Geologic Investigations of Proposed Power Sites at Cooper, Grant, Ptarmigan and Crescent Lakes Alaska

By GEORGE PLAFKER

GEOLOGY OF WATER-POWER SITES IN ALASKA

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A description of the proposed reservoir, dam, and tunnel sites on each lake with conclusions and recommendations

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CONTENTS

ILLUSTRATIONS

[All plates in pocket]

TABLES

GEOLOGY OF WATER-POWER SITES IN ALASKA

GEOLOGIC INVESTIGATIONS OF PROPOSED POWER SITES AT COOPER, GRANT, PTARMIGAN, AND CRESCENT LAKES, ALASKA

By George Plafker

ABSTRACT

Geologic conditions at Cooper, Grant, Ptarmigan, and Crescent Lakes on the Kenai Peninsula in south-central Alaska are discussed in relation to possible plans for development of hydroelectric power. The proposed power sites are in the central part of the Kenai Mountains, a rugged mountain mass underlain predominantly by tightly folded slate and graywacke of probable Mesozoic age. Unconsolidated glacial and postglacial deposits of Quaternary age mantle the bedrock over large parts of the area. Grant and Ptarmigan Lakes are situated in bedrock basins formed by glacial scour; Cooper and Crescent Lakes were formed by a combination of glacial scour and morainal damming.

The investigation indicates that diversion tunnels could be driven through relatively sound bedrock throughout their length at each of the sites. One of the two possible tunnel sites at Crescent Lake is considered to be geologically unfavorable because of the presence of a thick overburden of unconsolidated sediments and shear zones in the bedrock.

The dam sites at Grant and Ptarmigan Lakes are underlain by sound bedrock which is well suited for construction of concrete or rock-fill dams. The dam site at Cooper Lake is underlain by poorly sorted glacial deposits which are suitable foundation materials for an earth-fill dam. A bedrock gorge, 1,200 feet downstream from the outlet of Cooper Lake, may be suitable for construction of a concrete arch dam depending on the desired maximum elevation of water in the reservoir. The northeast abutment of Crescent Lake dam site and the reservoir wall immediately northeast of the dam site are composed of relatively permeable alluvium. Leakage through this alluvium may limit the level to which water can be stored in the reservoir.

INTRODUCTION

PURPOSE OF WORK

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 the potential water-power sites in Alaska. This report describes the geologic conditions and their relation to possible plans for the development of water power at Cooper, Grant, Ptarmigan, and Crescent Lakes on the Kenai Peninsula near Seward, Alaska.

PRESENT INVESTIGATION

The field work on which this report is based was carried on during the period August 14 to September 8, 1952. The geology of the dam sites, reservoir sites, and diversion tunnel routes at each of the four lakes mentioned above was mapped. This report should be considered as a preliminary reconnaissance study because of the limited time spent at each of these sites, the difficulty of working in these brush covered areas, and the indefinite development plans for the lakes. Base maps used for the dam sites, reservoir sites, and for the tunnel site at Grant Lake were prepared by the Conservation Division, U. S. Geological Survey. Topographic maps of the reservoir sites are at a scale of 1:24,000,and the dam-site maps are 1:4,800, except for the Grant Lake dam-site map, which is 1:2,400. The topography along the tunnel alignments of Cooper, Crescent, and Ptarmigan Lakes was modified from the Cooper Lake and Grant Lake Quadrangles, U. S. Corps of Engineers, scale 1:50,000, and aerial photographs made by the U. S. Air Force at a scale of about 1:40,000.

PREVIOUS INVESTIGATIONS

Previous geologic work in this area was regional in scope and directed primarily at investigations of mineral resources. The rocks along Kenai Lake were briefly described by Martin (1915). Tuck (1933, p. 469–530) described the geology at Solars mine near Grant Lake and at the many gold mines north of this area. However, no previous detailed work was done in the vicinity of any of the proposed power sites.

GEOGRAPHY

The lakes under consideration are located in the central part of the Kenai Peninsula of southern Alaska (fig. 1). In this area the Kenai Mountains have a general summit altitude of from 5,000 to 6,000 feet with as much as 5,000 feet local relief. These mountains constitute a rugged mass with little apparent arrangement of form or drainage. The dominant factor in the production of the present land forms was glaciation, which tended to accent the preglacial topography. At its maximum extent coalescent alpine glaciers filled the valleys to an altitude of about 4,000 feet leaving only the higher ridges and peaks protruding above the ice. Small cirque glaciers occur on north-facing slopes above an altitude of 2,500 feet in the vicinity of Kenai Lake, and supply the sediment which keeps the larger lakes and streams of this area turbid. Cooper, Grant,

