Geologic Reconnaissance of Possible Powersites at Tyee, Eagle, and Spur Mountain Lakes, Southeastern Alaska

GEOLOGICAL SURVEY BULLETIN 1211-B

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By JAMES E. CALLAHAN *and* ALEXANDER A. WANEK

GEOLOGY OF WATERPOWER SITES IN ALASKA

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A description of the geological factors which could affect the feasibility of three powersites on the mainland of southeastern Alaska, northeast of Ketchikan

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GEOLOGY OF WATERPOWER SITES IN ALASKA

GEOLOGIC RECONNAISSANCE OF POSSIBLE POWERSITES AT TYEE, EAGLE, AND SPUR MOUNTAIN LAKES SOUTHEASTERN ALASKA

By JAMES E. CALLAHAN and ALEXANDER A. WANEK

ABSTRACT

Tyee, Eagle, and Spur Mountain Lakes fill glacially scoured bedrock basins in the Coast Range of southeastern Alaska. The bedrock consists of granitic intrusive rocks and high-rank metamorphic rocks associated with or resulting from emplacement of the Coast Range batholith.

Spur Mountain Lake damsite is underlain by granodiorite and diorite, and the foundation properties of the bedrock are excellent. Serious disadvantages at this damsite are the narrowness of the ridge that forms the right abutment and two prominent joint sets that intersect the abutments at high angles. Two possible tunnel routes extend from the upper and lower ends of Spur Mountain Lake to the Hulakon River and Unuk River valleys, respectively. The routes are approximately the same length, and both are underlain by intrusive rocks which have similar physical properties. Both routes are geologically satisfactory, and the choice of one will probably depend on other factors. The reservoir is underlain and surrounded by impermeable granodiorite, diorite, or related rocks.

The abutments of the Tyee Lake damsite are in massive quartz diorite. The channel section is filled to an undetermined depth with coarse talus which is probably too porous to grout. If the talus deposit is too deep to be removed economically, it might be possible to develop the site by drawing the lake down. The tunnel and penstock route is underlain by granodiorite, composite gneiss, hornblendite, and quartz diorite, which are impermeable except possibly along two zones of close-spaced or open joints. The powerhouse site on Bradfield Canal is underlain by quartz diorite similar to the bedrock at the damsite.

The Eagle Lake powersite includes two possible damsites. One is at the outlet of Eagle Lake and is underlain by composite gneiss which consists of foliated biotite gneiss interlayered with banded quartz diorite and is largely concealed by thin deposits of soil and colluvium. The foliation strikes normal to the alinement of the dam, and minor leakage along foliation planes might be expected. The possibility of a deep buried channel or solution cavities in marble underlying the stream bed should be considered. The other damsite is located at the outlet of Little Eagle Lake about 2½ miles below the Eagle Lake damsite. The drainage area and storage capacity above the Little Eagle Lake site would be about 70 percent greater than that for the Eagle Lake damsite, but the dam

would have to be three to four times larger than the one at Eagle Lake to reach the same water level. This dam may be economically feasible because large volumes of impervious fill material near Little Eagle Lake are available for construction of an earthfill dam. Four saddles, which are probably abandoned stream channels, are in a low divide at the head of Eagle Lake. The depth and the permeability of fill in the saddles are unknown factors which should be investigated. The tunnel route extends from the headward part of the Eagle River to the head of Bell Arm and is underlain by poorly foliated gneissic quartz diorite.

INTRODUCTION

This report describes geologic conditions at three possible powersites, Tyee, Eagle, and Spur Mountain Lakes, on the mainland of southeastern Alaska. The examinations were made to aid evaluation and classification of public lands for waterpower resources.

GEOGRAPHY

LOCATION

The three powersites lie within an area bounded on the north by Bradfield Canal and the East Bradfield River, on the south by Burroughs Bay and the Unuk River, and on the west by the western crest line of the drainage area of Eagle Lake and the Eagle River (fig. 1). The area lies 50–60 miles north-northeast of Ketchikan and 40–50 miles southeast of Wrangell.

The sites are a maximum of 19 miles apart, and all lie within the Bradfield Canal 1:250,000-scale Alaska Topographic Map Series area. Spur Mountain Lake is on the Bradfield Canal (A–4) quadrangle map (1:63,360). Eagle and Tyee Lakes are on the adjoining Bradfield Canal (A–5) quadrangle map.

The lakes are accessible by float-equipped aircraft and are within a few miles of tidewater. None of the lakes are accessible by trails, and cross-country travel is extremely slow and difficult because of dense brush.

PHYSIOGRAPHY

The lakes are in the Boundary Ranges physiographic division of southeastern Alaska as defined by Wahrhaftig (1965). The maximum relief is between 4,000 and 5,000 feet near Tyee and Spur Mountain Lakes and between 3,000 and 4,000 feet near Eagle Lake.

The land forms resulted from Pleistocene and subsequent alpine glaciation. Many of the mountaintops are rounded and smooth. The valleys are U-shaped and steep walled. Many of the valleys contain rock-basin lakes such as Tyee and Spur Mountain Lakes. Most of the north-facing cirques contain small glaciers that are either stagnant or receding.

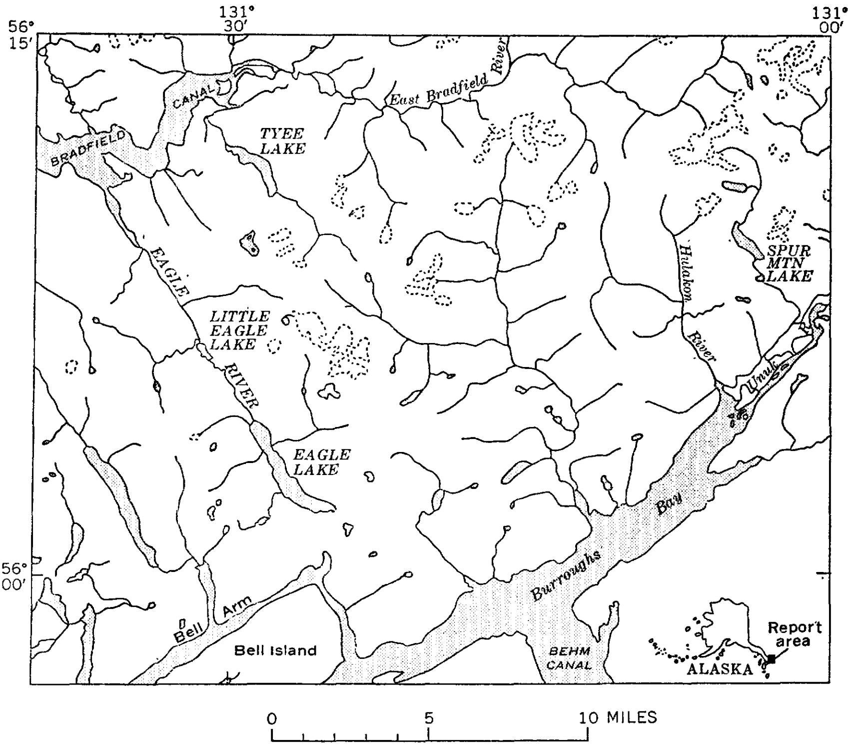

FIGURE 1.—Location of Tyee, Eagle, and Spur Mountain Lakes, southeastern Alaska.

Linear topographic features trend northwestward and parallel gneissic banding in the bedrock. The foliation is better developed in the vicinity of Eagle Lake and between the Eagle River and Tyee Lake and results in a more pronounced alinement of topography than in the Spur Mountain area. Near Spur Mountain, joints seem to control the character of the topography.

CLIMATE AND VEGETATION

The climate is moderate, with cool summers and mild winters. The daily and seasonal variations in temperature fall within a fairly narrow range. The U.S. Weather Bureau Station at Wrangell is the closest source of weather data for the report area. Average monthly temperatures and precipitation amounts for the period 1951–60 at Wrangell (U.S. Weather Bureau, 1965, p. 16, 49) are listed below:

Month	*Temperature (°F)*	*Precipitation (in.)*
January	27. 5	5. 40
February	32. 0	6. 59
March	35. 2	5. 91
April	42. 1	4. 72
May	49. 3	3. 99
June	54. 6	3. 52
July	57. 9	4. 83
August	56. 7	6. 39
September	51. 7	7. 56
October	44. 5	13. 05
November	37. 7	9. 45
December	33. 1	9. 13
Mean annual	43. 5	80. 54

The monthly temperatures for the winter months at Guard Island, near Ketchikan, and at Annette Island were higher than at Wrangell by 2°–5°F for the same period because of the modifying influence of the Pacific Ocean. The amount of precipitation is influenced in part by topography. Climate in the report area probably differs from that near the weather stations because the report area is farther inland and higher.

The area is densely forested to an elevation of 3,000 feet except where slopes are steep or the ground is wet. The forests are predominantly spruce and hemlock and have a dense undergrowth of various types of berry bushes and other shrubs. The slopes above timberline are generally covered by tangled alder brush or moss. Talus slopes and old slide scars are covered by dense low alder and devilsclub.

FIELDWORK

The possible powersites were examined during two sessions of fieldwork in the summer of 1964. The investigation of Eagle Lake was made June 22–27 by the writers. The investigations at Tyee and Spur Mountain Lakes were made September 2–10 by J. E. Callahan, who was assisted by George Kraemer. Logistic support was furnished by J. B. Dugwyler, Jr., hydraulic engineer, U.S. Geological Survey, who had established camps in the area for topographic surveys of the powersites.

Aerial photographic coverage of the powersites includes the following U.S. Air Force photographs: Spur Mountain, SEA 90–006 and 90–007, SEA 107–008 to 107–012, and SEA 108–113 to 108–117; Eagle Lake, SEA 113–047 to 113–054 and SEA 113–142 to 113–147; Tyee Lake, SEA 110–099 to 110–103 and SEA 113–053 and 113–054. All aerial photographs were taken in the summer of 1948. The scale of the photographs is about 1:40,000 at sea level.

