GEOLOGY OF DAM SITES IN SOUTHWESTERN WASHINGTON

PART II. MISCELLANEOUS DAM SITES ON THE COWLITZ RIVER ABOVE CASTLE ROCK, AND THE TILTON RIVER, WASHINGTON

By

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51-27

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NOTE: THE QUALITY OF THIS REPORT IS POOR. PAGES 98, 143, 186, 206, and 210 are missing. Efforts to obtain a better copy was fruitless.

Page

Page

Page

Page

Page

******

ILLUSTRATIONS

Preceding Page

	Preceding Page
Figure 10. Simplified geologic sections of Cowlitz River Valley at Mossy Rock dam site showing relation of the active gorge to the buried preglacial valley, sec. 8, T. 12 N., R. 3 E., W.M., Lewis County, Washington.	148
11. Preliminary geologic map of Mossy Rock dam site, south center sec. 8, T. 12 N., R. 3 E., W.M., Lewis County, Washington.	149
12. Drill hole locations and resistivity measurements, Mossy Rock dam site, sections 5 and 8, T. 12 N., R. 3 E., W.M., Lewis County, Washington.	178
13. Preliminary geologic map of Shut-In dam site, sections 9, 10, 15, and 16, T. 12 N., R. 3 E., Lewis County, Washington.	190
14. Geologic cross sections, Shut-In dam site, sections 9, 10, 15, and 16, T. 12 N., R. 3 E., W.M., Lewis County, Washington.	194
15. Enlarged geologic cross section, Shut-In dam site, showing filled preglacial channel.	194
16. Enlarged geologic cross section of Shut-In dam site showing material filling channel behind left abutment.	196
17. Preliminary geologic map of Cowlitz Falls dam site, sec. 6, T. 11 N., R. 6 E., W.M., Lewis County, Washington.	242
18. Geologic cross sections, Cowlitz Falls dam site, sec. 6, T. 11 N., R. 6 E., W.M., Lewis County, Washington.	247
19. Reconnaissance geologic map and geologic cross section, Tilton dam site, sections 34 and 35, T. 13 N., R. 2 E., W.M., Lewis County, Washington.	271

Preceding Page

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SUMMARY AND CONCLUSIONS

This report describes limiting geological conditions at a series of proposed dam sites on the Cowlitz River upstream from the town of Castle Rock, Washington and on one of its tributaries, the Tilton River. Preliminary plans for the development of the Mayfield, Mossy Rock, and Cowlitz Falls dam sites have been prepared by the Corps of Engineers, U. S. Army. The Mayfield and Mossy Rock sites have also been explored in some detail by drilling and other works by the Backus-Brooks Company of Minneapolis, Minnesota. Mayfield site has been further explored by additional drilling and engineering investigations by the City of Tacoma, Light Department. Shut-In dam site has also been explored and drilled by the City of Tacoma. In this investigation, surface exposures of the dam sites on the Cowlitz River were mapped in detail, and in some cases, knowledge of subsurface conditions was supplemented by geophysical investigations and data from the drill holes. Reconnaissance geologic maps were made of the dam sites on the Tilton River.

A background of factors common to all of the dam sites is developed in the first part of the report. Cultural development, climatic conditions, vegetation, and drainage are discussed. The stratigraphy and general geologic structures of the Cowlitz basin are outlined. A brief, general account is given of the development of the present Cowlitz River valley and of its relationship to older channels now filled with glacial deposits. Detailed descriptions of the individual dam sites follow.

Geologic and engineering features are outlined, weaknesses are pointed out, and reasons for selection or rejection are listed. These are supplemented by maps and cross sections.

Summaries of dam site descriptions arranged in order upstream follow.

Mayfield dam site. - Cowlitz River, mile 51.9, S$\frac{1}{2}$SW$\frac{1}{4}$ sec. 20, and N$\frac{1}{2}$NW$\frac{1}{4}$ sec. 29, T. 12 N., R. 2 E., Willamette Meridian, Lewis County, Washington. Average altitude of low water surface is 240 feet. Rock foundation is 40 to 60 feet below water level. First choice for a high dam falls between C-C' and D-D'. Weaknesses are the highly permeable sandstone-shale bed, B, covered by only a thin thickness of basalt below the river channel at D-D', and the tuff bed, F, in the left abutment at C-C'. Selection of a section about midway between them might improve the condition of the upper left abutment without dangerously reducing the thickness of the basalt above bed B in the foundation. Maximum height of pool level is 400 feet or possibly higher. The City of Tacoma, Light Department tentatively considered a pool level at 420 feet in their investigations. A dam with pool level at 400 feet would stand 160 feet above mean water level, and about 200 feet above foundation. Crest length would be about 500 feet. Maximum power development would be secured by use of all of the head without drawdown. Flow regulation would be obtained with storage at sites above. For a low dam with crest not exceeding 340 feet, choice is between D-D' and E-E'.

Both have defects: namely, the unconsolidated and permeable sandstone in the foundation at D-D' discussed in connection with a high dam, and the same sandstone in the upper left abutment at E-E' that would provide an avenue of leakage around the left abutment. D-D' is probably the better section. A dam at D-D' with pool level at 340 feet would stand 100 feet above water level and about 160 feet above foundation. Chances for water loss from the reservoir of either a high or low dam by seepage through glacial sediments filling the buried preglacial channel of the Cowlitz are probably not great because of character of sediments and length of path of leakage. Relatively impervious glacial sediments also fill a side channel extending from the main channel southwestward through section 20, T. 12 N., R. 2 E., to Mayfield Canyon downstream from the dam site. (See figs. 2, 7, 8, 9.)

Mossy Rock dam site. - Cowlitz River, mile 63.4, in south center sec. 8, T. 12 N., R. 3 E., Willamette Meridian, Lewis County, Washington. Average altitude of low water surface is 331 feet. Rock foundation is shallow. Controlling altitude of reservoir surface is 700 feet. Tentative feasible pool level is 620 feet. Further exploration of upper part of the right abutment may indicate possibility of raising pool level to altitude 640, which appears to be maximum possible for this site. A dam with pool level at 620 feet would stand 290 feet above foundation. Crest length would be about 610 feet. Storage capacity would be 416,400 acre feet. Site is satisfactory only if effective measures can be taken to prevent seepage through the buried preglacial valley of the Cowlitz River north of the right abutment. The problem of leakage from Mossy Rock reservoir is serious. Effectiveness of the permeable contact between the outwash and silt filling the buried valley as a conduit for leakage should be determined by field tests, if possible, and should be reviewed thoroughly in the light of revised geologic opinion. Remedial measures to prevent this seepage should consist of treating the east face of the fill as though it were the upstream face of an earth dam. (See figs. 10, 11, 12.)

Shut-In dam site. - Cowlitz River, mile 65.5, in SE¼ sec. 9 and SW¼SW¼ sec. 10, T. 12 N., R. 3 E., Willamette Meridian, Lewis County, Washington. Average altitude of low water surface is 427 feet. Controlling altitude of reservoir surface is 775 feet. Choice of dam section is at P-P4. At this point, rock foundation is at 224 feet or 192 feet below the bed of the stream. Right abutment is in rock to over 800 feet, and left abutment to 700 feet. A dam with pool level at 700 feet would stand 284 feet above stream bed and 476 feet above rock foundation, and would have a crest length of about 1,100 feet. Storage capacity would amount to 914,200 acre-feet. More storage is desirable for stream flow regulation and power production. Further exploration of the left abutment might indicate the possibility of raising the pool level to altitude 740 feet, which appears to be the maximum possible for this site. A dam with pool level at 740 feet would stand 324 feet above stream bed and 516 feet above rock foundation. Crest length at this altitude is about 1,240 feet, and storage capacity is 1,277,000 acre-feet. Greatest weakness is the lack of knowledge of geologic conditions behind the left abutment above altitude 700 feet including an area between the canyon wall and drill hole S-7 and extending downstream for at least 1,000 feet. Altitude of bedrock underlying this area and the character of its glacial cover should be ascertained by thorough exploration before the type and height of dam is determined. There is some possibility of leakage through the glacial sediments filling a channel nearly 2,000 feet wide that by-passes the left abutment, although the path of seepage is rather long. Bottom of the channel is at altitude 538 feet. Course of this channel should be outlined and permeability of the sediments determined by field tests. (See figs. 13, 14, 15, 16.)

Cowlitz Falls dam site. - Cowlitz River, mile 88.7, just south of center of sec. 6, T. 11 N., R. 6 E., Willamette Meridian, Lewis County, Washington. Site is suitable for a low dam. Purpose if for diversion rather than storage. Choice of section is C-D. Average altitude of low water surface is about 772 feet. Rock foundation is shallow. Controlling altitude of reservoir surface is 900 feet. A dam with pool level at 800 feet would present no difficulties or problems of leakage from the reservoir. Such a dam would stand about

50 feet above foundation. Width of valley at this altitude is about 260 feet, and crest length of a dam would be about 290 feet. Maximum practical pool level is probably about 850 feet. A dam to impound a reservoir to this level would stand 100 feet above foundation. Width of valley at this altitude is 430 feet, and crest length of dam would be about 475 feet. There would be possibility for leakage from the reservoir through the fill of the preglacial valley of Cowlitz River that lies about one mile north of the dam site. (See figs. 17, 18.)

Tilton dam site. - Tilton River, mile 2.0, in NE¼SE¼ sec. 34 and SW¼NW¼ sec. 35, T. 13 N., R. 2 E., Willamette Meridian, Lewis County, Washington. Purpose is power production. Average altitude of low water surface is 375 feet. Tentative feasible pool level is 550 feet. Width of valley at this altitude is about 575 feet and crest length of dam would be in the neighborhood of 750 feet. Dam would stand approximately 175 feet above foundation. Storage capacity would be negligible, and control of stream would depend on a reservoir farther upstream. Head available for power production would be reduced if dam is built at Mayfield site. Pool level in Mayfield reservoir at 400 feet would flood Tilton site to depth of 25 feet. Most critical factor is possibility of leakage from the reservoir through fill in one or possibly two buried valleys that probably by-pass the dam site. Site cannot be considered feasible until exploration of these channels is completed. (See fig. 19.)