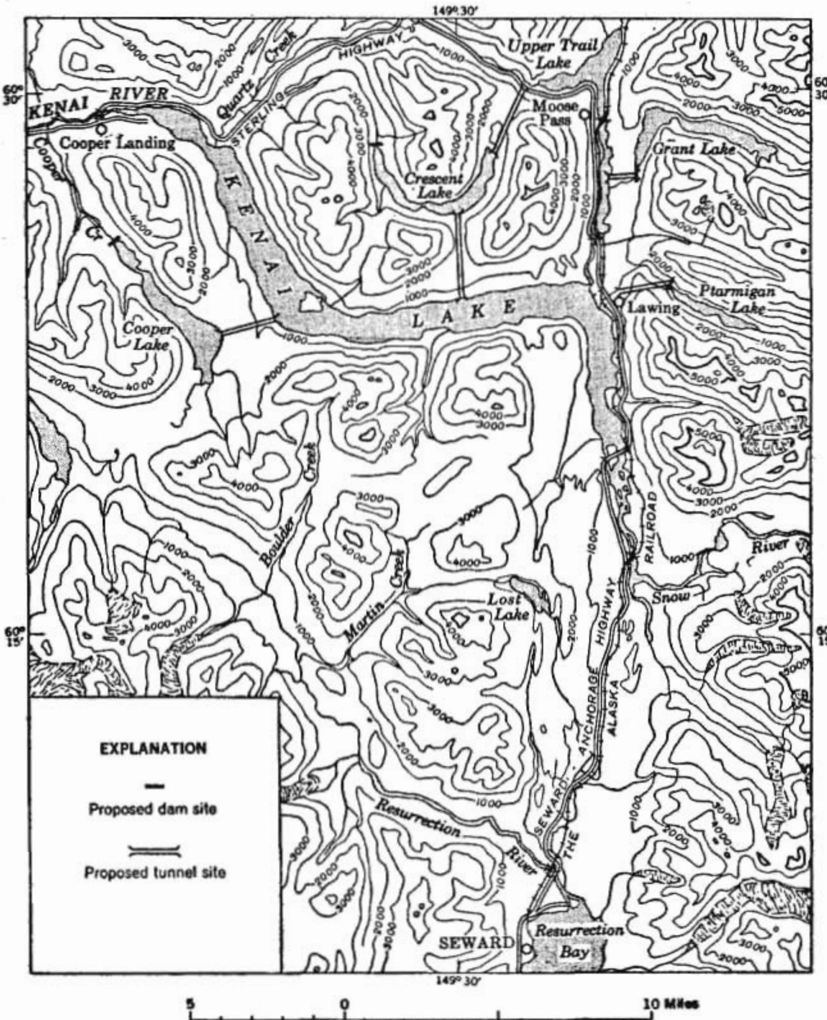

FIGURE 1.—Topographic map showing location of Cooper, Grant, Crescent, and Ptarmigan Lakes.

Ptarmigan, and Cresent Lakes drain westward into Cook Inlet by way of the Kenai River.

The climate of the Kenai Peninsula is characterized by cool summers and winters that are rather mild for the latitude. The Weather Bureau station nearest to the Kenai Lake area is at Seward, over 15 miles to the south. Average monthly temperature and precipitation records for this station over a 42-year period are summarized in table 1. These records would not be strictly applicable to the Kenai Lake area as the mean temperatures are slightly lower with increasing distance from the coast and an increase in altitude. It should be noted that, as most of the streams in this area head in glaciers, temperature can play as important a part in their discharge as precipitation.

Vegetation within the Kenai Mountains is controlled primarily by the physiographic features and the climate. The valleys are somewhat heavily timbered up to a general altitude of 2,000 feet, above which are bare uplands. Spruce forests cover most of the valley floors and gentle slopes below an altitude of 1,500 feet, but alder, hemlock, birch, cottonwood, and willow are also found in most localities Dense alder thickets are commonly found in the zone between the upper limit of the forested areas and the bare uplands.

WATER-POWER DEVELOPMENT

The water-power potential of the lakes under consideration was first investigated by Ellsworth and Davenport (1915, p. 118–126) who maintained gaging stations on the streams draining these lakes during part of the summer of 1931. Permanent gaging stations were established by the U. S. Geological Survey on Grant and Ptarmigan Creeks during 1947 and on Cooper and Crescent Creeks during 1949; discharge records for these stations can be obtained from the Survey office in Juneau.

TABLE 1.—*Average monthly temperature and precipitation at Seward, Alaska*

Month	Temperature	Precipitation	Month	Temperature	Precipitation
January	23. 5	5. 27	July	55. 3	2. 89
February	27. 4	5. 37	August	54. 6	6. 09
March	31. 0	3. 80	September	49. 0	9. 79
April	37. 6	4. 33	October	40. 2	10. 70
May	45. 8	3. 49	November	30. 9	7. 03
June	52. 6	2. 41	December	24. 9	6. 72

Discharge from these lakes is at a maximum and fluctuates greatly during the summer; in the winter, however, it is much reduced or may even be nonexistent. Storage is necessary to distribute the flow throughout the year to conform to the power demand. At the proposed power sites the lakes constitute natural storage basins. A constant flow could be maintained either by tapping the lakes a suitable distance below their present levels in order to allow for the required amount of drawdown during cold weather, or by tapping the lakes at their present levels and raising the lake levels a suitable amount by damming the lake outlets. The diversion from lake to powerhouse could be by tunnel, surface conduit, or a combination tunnel and conduit. Because this investigation is concerned primarily with the geologic aspects of the proposed developments, emphasis is placed on the possible tunnel alinements rather than surface conduit alinements between lake and powerhouse. Although conduits could be utilized in all cases, it is felt that their use would not permit year-round reliable power output as they would be subject to freezing and to possible disruption by landslides or snow avalanches.

REGIONAL GEOLOGY

BEDROCK

The four power sites considered in this report are located in a part of the Kenai Mountains that is composed of a thick series of slightly metamorphosed clastic sediments of probable Mesozoic age. Bedrock consists almost entirely of dark gray to black, thinly bedded slate interfingering in varying proportions with lenticular beds of fine- to medium-grained, hard massive graywacke. Interstratified with these, but in very minor amounts, are lenticular bodies of conglomerate less than 10 feet thick. In a few places the slate and graywacke bedrock is cut by veinlets or irregular masses of quartz.

In general, structures in this area are characterized by closely appressed isoclinal folds striking approximately north, which are in part overturned towards the west. In detail, there are considerable structural differences on either side of the north-trending valley in which are situated Upper and Lower Trail Lakes and the eastern arm of Kenai Lake (fig. 1). East of this valley strikes are nearly due north, and bedding dips uniformly to the east at angles ranging from 40° to 70°. To the west of this valley, however, attitudes are much more variable. Here the beds strike between north and N. 65° E. and dip from 70° W. to 45° E., although most commonly they are within 15° of the vertical. Everywhere jointing is well developed in the graywacke, and an imperfect incipient cleavage is found in the fine-grained rocks. Although local deviations are numerous, cleavage as a rule strikes nearly parallel to the bedding.

There are many faults in this area. However, the uniform bedrock lithology and extensive surface cover hinders efforts to locate and measure the displacement of the faults. Most of the stress associated with folding appears to have been relieved by slippage along many small bedding faults, which are generally tight.

In addition to the bedding faults there are two prominent, widely spaced conjugate sets of high-angle transverse fractures that strike between east and southeast and between north and northwest. These fractures are probably open and constitute lines of weakness as is indicated by their tendency to control drainage and by many of the rectangular topographic features in the vicinity of Kenai Lake.

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A well-developed set of vertical joints with an east strike is found throughout the area, particularly in the massive graywacke.

UNCONSOLIDATED DEPOSITS

Quaternary glaciation, controlled and directed by the preexisting topography, modified the terrain and removed any chemically weathered material that may have been present up to an altitude of about 4,000 feet. All of the lakes under consideration owe their origins primarily to glacial scour in the floor of U-shaped valleys.

The unconsolidated deposits that cover over one-half of the slate and graywacke bedrock are all of glacial or postglacial age. They can be classified into three groups as follows: Glaciofluvial deposits consisting of rudely stratified silt, sand, gravel, and boulders: stratified silt, sand, gravel, and boulders deposited by the present streams; and unstratified coarse rubble along the steeper slopes formed by extremely active mass-wasting processes. Both Cooper and Crescent Lakes are deepened by dams of glaciofluvial and alluvial deposits across their outlets.