PREVIOUS INVESTIGATIONS

The study area is included in the large area mapped by Buddington and Chapin (1929) during their regional work on southeastern Alaska. Because their field investigations were restricted mainly to accessible coastal areas and major river valleys, the geology near Eagle and Spur Mountain Lakes is not shown on their maps. Tyee Lake is partially included in their mapped area. In general, their descriptions of the intrusive and metamorphic rocks, particularly of those along Bradfield Canal (Buddington and Chapin, 1929, p. 49–56), are applicable, with some modifications, to the study area.

GEOLOGY

The dominant geological feature of the mainland of southeastern Alaska is the Coast Range batholith. The area from Burroughs Bay and the Unuk River north to Bradfield Canal is underlain by intrusive rocks of the batholith and by metamorphic rocks which consist predominantly of gneiss that has interlayered thin beds of marble or crystalline limestone. The metamorphic rocks contain a large volume of intimately associated intrusive igneous rocks which are thought to be related to the intrusion of the main batholith. The metamorphic rocks are part of a unit defined as the Wrangell-Revillagigedo belt of metamorphic rocks by Buddington and Chapin (1929, p. 49). Only the eastern part of the belt is represented in the study area. A very broad transition zone exists from the metamorphic to the intrusive rocks. As the batholith is approached from the southwest, the amount of concordant intrusive bodies interlayered with the gneissic rocks increases. The western part of the batholith is characterized by bands of gneiss in various stages of assimilation. The intrusive rock of the batholith is itself banded, and it is difficult or impossible to determine in the field whether some of the rocks are flow-banded intrusive rocks or partly assimilated metamorphic rocks.

Spur Mountain Lake lies well within the main body of the batholith. Tyee Lake is also within the west boundary of the batholith as defined by Buddington and Chapin (1929, p. 56), but much of the Tyee Lake area is underlain by gneissic rocks which are probably paragneisses. Eagle Lake and the Eagle River are within the belt of metamorphic rocks, although the Bell Arm area south of the head of Eagle Lake is shown as quartz diorite continuous with the main batholith of Buddington and Chapin (1929, pl. 1). The map units used in this report are defined mainly on the basis of predominant textural characteristics and to a lesser extent on the occurrence of minerals ordinarily associated with metamorphic rocks, such as garnet and kyanite. Of the units defined, only the quartz diorite at Tyee Lake can positively be assigned an igneous origin, and only the marble interbeds near Eagle Lake are known to be of sedimentary origin. It can be assumed that much of the gneiss associated with the marble beds was also derived from sedimentary rocks.

Buddington and Chapin presented evidence for a Late Jurassic or Early Cretaceous age for the rocks of the batholith. Recent isotopic dating (summarized by MacKevett and Blake, 1963) indicates a Cretaceous age. The age of the metamorphic rocks is much more difficult to determine. Buddington and Chapin (1929, p. 74) concluded that they are predominantly of Carboniferous and Triassic age but that they could include rocks which range from Ordovician to Cretaceous in age.

METAMORPHIC ROCKS

COMPOSITE GNEISS

Within this unit are included rocks which crop out along Eagle Lake and the Eagle River and around Tyee Lake (pls. 1, 2). The rocks are fine to medium grained and are characterized by well-developed gneissic banding. Parting parallel to the banding occurs locally and results from the alinement of platy or prismatic minerals. The gneiss contains a large proportion of interbanded medium- to coarse-grained quartz dioritic to granitic rock that has poorly developed segregation banding. The gneiss near Eagle Lake contains thin marble beds and amphibolite bands which may represent highly metamorphosed impure calcareous sediments. Flakes of graphite in the gneiss at Eagle Lake also suggest a sedimentary origin for the gneisses. Buddington and Chapin (1929, p. 56) reported marble beds associated with the gneiss near the head of Bradfield Canal.

The quartz diorite and related igneous rocks which are included in the gneiss unit are locally garnetiferous. With more detailed mapping than was possible during this investigation, some of the igneous rocks could be mapped separately from the gneiss of sedimentary origin at Eagle Lake.

Around Tyee Lake the mixed gneiss is in gradational contact with banded granodiorite, and the mapped contacts are arbitrary. Here, too, more detailed work would undoubtedly indicate a more complex distribution of igneous and metamorphic rocks than is shown on the geologic map (pl. 2).

Samples 6 and samples 9–16 in table 1 are from the composite gneiss unit. Samples 6, 9, and 10 are biotite gneiss of probable sedimentary origin. Samples 11, 14, 15, and 16 are representative of the interbanded rocks of probable igneous origin included in the composite gneiss unit.

TABLE 1.—*Modes, chemical analyses, and C.I.P.W. norms, in percent, of 16 rock samples from the Spur Mountain Lake, Tyee Lake, and Eagle Lake powersites*

[Chemical (rapid-rock) analyses by Paul L. D. Elmore, Samuel D. Botts, and Lowell Artis]

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Mineral composition (volume percent)																
Quartz	19		31	29	19	53	27	23	36	43	14	9		6	21	17
Plagioclase	51	41	23	57	46	3	31	41	31	29	55	25		62	46	46
Alkali feldspar	23		40	1		19	33	21			Trace			Trace	Trace	2
Hornblende	4	38		2	15			8			15	64		27	15	19
Biotite	2	21	6	9	19	24	9	4	27	19	15			4	17	16
Magnetite	1			2	1	1		3								
Garnet									4	7						
Kyanite									2	Trace						
Other										2	1	2		1	1	
Total	100	100	100	100	100	100	100	100	100	100	100	100		100	100	100
Chemical analyses																
SiO_2	66.6	49.3	73.7	67.8	59.2	79.1	70.0	65.1	66.4	67.1	60.1	64.0	52.9	55.0	58.9	60.9
Al_2O_3	16.5	17.0	14.0	16.7	17.5	7.4	15.5	16.5	16.0	14.8	17.5	12.1	19.4	15.6	17.0	17.1
Fe_2O_3	1.5	2.2	.64	1.5	3.1	1.2	.37	2.4	1.5	2.1	1.3	2.3	1.7	1.1	1.1	.84
FeO	1.8	6.4	.78	1.6	3.9	3.3	1.3	2.2	4.5	4.6	4.9	5.3	6.4	4.4	5.2	4.6
MgO	.7	8.1	.4	.7	2.1	2.1	.8	.7	2.0	1.9	2.6	5.6	3.8	3.5	3.4	2.9
CaO	4.3	9.7	1.3	4.0	6.8	.22	2.3	3.4	2.5	2.5	6.2	6.5	7.8	12.7	6.9	6.3
Na_2O	3.9	3.1	3.0	4.3	3.6	.75	3.4	4.3	2.5	2.4	3.4	.62	3.7	2.7	3.5	3.5
K_2O	3.2	1.6	5.2	1.3	1.3	3.9	4.7	3.3	1.9	1.0	1.8	.11	1.4	.65	1.4	1.8
H_2O-	.04	.02	.11	.06	.09	.10	.07	.08	.22	.16	.02	.09	.03	.09	.06	.07
H_2O+	.54	.61	.56	.84	.91	1.0	.68	.60	1.1	1.1	.85	1.2	.93	.82	.89	.81
TiO_2	.32	1.1	.29	.35	.75	.54	.40	.82	.63	.57	.62	1.4	.98	.82	.81	.67
P_2O_5	.33	.34	.16	.33	.40	.16	.25	.32	.39	.35	.31	.28	.66	.45	.39	.31
MnO	.08	.21	.00	.04	.10	.08	.03	.13	.16	.24	.16	.15	.16	.32	.12	.09
CO_2	.11	.10	.11	.15	.11	.18	.11	.11	.10	.11	.09	.22	.11	1.5	.14	.08
Total	99.92	99.78	100.25	99.67	99.86	100.03	99.91	99.96	99.90	98.93	99.85	99.87	99.97	99.65	99.81	99.97

See explanation at end of table.

TABLE 1.—*Modes, chemical analyses, and C.I.P.W. norms, in percent of 16 rock samples from the Spur Mountain Lake, Tyee Lake, and Eagle Lake powersites*—Continued

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
C.I.P.W. norms																
q	22.1		33.6	31.2	16.1	55.5	26.6	20.0	36.4	40.5	14.5	36.9	2.0	11.8	12.4	17.9
c			1.7	2.6		2.0	1.5	.7	7.5	6.5		.3				2.0
or	19.0	9.5	30.8	7.8	7.8	23.3	28.0	19.6	11.4	6.0	10.7	.7	8.3	3.9	8.4	10.9
ab	33.2	25.4	25.5	34.3	30.8	6.4	29.0	36.6	21.5	20.8	29.1	5.3	31.6	23.1	29.9	30.4
an	18.2	28.0	4.7	17.0	28.0		9.1	14.2	6.9	9.6	27.4	29.4	32.5	28.9	26.8	20.8
ne		.6														
wo	.2	7.4			1.1						.4		.6	9.2	1.8	
en	1.7	4.8	1.0	1.8	5.3	4.9	2.0	1.8	5.1	4.8	6.5	14.1	9.6	8.9	8.6	7.4
fs	1.7	2.0	.4	1.2	3.6	4.4	1.5	.9	6.4	6.4	7.3	5.9	9.1	6.5	7.6	7.0
fo		10.9														
fa		5.0														
mt	2.2	3.2	.9	2.2	4.5	1.8	.5	3.5	2.2	3.1	1.9	3.4	2.5	1.6	1.6	1.2
il	.6	2.1	.5	.7	1.4	1.0	.8	1.6	1.2	1.1	1.2	2.7	1.9	1.5	1.6	1.3
ap	.8	.8	.4	.8	1.0	.4	.6	.8	.9	.8	.7	.7	1.6	1.3	.9	.7
cc	.2	.2	.2	.3	.2	.2	.2	.2	.2	.3	.2	.5	.2	3.4	.3	.2
mg						.3										
Total	99.9	99.9	99.7	99.9	99.8	100.2	99.8	99.3	99.7	99.9	99.9	99.9	99.9	100.1	99.9	99.8