Cooper Creek dam site. - Tilton River, mile 4.0, in NE¼ sec. 25, T. 13 N., R. 2 E., Willamette Meridian, Lewis County, Washington. Purpose is power production. Average altitude of low water surface varies from about 475 to 490 feet through that part of the canyon that might be suitable for a dam. More detailed topography and further geologic study is necessary before a dam section is selected. Rock foundation is at stream bed throughout this stretch. Controlling altitude of reservoir surface is about 900 feet. For a dam with both abutments anchored in bedrock, maximum pool level is approximately 680 feet at S-S'. Such a dam would stand 280 feet above the stream. Width of valley at this altitude is 430 feet and crest length of a dam is estimated at 520 feet. Storage capacity is 29,000 acre-feet. More storage is desirable, and further exploration of the right abutment may indicate that the pool level can be raised. There is danger of leakage from the reservoir through glacial sediments filling the preglacial Tilton valley that lies behind the right abutment. Depth of this valley and the character of its fill must be thoroughly explored before the site can be considered feasible for a dam of any height. (See fig. 20.)

Bear Canyon dam site. - Tilton River, mile 6.5, in NE¼SE¼ and SE¼NE¼ sec. 19, and SW¼NW¼ and NW¼SW¼ sec. 20, T. 13 N., R. 3 E., Willamette Meridian, Lewis County, Washington. Choice of section is in the neighborhood of cross section U-U'. Average altitude of low water surface is 585 feet. Rock foundation is at stream bed. Controlling altitude of the reservoir surface is more than 1,000 feet. A high dam would be desirable at this location to provide maximum stream control and power development. However, bedrock is exposed in the right abutment only to altitude 700 feet. A dam with pool level to this altitude would stand approximately 115 feet above foundation, and its crest length would be about 500 feet. Storage capacity is 24,200 acre-feet. Further exploration of the right abutment may indicate that a higher pool level is feasible. There is the possibility of considerable leakage through glacial deposits that fill the preglacial Tilton valley that lies a short distance behind the right abutment. This valley and the materials filling it must be thoroughly examined before a dam at this site can be considered feasible. (See fig. 21.)

INTRODUCTION

Object of investigation

This report describes geologic conditions at a series of localities on the trunk stream of Cowlitz River upstream from the town of Castle Rock and on its tributary, the Tilton River, that have been designated as dam sites on general topographic conditions. Its purpose is to define the limiting conditions at each site, designating those that have promise as feasible projects and eliminating those that do not. These geologic investigations, together with topographic surveys and water-supply records, furnish basic data for water utilization studies by which the storage possibilities and their relations to power and flood control can be combined into a practical scheme for the utilization of the entire river by the adjacent communities. In this way, the Federal laws pertaining to classification of streams with respect to water-power resources can be exercised effectively.

Location and accessibility of the dam sites

The names and locations of the sites studied and reported on are listed in order proceeding upstream:

Cowlitz River

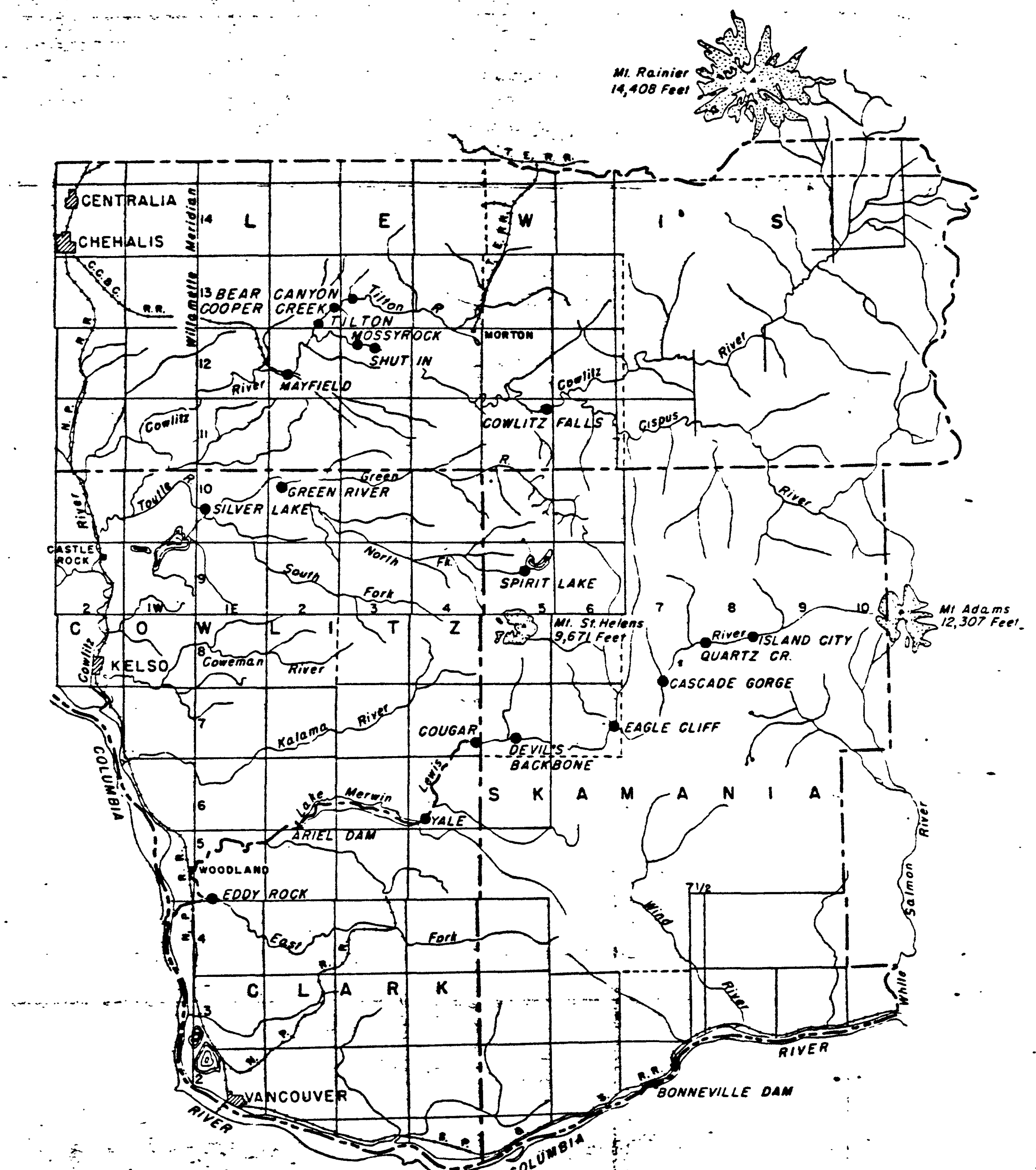
Site	Figure No.	Mile	Location (approximate)
Mayfield	7	51.9	S½ SW¼ sec. 20 and N½ NW¼ sec. 29, T. 12 N., R. 2 E.
Mossy Rock	11	63.4	SW¼ SE¼ sec. 8, T. 12 N., R. 3 E.
Shut-In	13	65.5	SE¼ sec. 9 and SW¼ SW¼ sec. 10, T. 12 N., R. 3 E.
Cowlitz Falls	17	88.7	NE¼ SW¼ sec. 6, T. 11 N., R. 6 E.

Tilton River

Site	Figure No.	Mile	Location (approximate)
Tilton	19	2.0	SE¼ NE¼ and NE¼ SE¼ sec. 34 and SW¼ NW¼ and NW¼ SW¼ sec. 35, T. 13 N., R. 2 E.
Cooper Creek	20	4.3	NE¼ sec. 25, T. 13 N., R. 2 E.
Bear Canyon	21	6.5	E½ sec. 19 and W½ sec. 20, T. 13 N., R. 3 E.

Ranges are numbered from the Willamette Principal Meridian.

Locations of the sites and their relationships to the Cowlitz basin as a whole are shown on figure 1. U. S. Highway No. 99 from Olympia, Washington, to Portland, Oregon, follows closely the course of the Cowlitz River downstream from Toledo, Washington. State Highway No. 5 branches from U. S. Highway No. 99 at Mary's Corner, 32 miles south of Olympia, crosses Cowlitz River at Mayfield, continues up the Cowlitz valley to its headwaters, finally joining U. S. Highway No. 410 on the divide between the Cowlitz and White River drainage. State Highway No. 5K branches from U. S. Highway No. 99 about two miles north of Mary's corner. It follows the course of the Tilton River from near the village of Cinebar to Morton, and joins State Highway No. 5 at Kosmos. Both 5 and 5K are surfaced, all-weather highways. From Highway No. 5, at least one abutment of each of the proposed sites on the Cowlitz River



INDEX MAP OF SOUTHWEST WASHINGTON SHOWING LOCATION
OF DAM SITE INVESTIGATIONS ON THE
LEWIS, TOUTLE, TILTON AND COWLITZ RIVERS

SCALE
10 0 10 20 30 MILES

and Tilton site is accessible by automobile road to within one-half to three-fourths of a mile. Bear Canyon and Cooper Creek sites are accessible from Highway 5K. Instructions for reaching each site are given under the detailed descriptions in the second part of this report.

The Cowlitz, Chehalis, and Cascade Railroad leaves the Northern Pacific Railway at Chehalis, Washington, enters the Cowlitz watershed near Salkum, crosses Cowlitz River at the upper end of Mayfield dam site, and terminates on Winston Creek. This line is joined at Onalaska, Washington by the Newaukum Valley Railroad, which in turn joints the Northern Pacific Railway at Napavine, Washington. The upper valley has access to the Rainier National Park Branch of the Chicago, Milwaukee and St. Paul Railway at Morton, Washington.