EARTHQUAKES

None of the faults in the vicinity of Kenai Lake are known to be active. However, this is a strongly seismic area in which shallow-focus earthquakes have been recorded, whose magnitudes are as high as 6.9 on the Gutenberg-Richter scale.[1] This area is closely equivalent to the Coast Ranges of California in frequency and magnitude of shocks. Consequently, the possibility of additional loads due to earthquake vibrations should be considered in designing structures at the proposed power sites.

COOPER LAKE

Cooper Lake is situated about 4 miles south of Cooper Landing at an elevation of 1167.7 feet above sea level (fig. 1). The lake drains via Cooper Creek into the Kenai River at a point about 1½ miles west of Cooper Landing. Between Cooper Lake and Kenai River, Cooper Creek flows down a steep-walled valley, dropping roughly 770 feet in a distance of 4½ miles. Cooper Lake is 6 miles long and is 2,000 feet wide at its upper end. The lake broadens rapidly to a maximum width of 5,550 feet at a distance of 1½ miles from the upper end and then tapers gradually towards the outlet. Two glacial streams and one clear-water stream flow into the upper end of the lake, and several smaller clear-water streams flow into the lower end of the

[1] U. S. Coast and Geodetic Survey, Preliminary seismic probability map of Alaska, September 1950. (Unpublished.)

lake. The area of the Cooper Lake drainage basin is about 30 square miles. The ridge separating Cooper Lake from Kenai Lake (pl. 1) ranges in altitude from 1,250 to 4,580 feet, and at its lowest point it is about 125 feet above the level of Cooper Lake. At their closest point the lakes are 1.8 miles apart, and at this point the ridge separating them is at a height of 1,600 feet, or about 450 feet above Cooper Lake.

A Forest Service trail 3¼ miles long leads from Kenai Lake, over the low pass between the two lakes, to the upper end of Cooper Lake.

Over 700 feet of head could be developed from Cooper Lake by diverting water from it via a tunnel into a powerhouse along Kenai Lake. The shortest distance between the two lakes, and the most suitable location for this tunnel, would be through the saddle in the vicinity of section *B–B′* as shown on plate 1. The required drawdown to maintain adequate flow during periods of low water could be provided in one of two ways as follows: Tap Cooper Lake from 30 to 50 feet below the present water level, or tap the lake near its present water surface and raise the lake level from 30 to 50 feet by means of a dam at the outlet.

The location and topography of the reservoir area are shown on plate 1. Also shown are the geology and topography of the dam and tunnel sites, and along sections in the vicinity of two possible dam alinements (*A–A′*, *B–B′*), and one of the possible tunnel alinements (*C–C′*).

RESERVOIR SITE

The reservoir site is in a broad, U-shaped valley whose profile to an altitude of about 4,000 feet is a result of glaciation (fig. 1). Glacial scour deepened the original stream valley, forming a basin-like depression in the slate and graywacke bedrock which is now occupied by Cooper Lake. The greatest depth sounded in Cooper Lake is over 400 feet, near the bend about 1½ miles north of the head of the lake. About 35 feet of the depth of Cooper Lake is accounted for by the presence of a natural dam of glaciofluvial debris at the present lake outlet; the remainder of the lake is in a rock basin.

DAM SITE

BEDROCK

Bedrock in the dam-site area consists almost entirely of slate and graywacke. These rocks crop out along Cooper Creek at the downstream limit of the dam-site area map, and one outcrop of slate occurs southwest of Cooper Creek at an altitude of 1,245 feet (pl. 1).

The slate is fine grained, well consolidated, and dark gray, blue black, or black in color. Interstratified in minor amounts with the slate are thin graywacke lenses which range from a trace up to 1 inch in thickness. Cleavage is imperfectly developed; the rock breaks into slabs along rough, irregular surfaces. A system of closely spaced intersecting joints cut the slabs of slate into small, angular pieces, rarely over 9 inches in length. The slate is mechanically weathered along the cleavage and joint planes to an average depth of 3 feet.

Graywacke occurs as a massive outcrop along Cooper Creek. It is gray, fine to medium grained, extremely hard, and is composed chiefly of angular fragments of quartz and feldspar along with numerous flat streaks of slate embedded in a fine-grained clayey matrix. Bedding in the graywacke can only be discerned from the orientation of the included slate streaks. This rock is exceptionally resistant, as it is susceptible to erosion and weathering only along a system of widely spaced joints which cut the rock into large blocks.

Both cleavage and bedding of the slate strike within 5° of N. 5° E. and dip from 45° to 60° E. At the point where Cooper Creek changes its direction of flow from west to northwest, a mass of slate on the north bank has slumped so that both dips and strikes are extremely variable. This slump block is mapped separately on plate 1. The graywacke strikes N. 30° E. and dips between 85° W. and 85° E. Discordant attitudes between the slate and graywacke indicate that they are in fault contact—the fault being concealed under the alluvium-filled gully separating rock of the two types.

UNCONSOLIDATED DEPOSITS

Unconsolidated glaciofluvial, talus, and alluvial deposits of Quaternary age unconformably overlie the slate and graywacke bedrock as shown on plate 1.

The glaciofluvial deposit is characterized by the following features: Moundlike, poorly drained topography; extremely rapid vertical and lateral variation in grain size, and rough stratification dipping upstream in at least one exposure. All of these features suggest that this deposit may be a kame which originally consisted of small deltas or outwash cones built out from the glacier's margin; the material later collapsing into its present form upon melting of the ice. The glaciofluvial deposit consists predominantly of poorly sorted, angular to subround gravel, cobbles, and boulders in a matrix of sand and silt. Scattered about on the surface of these deposits are boulders as long as 4½ feet, which may be supraglacial in origin. Postglacial weathering has resulted in the formation of a well-developed podsolic soil profile which serves to distinguish the glaciofluvial material from the younger alluvial and talus deposits. This soil is distinguished by a gray or white bleached horizon, 1 to 2 inches thick which is directly beneath the surficial organic matter and is underlain by a reddish-brown iron-enriched zone as much as 2½ feet thick.

Fan-shaped, unconsolidated deposits of talus and alluvium from the steep valley slope north of Cooper Creek overlie both the glacial deposits and bedrock. This material is composed of an angular or subangular sand, gravel, cobbles, and boulders showing little or no sorting or stratification. These deposits are too recently formed to have developed a distinguishable soil profile.