1. Granodiorite from right abutment of Spur Mountain Lake damsite (pl. 3). Granular texture. Plagioclase (An_{35}), hornblende, and biotite are subhedral to anhedral. Quartz and microcline are anhedral. Average grain size is 0.75 mm. Microcline grains are as much as 2 mm in diameter. Some hornblende grains enclose augite.
2. Meladiorite from band of dioritic rock on lakeshore 1,150 feet east of outlet of Spur Mountain Lake (pl. 3). Equigranular, with finely gneissic texture. Average grain size is 0.25 mm. Biotite laths are as long as 0.75 mm. All minerals are fresh and unaltered and show no indication of strain or deformation. Plagioclase is andesine (An_{40-45}). Apatite is the only common accessory mineral.
3. Quartz monzonite from an outcrop about 2,000 feet from the southeast end of Spur Mountain Lake, approximately on the tunnel route to Unuk River (pl. 3). Granitic texture. Microcline and quartz grains are as much as 2.5 mm in diameter. Plagioclase is fractured and extensively altered to kaolin and sericite. Biotite is altered in part to chlorite and locally to epidote. Plagioclase is andesine (An_{30-35}). Zircon is a common accessory mineral.
4. Quartz diorite (tonalite) from crest of Spur Mountain on tunnel route to Hulakon River (pl. 3). Granitic texture. Average grain size is about 0.50 mm. Plagioclase and quartz grains are as much as 1.5 mm in diameter. The plagioclase (An_{35}) is fractured and partly altered to sericite or kaolin. Much of the biotite is altered to chlorite and epidote.
5. Quartz diorite from left abutment of Tyee Lake damsite, 150 feet northwest of outlet (pl. 2). Variable grain size. Hornblende crystals are as much as 8 mm long. Quartz and plagioclase have maximum diameters of 3 and 5 mm, respectively. Light-colored minerals are largely unaltered. Hornblende is slightly altered to chlorite; biotite is partly altered to chlorite and epidote. Plagioclase is andesine (An_{47}).
6. Biotite gneiss (biotite-quartz granite) from point of land on south shore of Tyee Lake about 1 mile southeast of outlet (pl. 2). From mixed gneiss unit. Quartz and feldspar grains are anhedral; biotite grains are subhedral. Grain size varies across banding. Microcline grains have a diameter of as much as 1 mm. Plagioclase (oligoclase, An_{28}) occurs in scattered small grains and is highly altered to sericite. Biotite is partly altered to epidote. Microcline is free of alteration.
7. Granite (adamellite) from north shore of Tyee Lake, 2,800 feet east of outlet (pl. 2). Average grain size is about 0.3 mm. Plagioclase (andesine, An_{32}) grains have a maximum diameter of about 2 mm. Quartz and feldspar grains have irregular, embayed borders. Plagioclase and microcline are slightly altered. Biotite is partly altered to chlorite and is locally bleached. Larger grains are surrounded by complex intergrowths of finer material, which suggests shearing or crushing in a partly solidified magma during emplacement.
8. Granodiorite from crest of ridge 3,400 feet north-northeast of outlet of Tyee Lake (pl. 2). The rock is very inequigranular. Grain size ranges from submicroscopic to as much as 3.5 mm. The minerals are highly fractured, and plagioclase (oligoclase, An_{28}) is altered to sericite or kaolin along the fractures. The mafic minerals are well preserved and show only minor alteration of biotite to chlorite and hornblende to epidote. The rock appears to have undergone some postmagmatic crushing and recrystallization of the quartz and feldspar.

9. Garnetiferous biotite gneiss from left abutment of Eagle Lake damsite, about 1,000 feet north of lake outlet (pl. 1). Average grain size is about 1.5 mm. Anhedral garnet crystals have diameters of as much as 2 mm. Plagioclase is andesine (An_{30}). Biotite laths are bent and shredded, and some appear to bend around ovoid masses of quartz, feldspar, and garnet. Graphite flakes are common.
10. Garnetiferous biotite gneiss from left abutment of Eagle Lake damsite, 1,500 feet north of lake outlet (pl. 1). Texture and interrelation of minerals generally are similar to those of gneiss at locality 9. Magnetite and apatite are common accessory minerals. Plagioclase is andesine (An_{35-40}).
11. Garnetiferous gneissic quartz diorite from right abutment of Eagle Lake damsite, about 1,200 feet north of lake outlet (pl. 1). Average grain size is about 0.50 mm. Some plagioclase (andesine, An_{35-40}) grains have a diameter of 5 mm. Large plagioclase and quartz masses are enclosed by finely granular aggregates which are strung out parallel to gneissic banding. Undulatory extinction in quartz and bent twin lamellae in plagioclase are common throughout the thin section.
12. Amphibolite from left abutment of Little Eagle Lake damsite about half a mile north of outlet of Little Eagle Lake (pl. 1). Hornblende occurs in large irregular optically discontinuous masses or clots. Hornblende and plagioclase (bytownite An_{80}) occur in association; quartz occurs separately near edge of thin section. Bulk analysis and norms include a larger percentage of quartz than is in thin section. Accessory minerals include zircon and a widely disseminated sulfide, probably pyrite.
13. Rock from left bank of Eagle River about 3,500 feet below outlet of Little Eagle Lake (pl. 1). Mineral composition not tabulated. Thin section includes part of a biotite-hornblende gneiss band in contact with a rock principally composed of plagioclase, clinozoisite, diopside, and abundant relatively large euhedral zircon crystals.

14–16. Gneissic quartz diorite from southwest shore of Eagle Lake 5,500, 13,000, and 16,000 feet, respectively, from outlet of lake (pl. 1). From mixed gneiss unit. The rocks are roughly banded and show indications of deformation that include granulated quartz and feldspar, undulatory extinction in quartz, bent feldspar-twin laminae, and bent and shredded biotite laths. Plagioclase is andesine (An_{40}). Maximum grain size is about 3.5 mm in hornblende. Accessory minerals are apatite, corundum, and rutile. The three samples are nearly identical in megascopic appearance and texture.

Sample 12 is an amphibolite. The mineral composition of sample 13 was not tabulated because this sample includes the contact between two bands of widely divergent mineralogy. Sample 13 contains scattered grains of calcite, and the chemical composition of both samples 12 and 13 indicate that the rocks probably resulted from the high-grade metamorphism (amphibolite facies) of impure calcareous sediments.

MARBLE

Marble interbeds in the gneiss occur near Eagle Lake at two localities. One is on the east side of the Eagle River about half a mile below the outlet of the lake and the other is on the south side of Eagle Lake near the upper end (pl. 1). The marble interbed near the lake outlet crops out in the channel of a small tributary stream at an altitude of about 800 feet. The thickness of the bed ranges from 15 to 20 feet. The marble is dense, white, and medium grained and contains evenly distributed graphite flakes oriented parallel to the foliation in the adjacent gneiss. The marble exposed near the upper end of the lake is at least 12 feet thick, is coarsely crystalline and massive, and contains scattered small rounded grains of a pale-green mineral, probably diopside.

IGNEOUS ROCKS

Spur Mountain Lake and Tyee Lake lie within the Coast Range batholith. The predominant rock at both localities is medium-grained inhomogeneous crudely banded granodiorite (pls. 2, 3). The granodiorite grades locally to quartz monzonite and quartz diorite. Diorite bands large enough to map occur at Spur Mountain Lake, and hornblendite masses or bands were seen at both localities. Coarse massive quartz diorite underlies the outlet area of Tyee Lake, apparently as a discordant body crosscutting the gneissic banding in the granodiorite and composite gneiss which surrounds the lake.

The relative ages of the different igneous rocks are not completely known. The hornblendite bodies at Spur Mountain Lake are brecciated and appear to be intruded by granodiorite. At an exposed contact between diorite and granodiorite at Spur Mountain Lake, the granodiorite appears to be intruded along preexisting planes of foliation and joints in the diorite.

GRANODIORITE

Granodiorite is medium to coarse grained, light gray, and generally compositionally banded. The thickness and the composition of bands are variable. In addition to the large mappable bands of diorite described in the section above, small inclusions or segregations of dioritic or more basic rock occur throughout the granodiorite. Although the average composition of the unit as mapped is probably granodiorite, much of the rock is locally quartz dioritic or quartz monzonitic (table 1). The granodiorite is classified as an igneous rock in this report, although it could be considered a metamorphosed intrusive rock (orthogneiss). Some of the granodiorite examined shows microscopic evidence of postmagmatic deformation.

HORNBLENDITE

Rock composed predominantly of hornblende crystals and minor interstitial plagioclase and some biotite occurs at Spur Mountain Lake and Tyee Lake. At Tyee Lake the hornblendite crops out for about half a mile along the crest of the ridge about half a mile northeast of the lake outlet (pl. 2). It appears to be in gradational contact with granodiorite which crops out to the northeast. Hornblendite occurs as a band or elongate mass about 50 feet wide in the granodiorite on the crest of Spur Mountain. Similar rocks crop out on the southeast shore of Spur Mountain Lake about 4,000 feet northwest of the outlet. The hornblendite bodies near Spur Mountain are severely fragmented and are intruded by heavy irregular veins of granitic or granodioritic rock; they are not large enough to be shown on the geologic map.

DIORITE

Diorite crops out along the shore of Spur Mountain Lake from 600 to 1,200 feet east of the outlet of the lake (pl. 3) in a band about 600 feet wide which trends N. 10°–15° W. This band probably extends to the northeast shore of the lake directly opposite the outlet. Another outcrop of diorite is on the southwest shore of the lake about 4,000 feet northwest of the outlet, where the diorite is in gradational contact with the hornblendite described above. The rock is generally finer grained and more distinctly banded than the granodiorite.

QUARTZ DIORITE

The outlet of Tyee Lake and the hill west of the outlet are underlain by coarse-grained quartz diorite inferred to be part of a discordant body which cuts the gneissic rocks exposed around the lake (pl. 2). Quartz diorite with similar characteristics crops out along Bradfield Canal east of the mouth of Tyee Creek. The quartz diorite is massive and contains scattered schlieren of fine-grained gneissic rock.