Previous investigations

Relatively little systematic work has been done in the part of the Cowlitz River drainage basin described in this report. During 1927 and 1928, the late Ira A. Williams, consulting geologist of Portland, Oregon, made extensive examinations of the Mayfield and Mossy Rock dam sites for Ralph D. Thomas, consulting engineer, on behalf of the Backus-Brooks Company of Minneapolis, Minnesota. His findings are presented in a series of four comprehensive, well-illustrated reports that merit careful study by every serious investigator of these dam sites. 1/

1/ Thomas, Ralph D., Report on Proposed Hydro-Electric Development, Cowlitz River, Washington, to the Backus-Brooks Company, Minneapolis, Minnesota; Three volumes; December 1928; Unpublished private reports. Vol. II, Exhibit "A", Report on Geologic Conditions at Dam Site No. 2, Mayfield Canyon, Cowlitz River, Washington, by Ira A. Williams, September 1926; Vol. II, Exhibit "B", Report on Geologic Conditions beneath Dunn Flat, Young's Canyon, Cowlitz River, Washington, by Ira A. Williams, January 1928; Vol. III, Exhibit "C", Preliminary Presentation of the Comparative Merits of Two Prospective Dam Sites in Young's Canyon, Cowlitz River, Washington, by Ira A. Williams, July 1927; Vol. III, Exhibit "D", Report on Geologic Conditions at Dam Site No. 2, Young's Canyon, Cowlitz River, Washington, by Ira A. Williams, July 1928.

A year later in October 1929, J. T. Pardee, 2/ U. S. Geological Survey,

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2/ Pardee, J. T., Unpublished report to U. S. Geological Survey, 1929.

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made a reconnaissance of the same two sites. Mapping was not attempted, and his report consists chiefly of notes supplemented by pencil sketches. These sites have also been described by the Corps of Engineers, U. S. Army. 3/ The State of Washington has published a necessarily much

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3/ Report from the Chief of Engineers, United States Army, on Cowlitz River, Wash., covering Navigation, Flood Control, Power Development, and Irrigation, made under the provisions of House Document No. 308, 69th Congress, First Session. Seventy-first Congress, 3d Session, House Document No. 666. Washington 1931.

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generalized preliminary geologic map of the State by H. E. Culver, 4/

4/ Culver, H. E., Preliminary geologic map, State of Washington. Department of Conservation and Development, Division of Geology, Pullman, Wash., 1936.

__ The Geology of Washington. Part I, General Features of Washington (to accompany the preliminary geologic map, 1936). Washington Department of Conservation and Development, Bull. No. 32, Olympia 1936.

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which illustrates the areal geology of the Cowlitz River basin, and there is an accompanying text. Coomb's 5/ description of Mount Rainier

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5/ Coombs, Howard A., The Geology of Mount Rainier National Park. Univ. Washington Publications in Geology, Vol. 3, No. 2, pp. 131-212. July 1936. Figs. 28. Map in pocket. Seattle, Washington.

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appeared the same year, and is an excellent summary of the geology in the vicinity of the mountain, but contains nothing of immediate application to the dam site areas. Erdmann and Warren [6] mapped dam sites in

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6/ Erdmann, Charles E., and Warren, Walter. Report on the Geology of Three Dam Sites on Toutle River, Cowlitz and Skamania Counties, Washington. U. S. Geological Survey, March 1938. Unpublished report covering the Silver Lake, Green River, and Spirit Lake dam sites.

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the Toutle River basin of the Cowlitz River in 1936, and their report became available two years later. Most of these investigations, as well as others relating to river surveys and water power investigations, have been listed and summarized by Johnson. [7] Erdmann [8] visited the river

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7/ Johnson, Arthur. Summary of Investigations on Cowlitz River and Tributaries, Washington. U. S. Department of the Interior, Geological Survey. Mimeograph press notice 123585, October 1940.

8/ Erdmann, Charles E., Report on Geologic Reconnaissance of Shut-In dam site, Cowlitz River, Lewis County, Washington. Unpublished report to U. S. Geological Survey, May 1942.

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again in April 1942 to make a reconnaissance of Shut-In dam site.

Erdmann and Warren [9] made a preliminary report on dam sites on the

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[9] Erdmann, Charles E., and Warren, Walter. Preliminary Report on the Geology of Miscellaneous Dam Sites on Cowlitz River above Castle Rock, Washington. U. S. Geological Survey, August 1943. Unpublished report covering the Mayfield, Mossy Rock, Shut-In, and Cowlitz Falls dam sites.

Cowlitz River in August 1943.

The map of the Columbia National Forest, Washington, by the U. S. Forest Service (1935), on a scale of 4 miles to the inch, is an excellent base map of the region. Topographic maps of the U. S. Geological Survey cover most of the Cowlitz River basin described in this report. The Chehalis, Eatonville, and Mt. St. Helens sheets are 30-minute quadrangles on a scale of 1:125,000, and show the river from below Mayfield dam site to above Cowlitz Falls. The headwaters of the Cowlitz are shown on the Mt. Rainier quadrangle to the same scale. Contour intervals are fifty feet for the Chehalis quadrangle and one hundred feet for the others. The lower part of the basin from about river mile 45 down to Castle Rock, Washington, is shown on the Alequa and Toutle quadrangles by the Corps of Engineers, U. S. Army, on a scale of 1:62,500 and with contour intervals of 20 and 100 feet respectively.

Present investigation

The investigation covered by this report was carried out during the field seasons of 1935, 1936, 1942, 1946, 1947, and 1948 by engineers and geologists of the Geological Survey. In addition, the City of Tacoma, Department of Public Utilities started an investigation of foundation conditions at Mayfield and Shut-In dam sites during the Fall of 1947 that is still in progress (March 1949). Results of their work have been made available to Geological Survey personnel. The complete study involved four distinct phases: topography, geology, geophysics, and drilling.

Topography. - During 1935 and 1936, as a part of a program of river utilization surveys, the Cowlitz River was mapped by the U. S. Geological Survey in cooperation with the State of Washington, from a point near the west line of sec. 32, T. 12 N., R. 1 E., to the east line of sec. 25, T. 12 N., R. 6 E., a distance of 55 miles.[10/] These maps are on a scale

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10/ Plan and profile of Cowlitz River, mile 42 to mile 97, Cispus River to mile 32, and Tilton River to mile 19. 6 plan sheets, 1 sheet of dam sites, 5 profile sheets. U. S. Department of the Interior, Geological Survey, 1943.

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of 1:24,000 (1 inch = 2,000 feet) with 10 and 20-foot contour intervals on land and 5-foot contour intervals on the river surface. Topography was carried from 100 to 300 feet above the river surface. Special surveys were also made of the dam sites described in this report. Mayfield, Mossy Rock and Cowlitz Falls dam sites were mapped on a scale of 1:2,400 (1 inch = 200 feet) with 5-foot contour interval on land and 1-foot contour interval on the river surface. Shut-In dam site was mapped on a scale of 1:4,800 (1 inch = 400 feet) with 10-foot contour interval on land and 1-foot contour interval on the river surface. Topography at dam sites was carried well above the altitude of the probable crest of the dam, and in reservoir areas was carried well above the highest pool level. This work was directed by Arthur Johnson, Hydraulic Engineer of the Geological Survey.

Geology. - The geological investigation involved two distinct studies: (1) systematic mapping and examination of the surface geology of the proposed dam sites; and (2) determination of the preglacial course of the Cowlitz River and its relationship to the dam sites and reservoir areas. The investigations of Mayfield, Mossy Rock, and Cowlitz Falls dam sites were made during the field season of 1936 with funds supplied jointly by the Public Works Administration and the State of Washington. A geologic reconnaissance of Shut-In dam site was made in April 1942, and detailed geologic mapping was done in September and October 1946 and 1947. Examination of churn drill samples and diamond drill cores obtained at Mayfield and Shut-In dam sites in connection with the investigations of the City of Tacoma was made in September 1947, and April and August 1948.

Through the courtesy of the Backus-Brooks Company of Minneapolis, Minnesota, the results of their engineering explorations at the Mayfield and Mossy Rock dam sites have been made available to this investigation. Many valuable supplemental data have been obtained from their reports. The investigation by the Geological Survey is not intended to duplicate the work of the engineers and geologists of the Backus-Brooks Company, but rather to systematize the geology of the Cowlitz valley in order that there may be a broader and sounder basis for interpretation of past results and more careful preparation and direction for future studies.

Charles E. Erdmann, Regional Geologist, Mineral Classification Branch, supervised all of the geologic work, mapped the geology of Cowlitz Falls dam site, made a reconnaissance of Shut-In dam site, and spent short periods in October 1946 and September 1947 on field work in connection with the course of the preglacial Cowlitz River. Surface geology at Mayfield and Mossy Rock dam sites was mapped by Walter C. Warren, and at Shut-In dam site by A. F. Bateman, Jr. Additional field work on the preglacial course of the Cowlitz River, examination of samples obtained by drilling at Mayfield and Shut-In sites, and reconnaissance of the Tilton River dam sites were also by Bateman. F. A. McMillin also contributed to the field work at Shut-In site.

The special dam site maps were used as bases for geologic mapping. The accompanying geologic maps show only the 50-foot contours, but profiles of the cross sections are taken from the 5 or 10-foot contours of the special dam site maps. Observation points were located by means of compass and either tape or pace traverses from bench marks set by the topographers.

Geophysics. - Geophysical investigations to determine the depth of bedrock were made at Mossy Rock dam site during the 1936 field season and at Shut-In dam site in August 1943. Electrical resistivity methods following the Wenner electrode configuration and standard Gish-Rooney technique were employed at each site. Work at Mossy Rock dam site and at Dunn Flats on its right abutment was by Roland K. Thies, and that at Shut-In site and at a small channel by-passing the left abutment by B. E. Jones and H. C. Spicer. Additional work was done at Shut-In site with a portable refraction seismograph under the direction of Mr. E. R. Shepard, Engineer, U. S. Corps of Engineers. One seismic test was also made near Cowlitz Falls dam site.

Drilling. - In September 1947, the City of Tacoma, Department of Public Utilities, started a drilling program in connection with a detailed study of foundation conditions at Mayfield and Shut-In dam sites. Eleven holes were drilled to bedrock in the filled, preglacial river channel behind the right abutment of Mayfield site, figure 8, and cross sections E-E' and F-F', figure 9; and 48 holes were drilled in the vicinity of the proposed dam axis, figure 8. Seven holes were drilled on resistivity line locations in the area of the channel by-passing the left abutment of Shut-In site, figure 13, cross section P-P^4, figure 14; and eight holes have been drilled in the bottom of Shut-In canyon along the proposed dam axis, figure 13.