Loose, subrounded to rounded gravel, cobbles, and boulders of reworked glacial material occur along the shore of Cooper Lake and in the bed of Cooper Creek where it flows over unconsolidated deposits. These beach and stream deposits are probably nowhere more than 5 feet thick.

TUNNEL SITE

An approximate alinement for diverting water from Cooper Lake to Kenai Lake is shown on plate 1, section *C-C'*. The desired hydrostatic head could be achieved by tunneling from Cooper Lake to a powerhouse along Kenai Lake, or by tunneling almost horizontally through the ridge to about the 1,100-foot contour and then running a conduit from tunnel to powerhouse.

The ridge along the tunnel alinement is underlain almost entirely by well-consolidated, blue-black to black slate and hard, gray or black graywacke. The ratio of slate to graywacke varies considerably along the tunnel alinement. In general, the western part consists of slate with up to 30 percent graywacke in beds less than 50 feet thick while in the eastern part massive graywacke in beds up to 500 feet thick constitutes 50 percent or more of the bedrock.

Bedding in these rocks strikes from N. 5° E. to N. 25° E. and dips from 70° W. through 70° E. The slaty rocks generally show high-angle cleavage with strikes ranging from north to N. 15° E.—at a small angle to or almost parallel to the bedding.

Joints spaced from 6 inches to 10 feet apart occur in two persistent sets throughout the area. One set is vertical and strikes east; the other set is generally within 10° of the horizontal. In addition, discontinuous high-angle joints trending roughly northeast and northwest are well developed locally. The joints divide the graywacke into large blocks, and, in combination with bedding and cleavage, they divide the slate into slabs with irregular, angular edges.

No faults were observed, although it is probable that many bedding faults occur throughout the bedrock. However, a system of high-angle, conjugate fractures striking N. 70° E. and N. 35°–45° W. is indicated by widely spaced, well-defined linear depressions crisscrossing the tunnel area. These fractures may be joints or faults, but in any case they constitute lines of weakness as evidenced by their topographic expression and tendency to control drainage.

CONCLUSIONS AND RECOMMENDATIONS

RESERVOIR SITE

The floors and walls of the reservoir would be composed of bedrock or bedrock overlain by alluvium which is sufficiently tight to insure minimum water loss through leakage.

DAM SITE

Foundation conditions in the dam-site area are quite variable and, consequently, the type of dam to be constructed would depend upon its location within this area. Cross sections through two of the possible dam alinements are shown on plate 1, sections $A–A'$ and $B–B'$.

Earth-fill dam.—Most of the dam-site area is underlain by unconsolidated glacial and alluvial deposits which are suitable in varying degrees as foundation materials for low earth-fill dams. The glaciofluvial deposits exposed near the surface are relatively impermeable and would not be subject to excessive seepage or compaction under load. The silt present in this material may be susceptible to piping, and may therefore require a cutoff to reduce the velocity of water seeping under the dam. This cutoff could be extended to bedrock if necessary as the unconsolidated deposits along line $A–A'$ (pl. 1) are probably less than 25 feet thick. The alluvial and talus deposits north of Cooper Creek may be rather permeable, requiring either a cutoff to bedrock or removal to prevent excessive seepage.

Stripping for a fill dam would involve only removal of the mat of vegetation and organic soil less than 5 feet thick, along with a relatively small amount of loose alluvium in the bed of Cooper Creek.

More detailed investigations along the following lines are suggested: The lithology of the unconsolidated materials down to bedrock and depth to bedrock should be determined along the dam axis in unconsolidated deposits to determine whether highly permeable or plastic strata are included in or underlie the glaciofluvial deposits. Permeability of the unconsolidated materials, particularly the talus, should be determined by observing rates of water leakage from pits or drill holes along the dam axis.

Concrete or rock-fill dam.—The narrow gorge in graywacke at the downstream limit of the mapped dam-site area may be a suitable site for a concrete or rock-fill dam. The foundation is sufficiently sound and the valley profile is such that an arch dam might be utilized here. At this site massive graywacke is exposed from Cooper Creek to an altitude close to 1,200 feet, and is overlain by unconsolidated deposits on both banks at an altitude above 1,200 feet. The desired reservoir altitude and the thickness of the unconsolidated material overlying the graywacke would be limiting factors determining the suitability of this site. More detailed investigations along the following lines are suggested: A detailed topographic map of the area at and immediately below this site should be made; holes should be drilled through the unconsolidated deposits into the bedrock on both abutments to determine depth to bedrock; and water-pressure tests should be made in drill holes on both abutments and one hole along Cooper Creek to determine rates of water leakage to be expected along joints in the bedrock.

Construction materials.—Adequate coarse fill material is readily available from the glaciofluvial deposits along Cooper Creek and on the southwest shore of Cooper Lake. Riprap could be obtained from cobbles and boulders in these deposits or it could be quarried from massive graywacke along Cooper Creek downstream from the dam site. There are no fine-grained soils suitable for an impervious core section in the dam-site area.

Natural concrete aggregate could be obtained from the glaciofluvial deposits although treatment would be required to remove undesirable size fractions present in these deposits. Suitable aggregate could also be quarried from the graywacke immediately downstream from the dam-site area.

TUNNEL SITE

Except for short distances at the portals and in local shattered zones along widely spaced faults, the rocks to be encountered in the tunnel can be expected to stand unsupported for an indefinite period. There would probably be some ground-water inflow from joints and fractures throughout the tunnel. Excessive quantities of water under high pressures might be presented in the fault zones, especially where overburden is at a maximum.

The most favorable tunnel alinement would be at right angles to the strike of the bedding, or nearly due east. The slate would be relatively easily broken and removed, but overbreakage may be considerable due to the system of intersecting joint, cleavage, and bedding planes. Drilling and breaking the graywacke would probably be more difficult, although overbreakage could be more readily controlled than in the slate. Use of a combination tunnel and conduit would minimize the amount of tunneling required in the graywacke.

A diamond-drill program undertaken prior to selection of the final tunnel alinement would help determine whether any large faults are present in the area; the nature of the linear depressions crossing the area; the inflow of ground water to be expected during tunneling operations; and the spacing, nature, and pattern of joints at depth.