UNCONSOLIDATED DEPOSITS

The largest deposits of unconsolidated material within the study area are the deltaic and alluvial deposits at the heads of Burroughs Bay and Bradfield Canal. However, the deposits more directly related to the present investigation are glaciofluvial and alluvial deposits at the heads of Tyee and Spur Mountain Lakes, flood-plain deposits along the Eagle River, talus, colluvium, and soil cover.

The alluvial plains at the heads of Tyee and Spur Mountain Lakes are underlain by moderately well sorted and stratified gravel, sand, and silt. The deposits probably include beds of lacustrine silt and possibly some buried morainal material. Smaller alluvial plains occur at the head of Eagle Lake and above the small pond below the outlet of Spur Mountain Lake.

In addition to the broad deltaic areas at the heads of the lakes, smaller deltas have been built into Spur Mountain and Eagle Lakes by tributary streams. These small deltas are made up predominantly of subangular to subround gravel and some sand, and the deposits are probably more poorly sorted and stratified than the deposits at the heads of the lakes.

The flood plain of the Eagle River between Eagle Lake and Little Eagle Lake is underlain by sorted and stratified sand and gravel. The basin of Little Eagle Lake contains a large volume of alluvium that probably includes beds or lenses of fine sand, silt, and peat or highly organic silt as well as coarser sand and gravel.

Talus deposits composed of large angular blocks of bedrock occur along the lower slopes of the mountains surrounding Tyee and Spur Mountain Lakes. The gorge of Tyee Creek and the deep draw which trends northwest from the outlet area are filled with large blocks of quartz diorite. No deposits of large talus blocks were noted at Eagle Lake.

Colluvium composed of angular unsorted rubble has collected at the base of steep slopes along Eagle Lake and the Eagle River as a result of rockfalls, snow avalanches, and rapidly running water during periods of high runoff.

STRUCTURE

The strike of gneissic banding or foliation and the trends of observed contacts are generally northwest throughout the study area. Measured strikes range from north to west-northwest. Dips are consistently to the north and east at Spur Mountain Lake; the average is about 50° NE. Dips at Tyee Lake are also predominantly to the north and east, but they are variable. At Eagle Lake, dips are generally steep and range between 70° NE. and 70° SW. Abrupt changes of dip at Eagle Lake suggest widespread tight folding.

Joints are steeply dipping to vertical. Figures 2, 3, and 4 are contour diagrams of poles plotted to joints measured at Spur Mountain Lake, Tyee Lake, and Eagle Lake, respectively. The joint systems at Spur Mountain Lake and Eagle Lake are similar; two major sets strike N. 65° E. and N. 10° W., respectively, and dip vertically or near vertically. The northeasterly striking set is also present at Tyee Lake.

In the main, joints are laterally persistent but widely spaced. No slickensides or other evidence of movement on joint faces were observed.

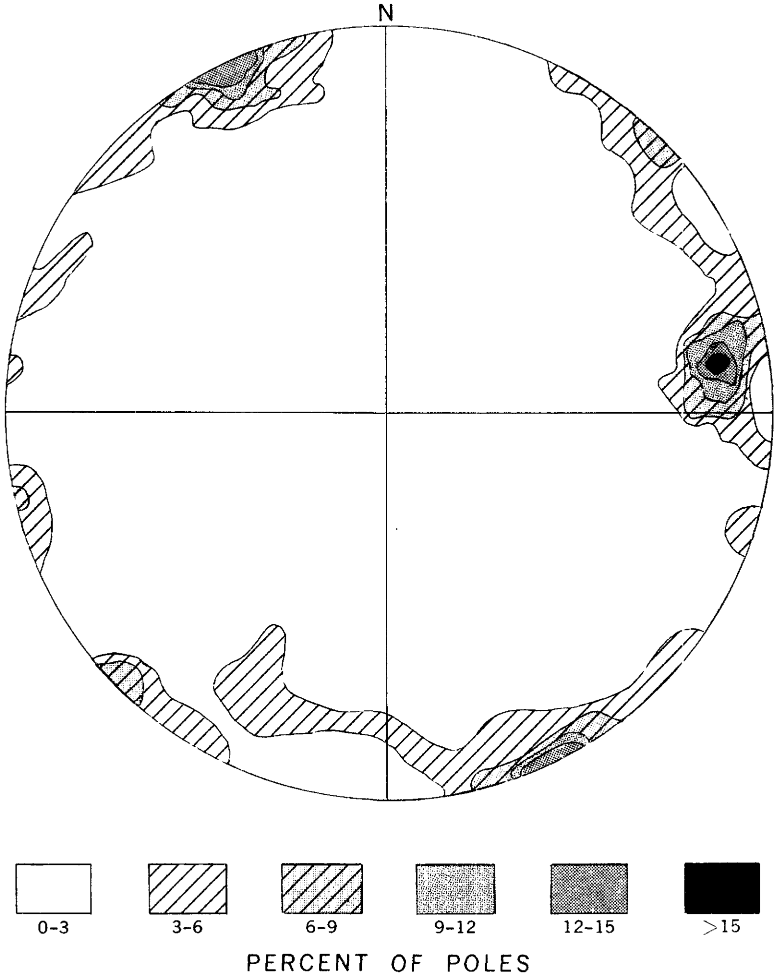

FIGURE 2.—Contour diagram of poles of 120 joints measured in the Spur Mountain Lake powersite area. Poles plotted on lower hemisphere. Contoured on percent of poles. (Billings, 1954, p. 108–114.)

Evidence of faulting in the outcrop could not be found because of the lack of persistent distinctive marker horizons or layers and the heavy brush cover in the area. Microscopic indications of strain and movement, such as undulatory extinction and granulated minerals, were observed in thin section, but they could denote protoclastic texture.

Linear topographic features seen on aerial photographs are common throughout the study area. Near Spur Mountain Lake and Tyee Lake the most obvious and persistent lineaments parallel the major

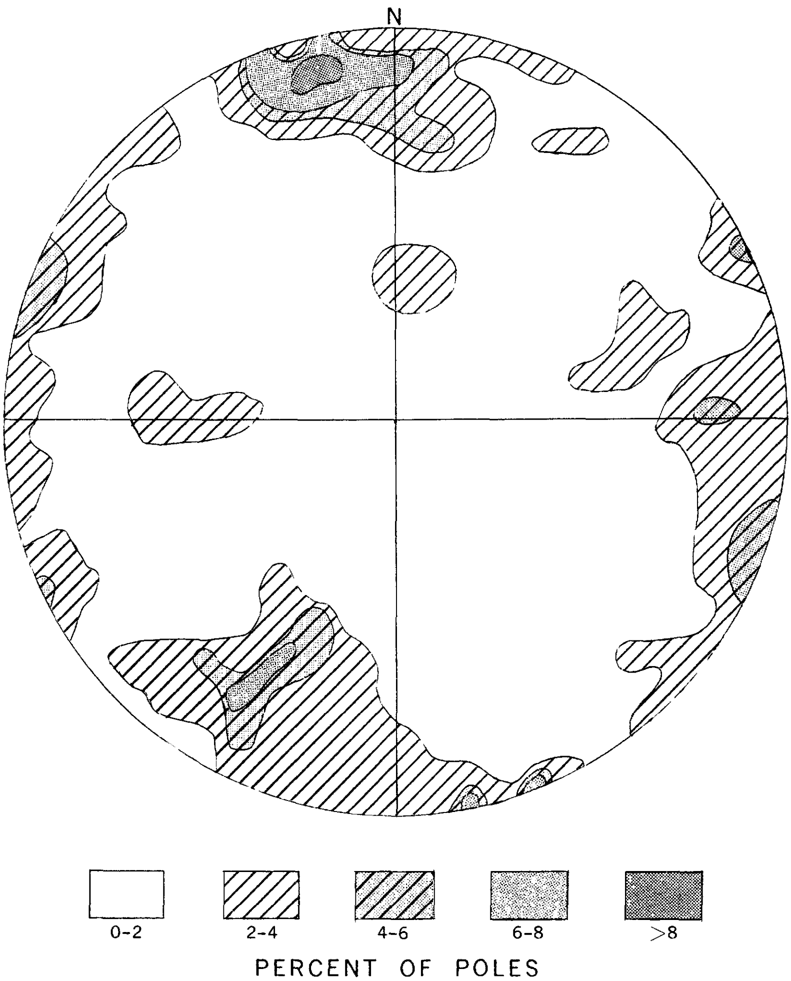

FIGURE 3.—Contour diagram of poles of 127 joints measured in the Tyee Lake powersite area. Poles plotted on lower hemisphere. Contoured on percent of poles. (Billings, 1954, p. 108–114.)