Cultural development

The principal towns in the Cowlitz Basin above Castle Rock, Washington, with their populations in 1940, are: Toledo, 523; Winlock, 861; Mayfield, 45; Mossyrock, 400; Ajlune, 450; Riffe, 175; Randle, 200; Packwood, 200; and Morton, 778. Their chief industries are agriculture and lumbering. what is total in towns? what is total including rural?

1950

A dam on the Cowlitz River at Mayfield site would flood a relatively small acreage of farm land along the river bottom; at either Mossy Rock or Shut-In sites, one would inundate the village of Riffe and a slightly larger acreage of farm land; and one at Cowlitz Falls site with pool level higher than altitude 850 would flood the broad flat farm land? at the junction of the Cowlitz and Cispus Rivers known locally as the "Big Bottom." On the Tilton River, a dam at Tilton site would not flood any farm land, but one either at Cooper Creek or Bear Canyon site would flood a small acreage of farm land. A dam at any of the sites except Tilton site would require relocation of portions of Highways No. 5 or 5K.

Failure of a dam at any one of these sites could cause considerable flood damage to the towns of Toledo, Castle Rock, population 1,182, Kelso, population 6,749, and Longview, population 12,385, in the lower part of the Cowlitz Basin, as well as to farm land on the river bottoms and lower benches.

Climate

Climatic conditions in the Cowlitz River Basin vary from temperate to arctic because of the great range in altitude from the western lowlands to Mount Rainier and other mountains of the Cascade Range in the headwaters area. The mean temperature decreases with increasing altitude, and the mean annual precipitation increases from about 45 inches in the western lowlands to 120 inches in the higher mountains. In general, that part of the Cowlitz valley covered by this report has a climate characterized by mild, sunny summers with very little precipitation, and cool winters with high precipitation, that usually comes in the form of gentle to moderate rains, often lasting several days. During most winters, snow seldom falls in the lower parts of the valley, and, when it does, lasts only a few days, but deep snows cover the mountains.

The U. S. Weather Bureau maintains stations at several locations in the basin. The following summary of climatic data was compiled from their records. 11/

11/ Climatological data, Washington section, 1950, U. S. Department of Commerce, Weather Bureau.

Record	Kosmos	Randle	Packwood	Ohanapecosh
Altitude, approximate.........feet	775	940	1060	2,004
Length of record............years	34	23	3	14
Annual mean precipitation...inches	56.85	56.99		55.33
Monthly mean precipitation..inches				
January	7.88	7.59	7.42	7.42
February	5.61	6.28	5.87	6.68
March	5.67	6.71	5.79	5.86
April	4.02	3.71	2.79	3.89
May	3.03	3.07	2.39	3.17
June	2.62	2.60	2.27	2.58
July	0.98	0.70	0.50	0.78
August	1.54	1.21	0.79	0.99
September	2.92	2.17	1.79	2.44
October	4.99	5.60	4.82	5.50
November	8.30	7.52		6.56
December	9.29	9.83		9.46
Annual mean snowfall........inches	28.3	23.7	33.8	95.0
Annual mean temperature..... °F	50.4			
Monthly mean temperature.... °F				
January	36.6			
February	40.0			
March	44.4			
April	49.2			
May	54.0			
June	59.4			
July	64.6			
August	63.9			
September	58.6			
October	51.4			
November	43.8			
December	38.6			
Highest temperature......... °F	105		108	
Lowest temperature.......... °F	-15			

Vegetation

Originally, the Cowlitz basin was heavily timbered except for small, open meadows locally called "prairies". Douglas fir, western hemlock, and western red cedar are the dominant forest trees. Douglas fir attains huge size and is the most important timber tree. It is associated with western hemlock and tends to grow on soils having excessive underdrainage. Western red cedar requires more adequate summer moisture, and when found in large, thrifty growth, indicates a high ground water situation. The most common deciduous trees are Oregon maple, vine maple, red alder, and willow. They make abundant growth only on moist slopes or bottom lands where drainage is restricted. Underbrush is usually very thick, and moss covers the ground and rock outcrops in forested areas. Most common shrubs are: cascara, Oregon-grape, blackberry, evergreen blackberry, dogwood, red huckleberry, thimbleberry, salal, rhododendron, yew, madrona, and devil's club. Bracken fern forms a dense tangle in all openings.

Except in the higher mountains, most of the virgin timber has been cut, and the land in the river bottoms and on relatively flat benches has been brought under cultivation. The rougher cut-over slopes make up large areas and are covered with a tangle of down timber, slashings, second-growth, evergreen blackberries, and other shrubs that is so dense as to be practically impenetrable.

All field work was greatly hindered by this dense vegetation, not only because visibility was almost never more than about 100 feet, but also because of the physical difficulty in moving over the ground.

Acknowledgments

Many thanks are due the members of the Geological Survey with whom the writers were associated in the field. B. E. Jones, Chief, Water and Power Division, has given fullest cooperation in connection with the geophysical investigations. Arthur Johnson, under whose supervision the river and dam site surveys were made, has at all times aided and encouraged the topographers in the painstaking task of making the topographic maps faithfully show the relationship between the land forms and the geology. Mr. Johnson took an active part in the geologic reconnaissance of Shut-In dam site, has on several occasions conducted the writers over the ground in preliminary reconnaissance of various features of the work, and has facilitated the work in every way. Mr. Roland K. Thies assisted with the geophysical work in 1936, and Mr. H. C. Spicer in 1943. Mr. E. R. Shepard, U. S. Corps of Engineers, carried out the seismic investigation.

Special thanks are due those who arranged for the loan of Ira A. Williams' comprehensive reports on the exploration of Mayfield and Mossy Rock dam sites. The borehole information in those reports supplements and extends the geophysical data obtained by the Geological Survey, and has greatly increased the scope of the present report. Among them are Mr. A. A. Figen, Secretary, The Backus-Brooks Company, Minneapolis, Minnesota; Mr. Charles J.

Barthalote, State Supervisor of Hydraulics, Olympia, Washington; Mr. Harold H. Hartman, Seattle, Washington; and the late Mr. C. C. Garland, Tacoma, Washington.

Grateful acknowledgment is also made to officials of the City of Tacoma, Department of Public Utilities, especially Mr. J. Frank Ward, Superintendent of Light Division, for furnishing results obtained by their drilling program. The drill holes have served as a check on results obtained by geophysical methods and have clarified foundation conditions at Shut-In and Mayfield sites.

Mr. J. Hoover Mackin, professor of geology, University of Washington, Seattle, Washington, has been especially helpful in connection with glaciation in western Washington.

TOPOGRAPHY AND DRAINAGE

Cowlitz River

Cowlitz River flows in a general southwesterly direction draining the west slopes of the Cascade Mountains from Mount Rainier on the north to Mount Adams and Mount St. Helens on the south. Melt waters from Ohanapecosh, Whitman, Cowlitz, and Paradise Glaciers on the southeastern slopes of Mount Rainier feed Muddy Fork and the Ohanapecosh River which unite in sec. 1, T. 13 N., R. 9 E., Willamette Principal Meridian, to form the Cowlitz River. The total length of the Cowlitz River from this junction to Longview, Washington, where it flows into the Columbia River, is 131 miles.

The principal tributaries of the Cowlitz River are: the Cispus River which heads at the crest of the Cascade Mountains in the vicinity of Cispus Pass and enters the Cowlitz River 91 miles above its mouth; the Tilton River which heads on the Mineral Creek-Tilton River divide about 8½ miles northeast of Morton, Washington and enters the Cowlitz River 58 miles above its mouth; and the Toutle River which heads in the vicinity of Mount St. Helens, and enters the Cowlitz River near Castle Rock 17 miles above its mouth.

Since most of the drainage basin has a dense forest cover, the river water carries very little silt load except in time of flood, and is usually a light emerald-green in color.

Drainage area

The total area of the Cowlitz watershed is approximately 2,460 square miles, of which about 4 percent is above timberline, 10 percent is in river bottoms, 10 percent is in bench lands and rolling ridges below altitude 2,500 feet, and 76 percent is in steep valley walls and mountains. Drainage areas of its principal tributaries are:

Cispus River	453 square miles
Tilton River	161 square miles
Toutle River	510 square miles

Approximately 70 square miles of the Cowlitz watershed lies within the boundaries of Mt. Rainier National Park.

Flood discharge

Discharge rates of the Cowlitz River at various points along its course are:[12/]

Location	Length of Record, Years	Discharge in second-feet		
		Maximum	Minimum	Average
Packwood	24	36,600	160	1,522
Harmony bridge near Mossyrock	14	81,000	630	5,142
Mayfield	11	42,600	766	5,195
Castle Rock	12	139,000	998	8,856
Mouth	-			10,000 (approx.

Discharge rates for its tributaries are:

Cispus River, 8 mi. SE of Randle	11	20,000	183	1,313
Tilton River near Cinebar	5	9,850	66	782
Toutle River near Silver Lake	21	35,600	240	1,906

12/ Johnson, Arthur, Op. cit., October 1940; and Surface Water Supply of the United States, 1945, Part 12: Pacific Slope Basins in Washington and Upper Columbia River Basin: U. S. Geological Survey Water-Supply Paper 1044.

The maximum recorded discharges occurred December 21 to 23, 1933. No measurement was made at Mayfield during this flood. The flood of 1906 was even greater than that of 1933, but no discharge records were obtained.

Flood and high water have usually come in the winter months from November to January inclusive, as a result of late fall and winter rains. Average duration of high water is about 2 days, and maximum duration is 5 days. Melting snows cause another period of high run-off in May and June.

Cowlitz valley

Relief in the Cowlitz watershed ranges from a few feet above sea level at the mouth of the river to over 14,000 feet at the headwaters on the slopes of Mount Rainier. From its origin at the junction of Muddy Fork and the Ohanapecosh River until it emerges from the Cascade Mountains into the southern extension of the Puget lowlands at about mile 50, the Cowlitz River flows in a valley made up of a series of connected segments. Each segment is remarkably straight throughout its length, and apparently is controlled in orientation by one of several systems of major joints or other structural features. Trends of these segments are as follows:

VIEW UP COWLITZ VALLEY FROM POINT BEHIND RIGHT BANK IN SW¼, NE¼ SEC. 12, T.12N., R.3E., ALTITUDE ABOUT 1700 FEET.