GRANT LAKE

Grant Lake is situated 1½ miles due east of Moose Pass at 700 feet altitude (fig. 1). Grant Creek flows from the lake into Trail Creek, which connects Upper and Lower Trail Lakes. Grant Creek is 1 mile long and descends through a narrow box canyon for most of the way to its junction with Trail Creek—a drop of 228 feet. Between Grant Lake and Upper Trail Lake is a low ridge which is only 4,000 feet wide near the outlet of Grant Lake. Grant Lake is slightly more than 6 miles long and from 1,500 to 3,000 feet wide. The lake makes a right-angle bend 2 miles above the outlet, the lower segment trending slightly east of north, and the upper segment trending slightly south of east. A large glacial stream empties into the upper end of the lake, and several smaller glacial and clear-water streams drain into the lake along its length. The total drainage area of Grant Lake is about 44 square miles.

A good wagon trail 1¾ miles long (the Portage Trail) leads from the railroad bridge at Moose Pass to Grant Lake. The lake outlet is accessible from Upper Trail Lake via an unused lumber trail 0.6 mile long (pl. 2).

About 200 feet of hydrostatic head could be developed from Grant Lake by diverting water from it to a powerhouse along Upper Trail Lake. This could be accomplished by means of a tunnel, or combination tunnel and conduit, through the ridge between these two lakes (pl. 2). The required drawdown could be provided by tapping Grant Lake 30 to 50 feet below its surface, or by raising the lake level 30 to 50 feet by means of a dam at the outlet.

The location and topography of the reservoir, dam site, and tunnel site are shown on plate 2. Plate 2 also shows the geology at the dam sites, parts of the tunnel sites, and along cross sections through these areas.

RESERVOIR SITE

The reservoir site is a broad U-shaped valley which was glaciated to an altitude of about 4,000 feet. Grant Lake occupies part of a deep rock basin excavated in the valley floor by glacial erosion. (See fig. 1.)

DAM SITE

BEDROCK

The dam-site area is underlain by a uniformly dipping sequence of interbedded slate, sandy slate, and graywacke, which is well exposed along Grant Creek and the shores of Grant Lake.

The slate is fine grained, well consolidated, and dark gray to black in color. The rock breaks into thin slabs along fairly smooth, subparallel bedding and cleavage planes. Locally, the slate contains considerable amounts of sand and rock fragments. Slate containing sand and rock fragments is somewhat more massive than the remainder of the slate and breaks into slabs up to 6 inches thick along rough, irregular bedding and cleavage planes. Where possible, the more massive slate is shown separately on the dam-site map as "sandy slate." A system of intersecting joints cuts the slabs of both slate and sandy slate into angular pieces generally less than 1 foot long. Because the slate is readily susceptible to mechanical erosion along the joints, bedding planes, and cleavage planes, it generally underlies the valleys in this area.

Massive beds of graywacke as thick as 200 feet form the ridges in the dam-site area. The rock is gray, fine to medium grained, and extremely hard and tough. The graywacke is relatively resistant to erosion, as it is only susceptible to attack along a system of widely spaced joints which cut the rock into large angular blocks.

Bedding and cleavage generally strike between north and N. 5° E. with dips ranging from 42° to 60° E.

A small anticline about 35 feet across is exposed along the south bank of Grant Creek 50 feet downstream from the point at which the 690-foot contour crosses the creek. The axis of this anticline strikes parallel to the strike of the bedding, and the east limb dips 60° E. The west limb is cut off near the fold axis by a tight normal fault which strikes N. 20° E. and dips east at a high angle.

Widely spaced, high-angle, eastward trending joints are present throughout the dam-site area. Closely spaced intersecting joints from 1 to 5 feet apart without obvious consistent orientation also occur throughout the bedrock and particularly in the slate.

UNCONSOLIDATED DEPOSITS

Small areas of alluvium occur on both sides of Grant Creek at the dam site, and one extensive area of alluvium occurs east of the dam site on the south shore of Grant Lake (pl. 1).

These unconsolidated deposits consist predominantly of roughly sorted, subrounded to rounded gravel, cobbles, and boulders in a matrix of sand and silt.

TUNNEL SITE

The power potential of Grant Lake could be developed by tunneling in a westerly to northwesterly direction from the outlet of the lake to a powerhouse on Upper Trail Lake, or by tunneling almost horizontally through the ridge between these lakes approximately to the 700-foot contour and then running a conduit from tunnel to powerhouse.

The ridge between Grant and Upper Trail Lakes is underlain by interbedded slate and graywacke, as shown in plate 2, section *C-C′*.

About 70 percent of the bedrock consists of well-consolidated dark slate in beds up to several hundred feet thick; the remainder is hard, massive graywacke in beds up to 200 feet thick.

The strike of both bedding and cleavage in this area is between north and N. 10° E. although in a few places divergent strikes from N. 15° W. to N. 25° E. were measured. Bedding dips from 35° to 65° E. with evidence that at least part of the section is overturned.

A set of widely spaced, high-angle joints trending roughly eastward is well developed in the tunnel area. These joints, along with several poorly developed sets generally spaced from 1½ to 5 feet apart cut the graywacke into large blocks, and in combination with bedding and cleavage, they cut the slate into slabs with rough, angular edges.

The only fault found in the tunnel area is at the sharp bend in Grant Creek where the stream changes course from due south to southwest (pl. 2). At this point there is a fault trending N. 50° E. and dipping 65° S. which is in line with, and probably controls, the lower course of Grant Creek. The zone of fractured rock adjacent to the fault is between 15 and 20 feet wide and contains several small quartz veins. The fault contains up to 3 inches of clay gouge.

CONCLUSIONS AND RECOMMENDATIONS

RESERVOIR SITE

The floors and walls of the reservoir would be composed of bedrock or bedrock overlain by alluvium that is sufficiently impermeable to insure minimum water loss through ground-water leakage.

The height of water in the reservoir would be limited by the drainage divide traversed by the Portage Trail. This divide is about 50 feet above the present lake surface; therefore, a small wing dam would be required to prevent overflow through this pass if the lake level is raised more than 50 feet.

DAM SITE

Foundations.—Bedrock in the dam-site area, particularly the graywacke, is suitable as a foundation for either a concrete or rock-fill dam. Section *A-A′* (pl. 2) is along one of the more favorable dam alinements. Along this alinement, only a thin mat of vegetation and organic soil would have to be removed to expose fresh, sound graywacke and sandy slate bedrock.

The bedrock should have sufficiently high compressive and shear strength to support the contemplated load. The rock itself is relatively impermeable and insoluble; some seepage could take place along the joint planes although from surface indications they are generally tight. The amount of seepage to be expected could be determined by means of pressure tests in drill holes along the dam alinement on both abutments and in the stream bed.