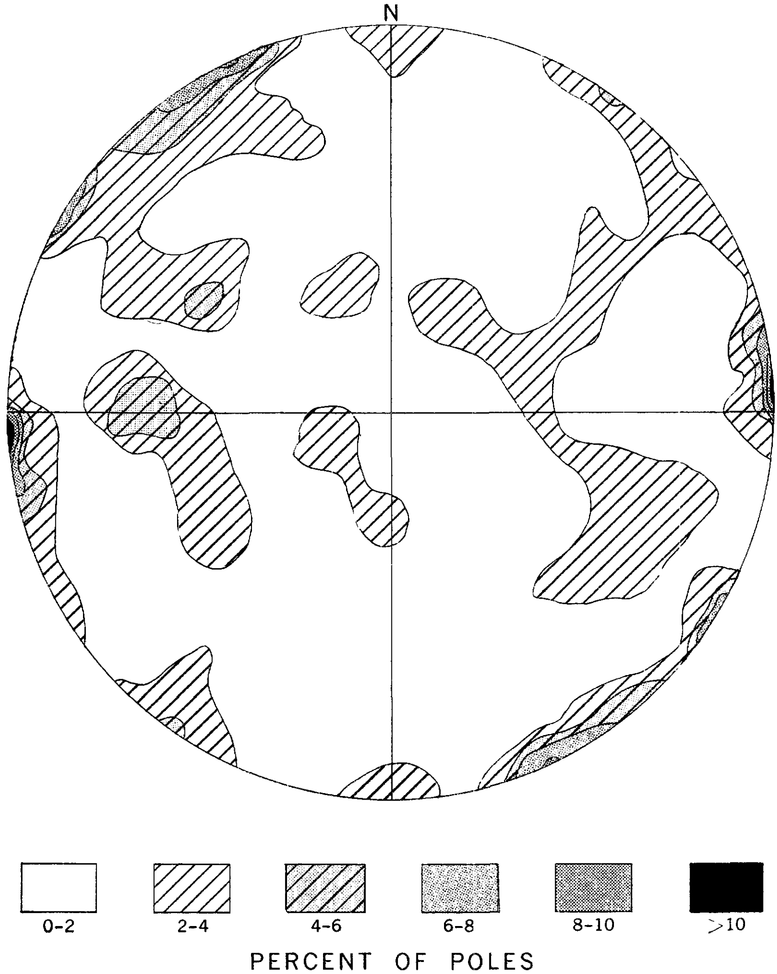

FIGURE 4.—Contour diagram of poles of 96 joints measured in the Eagle Lake powersite area. Poles plotted on lower hemisphere. Contoured on percent of poles. (Billings, 1954, p. 108–114.)

joint directions. At Eagle Lake the most obvious and longest lineaments are parallel to the foliation. Some of the lineaments at Eagle Lake are wide, show considerable relief, and may represent solution channels developed along marble beds. Some of the lineaments at Eagle Lake can be traced on the photographs for 4 or 5 miles along the valley with no apparent offset.

In addition to the lineaments described, which are of local significance only, segments of several lineaments of regional significance traverse the study area. Bell Arm, Burroughs Bay, and the valley of the Unuk River are parts of a system of east-northeast-trending lineaments which were interpreted as faults by Twenhofel and Sainsbury (1958, p. 1442). A lineament of similar size extends parallel to the Unuk River from the Hulakon River northeastward across Spur Mountain for about 15 miles and includes the upper valley of Spur Mountain Lake.

The valley of the Eagle River and Eagle Lake is a segment of the Coast Range lineament, a major linear feature defined by Twenhofel and Sainsbury (1958, pl. 2).

EARTHQUAKES

The nearest recorded earthquake epicenters lie 75–100 miles west of the study area. Earthquakes were felt on a single occasion each at Hyder, Ketchikan, and Wrangell (Heck, 1958), but no damage was reported. Earthquake epicenters in southeastern Alaska and coastal British Columbia appear to roughly parallel major linear topographic trends, the largest of which include Chatham Strait–Lynn Canal and the west coasts of Baranof, Chichagof, and the Queen Charlotte Islands (St. Amand, 1957). These lineaments are considered to be traces of active fault zones (Twenhofel and Sainsbury, 1958). One of the major lineaments is the Coast Range lineament described previously. Evidence of recent movement along the Coast Range lineament is lacking. However, the region seems to be subject to crustal unrest as shown by post-Pleistocene uplift (Twenhofel, 1952). The uplift can be attributed to either glacial rebound or tectonic disturbances, but in either case such adjustments could be accompanied by seismic shocks. All heavy, rigid structures should be located on bedrock and designed to withstand moderately severe earthquakes.

SPUR MOUNTAIN LAKE POWERSITE

TOPOGRAPHY AND DRAINAGE

Spur Mountain Lake (pl. 3) is about 4 miles north of the head of Burroughs Bay, an arm of Behm Canal. The lake occupies a narrow bedrock basin in a U-shaped glacial valley that is a hanging valley tributary to the wider and deeper trough in which the Unuk River flows. The valley has a sinuous course from east to south to southwest in the upper part, then turns abruptly southeast at the head of the lake. The valley is about 6½ miles long. Valley walls show evidence of alpine glaciation to an altitude of about 3,500 feet.

Spur Mountain Lake is at an altitude of about 1,889 feet. The lake is about 1½ miles long, averages about one-fourth mile in width, and is 253 feet deep. Its deepest part, at an altitude of 1,636 feet, is about half a mile from the southeast end of the lake (pl. 3). The outlet stream flows southwest out of the lake, drops about 190 feet in one-fourth mile to a small flood plain, turns abruptly to the southeast, and flows into a small pond. Below the pond the stream drops about 1,500 feet in 2 miles to the flood plain of the Unuk River. The lake is fed mainly by two streams, one of which flows into the head of the lake and drains the greater part of the basin. The other stream flows into the lake from the southwest, draining a large tributary valley. In addition, numerous small streams and rivulets flow in precipitous courses from the valley walls along the lower two-thirds of the lake. Although the stream at the head of the lake and some of the minor streams have small glaciers at their sources, no appreciable amount of silt was being carried into the lake in September 1964. The drainage area of the lake is about 10 square miles.

The reservoir site includes the lake and that part of the upper valley which would be inundated by raising the water level. Because of the flat gradient of the valley floor above the lake, a 50-foot rise in the lake level would almost double the length of the lake.

The damsite is at the outlet of the lake and consists of a low northwest-trending bedrock ridge or lip which impounds the lake. The ridge is breached at the outlet and at a deep saddle through the left abutment about 600 feet southeast of the outlet (pl. 3). Southeast of the saddle the left abutment widens to a broad flat-topped hill. The ground surface of the right abutment rises gradually to an altitude of about 2,100 feet, then drops into a shallow depression where it merges with the main valley wall. The right abutment is very narrow in a northeast-southwest direction, normal to the axis of the proposed dam.

DEVELOPMENT

The topography and the underwater contours on the lake bottom indicate that the greatest amount of storage for a given change in the water level would be obtained by raising the water level of the lake by construction of a dam. The water would be drawn down by means of a tunnel at the present surface (pl. 3). This method would take advantage of the flat valley bottom above the lake. Another method would involve simply drawing the lake down below its present surface. A combination of the two methods could also be used.

Raising the lake to the 2,000-foot level would increase the storage capacity by about 48,000 acre-feet. Raising the water level to an altitude much above 2,000 feet would not increase the storage capacity appreciably. A dam with a crest altitude of 2,000 feet would be about 1,660 feet long. It would essentially be in two sections, one on each side of the 1,996-foot knob east of the outlet.

Another method, which would result in about 60 percent as much storage capacity as the above scheme, would be to build a dam with a crest altitude of 1,950 feet and to tap the lake about 40 feet below the surface at the 1,850-foot level. This would lengthen the tunnel routes by several hundred feet, but the crest length of the dam would be reduced to about 790 feet, which would include a 590-foot-long main dam and a 200-foot-long dam in the saddle in the left abutment.

Water from Spur Mountain Lake could be diverted for the generation of power by means of a surface conduit down the valley parallel to the outlet stream or by one of two possible tunnel routes (pl. 3). Because the geologic problems encountered in the construction of a surface conduit would be of little significance, only the tunnel routes will be discussed. One of the tunnel routes extends from the southeast tip of the lake, about 1,400 feet southeast of the outlet, to a powerhouse on the Unuk River about 5,000 feet upstream from its confluence with the outlet stream. The length from intake to powerhouse is about 11,200 feet. If a near-horizontal grade is maintained in the tunnel, this length would include a tunnel about 7,500 feet long and a penstock about 3,700 feet long. The penstock could be a surface conduit, a buried conduit, or a tunnel with an inclination of about 60 percent. The other tunnel route is near the upper end of the lake; the tunnel would be cut through Spur Mountain to a powerhouse on the Hulakon River. A horizontal tunnel would be about 7,200 feet long, with a 2,800-foot penstock inclined at about 60 percent. The penstock could be one of the three types described above.

DAMSITE

The longest section of the dam would be underlain by medium-grained hornblende-biotite granodiorite, which grades locally to quartz monzonite and quartz diorite. The rock is banded; the banding ranges in development from very obscure to moderately pronounced. The rock does not part parallel to the banding. Thus, the banding is probably primary flow structure. Elongate inclusions of fine-grained and finely banded diorite occur in the granodiorite. Joints cut the granodiorite at intervals ranging from a few inches to more than 15 feet. Most of the talus blocks at and below the outlet are several feet in diameter. After removal of soil cover and colluvium, the rock surface would be an excellent foundation for any type of dam.

The contact between the granodiorite and the diorite east of the outlet is exposed at the lake shore near the north end of the saddle in the left abutment. The contact appears to trend through the saddle parallel to the general strike of the gneissic banding.

The diorite is generally finer grained and more distinctly banded than the granodiorite. Locally, some partings are developed in the diorite parallel to the banding. Separation of the two rock types into mappable units is arbitrary because the diorite contains a large percentage of interbanded coarse granitic rock. The strength of the diorite does not differ significantly from that of the granodiorite, and the partings in the diorite are less continuous than the joints which cut both rock types. Both the diorite and the granodiorite are dense, compact rocks which have negligible permeability except where fractured.

Narrow abutments and unfavorably oriented joints are factors which might considerably affect the design and the cost of a dam. A careful and complete subsurface exploration should be made in the damsite area. The two major joint sets strike at high angles through the abutments. The joints are generally tight and widely spaced, but some of them are continuous for several tens of feet. Three prominent notches in the right abutment parallel the northeast-striking joints. The deep saddle in the left abutment and the outlet lie along the trend of north-northwest-striking joints.

Bedrock is at or near the surface along most of the longer (western) section of the possible dam axis. The rock would be a competent foundation for a concrete gravity dam, which would have the base best suited to the narrow abutments of the damsite. The depth and type of unconsolidated fill in the saddle in the left abutment would determine the type of dam required for the shorter section. Although bedrock is present at the lakeshore at the upper end of the saddle, the bedrock surface may plunge abruptly under cover away from the lake.

Subsurface exploration should include core drilling at several points along the possible dam axis. Holes drilled at an angle from both banks of the outlet stream and from either side of the deep saddle would cross beneath these features and intersect possible narrow buried channel deposits that might be missed by vertical holes. The cores would indicate the character of the bedrock at depth, particularly the frequency of joints and fractures, and the degree of weathering along them. Core drilling should be followed by pressure or pumping tests to determine the amount of seepage to be expected under the dam and through the abutments. A resistivity survey along the possible dam axis, especially in the deep saddle in the left abutment, might be used to supplement drilling to determine the depth of the unconsolidated deposits.