This view shows the broad, flat-bottomed, steep-walled character of the upper valley in the reservoir area for either Shut-In or Mossy Rock dam site. Photograph by A.F. Bateman, Jr.

Number of segments	Trend
1	N. 11° E.
9	N. 44° to 72° E.
2	N. 90° to 94° E.
12	N. 119° to 139° E.

Headwater tributaries. - The Chanapecosh River, Muddy Fork, Clear Fork, Summit Creek, and smaller headwater tributaries flow in deep, narrow canyons with steep gradients, whose walls have been smoothed and streamlined by glaciers that moved down the valleys.

Upper valley. - From the junction of its two main headwater tributaries to the head of Shut-In Canyon at mile 66 in S½ sec. 10, T. 12 N., R. 3 E., the Cowlitz River meanders over the flat surface of stream and glacial deposits that partially fill a steep-walled, U-shaped valley from one to three miles wide. The average gradient of the stream over this distance is slightly more than 11 feet per mile. The character of the valley is shown in Plate I. A dam at either Shut-In or Mossyrock site would flood the lower 18 or 19 miles of this section. Stream gradient in the reservoir area is about 14½ feet per mile.

Mountain summits on either side of the valley rise to altitudes varying from 2,500 feet near Shut-In Canyon to 5,000 feet at the upper end. Glaciers advancing down the valley have truncated the spurs between tributary streams and have smoothed the valley walls. At maximum, ice must have almost completely filled this section of the

VIEW UP SHUT-IN CANYON FROM LEFT RIM AT CROSS SECTION N-N',
FIGURE 2.

Note the narrow, V-shaped trough through which the Cowlitz River flows. Photograph by C.E. Erdmann.

This term conveys nothing to the reader unless he is familiar with D+M paper

valley and approached "second-phase" glaciation as defined by Davis and Mathews.13/ Apparently ice moved from Cowlitz to Tilton drainage

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13/ Davis, N. F. G., and Mathews, W. H., Four phases of glaciation with illustrations from southwestern British Columbia: Journal of Geology, Vol. LII, No. 6, Nov. 1944.

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through Fern Gap, and across the Highland Creek-Cowlitz divide, presumably into the Cowlitz valley, but in neither case was direct evidence found to establish the direction of ice movement.

Shut-In Canyon. - At mile 66, the Cowlitz River leaves the broad, open upper-valley and is confined to a narrow, V-shaped trough locally known as Shut-In Canyon, in which it flows for the next two miles. Plate II shows the character of this trough. The canyon walls rise approximately 325 feet to a fill terrace discussed in a following section of this report. Gradient of the stream through this trough is 21½ feet per mile.

Rock-walled canyons. - From mile 64 at the head of Dunn Canyon in SW¼ sec. 8, T. 12 N., R. 3 E., to mile 50.5 in SW¼ sec. 24, T. 12 N., R. 1 E., the Cowlitz River follows a superimposed course that intertwines with the left bank of its preglacial channel. In places, the superimposed course overlies the old valley wall, and the river has cut a series of narrow, vertical-walled, slot-like canyons into bedrock. Mossy Rock and Mayfield dam sites are located in such canyons.

VIEW DOWNSTREAM THROUGH DUNN CANYON, MOSSY ROCK DAM SITE, FROM POINT ON LEFT BANK OPPOSITE BM 431, FIG. 11.

View shows Cowlitz River occupying a narrow, slot-like canyon in the post-glacial, superimposed section of its course. Photograph by Walter Warren.

Plate III shows one of the bedrock canyons. Separating these canyons are more open stretches where the superimposed course lies within the old channel, and the river has cut a somewhat wider valley into the fill materials. Stream gradients in the canyon sections average 10½ feet per mile, and in the open stretches 16 feet per mile.

Lower valley. - From mile 50.5 to its mouth, the Cowlitz River is intrenched in the alluvial flats of a broad valley up to 3 miles in width, that lies in the southern extension of the Puget lowland. Gradient of the river is about 5 feet per mile.

Fill terrace. - From the upper end of Shut-In Canyon to a short distance below the mouth of the Tilton River, the Cowlitz Valley has been filled with alluvium and glacial debris to a height above the river varying from 270 feet at the lower end to 410 feet at the upper end. It is noteworthy that there is little or no development of this surface in the broad upper valley above the village of Riffe. The remnant found farthest upstream is on the right bank of the river in SW¼ SW¼ sec. 7 and NW¼ NW¼ sec. 18, T. 12 N., R. 4 E. From this point downstream along the right bank, fragments of the fill surface are numerous but rather small, except for an area known as "Dunn Flats" that includes N½ sec. 8, and portions of sections 5 and 6, T. 12 N., R. 3 E. On the left bank, the Swofford Valley is at this level, as well as a large area attaining a maximum width of about 2 miles and extending from Sulphur Creek downstream to include the "Ajlune Plain,"

where is Riffe

All very difficult to follow because locations in terms of T+S, and because terraces not distinguished by color on map, Fig 2 which also carries no contours.

VIEW ACROSS COWLITZ VALLEY FROM RIGHT WALL AT UPPER END OF SHUT-IN CANYON, NW$\frac{1}{4}$, SE$\frac{1}{4}$, SEC. 10, T.12N., R.3E.

Shows fill terrace on left bank. In background is bedrock ridge that separates portions of the fill surface.. Photograph by C.E. Erdmann.

"Mossyrock Plain," and the "Klickitat Prairie," as these flat meadowlands are called locally. A bedrock ridge extending in a southeasterly direction from SW$\frac{1}{4}$, T. 12 N., R. 2 E., skirting the eastern margin of the village of Mossyrock, and continuing for about 4 miles farther, separates this area into two parts. Plate IV shows part of this fill surface and the dividing ridge. This ridge is not continuous, but is made up of a number of separated knobs projecting above the fill.

In general, the fill surface is flat to gently undulating, but in NW$\frac{1}{4}$ sec. 15 and E$\frac{1}{2}$ NW$\frac{1}{4}$ sec. 16, T. 12 N., R. 3 E., masses of till project above the general level. The surface slopes from an altitude of from 800 to 850 feet at the upper end to 580 to 600 feet at the lower end. Gradient is slightly more than 30 feet per mile.

This surface appears to tie in with that of an even more extensive mass of gravel fill extending from the Cowlitz River in sections 3, 10, and 9, T. 12 N., R. 2 E., northward up the right bank of the Tilton River for about 5 miles and including a large area between the Tilton River and Mill Creek. Gradient on this surface is about 50 feet per mile, and at its upper end this surface lies at least 100 feet higher than the one in the Cowlitz valley.

From 2 or 3 feet to as much as 20 feet of non-stratified, limonitic, yellow-brown, lean, sandy, silty clay, believed to be loessal, underlies the Cowlitz fill surface in most places. Beneath it, the fill is made up of thick deposits of well-stratified and often highly cross-bedded

LOOKING NORTHWEST ACROSS SURFACE OF REMNANT OF BENCH NO. 1
FROM CENTER OF SOUTH LINE, SEC. 25, T.12N., R.3E.

Remnant of this same bench can be seen in right background.
Location is in sections 9 and 10 on right bank of river.
Fill terrace can be seen in middle and left background.
Photograph by A.F. Bateman, Jr.

gravels and sands described on page 64, and tentatively assigned to the Iowan stage of the Wisconsin epoch. At one locality on the "Mossyrock Plain" (SE¼ SW¼ sec. 18, T. 12 N., R. 2 E.) the log of a water well and an open drainage ditch show that till rather than gravels underlie the yellow-brown soil. The sediments were deposited in a broad valley already partially filled by an older series of glacial sediments that had undergone considerable weathering. These older deposits are described on page 52. At that time the Cowlitz River was flowing at a level from 15 to 25 feet higher than now. Immediately preceding the period of gravel and sand deposition, ice erosion, stream corrasion by rather large floods of water, or a combination of both, completely removed the weathered material from the surface of the underlying glacial sediments, although where undisturbed they show a weathered zone approximately 20 feet thick.

The Tilton surface is underlain by similar gravels for the most part, but in several localities is underlain by some very old, highly weathered gravel deposits that are described on page 48.

Benches. - Several bench levels are prominent in the Cowlitz Valley. Starting with the highest, they are:

1. A bench is extensively developed on both sides of the Cowlitz Valley and in the delta-shaped area between the Cowlitz and Tilton Rivers at altitudes varying from 1,600 feet to 1,200 feet above sea level, or from 800 to 1,000 feet above the river. Plate V shows this bench level.

The remnant found farthest upstream is on the right bank of the Cowlitz River in E½ sec. 25 and W½ sec. 24, T. 12 N., R. 4 E., at altitudes from 1,600 on the river edge to 1,800 feet. Alta Vista on the north slope of Green Mountain (E½ sec. 25, T. 12 N., R. 3 E. and W½ sec. 30, T. 12 N., R. 4 E.) at altitudes from 1,400 to 1,700 feet lies on another part of this bench level. Above the right wall of Shut-In Canyon, this bench extends through sections 10, 9, and 4, T. 12 N., R. 3 E., at altitudes from 1,390 to 1,600 feet, and on down diagonally through section 5 to end in NE¼ sec. 6 above Harmony at an altitude of 1,200 feet. The Eatonville quadrangle shows a relatively flat area about one mile wide between 1,200 and 1,400 feet extending upstream along the left bank of the Tilton River from a point opposite the mouth of Cinnebar Creek to a point opposite the mouth of Alder Creek that ties in with the high bench in the Cowlitz Valley. Beyond the mountains, several high ridges between Mayfield and Alpha (see Chehalis quadrangle) have rather flattish tops at altitudes from 1,000 to 1,150 feet that may represent the extension of this bench surface into the eastern margin of the Puget Lowland.