In designing a dam at this site it should be noted that the low divide traversed by the Portage Trail (pl. 2) could be used as a natural spillway if the lake level were raised 50 feet.

Construction materials.—Graywacke in the dam-site area would be excellent for crushed concrete aggregate and for rock fill. In addition, natural aggregate could be obtained from the alluvium to the east of the dam site, but washing and screening would probably be required to remove undesirable size fractions that are commonly present.

TUNNEL SITE

Except for widely spaced fracture zones which cross the tunnel area, bedrock appears to be uniformly fresh, sound, and tight. The most favorable alinement for the tunnel would be at right angles to the bedding strike or almost due west. Support would probably be required at the tunnel portals and in local closely jointed or fault zones. In general, the rocks that will be encountered in the tunnel can be expected to stand unsupported for an indefinite period. Some ground-water seepage could be expected from joints and fractures throughout most of the tunnel area. However, since the tunnel would never be more than 200 feet below the surface, the water inflow would probably be small.

The slate would be relatively easily broken and removed, but overbreakage may be considerable due to the closely spaced system of intersecting joints, bedding, and cleavage planes. Drilling and breaking the graywacke would be more difficult, but overbreakage could be more readily controlled.

A diamond-drill program undertaken prior to selection of the final tunnel alinement would help determine whether or not any large faults are present in the area; the inflow of ground water to be expected during tunneling operations; and the spacing, nature, and pattern of joints at depth.

PTARMIGAN LAKE

Ptarmigan Lake is situated 2.2 miles east of Lawing at an altitude of 755 feet (fig. 1). The lake drains into Kenai Lake via Ptarmigan Creek, which is about 3 miles long and drops 319 feet between the two lakes. Ptarmigan Lake is 3.4 miles long and is between 1,000 and 4,000 feet wide. A glacial stream 7½ miles long empties into the head of the lake and one small glacial stream and several small clear-water streams drain into the lake near its lower end. The drainage area of Ptarmigan Lake is about 33 square miles.

A good Forest Service foot trail 5 miles long leads from the Seward-Anchorage Highway 1.2 miles north of Lawing to Ptarmigan Lake.

The power potential of Ptarmigan Lake could be developed by diverting water from it into a powerhouse located near the lower end of Ptarmigan Creek. A tunnel or combination tunnel and conduit could be used to conduct water from lake to powerhouse. The required drawdown could be provided by tapping the lake 30 to 50 feet below its surface, or by damming the outlet in order to raise the lake level 30 to 50 feet above the tunnel intake.

The topography and geology of the tunnel and dam sites, and the topography of the reservoir site are shown in plate 3.

RESERVOIR SITE

The reservoir site is in a broad, U-shaped valley which was formed by glaciation to an elevation of about 4,000 feet. (See fig. 1.) Ptarmigan Lake occupies a portion of a rock basin gouged by glacial ice, and has a maximum depth of 235 feet.

DAM SITE

BEDROCK

The dam-site area is underlain by slate that contains minor amounts of graywacke in lenses less than 2 inches thick. The slate is fine grained, well consolidated, and blue black to black in color. The rock breaks into slabs as much as several inches thick along shiny, undulating, subparallel cleavage and bedding planes. The slabs of slate are cut into irregular pieces generally less than one foot long by a system of intersecting joint planes. As everywhere in this area the high-angle, east-trending joints are the most prominent and persistent set cutting these rocks. The slate is weathered along bedding, cleavage, and joint planes to an average depth of 3 feet.

The slate at the dam site appears to be on the overturned limb of an isoclinal fold. Strike of both bedding and cleavage is between north and N. 10° E. The beds dip from 50° to 70° E. and the cleavage is either parallel to the bedding, or has a slightly lower angle of dip than the bedding.

The slate along the steep east bank of Ptarmigan Creek, immediately below the lake outlet, has been undercut by the stream so that the angle of dip of the slate is progressively less from top to bottom of the bank, owing to surface creep.

UNCONSOLIDATED DEPOSITS

Unconsolidated deposits in the form of beaches up to 10 feet wide and several feet deep are found along the lake shore at the dam site. The beach pebbles are predominantly slate shingle derived from the local slate bedrock. At the eastern limits of the dam-site area the slate pebbles are mixed with coarse cobbles of graywacke and quartz derived from beds of massive graywacke to the east and north of the dam-site area.

TUNNEL SITE

An approximate alinement for diverting water from Ptarmigan Lake to a powerhouse near Kenai Lake is shown in plate 1, section *B-B′*. The diversion could be accomplished by tunneling directly to the powerhouse or by tunneling nearly horizontally through the ridge west of Ptarmigan Lake to the 750-foot contour and then running a conduit from tunnel to powerhouse.

Most of the ridge between Ptarmigan and Kenai Lakes is underlain by well-consolidated dark slate. In the extreme western part of the tunnel area the slate is interbedded with thick beds of hard, massive graywacke. The alluvial fan deposited by Ptarmigan Creek consists of well-stratified and rounded sand, gravel, and cobbles.

Through most of the tunnel area both bedding and cleavage strike between north and N. 10° E. with dips between 45° and 70° E.

There is a well-developed joint system cutting these rocks; most prominent of which is the high-angle east-trending set. Three well-developed fracture sets showing varying degrees of displacement cut the slate bedrock in the tunnel area. Two of these sets are almost at right angles to each other, striking about N. 20° W. and N. 65° E. with dips at high angles to the northwest and southeast respectively. The third set trends nearly parallel to the bedding. Most of the faults are very tight with little or no gouge along the fault planes or shattering of the adjoining rock. Locally, however, up to 6 inches of clay gouge is developed along the faults and the adjoining rock is somewhat shattered as in the highway cuts south of Lawing. Small faults control the course of Ptarmigan Creek throughout most of its length; however, they are too closely spaced (about 150–500 feet) to be shown on plate 3.

CONCLUSIONS AND RECOMMENDATIONS

RESERVOIR SITE

The floors and walls of the reservoir site would be composed of bedrock or alluvium underlain by bedrock which is sufficiently impermeable to insure minimum water loss through ground-water leakage.

DAM SITE

Foundation.—Bedrock at this site is well suited as the foundation for concrete or rock-fill dam. One of the possible alinements is along section *A-A′* (pl. 3). The profile of the stream valley and soundness of the foundation are such that an arch dam could be considered at this site. Stripping would involve removal of less than five feet of vegetation and weathered rock, along with the loose, slumped slate on the east bank of Ptarmigan Creek. The bedrock would probably be subject to minor seepage along joint and cleavage planes, the amount of which could be measured by means of pressure tests in drill holes along the dam axis on both abutments and in the stream bed.