TUNNEL ROUTES

Both tunnel routes are underlain by similar rocks, and geologic conditions are similar insofar as the construction and maintenance of a tunnel is concerned (pl. 3). The rocks along the Unuk River route appear more uniform than those along the Hulakon River route. The rocks along the Unuk River route are similar to the medium- to coarse-grained granodiorite exposed in the right abutment of the damsite. One fairly representative sample examined in thin section is quartz monzonite (loc. 3, table 1). In general, the rock has poorly defined banding. Joints in the rock are spaced several feet apart.

The rocks along the Hulakon River tunnel route are predominantly medium- to coarse-grained quartz diorite or granodiorite. Narrow interbands of dark-gray diorite gneiss are common in the granodiorite. The 50-foot-wide hornblendite zone described on page 11 is near the tunnel alinement at the crest of Spur Mountain.

Because the bedrock is similar along the two tunnel routes, the choice of routes is based on structure and topography; other possible factors, such as accessibility of the powerhouse and transmission line rights-of-way, are beyond the scope of this report.

A tunnel along the Hulakon River route would be under adequate cover for its full length. It would pass near the major lineament at the head of the lake but would not cross the lineament. Other lineaments observed along this route are believed to be joint controlled.

The Unuk River tunnel route parallels the valley below the lake outlet. Along the most direct route the tunnel would come within a few hundred feet of the valley wall at a point about 4,500 feet from the lake. At this locality several strong lineaments shown on the aerial photographs parallel the major joint set that strikes N. 60°–70° E. (pl. 3). Another lineament interpreted possibly as a small fault or shear zone strikes about N. 20° E. To avoid possible excessive leakage from the tunnel at this locality, the tunnel alinement could be shifted slightly east or a reinforced lining could be used in this part of the tunnel. Otherwise, neither tunnel would require a lining except to provide for a smoother hydraulic flow.

Both tunnels would be driven from points where tributary streams enter the lake. The streams have built small deltas into the lake, and some provision would have to be made to prevent the coarser sediments that are carried into the lake from entering the tunnel intake. Another source of sediment which might affect the intake of the Hulakon River tunnel is the main stream entering the lake opposite the intake.

POWERHOUSE SITES

Neither of the powerhouse sites was examined, but no evidence to indicate a significant difference in bedrock lithology from rocks elsewhere in the area was seen on the aerial photographs. At the Unuk River site the powerhouse could be built on bedrock near the water's edge on the northernmost side channel of the river. At the Hulakon River site the powerhouse would have to be built several hundred feet back from the river at the base of the valley wall in order to have a bedrock foundation. Because of the flatness of the valley floor, this would not entail a significant loss of head.

RESERVOIR SITE

The rocks exposed around the reservoir site are predominantly granodiorite or quartz diorite. The diorite zone which trends through the left abutment of the damsite can be correlated with rocks of similar lithology on the northwest shore of the lake. Diorite, grading to hornblendite, crops out on the southwest shore of the lake about 4,000 feet from the outlet.

The reservoir site is a rock basin carved in massive impervious intrusive granodiorite (pl. 3). Except at the damsite area, significant water losses from the reservoir would be unlikely. The slopes above the lake are steep, but no evidence of large-scale landslides, rockfalls, or snow avalanches was observed. It is unlikely that raising the water level by 50 or 100 feet would cause any change in the stability of the slopes.

CONSTRUCTION MATERIALS

Surficial deposits underlying the alluvial plain above the head of Spur Mountain Lake are the nearest large source of construction materials to the damsite. These deposits consist of beds or lenses of gravel, sand, and possibly some glacial silt. The gravels consist of cobbles and pebbles of intrusive rock similar to the bedrock exposed around the lake, and they should make good coarse aggregate. A more limited supply of fine to coarse aggregate could be obtained from the flood plain immediately above the small pond below the outlet. Clean gravel could be obtained from the small delta built by the large tributary stream near the head of the lake. Large angular blocks of intrusive rock suitable for riprap are in all the talus deposits around the lake.

TYEE LAKE POWERSITE

TOPOGRAPHY AND DRAINAGE

Tyee Lake is about 1½ miles due south of the head of Bradfield Canal at the lower end of a northwest-trending glacial valley which extends 6 miles above the lake outlet (pl. 2). The lake is about 2¼ miles long and has a maximum width of 2,000 feet and a surface area of approximately 425 acres. The surface of the lake was at an altitude of 1,387 feet on July 24, 1963, and the lowest part of the lake bottom is at an altitude of less than 1,060 feet. Tyee Lake is drained by Tyee Creek. The creek flows north out of the lake through a deep, narrow gorge, turns northwest about 2,300 feet from the outlet, continues northwest to its intersection with Hidden Creek, and flows north-northeast from Hidden Creek into a slough of Bradfield Canal. The drainage area of Tyee Lake is about 14 or 15 square miles. A large stream flows into the upper end of the lake, and two smaller tributaries flow into the lake from the northeast and southwest. Three small glaciers lie within the drainage basin, but they apparently do not contribute much silt to the lake because the water is clear.

DEVELOPMENT

According to a report of the Federal Power Commission and U.S. Forest Service (1947, p. 61), complete regulation of the discharge of Tyee Lake (estimated 182 cubic feet per second) would require storage of 72,000 acre-feet of water. This storage capacity could be attained by raising the water level to an altitude of about 1,510 feet by a dam at the outlet of the lake, by drawing the lake down to 1,160 feet by means of a tunnel 227 feet below the present water surface, or by a combination of the two methods. The water could be conveyed to a powerhouse site on Bradfield Canal near the mouth of Tyee Creek by a tunnel which has its intake on the north shore of Tyee Lake. The Federal Power Commission and U.S. Forest Service (1947) mentioned an inclined tunnel with a 20-percent grade but suggested that a horizontal tunnel which has an inclined penstock would cost less to build. The location of the intake would depend on whether or not the lake is to be drawn down below its normal level. The shortest tunnel-penstock route would extend from a point near the outlet of the lake north to the powerhouse site. However, to insure sufficient rock cover in the draw about 1,800 feet north of the outlet, the route should pass east of the 1,500-foot contour in the draw (pl. 2). This would place the intake about 1,100 feet east of the outlet. Assuming a horizontal tunnel at the present water level, the tunnel would be about 4,800 feet long and the penstock 1,800 feet long.

To develop the storage by drawdown alone, the tunnel intake would have to be at least 2,200 feet east of the lake outlet to reach the required depth. This would place the intake almost under the center of the lake and would result in a tunnel about 5,600 feet long and a penstock 1,600 feet long.

DAMSITE

The narrowest constriction in the gorge of Tyee Creek is between 100 and 150 feet north of the lake outlet, as shown along alinement *A–A′* (pl. 2). However, a greater width of bedrock is exposed 150–200 feet further downstream, near alinement *B–B′*. The exact location and type of dam would largely depend on the depth and permeability of the fill which underlies the floor of the gorge, but the axis would undoubtedly fall somewhere between alinements *A–A′* and *B–B′* (pl. 2). At the 1,510-foot altitude, the length of the crest line or chord of the dam would be 283 feet along alinement *A–A′*, and the crest would be about 144 feet above the surface of Tyee Creek. Along alinement *B–B′*, the length would be 332 feet, and the crest would be about 162 feet above the surface of the creek. The site is well suited topographically for an arch or gravity-arch dam, which would occupy most of the area between the two alinements.

Bedrock in both abutments consists of coarse-grained biotite-hornblende quartz diorite. The quartz diorite sample described in table 1 (loc. 5, pl. 2) is representative of the bedrock at the damsite and in the exposures for several hundred feet along Tyee Creek above and below the damsite. The quartz diorite is cut by irregular pegmatite veins and dikes from ½ to 6 inches thick. Well-defined aplite dikes as much as 2 feet thick cut the quartz diorite. The two largest dikes observed are shown on the geologic map (pl. 2). The dikes are composed of some or all of the mineral constituents of the quartz diorite but in different proportions. The dikes do not differ significantly from the quartz diorite in foundation properties.

The quartz diorite is massive and structureless. In both abutments the rock is cut by many randomly oriented joints and irregular fractures, but only those belonging to the major joint sets persist. Although some of these can be traced from top to bottom of the bedrock exposures in the canyon walls, the major joints strike nearly normal to the abutments and have steep or vertical dips.

The channel section of the damsite is covered by large angular blocks of talus. The thickness of this deposit can be determined only by drilling or by geophysical methods. Straight-line projections of the bedrock walls into the subsurface indicate a possible depth of nearly 200 feet along alinement *A A′* and more than 100 feet along alinement *B–B′* (pl. 2). Depths greater than this are possible if the gorge is eroded along a fault or shear zone; a deep stream channel filled with stream gravel and talus may be present. Although no evidence of shearing or crushing was observed in the outcrops in the abutments, the gorge does not parallel any of the known sets of joints, and the talus deposit is wide enough to cover a fault zone.

In summary, the abutments of the damsite are composed of competent massive unweathered quartz diorite which is capable of supporting any size or type of dam. The attitudes of the persistent joints in the abutments are parallel or at low angles to the axis of the dam. The joints are generally widely spaced and tight, and serious leakage or movement along them is unlikely.

The channel section is filled with coarse angular material to an unknown depth. The fill may be too permeable to hold grout or for other treatment, and complete removal of the material prior to construction of the dam may be required. If the depth of the fill is such that removal would be more costly than a longer tunnel, it might be preferable to develop the required amount of storage by drawing the lake down below its present surface.

TUNNEL ROUTES

Two tunnel-penstock routes are shown on plate 2. These cover the two possible extremes of developing storage by raising the lake or by drawdown. A tunnel route for utilizing storage developed by a combination of the two methods would lie between them. North of the draw, 1,800 feet north of the lake outlet, the two routes would be the same except for the difference in altitude.