The surface of this bench has a down valley gradient of about 25 feet per mile. In the mountains, at all localities observed, the surface has been covered with a light, yellowish-brown, lean, silty clay soil with a massive structure and porous texture. In NE¼ sec. 9, T. 12 N., R. 3 E., a cut along a logging road exposed 2½ feet of this soil containing numerous rounded, stream-worn pebbles and cobbles, and a few weathered fragments of bedrock. The pebbles and cobbles, almost entirely andesite, had weathered rinds from 1/8-to 1/4-inch thick. Beneath the soil, very badly weathered andesite was exposed to a total depth of 5 feet. Road cuts show several feet of brown soil on this bench on the north flank of Green Mountain. In places the soil contains scattered cobbles, some of which are decomposed, and all badly weathered. Scattered glacial boulders with weathered rinds up to 1/4-inch thick were observed up to altitude 1,700 feet. On the slope below this bench level at an altitude of 1,250 feet, bedrock consisting of flows of andesite and volcanic agglomerate are very deeply weathered to a depth of at least 5 feet. Sheeting has developed parallel to the ground surface.

Beyond the mountains, the flat topped ridges at 1,000 to 1,150 feet are underlain by old, very deeply weathered gravels that are described on page 48.

2. Approximately 200 feet below bench No. 1 is a second bench that is of much more limited extent. The most prominent remnant, in SW¼ SW¼ sec. 12, T. 12 N., R. 3 E., at an altitude of 1,200 feet, bevels lava flows of the Keechelus formation. The rock is weathered to a depth of 3 to 6 inches. Behind this portion of the bench is a small valley cut into rock that apparently served as a diversion channel for melt waters while the main valley was filled with ice. Bottom of the channel is at 1,150 feet. This bench level can be

traced downstream for about three-fourths of a mile, and then does not occur again except for a small bench at 1,180 feet on the north wall of Shut-In Canyon near the line between sections 9 and 10. Upstream, a bench at this level includes most of N½ SE¼ sec. 7, T. 12 N., R. 4 E.

3. A third bench, 170 feet below bench No. 2 or at 1,030 feet in the extreme southwest corner of section 12, truncates flows of the Keechelus formation. The rock is weathered to a depth of 3 to 6 inches and in places is covered with a few feet of gravels similar to those underlying the fill terrace. Cut into this bench is another spillway channel with bottom at 950 feet. South of Ajlune, a bench at 1,000 feet altitude covers S½ S½ sec. 21, T. 12 N., R. 3 E. Several isolated rock knobs in sections 16, 21, and 22 reach approximately 1,000 feet.

4. In many localities, portions of the surface of the fill terrace appears to have been smoothed by lateral stream planation. Along the edges of the valley a few small benches have been cut into bedrock as well as into gravels and till, suggesting that the river remained at this level for some time.

After the stream established its course on the fill surface, it started cutting downward. The rate of cutting was no doubt largely controlled by base level in the lower reaches of the river. At least it was not uniform, and benches were cut into the unconsolidated valley fill materials at several levels. They are:

5. About 20 feet below the fill surface and about 340 feet above the river. This bench is well developed in SE¼ and S½ SE¼ sec. 9, and in the northern part of sec. 16, T. 12 N., R. 3 E., at an altitude of 750 feet near the river, rising gradually to an altitude of 780 feet.

6. About 60 to 70 feet below the fill surface and about 290 to 300 feet above the river. This bench is well developed in SE¼ sec. 10, SW¼ sec. 11, and NE¼ NW¼ sec. 14, T. 12 N., R. 3 E., at altitudes from 730 to 740 feet on the margin nearest the river, rising to altitudes of 750 to 765. At the lower end of Shut-In Canyon, this bench is found in SW¼ SW¼ sec. 9, T. 12 N., R. 3 E., at an altitude of 700 feet near the river, rising to 720 feet. Gradient on this bench is about 20 feet per mile down valley.

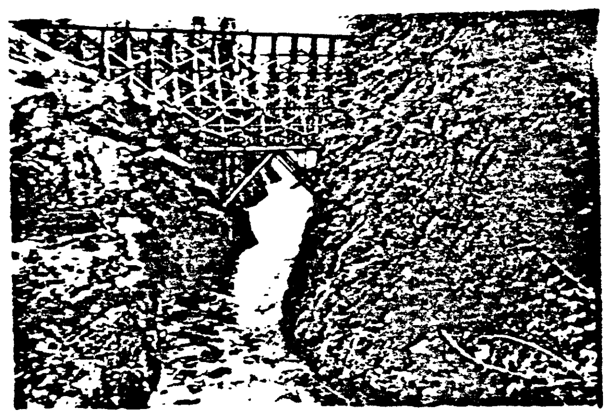
7. About 130 feet below the fill surface and 230 feet above the river. This bench is developed in NW¼ NW¼ sec. 14, T. 12 N., R. 3 E., at an altitude of 670 to 680 feet.

8. About 300 feet below the fill surface at Riffe, varying to about 200 feet at the lower end of the fill terrace. This bench is well developed from Riffe at altitudes from 540 to 560 feet to Mayfield at altitudes from 380 to 420 feet, through which distance its surface slopes down valley with a gradient of approximately 12 feet per mile. Because its gradient varies from the gradients of the river through various reaches of its course, the height of the bench above the

river varies from 60 to 90 feet at Riffe, to 100 to 140 feet at the lower end of Shut-In Canyon, to 120 to 160 feet at Mayfield. Below Mayfield, this bench extends into the lowlands where its gradient decreases to about 6 feet per mile. At the mouth of Mill Creek, it stands 130 to 150 feet above the river at altitudes from 360 to 380 feet. Upstream this bench extends at least as far as Nesika.

All benches cut into the unconsolidated fill beneath the fill terrace, down to and including No. 8, are covered with the same light yellowish-brown loessal soil found on the surface of the fill terrace.

9. In its downward cutting, the superimposed stream encountered bedrock along certain reaches of its course: namely, from mile 64 to 59 and mile 54 to 50.5. The valley it carved varied in depth from about 300 feet at mile 64 to about 150 feet at mile 50.5. Alpine glaciation smoothed the walls of this valley and gave it a characteristic U-shape. Where the lower part of this valley was in rock, subsequent rejuvenation of the stream has enabled it to cut narrow slot-like canyons from 100 to 160 feet into the bottom of the valley. Remnants of the old valley bottom remain as rock cut benches. At Mossy Rock dam site, mile 63.5, these benches are at an altitude of 435 to 450 feet, about 55 to 70 feet above the river surface, and 105 to 120 feet above the bottom of the gorge. (See Plate III.) At Mayfield dam site, mile 52, the benches are at an altitude of 350 to 360 feet, some 110 to 120 feet above water surface and 150 to 160 feet



VIEW DOWNSTREAM THROUGH CANYON AT MAYFIELD DAM SITE FROM POINT ON RIGHT BANK 1000 FEET ABOVE RR TRESTLE.

Rock-cut bench on left bank is 120 feet above the water surface. Photograph by A.F. Bateman, Jr.

above the bottom of the gorge. (See Plate VI.) Gradient of the valley bottom is about 10 feet per mile.

10. Along the river bottoms, benches underlain by inactive alluvium or by gravel fill occur at several levels from 20 to 50 feet above the river.

STRATIGRAPHY

The bedrock formations of the Cowlitz drainage basin are Tertiary in age. Older rocks are covered by a continuous blanket of unknown thickness composed of Tertiary volcanic materials with subordinate amounts of interbedded and associated shales and sandstones. Glacial drift and alluvium partly fill the valleys and cover the older formations on many of the ridges and valley slopes. Although all of the dam sites have foundations in the lava rock, surficial Quaternary deposits are involved in each. Tertiary sandstones and shales are involved in Mayfield dam site, only. Areal distribution of the deposits is shown on figure 2.

TERTIARY

Eocene

Puget Group

A thick series of continental deposits consisting of massive sandstones, many of which are arkosic, interbedded with massive, sandy shales, carbonaceous shales, and coal, occurs on the west slopes of the Cascade Range in southwestern Washington. Near the boundary between the mountains and the Puget lowlands, these deposits interfinger in a complex manner with a marine and brackish water facies called the Cowlitz formation. The grayish-brown sandstones and sandy shales of the Cowlitz formation contain a marine invertebrate fauna, subtropical in character, that is similar to the Upper Eocene Tejon of California.[14] Strata of

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[14] Weaver, Charles E., Geology of Oregon and Washington and its relation to occurrence of oil: A.A.P.G. Bull., vol. 29, No. 10, Oct. 1945.

the continental Puget Group crop out at numerous localities in the Cowlitz drainage basin, and lie behind the right abutment of Bear Creek Canyon dam site, but are not directly involved in any of the proposed dam or reservoir sites. Exposures of this group occur in the neighborhood of Morton, about 8 miles east of Shut-In dam site, and consist largely of sandstone, siltstone, carbonaceous shale and coal, with predominant northerly strike and steep dips to the east.

Oligocene

Lincoln formation

Marine, shaly, tuffaceous sandstones with grits and conglomerates of this formation probably covered all of southwest Washington at one time. These strata are found in the lower Cowlitz valley, but are not involved in the dam or reservoir sites.

Miocene

Keechelus andesite series (?)

This series of volcanic rocks is exposed in the western part of the Cascade Range south of Snoqualmie Pass. It consists of andesite and basalt lava flows, tuff beds, agglomerates, and intercalated sediments of lacustrine and fluvial origin. In thickness, it averages more than 2,000 feet and locally in White River Canyon is about 5,000 feet. On the east side of the Cascade Range it is reported by Warren[15] to pass

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15/ Warren, W. C., Relation of the Yakima Basalt to the Keechelus Andesitic Series, Jour. of Geol. vol. 59, 1941, pp. 795-814.

under the Columbia River basalts.

More than 800 feet of [illegible] volcanic rocks with intercalated sediments are present at Mayfield dam site, from 1,200 to 1,400 feet of extrusives in the Mossyrock-Shut-In area, and from 200 to 300 feet at Cowlitz Falls dam site. Because these rocks have not been traced from area to area, their stratigraphic relationships are unknown. Data are insufficient to work out a generalized geologic section of extrusive rocks exposed in the valleys of the Cowlitz and Tilton Rivers, or to determine their total thickness.