Suitable spillway sites for a fill dam occur on both abutments as shown on plate 3.

Construction materials.—The only construction material at the dam site is slate. Because it is soft and tends to break into small slabby fragments, the slate would not be suitable for concrete aggregate and would not produce fragments large enough to be used in a rock fill.

Beds of hard, massive graywacke and conglomerate, cut by numerous quartz veins, are exposed along the north side of Ptarmigan Lake about 1,000 feet east of the dam site. Rock suitable for aggregate and fill could probably be obtained from these beds.

Clean, well-rounded and well-graded natural concrete aggregate could be obtained in the lowland along the Alaska Railroad route or from the alluvial fan at the mouth of Ptarmigan Creek. Suitable concrete aggregate could also be quarried from the graywacke and conglomerate east of the dam site area.

TUNNEL SITE

The shortest and geologically most favorable tunnel alinement would be in the vicinity of line *B-B′* (pl. 3).

Bedrock throughout most of the tunnel area would probably be relatively sound and tight. Support would be required at the tunnel portals and in narrow, closely jointed or faulted zones that would be encountered about every 150 to 500 feet. In the remainder of the tunnel, however, the rock to be encountered can be expected to stand unsupported for an indefinite period.

There would probably be ground-water inflow from joints and fractures throughout most of the tunnel. Excessive quantities of ground water may be encountered in the fault zones, and this water may be under high pressures in places where the overburden is several hundred feet thick.

The slate would be relatively easily drilled and broken although overbreakage may be difficult to control due to the system of closely spaced cleavage, bedding, and joint planes, and the presence of shattered rock along the faults.

A diamond-drill program undertaken prior to selection of the final tunnel alinement would help determine the location and nature of faults present in the area; the inflow of ground water to be expected during tunneling operations; and the spacing, nature, and pattern of joints at depth.

CRESCENT LAKE

Crescent Lake is situated at an altitude of 1,454 feet near the center of a somewhat isolated group of hills bounded on the south and west by Kenai Lake, on the east by the Trail Lakes, and on the north by the valleys followed by the Seward-Anchorage and Sterling Highways (fig. 1). As its name implies, this lake is remarkably crescentic in plan with the convex side toward the south. The lake is 6 miles long and is slightly less than 2,000 feet in average width. The total drainage area of Crescent Lake is only 22 square miles. The lake is drained westward via Crescent Creek and Quartz Creek into Kenai Lake; a difference in altitude of slightly more than 1,000 feet. At its closest point Crescent Lake is 14,500 feet north of Kenai Lake, with a divide 1,850 feet in height between the two lakes. The upper end of the lake is about 14,500 feet southwest of Moose Creek; the pass forming the drainage divide between Crescent Lake and Moose Creek is 1,494 feet in height, or 50 feet above the altitude of the surface of Crescent Lake.

Between 900 and 1,000 feet of hydrostatic head could be developed from Crescent Lake by diverting water from it into a powerhouse along either Moose Creek or Kenai Lake, along one of the following possible alinements. One alinement is from the upper end of Crescent Lake northeastward to Moose Creek; the other is from near the middle of Crescent Lake south to Kenai Lake. Adequate flow during periods of low water could be maintained either by tapping Crescent Lake 30 to 50 feet below the present water surface, or by raising the lake level an equal amount by means of a low dam at the outlet.

A Forest Service trail 3½ miles long leads from Kenai Lake to the middle of Crescent Lake, as shown on plate 4.

The location, topography, and geology of the reservoir site, dam site, and tunnel sites are shown on plate 4.

RESERVOIR SITE

In cross section, the valley occupied by Crescent Lake is U-shaped due to glaciation up to an altitude of about 4,000 feet (fig. 1). The lake occupies two basin-like depressions gouged out of the valley floor by glacial ice. In the basin at the lower end of the lake the water reaches a maximum depth of 123 feet; the depth in the upper basin is almost 300 feet. The basins are connected by an island-studded constriction near the west-central part of the lake, at which point the water is less than 20 feet deep. Following retreat of the glaciers the two basins probably contained separate lakes. Subsequently, rapid accumulation of alluvium at the lower end of the valley in which the lakes are situated probably resulted in a rise of water level to the point where the two basins became connected, forming the present Crescent Lake.

DAM SITE

The foundation material at the dam site consists of unconsolidated streams and fluvioglacial deposits.

The east side of Crescent Lake at the dam site is underlain by an alluvial-fan deposit which slopes gently from the east side of the valley down to Crescent Creek. The alluvial-fan deposit consists predominantly of stratified, subrounded to rounded gravel and cobbles in a matrix of silty sand. This alluvium is probably more than 50 feet deep at the dam site.

The material forming the west abutment of the dam site is poorly exposed, but appears to consist predominantly of coarse, angular to subrounded gravel and cobbles in a fine sandy silt matrix. The low knob on this abutment may be an ice-contact deposit of glaciofluvial material or possibly bedrock concealed under a thin mantle of unconsolidated material. Behind this knob, the base of the valley slope is mantled with coalescing fans of coarse alluvium.

Loose, subrounded to rounded gravel and cobbles of reworked unconsolidated material occur along the shores of Crescent Lake and in the stream bed at the dam site.

TUNNEL SITE

Development of the power potential of Crescent Lake could be accomplished by diverting water from it to a power site along either Kenai Lake or Moose Creek. Both alinements would be about 14,500 feet long.

Crescent Lake–Kenai Lake Tunnel Alinement.—A tunnel or combination tunnel and conduit would be required to divert water from Crescent Lake to a power site along Kenai Lake. The shortest distance between the two lakes is southward from a point near the middle of Crescent Lake, as shown on plate 4, section *C–C′*.

Slate with interbedded thin lenses of graywacke constitutes almost all of the bedrock in this area. Locally, the graywacke lenses may attain a thickness of 30 feet and grade into pebble conglomerate.

Throughout most of the tunnel area both bedding and cleavage generally strike between north and N. 10° E. with steep easterly dips. Shear zones in the slate are exposed on the ridges both east and west of the tunnel alinement and north of Crescent Lake opposite the tunnel area. Bedrock exposed along the stream emptying into Kenai Lake and along the shore of Kenai Lake near the south end of section *C-C′* is tightly folded and extensively fractured. West of this folded zone, the rocks exposed along the shore of Kenai Lake strike N. 25° E., whereas to the east of this zone the beds strike between north and N. 10° E. as in the remainder of the tunnel area.