The tunnel routes are underlain by granodiorite, injection gneiss, hornblendite, and quartz diorite. The penstock route is underlain by quartz diorite.

Both tunnel intakes would be located in massive granodiorite. The rock is unweathered and generally shows poor banding. Parting does not occur along the banding. The sample described from locality 7 (table 1) is representative of the granodiorite. A tunnel cut in this rock would not require lining. Injection gneiss crops out along the crest of the ridge directly north of the tunnel intake. The longer tunnel would probably intercept the injection gneiss within 700 feet of the intake and penetrate this rock type for about 2,600 feet. The short tunnel would reach the injection gneiss within 300 feet and would be in the gneiss for about 2,400 feet. The gneiss is distinctly banded and has local parting parallel to the banding. Because the banding ordinarily strikes at high angles to the tunnel alinements and has steep dips, such parting should not cause any difficulty in the construction or maintenance of the unlined tunnel. About 2,400 feet north of the lake and on the crest of the second ridge between Tyee Lake and Bradfield Canal, the tunnel routes are underlain by medium- to coarse-grained hornblendite composed mainly of hornblende and about 5–10 percent andesine. The hornblendite is cut by thick irregular pegmatite veins and dikes. The hornblendite grades toward the northeast into a medium-grained granodiorite which may underlie a short segment of the tunnel routes. The northernmost 1,100–1,200 feet of the tunnel routes and the penstock route are in quartz diorite similar to that exposed at the damsite.

The joints along the tunnel and penstock routes are generally tight and widely spaced. An examination of the aerial photographs indicates that the tunnel routes cross two well-defined lineaments. One of these follows an extension of the west-northwest-trending draw 1,800 feet north of the outlet of Tyee Lake. The other lineament is a shallow depression along the crest of the ridge about 2,800 feet north of the outlet (pl. 2). These features are parallel to the northwest-striking set of joints and are probably due to closely spaced jointing. No evidence of faulting was observed in the outcrop along the tunnel routes. However, the lineaments do represent lines of weakness, and the tunnel may require a reinforced lining where it crosses them, particularly the one in the draw where rock cover is at a minimum.

The penstock route is normal to the slope of the ridge, which averages about 80 percent. This orientation would present the least possible exposure to avalanches, rockslides, or rockfalls. Such hazards cannot be completely eliminated, however, and the cost of construction of an inclined tunnel or a buried conduit should be weighed against that of repair and maintenance of an above-ground penstock.

POWERHOUSE SITE

A relatively flat area immediately east of the mouth of Tyee Creek would make a suitable site for a powerhouse if it is first stripped of the large blocks of bedrock which have accumulated at the base of the steep slope above the site. The bedrock surface underlies the colluvium near water level.

The bedrock is quartz diorite that is similar in lithology to bedrock at the damsite, and it would be a competent foundation for a large structure. Most of the unconsolidated material overlying bedrock at the base of the slope is covered by several years' growth of moss and no recent avalanche or slide scars are visible. However, because of the steep slope, the powerhouse should be designed and situated to minimize the threat from this hazard.

RESERVOIR SITE

Tyee Lake lies in a rock basin surrounded and underlain by dense and impermeable igneous and metamorphic rocks (pl. 2). Leakage from the reservoir could occur only near the outlet by drainage through the talus in the gorge of Tyee Creek or through surficial deposits in the deep saddle which trends northwest from the outlet. The saddle is at an altitude of 1,580–1,600 feet and is probably a former outlet of the lake. If the lake is to be raised more than 100 feet, the saddle should be explored by geophysical methods or by drilling to determine the depth of surficial material. It is possible that a deep buried stream channel underlies the talus.

No indications of recent large landslides, rockfalls, or snow avalanches are evident around the reservoir site. A cliff that is 1,300 feet high rises almost vertically above the water surface at a point about 2 miles southeast of the outlet. Single rockfalls involving masses large enough to cause dangerous waves seem unlikely because the most persistent joints trend normal or at high angles to the face of the cliff. However, raising the water level by 100–150 feet could affect the stability of the talus deposit near the foot of the cliff and cause rockfalls. The possibility of overtopping waves should be considered in the design of the dam.

CONSTRUCTION MATERIALS

Significant quantities of sand and gravel are not available at the outlet of Tyee Lake. The nearest source of supply of coarse to fine aggregate in significant quantity is in the alluvial plain at the head of the lake (pl. 2), where beds or lenses of clean sand and gravel may occur. The construction of a road around the lake would be impractical because of the steep slopes, but it may be possible to move the materials down the lake to the damsite by barge. Aggregate could be manufactured from the bedrock or talus deposits near the outlet, or it could be hauled to the site from the alluvial plain at the head of Bradfield Canal. The bedrock at the outlet would make excellent crushed aggregate.

EAGLE LAKE POWERSITE

TOPOGRAPHY AND DRAINAGE

Eagle Lake lies at the south end of a north-northwest-trending glacial valley between Bell Arm and Behm Canal and Bradfield Canal (fig. 1). The upper end of Eagle Lake is within 1½ miles of Bell Arm and is separated from it by a low divide. However, the lake is drained by the Eagle River, which flows northward into Bradfield Canal, about

9 miles from the outlet of the lake. The water surface altitude of Eagle Lake was 296.5 feet on July 26, 1964. Eagle Lake is about 4 miles long and has an average width of about 2,500 feet (pl. 1). The surface area of the lake is about 1,100 acres. Little Eagle Lake, approximately 3,500 feet long and less than 1,000 feet wide, is on the Eagle River nearly 2½ miles below the outlet of Eagle Lake. The water-surface altitude of Little Eagle Lake was 244.7 feet on July 26, 1964. Because of the small difference in altitude between the two lakes, a possible damsite below the outlet of Little Eagle Lake was also examined briefly. The drainage basin above the outlet of Eagle Lake is 26–27 square miles. The height of the water level of the reservoir would be limited by the saddles which cut the divide between Eagle Lake and Bell Arm. The divide is a low bedrock ridge with an altitude of 420 feet which is cut by four saddles with altitudes ranging between 360 and 380 feet.

The maximum relief in the drainage area is about 4,600 feet. Most of the water flowing into Eagle Lake and the Eagle River is obtained from the five large lateral tributaries which enter the main valley from the southwest and northeast.

The storage capacity and drainage area for a reservoir that includes all the drainage area above Little Eagle Lake would be 60–70 percent greater than one which takes in only the basin of Eagle Lake. Presumably, the runoff would be increased proportionally, and the water level required for regulation would be about the same for both sites.

EAGLE LAKE DAMSITE

The damsite at Eagle Lake is at the narrow constriction in the valley of the Eagle River about 1,500 feet below the outlet of the lake (pl. 1). The right abutment is part of the main valley wall and rises from the water level with a uniform slope of about 30°. The left abutment is part of a broad ridge which extends for some distance from the main valley wall. The ridge is surmounted by two large glaciated knobs and several smaller ones which are elongated nearly parallel to the main valley. The ridge is an extension of the spur formed at the intersection of the main glacier of the Eagle River valley and the glacier which occupied the large tributary valley west of the outlet. The area was covered by the Cordilleran ice sheet in late Pleistocene time (Coulter and others, 1965). The ice apparently flowed southward, and the divide at the head of Eagle Lake appears to have been overridden by the ice at that time. The divide is similar to the bedrock lip which characterizes the outlet ends of many glacial valleys in southeastern Alaska. The subsequent reversal in the direction of drainage could be attributed to later modification by alpine glaciation, tilting of the land surface due to tectonic disturbances, or differential adjustment of the land surface resulting from the removal of the ice load.

A dam alinement that has a crest altitude of 400 feet would have a crest length of about 495 feet. The water-surface altitude of Eagle River at this locality is 286 feet, about 10 feet lower than the surface of Eagle Lake.

Bedrock is exposed along the west side of the river and in the knobs above the left abutment. The areas between rock outcrops on the left abutment are covered by a soil mantle which contains a growth of thin brush and muskeg. The soil cover may be as much as 10 feet thick. The right abutment is heavily wooded, and the underbrush is very dense. The only bedrock exposures on the right abutment are in the bottoms of gullies and small tributaries flowing into the Eagle River. Judging from the depth of the gullies, the soil cover and colluvium is probably less than 10 feet thick.

The bedrock in the left abutment is medium-grained garnetiferous biotite gneiss. Samples from localities 9 and 10 (pl. 1) were taken from the left abutment. These rocks are distinctive in that they contain kyanite and a large percentage of garnet. Bedrock exposed near water level in the left bank of the river above and below the damsite is similar megascopically to the two samples described (table 1). There are few exposures of bedrock in the right abutment. The sample from locality 11 (pl. 1) is medium-grained biotite-hornblende gneissic quartz diorite. The foliation in this sample is less distinct and the fissility less well developed than in the biotite gneiss of the left abutment. Bedrock exposed 1,500 feet downstream and on strike with locality 11 is similar megascopically. Because of the paucity of exposures along the right abutment, no attempt has been made to separate the bedrock into the map units as described. More detailed mapping, subsurface sampling, and more comprehensive thin section studies could provide a basis for doing so.

Although the biotite gneiss appears to be slightly more susceptible to weathering than the quartz diorite, the lithologic differences between these rock types are not likely to affect foundation properties.

The Eagle River has eroded a channel along the foliation in the gneiss. Consequently, fissility in the bedrock would provide the shortest path of percolation of water passing under the dam or through the abutments. Foliation planes at the surface are open enough to allow weathering to some depth in the rock, but it is probable that weathering penetrates only a few feet below the surface. Bedrock is exposed along the banks of the Eagle River at places above and below the damsite. The presence of a deep alluvium-filled channel beneath the stream bed seems unlikely. However, the possibility that the Eagle River has eroded a channel along a marble interbed cannot be ruled out. If so, a deep solution channel may underlies the stream.

The major joint set strikes at an angle of about 50° to the proposed axis of the dam. The second joint set is subparallel to this axis. The joints are tight, and the loss of water by leakage along joints would be minimal.