The rocks at Mayfield and Cowlitz Falls have been correlated tentatively with the Keechelus. In the Mossyrock-Shut-In area, the rocks look older than those at Mayfield and Cowlitz Falls, and locally are deeply weathered. Possibly, with these facts in mind, when mapping Mossyrock dam site Mr. Warren thought they might belong to the basic lavas associated with the Eocene Puget Group. Exposures of this group occur in the neighborhood of Morton, and consist largely of sandstone, siltstone, carbonaceous shale, and coal. They have predominant northerly strike and steep dips to the east. The extrusive rocks in the vicinity of Mossyrock and Shut-In dam sites in general dip southward. What appears to be Keechelus rocks crop out in the ridge south of Morton with similar attitude, and seem to overlie the Eocene sediments unconformably. For these reasons, general as they may be, the volcanic extrusives in the Mossyrock-Shut-In area are assigned tentatively to the Keechelus andesite series and are thought to represent the lower part of the series in this

Igneous rocks in mining area near Morton are mostly intrusive, not extrusive - Marlen area. The rocks at the dam sites on the Tilton River resemble those in the Mossyrock-Shut-In area.

Individual flows tend to be thick and massive. Where flow contacts can be recognized, they cannot be traced for any considerable distance because of the heavy cover. At Mayfield and Cowlitz Falls, flows can be recognized on the basis of lithology, but in the other areas, the exposed rocks exhibit great similarity and it is very difficult to separate the flows on this basis. The flows are lenticular in structure; some are composite, consisting of both flow agglomerate and fore-set sheets of lava so that the internal structure is very confusing. The location and character of the vents from which these lavas were extruded are unknown. However, the massive character of the lava, and the thickness and comparatively wide extent of some of the flows, suggest that the vents were of the fissure type.

Rock types included in the Keechelus of this area are:

Lavas of andesitic or basaltic composition, medium to dark gray, fine-grained, dense, and massive. The ground mass is commonly aphanitic, imbedding small phenocrysts of plagioclase feldspar in varying amounts, and sometimes phenocrysts of ferromagnesian minerals. The upper parts of many flows are vesicular in character, containing scattered gas cavities and many amygdules of quartz, calcite, and a dark green to black, greasy, clay-like material thought to be chlorophaeite.

Flow agglomerates of essentially the same composition as the lavas, but varying considerably in texture and other features. In general they are made up of an aphanitic groundmass including and cementing angular to rudely-rounded fragments of the lavas, phenocrysts, mostly of plagioclase, and amygdules. Some contain a good deal of volcanic glass in rounded and irregular masses. On a weathered surface they appear brown or brownish-gray in color, mottled by gray and dull green splotches where amygdaloidal minerals have broken out. On a freshly broken surface they are medium to dark gray or brownish-gray. All are moderately altered, probably by gases accompanying the flow.

Tuffs of fragmental volcanic material with an occasional small, rounded, stream-worn pebble cemented by a clayey matrix. The tuffs are rather soft, mostly fine-grained, and distinctly stratified.

Sediments consisting of soft, friable, poorly consolidated, gray to buff sandstones and black or variegated shale.

Dikes of basalt or andesite whose superior hardness sometimes causes them to stand out in relief. The dike rocks are very dense and fine-grained, but some contain minute phenocrysts of plagioclase feldspar. Freshly broken surfaces are dark gray to black, which weathers to olive-drab or greenish-gray. Well-developed, closely spaced jointing normal to the walls breaks the dike rocks into small columns a few inches square. The dikes appear to occupy a rectangular fracture pattern in the extrusive rocks which they cut. In many cases they are so thoroughly welded to the walls of country rock that the boundaries are difficult to locate.

Where seen, contact zones between lava flows are of three types:

1. Tight and indistinct with little brecciation or alteration by gases and little evidence of subsequent weathering. Contacts of this

type usually separate flows ... are similar in appearance and composition. The time interval between flows was probably relatively short.

2. Scoriaceous and shaly. Evidently sufficient time elapsed between major units for the accumulation of thin layers of soil or ashy clays. When these beds were overridden by another lava sheet, thermal metamorphism baked them into brick-like material varying in color from pink to dull red to reddish-gray. These contact zones are from a few inches to 2 or 3 feet thick. Although fairly well indurated, they are much softer than the enclosing lavas and are usually etched out by weathering and erosion to depths equalling their thicknesses.

3. Brecciated. Some flows have brecciated tops varying from a few inches to several feet in thickness that are usually bright red to grayish-red in color. This zone is made up of angular to slightly rounded fragments of hardened lava in a fine matrix of red powder or lava of the same composition. In many cases, phenocrysts of plagioclase feldspar are very numerous, and vesicles and amygdules are present. Texture of the zone varies from massive to spongy. Brecciation probably resulted from continued movement of molten lava under a hardened crust. The red color probably is the result alteration by accompanying gases. In some instances, this zone is overlain by a thin brecciated zone that appears to be more closely associated with the overlying flow. This zone is usually dark colored.

These rocks are discussed in more detail in the section of the report devoted to individual dam sites.

QUATERNARY

Pleistocene

During the Pleistocene epoch the western slopes of the Cascade Mountains and the Puget Sound structural trough were subject to extensive and repeated glaciation. Russel first noted the existence of two till sheets separated by interglacial sediments in the Puget Sound area. Later Bretz[16] recognized the possibility of another still older drift sheet on the Mima Prairie. From extensive field work in this area, Mackin[17] is now of the opinion that there are four drifts that can be separated on the basis of (1) depth of oxidation and weathering of the drift sheet in situations where it has been subject to weathering since deposition, and (2) the thickness of weathered and decayed rinds shown by boulders, cobbles, and pebbles near the upper surface of the drift.

16/ Bretz, J. Harlan, Glaciation of the Puget Sound Region: Washington Geological Survey, Bull. No. 8, 1913.

17/ Mackin, J. Hoover, Unpublished field data obtained by personal communication.

The extent of ice during the last or Wisconsin glacial stage is fairly well known. Valley glaciers were extensively developed on the western slopes of the Cascade Mountains, and a massive lobe of ice fed by snowfields to the north in British Columbia occupied much of the Puget Sound lowland. North of the Skagit River the valley glaciers and the Puget lobe coalesced to form a nearly continuous blanket of ice.

South of the Skagit River, Cascade ice was distinct from the Puget lobe. In fact, ice from the Puget lobe invaded the Cascade valleys to varying distances within the mountain front, from approximately 21 miles up the North Fork of the Stillaguamish on the north to 2 miles up the White on the south.[18/] This invasion impounded lakes in each of the

18/ Mackin, J. Hoover, Eastern margin of the Puget glacial lobe.: Geol. Soc. America Proc., 1937, p. 248.

valleys except the White. Bretz[19/] mapped the terminal moraine of the

19/ Bretz, J. Harlen, op. cit.

Puget lobe and shows its maximum extension in the vicinity of Tenino, Washington. Subsequent work by Glover[20/] shows that Wisconsin ice extended as far south as the Hanaford Valley, a few miles north of

20/ Glover, Sheldon L., Supervisor, Division of Mines and Geology, Department of Conservation and Development, State of Washington: personal communication.

Centralia, Washington. Bretz also shows that the outwash-bearing streams discharged through the present valley of the Chehalis River. Hence, it would appear that during the Wisconsin age neither ice nor outwash-bearing streams crossed the divide between present Chehalis and Cowlitz drainage. The Nisqually was the most southern of the large Cascade valleys blocked by Puget ice and its deposits.

Much less is known of the earlier glaciers, but they probably followed about the same routes and were probably similar in character.

Geologic mapping in the Cowlitz River basin has revealed till and other glacial and interglacial deposits that appear to be related to three glacial ice advances. Very little is known concerning the routes followed by the glaciers that left the earliest deposits. However, several lines of evidence suggest that they were alpine in character, headed in the Cascade Range and were not part of a continental glacier extending down the Puget lowland. They are:

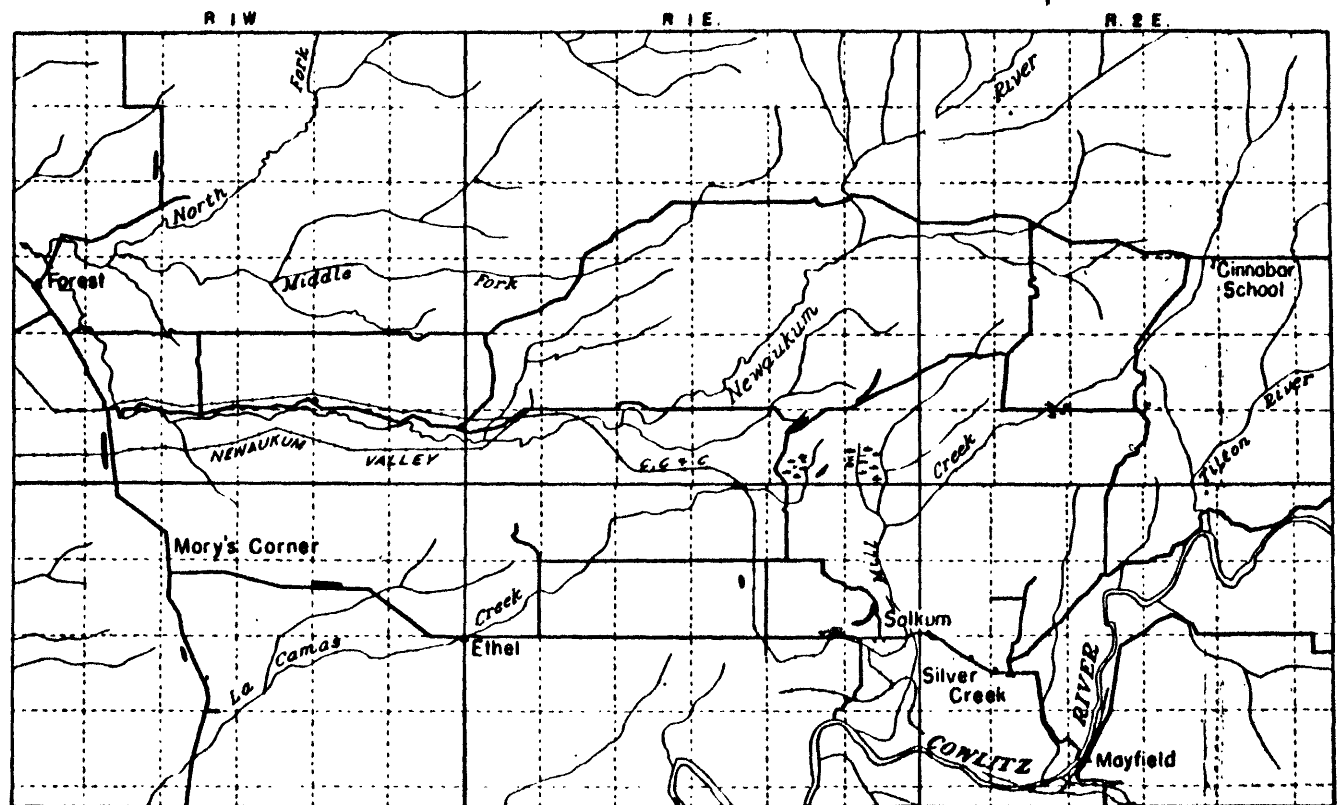
1. Rock types found in the gravels and tills consist of andesites and basalts common in the Keechelus flows exposed in the Cowlitz valley and adjacent areas.