The divide between Crescent and Kenai Lakes and the lower ridge slopes throughout this area are mantled to varying depths by unconsolidated fluvial, glaciofluvial, alluvial, and rubble deposits as shown on plate 4.

Crescent Lake–Moose Creek Tunnel Alinement.—An approximate alinement for diverting water from Crescent Lake to a powerhouse near Moose Creek is shown on plate 4, section *B-B'*. The desired hydrostatic head could be achieved by one of two general procedures as follows: A tunnel or combination tunnel and conduit; or a conduit the entire distance from Crescent Lake to the powerhouse.

The divide between Crescent Lake and Moose Creek consists of about equal amounts of black, well-consolidated and thinly bedded slate interbedded with gray, fine- to medium-grained, hard, massive graywacke.

The beds in this area are isoclinally folded and overturned toward the west with dips uniformly from S. 45° to 55° E. The bedding strikes about N. 25° E. near the upper end of Crescent Lake, and gradually changes towards the east along the line of the tunnel; thus in the vicinity of the Seward-Anchorage Highway attitudes range from N. 45° to 55° E.

An irregular system of joints cuts the graywacke into large blocks; in combination with bedding and cleavage they cut the slate into thin irregular slabs.

Four coalescing alluvial fans mantle the bedrock along the west side of the valley between Crescent Lake and the small lake drained by Carter Creek (pl. 4). The alluvium consists of sub-rounded to rounded gravel, cobbles, and occasional boulders. This material is probably nowhere more than 75 feet thick, and at the drainage divide between the two lakes the alluvium is probably less than 15 feet thick. A similar deposit of alluvium is being built out from the extreme northwest corner of Crescent Lake.

The aluvium deposited in the flood plain of Moose Creek consists of rounded gravel and cobbles in a matrix of fine sand and silt.

CONCLUSIONS AND RECOMMENDATIONS

RESERVOIR SITE

The wall of the reservoir immediately northeast of the dam site is an alluvial fan composed of unconsolidated subrounded to rounded gravel and cobbles in a silty sand matrix. The material in this alluvial fan is probably quite permeable as indicated by the influent nature of the stream flowing over it, and the growth on the fan of cottonwood trees, which require relatively permeable, saturated soils. Consequently, there may be a considerable amount of leakage through this material if the lake level is raised, and it may be difficult or impossible to store water to the desired level in the reservoir.

The walls and floor of the remainder of the reservoir would consist of bedrock or alluvium-covered bedrock which is almost certainly sufficiently impermeable to insure negligible leakage.

Information on the permeability of the unconsolidated material at the lower end of the lake should be obtained early in the planning stage by observing rates of water flow into or out of test holes sunk into the material.

DAM SITE

Foundations.—The foundation material at the dam site has adequate physical properties to support a low earth-fill dam of proper design. One of the possible dam alinements is along section *A-A′* (pl. 4). However, seepage through the foundation and attendant piping of finer fractions in this material will be a critical factor in determining the ultimate suitability of this site. From surface indications, the alluvial-fan deposit appears to be quite permeable, and there is little possibility that this condition would change with depth. The exact nature of the material forming the west abutment is not known well enough for an estimate of its permeability to be made from surface indications, although it appears to be poorly sorted and would probably be less permeable than the material of the east abutment. Subsurface investigations of the unconsolidated deposits should be made along the proposed line of the dam to determine the type of material on the west abutment, the depth of unconsolidated deposits, and the permeability and susceptibility to piping.

Construction Materials.—Coarse fill material is readily available everywhere in the vicinity of the dam site. There is no clay suitable for an impervious core section in the area.

TUNNEL SITE

Crescent Lake–Kenai Lake Tunnel Alinement.—A tunnel in the vicinity of line *C-C′* shown on plate 4, would encounter unconsolidated materials near Crescent Lake and bedrock for most of the remaining distance. The length of tunnel required in the unconsolidated material can only be guessed at without subsurface exploration, but the range is probably between 500 and 1,200 feet. In the unconsolidated materials a tunnel would require support and lining throughout. The tunnel would probably also require a considerable amount of support in the slaty bedrock as the rock is tightly folded and faulted where exposed at the surface.

The necessity of tunneling both in unconsolidated material near Crescent Lake and in the tightly folded bedrock near Kenai Lake could be avoided by following a parallel alinement 4,000 feet to the west. A tunnel at this location would be slightly longer, but it would probably be in relatively sound bedrock throughout its length.

Crescent Lake–Moose Creek Tunnel Alinement.—This alinement would probably be more favorable than the one to Kenai Lake for the following reasons: Both the powerhouse site and Crescent Lake would be readily accessible from the Seward-Anchorage Highway; if a tunnel is used, it would be in bedrock throughout its length; and the necessity of tunneling may be avoided by utilizing a conduit across the divide from Crescent Lake to Carter Creek.

A diversion tunnel along line *B-B′* (pl. 4) would encounter slate and graywacke throughout its length. Bedrock in the tunnel area would be relatively sound and tight, with support required only for short distances at the portals and in widely spaced fault zones. In the remainder of the tunnel, the rock to be encountered can be expected to stand unsupported for an indefinite period. Because the tunnel would never be more than one hundred feet underground, the ground-water inflow would probably be a relatively minor factor in tunneling.

The slate would be relatively easily drilled and broken although overbreakage may be difficult to control due to the system of closely spaced cleavage, bedding, and joint planes. Drilling and breaking the graywacke would be somewhat more difficult, but overbreakage should be easier to control.

The low drainage divide between Crescent Lake and Carter Creek suggests that a cut-and-cover conduit may be utilized to conduct water from Crescent Lake across this divide, and then via a conduit to a powerhouse along Moose Creek. This could be accomplished by laying the conduit in a cut from Crescent Lake across the drainage divide to an altitude of about 1,450 feet along Carter Creek. The cut would have to be about 7,750 feet long and would attain a maximum depth of 50 feet at the divide. A cut to the west of line *B-B′* would be in alluvium most of the way, although it is likely that at least 35 feet of rock excavation would be required at the divide and near the outlet of the lake drained by Carter Creek.

Before the relative costs of a tunnel and conduit along this alinement could be estimated, a series of holes should be drilled to bedrock along the line of the conduit to determine the amounts of common and rock excavation that would be required.

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