Avalanche scars of varying freshness occur at several places along the Eagle River valley. One avalanche, on the left side of the valley about 4,500 feet below the damsite, occurred since the aerial photographs were made (1948). The avalanches do not appear to involve large masses of fresh rock but are probably composed mostly of loose joint blocks, soil, and vegetation mixed with snow. The topography is such that avalanches would not be a problem on the left abutment, but the right abutment is relatively steep and the slope is continuous with the main valley wall. The many deadfalls and jumbled blocks of gneiss on the right abutment indicate considerable recent avalanching. The removal of the vegetation around the damsite and the raising of the water level could alter the stability of the slope and pose a direct threat to the dam, particularly during spring seasons that follow heavy accumulation of snow.

The damsite is suited for a concrete gravity dam or an earthfill dam.

LITTLE EAGLE LAKE DAMSITE

The topography of the damsite at Little Eagle Lake is similar to that at the Eagle Lake damsite (pl. 1). The left abutment is a broad low ridge extending out from the main valley wall, and the right abutment is part of the main valley wall. The damsite is at the intersection of the main valley and a large tributary valley from the west. The left abutment is topographically similar to the left abutment at the Eagle Lake damsite. The basin of Little Eagle Lake appears to be the result of the increased glacial erosion which often occurs at the intersection of a trunk glacier and a large tributary.

The Eagle River flows out of Little Eagle Lake at low gradient for about 2,200 feet and then at sharply increasing gradient to a 10-foot waterfall about 2,900 feet below the lake outlet. An alinement which would require the smallest dam is located about 100 feet above the falls. A dam to the 400-foot altitude would have a crest length of about 1,450 feet. The crest of the dam would be 165 feet above the water surface.

Bedrock exposures are scarce except along the riverbank at and below the falls. The flat or gently sloping ground of the left abutment is covered by poorly drained muskeg which is interspersed with heavily timbered and brushy areas. Judging from the scattered small exposures of gneiss in areas of low relief, the soil cover must be very thin over much of the left abutment.

The right abutment was not examined. It is heavily wooded and probably is underlain by the same unsorted rubble cover that characterizes the right abutment of the Eagle Lake site.

Bedrock exposed at the Little Eagle Lake damsite is a fine- to medium-grained biotite-hornblende injection gneiss. The gneiss crops out continuously along the riverbanks below the damsite. At a point about 1,500 feet downstream from the damsite, the gneiss is cut by many quartz-feldspar veins and dikes, most of which have been injected along preexisting joints and foliation. The foliation in the gneiss strikes parallel to the Eagle River and dips 65°–80° E. As at the Eagle Lake damsite, the foliation provides the most direct route for water passing under the dam or through the abutments. The foliation planes appear as tight as those in the gneiss at the upper damsite, and it is doubtful that much grouting would be required to prevent leakage. The stream flows over bedrock in the damsite area. The joints are less likely than the foliation to cause leakage.

The discussion regarding avalanches at the Eagle Lake damsite applies as well to the Little Eagle Lake site. No particular hazard exists on the left abutment, but conditions on the right abutment are such that avalanches can be expected under the proper conditions.

Topographically, the damsite would probably be best suited for an earthfill dam, although the foundation rock is quite capable of supporting a concrete dam.

SADDLE DAMSITES

The divide at the head of Eagle Lake was not examined. However, a careful study was made of this site on the aerial photographs. The ridge which forms the divide is elongated parallel to the strike of the foliation in the gneiss. This suggests that the ridge may be underlain by a band of rock more resistant than the normal gneiss. The marble outcrop at the head of the lake is also on strike with the ridge. The thickness of the marble is not known, but it seems likely that most of the ridge is underlain by more resistant rock. When the valley of the Eagle River was occupied by a glacier, melt water probably flowed through the saddles in the divide. If so, it is possible that the saddles are underlain by alluvium-filled channels to an unkown depth, and leakage might occur even if the water level is not raised above the level of the saddles.

Auxiliary dams or dikes would be required in each of the four saddles if the lake is raised above an altitude of 360 feet. The abutments for these structures would probably be in competent gneiss, but it might be necessary to remove large amounts of unconsolidated material from the channel sections.

If one or more marble layers is present, it would strike parallel to the alinement of the auxiliary dikes. The dip of the beds or foliation is as steep here as elsewhere in the area, so leakage through solution cavities in the marble would be unlikely.

The strike of the major set of joints is through the divide, and the joints may have localized erosion in the saddles.

To fully evaluate the powersite, further surface and subsurface investigations in the divide area are necessary. The evaluation could be aided considerably by topographic mapping at the same scale as the damsite maps (1 : 2,400).

TUNNEL ROUTE

The shortest tunnel route from Eagle Lake to Bell Arm would extend nearly due south to tidewater from a point on the lakeshore about 600–700 feet west of the mouth of the stream flowing into the head of the lake. Because alluvium is being deposited along the front of the delta at the head of the lake, the intake should probably be located further to the west to prevent sediment from entering the tunnel. A horizontal tunnel would have a length of 3,500–4,000 feet, depending on the location of the intake in relation to the head of the lake and the underwater slope and depth of the lake at this point. The route shown on plate 1 has been chosen on the basis of available information but might be changed as data on the underwater topography and the rate of accretion of the delta is acquired. The penstock could be an inclined tunnel, a surface or buried conduit, or a combination of these. The length of the penstock would be from 1,500 to 2,000 feet, depending on the location of the powerhouse.

The bedrock which crops out in the vicinity of the tunnel route is gneissic garnetiferous quartz diorite. The rocks that were examined are uniform in color, medium to coarse grained, and megascopically similar. The gneissic texture in the bedrock is not well defined.

The marble interbed exposed near the head of the lake may intersect the tunnel near the intake, and the possible presence of other marble interbeds concealed by the soil mantle and vegetation should not be overlooked.

The foliation in the gneiss strikes almost normal to the tunnel alinement, and the attitudes range from steep to vertical. The foliation is not well developed, and partings are widely spaced in the bedrock. The jointing is also widely spaced. The observed engineering properties of the bedrock are favorable for tunnel construction. The tunnel route does parallel a drainage which follows the major joint trend. This drainage is one of a series of prominent linear features at the head of the lake and may indicate a zone of closely spaced or open joints. No evidence of shearing or crushing was observed in the gneiss at the widely separated outcrops near this lineament. The tunnel could be alined to avoid intersecting the lineament.

The slopes at the lakeshore at this locality are covered by an undetermined thickness of colluvium. The colluvium may not be too thick to be stripped away prior to construction. If it is stripped away, the stability of the unconsolidated material further up the slope might be affected, and some measures would be required to prevent avalanches or to protect the intake from them.

POWERHOUSE SITE

The head of Bell Arm is chiefly a tidal flat which is underlain by deposits of fine sand or silt intermixed with organic material. Such foundation material would make an undesirable site for the heavy structure necessary in a powerhouse installation. The nearest place where a bedrock foundation is present is probably near the 43-foot bench mark about 1,600 feet from Bell Arm (pl. 1). It might also be feasible to extend the penstock down the east side of the valley in order to bypass the tidal flat and to build the powerhouse on bedrock near sea level. A third scheme would be to drive pilings or construct piers to bedrock in the upper part of the tidal flat. Whether pilings or piers could be used would depend on the depth to bedrock.

RESERVOIR SITE

The reservoir site is underlain by dense and impermeable metamorphic rocks. Serious leakage from the reservoir could occur only in the bedrock near the damsites or at the head of Eagle Lake.

The steep slopes around the reservoir site are apparently susceptible to avalanches, but none of the avalanche scars observed appear deep or wide enough to have involved volumes of material large enough to create dangerous waves.

CONSTRUCTION MATERIALS

Sources of fine and coarse aggregate are readily available to both damsites and the tunnel route. The delta of the large tributary immediately west of the Eagle Lake damsite is one source which should contain deposits composed of fine to coarse materials (pl. 1). Sorting and stratification in these deposits is probably best near the lakeshore. Another possible source for construction material is in the deposits underlying the flood plain of the Eagle River below the Eagle Lake damsite.

The area around Little Eagle Lake is underlain by alluvial deposits of silt or fine sand in the swampy area just south of the left abutment ridge and coarser sand and gravel along the Eagle River and the major tributary from the west which flows into Little Eagle Lake (pl. 1).

The alluvial plain above the head of Eagle Lake is probably underlain by fairly well sorted silt, sand, and gravel deposits.

Talus deposits composed of blocks large enough for riprap were not observed around Eagle Lake, although some of the areas of colluvium that are covered by brush may contain large blocks.

It may be necessary to quarry some of the more poorly foliated quartz diorite if a source of riprap is required. The rock is well suited for concrete aggregate. No minerals which would be chemically reactive with cement are present in the rocks. The rock is resistant to weathering, and the foliation is not well enough developed to result in a predominance of flat or elongated particles, except in the cobble or larger size range.

SUMMARY

The two damsites are similar in the physical properties of the foundation rock and in the attitudes of planar features which could cause seepage under the dam or through the abutments. Bedrock is not continuously exposed along the channel at the Eagle Lake damsite, and angle drilling beneath the channel will be necessary to determine whether a buried alluvium-filled channel or a solution cavity in marble is present.

The overall size of a dam at the Little Eagle Lake site would be three to four times the size of one at the Eagle Lake site. However, it is possible that a large and readily accessible source of impervious fill material immediately upstream from the damsite would make the construction of an earthfill dam of this size feasible.

The colluvium is probably thin on the abutments of both damsites. Trenching or resistivity surveys would determine the profile of the bedrock surface. However, at least one or two holes should be drilled into bedrock for pressure or pumping tests.

Seismic or resistivity surveys or drilling in the four saddles in the divide at the head of the lake will be necessary to determine the depth and permeability of the fill. More detailed topographic and geologic mapping in this area is required.

Subsurface exploration in the tidal flat at the head of Bell Arm should be accomplished to determine a locality near tidewater at which it would be practical to construct piers or drive pilings to bedrock for a powerhouse foundation.

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