock along the penstock route should be investigated to determine if rock creep has occurred. At least 2 drill holes 75 to 100 feet deep should be put down, and possibly 1 exploratory adit should be excavated to check the rock.

CONSTRUCTION MATERIALS

A few small exposures of gravel were noted along the north fork of Battle Creek, and gravel probably underlies the grassy meadows for about 0.6 mile downstream from the small lake that is 0.5 mile from the damsite on a S. 10° W. line. (See Seldovia C–3, topographic quadrangle map.) However, the gravel appeared deficient in sand, and the volume of the deposits is small.

An adequate supply of sand and gravel is available at the upper end of Bradley Lake.

MILE 6.7 POWERSITE

DAMSITE

TOPOGRAPHY

A two-stage development of Bradley River would require a second dam at river mile 6.7, with a powerhouse near mile 5.0 (pl. 6). At this site the river surface is at an altitude of 530 feet, and 100 feet downstream from the possible axis there is a 35- to 40-foot waterfall. The river has cut a small V-shaped gorge 70 feet deep into the bottom of a slightly wider canyon, and both abutments rise at an angle of about 70° to near altitude 585 feet before the slope flattens. On the left (southwest) abutment a small knob with its top a few feet above 600 feet is separated from the main valley wall by a small saddle with a floor at 590 feet. On the right (northeast) abutment a small flat area ranges in altitude from 595 to 605 feet. At the narrowest section the canyon is 50 feet wide at an altitude of 530 feet; 130 feet, at 580 feet; and 240 feet, at 600 feet.

BEDROCK

Bedrock at the mile 6.7 damsite is interbedded conglomeratic argillite and graywacke. The rock is similar to that in the western part of the tunnel routes from the Bradley Lake damsite, but there appears to be slightly more argillite, with embedded chert and graywacke particles. The waterfall at the site is caused by a massive resistant very fine grained graywacke bed with a few minute quartz-calcite veins. Argillite crops out immediately downstream from the waterfall and grades into cherty argillite in about 100 feet. Upstream from the massive graywacke bed, argillite with many embedded particles of graywacke, chert, and some quartzite is exposed. The number of particles increases upstream, and in one bed 200 feet upstream from the outcrop of the graywacke bed, graywacke and chert particles make up 75 percent of the rock.

STRUCTURAL FEATURES

The strike of the beds at the damsite ranges from N. 20° to 30° E., and the dip ranges from 86° W. to 71° E. The argillaceous beds dip to the west, but the massive graywacke bed at the head of the falls dips 71° E. and probably is overturned.

From topography, a fault is inferred in the left (southwest) abutment about 120 feet from the edge of the river at section *B–B′*, plate 6. Surface indications are a notch at the section, a small draw that trends about N. 30° W. from the notch, and a deep, narrow talus-filled draw northwest of the map area. Three minor faults with ½ to 6 inches of crushed rock along them were found at the site, and undoubtedly others are present beneath the cover of vegetation and broken rock. Much of the argillaceous rock is closely jointed and fractured and breaks into small pieces.

FEASIBILITY

The damsite is feasible for a concrete dam. Topography limits the maximum flow line to an altitude of 590 to 600 feet. The height of the dam would be about 70 feet. The site might be considered for an arch dam if future exploration showed that the argillaceous beds upstream from the massive graywacke bed are not badly fractured and if the fault in the left abutment is only a minor one.

RESERVOIR SITE

The main part of the reservoir will lie in the deep, narrow canyon of Bradley River and the northward extension of this canyon beyond where the river leaves it at mile 7.0. If the flow line is above 595 feet, an auxiliary dam will be necessary in a notch 2,000 feet northeast of the damsite.

The large fault, which controls Bradley River from mile 7.0 to 8.3, and a smaller branch fault strike through the notch. Overburden conceals the poor foundation conditions expected, and additional detailed investigations are necessary. However, a 10- to 20-foot-high earth dam probably could be built here.

CONDUIT ROUTES

The proposed tunnel line to the northwest was not examined. However, the rocks along it probably are similar to the interbedded graywacke, cherty argillite, and slate exposed along the river, 3,000 feet to the north. The strike of these beds ranges from N. 10° to 60° E., and the dip ranges from 25° to 75° W., with one bed dipping 65° E. On aerial photographs some prominent lineaments bear N. 35° W., and one of these ties in with the inferred fault in the left abutment at the damsite. If investigations show that the fault is large, the tunnel route should be located to avoid the lineaments. The rock along the tunnel line will be moderately strong, and it should stand fairly well. The tunnel probably would have to be lined for operation.

CONSTRUCTION MATERIALS

Gravel for concrete aggregate may be available in Bradley River valley upstream from river mile 7.0. The gravel is mainly cobbles and lacks small sizes and sand. Chert particles make up a large percentage of the deposit. Sand and gravel are available along the river in the vicinity of mile 5.0.

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