2. The summits of the hills between the Deschutes and Newaukum Rivers that extend into the Puget lowland as far as Centralia have never been glaciated.21/

21/ Bretz, J. Harlen, op. cit.
Mackin, J. H., unpublished field data: personal communication.

3. Occurrence of these deposits near the south edge of the hills mentioned under item 2 in locations that would be protected from ice moving southward in the Puget lowland. One would expect those areas to be drift free if the deposits were derived from Puget ice.

Deposits made during later glacial stages were by glaciers of the alpine type heading in the higher mountains of the Cascade Range that advanced down the valleys of the Cowlitz River and its tributaries.



RECONNAISSANCE MAP SHOWING KNOWN OUTCROPS OF ANCIENT DRIFT (?) IN VICINITY OF COWLITZ AND NEWAUKUM RIVERS, LEWIS COUNTY, WASHINGTON

SCALE

1 0 1 2 3 4 5 6 7 8 9 10 MILES

EXPLANATION

ANCIENT DRIFT (?)

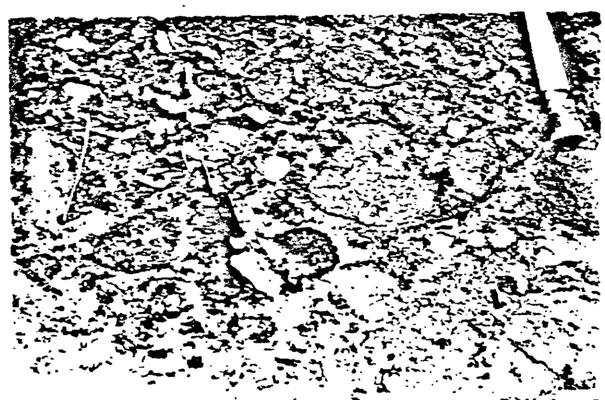
#474

From these data, it is concluded tentatively that at no time in the Pleistocene was the valley of the Cowlitz River blocked either by ice or by outwash deposits of a continental glacier extending down the Puget lowlands.

Ancient drift (?)

A brownish-red to limonitic yellow-brown, deeply iron-stained, highly weathered deposit of gravels is exposed at many localities between the Cowlitz River below the mouth of the Tilton River and the various forks of the Newaukum River at approximate altitudes from 220 to 1,100 feet above sea level. Locations of known exposures are shown on figure 3. In a road cut 1.65 miles east of Mary's Corner on State Highway No. 5 in SE¼NE¼ sec. 10, T. 12 N., R. 1 W., one of the best exposures reveals the following section:

<u>Soil</u>. - Light gray, sandy, silty clay, with a coarse granular structure. Apparently formed by action of humus on underlying material.	1.0 feet
<u>Clay</u>. - Dark red to light yellowish-red, lean, sandy, silty clay with a granular structure. The clay fraction is tough and highly plastic. Clearly derived from underlying material.	1.2
<u>Gravel</u>. - Brownish-red to reddish-yellow gravel with many cobbles and a lean silty clay matrix. At bottom of exposure, 92 percent of cobbles could be carved with a knife.	7.8
<u>Covered</u>	
Total	10.0 feet



DECOMPOSED GRAVELS OF THE ANCIENT DRIFT (?) IN ROAD CUT
ON STATE HIGHWAY NO. 5, 2.1 MILES EAST OF MARY'S CORNER
(SEE FIGURE 3)

Surface had been cleaned with spade which easily cut through both matrix and the largest cobbles. Maximum diameter of cobbles in picture is 4 inches. Photograph by A.F. Bateman, Jr.

The age and mode of origin of these deposits are unknown. Tentatively, they are considered [illegible] gravels and tills related to an early Pleistocene ice advance, possibly Nebraskan or Kansan. All of the surface exposures found to date consist of the gravel phase, but what is believed to be till has been found beneath the gravels in a well. The attitude of these deposits is horizontal, and all appear to underlie erosional rather than depositional surfaces. Hence, the total depth of the zone of weathering and oxidation is unknown.

These deposits have not been recognized in the Cowlitz valley above the mouth of the Tilton River. They are of particular interest because of their occurrence in the vicinity of the buried channel behind the right abutment of Mayfield dam site.

The gravel phase consists of what originally were fairly well-graded gravels, with a silty clay matrix, containing many cobbles varying in size up to 13 inches in maximum diameter. Plate VII shows an exposure of typical material. The surface exposures are iron-stained, leached, and oxidized, resulting in a mottled appearance with predominant colors of brownish-reds and brownish-yellows, but with streaks and masses of white, black, purple, and dark browns. Except for a few scattered angular fragments, the pebbles and cobbles are well-rounded in shape. Some are faceted on one or two sides, suggesting abrasion while held firmly by ice, but none were found with striations. Many of the pebbles and a few cobbles are crushed and broken. All are composed of andesitic and basaltic rocks such as are found in the flows of the Keechelus formation and intersecting dikes. The matrix is a plastic clay containing a small amount of sand consisting mostly of subrounded to subangular quartz grains. Scattered, angular grains of black ferromagnesian minerals and a few rounded and frosted quartz grains are also present.

The till is a light reddish-gray to brownish-gray, massive, compact mixture of boulders, cobbles, and pebbles, with a non-plastic sandy silt matrix. The boulders and cobbles are composed of andesitic and basaltic volcanic rocks similar to those found in the gravel phase. They range to a maximum size of 18 inches. Some are striated, grooved, and polished. The matrix is made up of angular quartz grains, small rounded grains of volcanic rocks, scattered grains of a light-yellow, resinous clay mineral, a few small fragments of lignite, and rounded blebs of carbonaceous material.

The relationship between the gravels and till is shown in the following section:

Dug well, 0.9 miles west of Salkum, Washington,
SW¼SE¼ sec. 11, T. 12 N., R. 1 E.
Altitude of ground surface 652 feet.

Soil. - Light reddish-brown silty clay with a loose granular structure. Contains small scattered pebbles that can be crushed with finger.	12.0 feet
Clayey gravel. - Brownish-red gravel with many cobbles and boulders to maximum size of 18 inches and a light gray, lean, silty clay matrix. Pebble sockets, joint surfaces, and irregular splotches stained rust-brown and dark brownish-black. Cobbles and boulders covered with from 1/16 to ½ inches rusty clay. A few completely decayed, but most are hard, especially toward lower part.	14.0

Ground Water Surface

Till (?)	- Dark, brownish-gray, dense, compact with non-plastic sandy silt matrix. Cobbles and boulders to 18 inches maximum, composed of volcanic rocks, some rotten, but mostly sound. Some striated and polished.	5.0
	Total	31.0

Weathering and oxidation of these deposits extends to an unknown but considerable depth. In many of the surface outcrops of gravels, especially those located on higher ridges, nearly 100 percent of the boulders and cobbles are so decayed and softened as to be easily carved with a knife, and so leached that they are very light in weight. The original mineral grains have been completely altered, but still retain their crystal outlines. The feldspars have been altered to a chalky or yellowish-white kaolin and the ferromagnesian minerals to a brown, iron-stained, clayey powder. Many pebbles and cobbles are coated with a film of kaolin one-sixteenth to one-eighth inch thick, and many pebble sockets are deeply stained with iron and manganese oxides. In other surface exposures of the gravels, weathering has not progressed so far and many of the larger cobbles and boulders are still sound, although they exhibit rinds of weathered material from one-eighth to one inch thick. Quite often these exposures of less weathered material are found on slopes below exposures of the highly weathered material. Apparently the cover protecting these materials from weathering has been removed in comparatively recent times. The till as seen in the well at depths of 26 to 31 feet below ground surface is less weathered than the gravels. Most of the cobbles and boulders are sound although they emit a dull thud when hit with a hammer, show weathered rinds up to one-half inch thick, and contain kaolinized feldspar grains in their outer 2 to 3 inches. A few boulders are completely rotten.

No satisfactory explanation has yet been developed to account for the cracking and slickensiding of the outer surfaces of some of the pebbles, since the unit apparently shows no evidence of tectonic deformation or of having been heavily loaded by either ice or sediments.

Older drift

Unconsolidated but extremely compact glacial sediments are exposed in the Cowlitz River valley from at least three miles downstream from Mayfield dam site to 1½ miles above the village of Riffe, and in the Tilton River valley from the river's mouth to Morton. These deposits are distinguished from the Ancient drift (?) in being much less weathered, but nowhere on the surface have been found in contact with it. The Older drift underlies the Younger drift unconformably and is further distinguished from it by being much more dense and compact.

The Older drift is tentatively considered to be Illinoian and is divided into two parts that have been given the field names Shut-In Glacial Deposits and Tilton Deposits. Exposures of these sediments in parts of the Cowlitz and Tilton valleys are shown on figure 2.

reason for 2 names

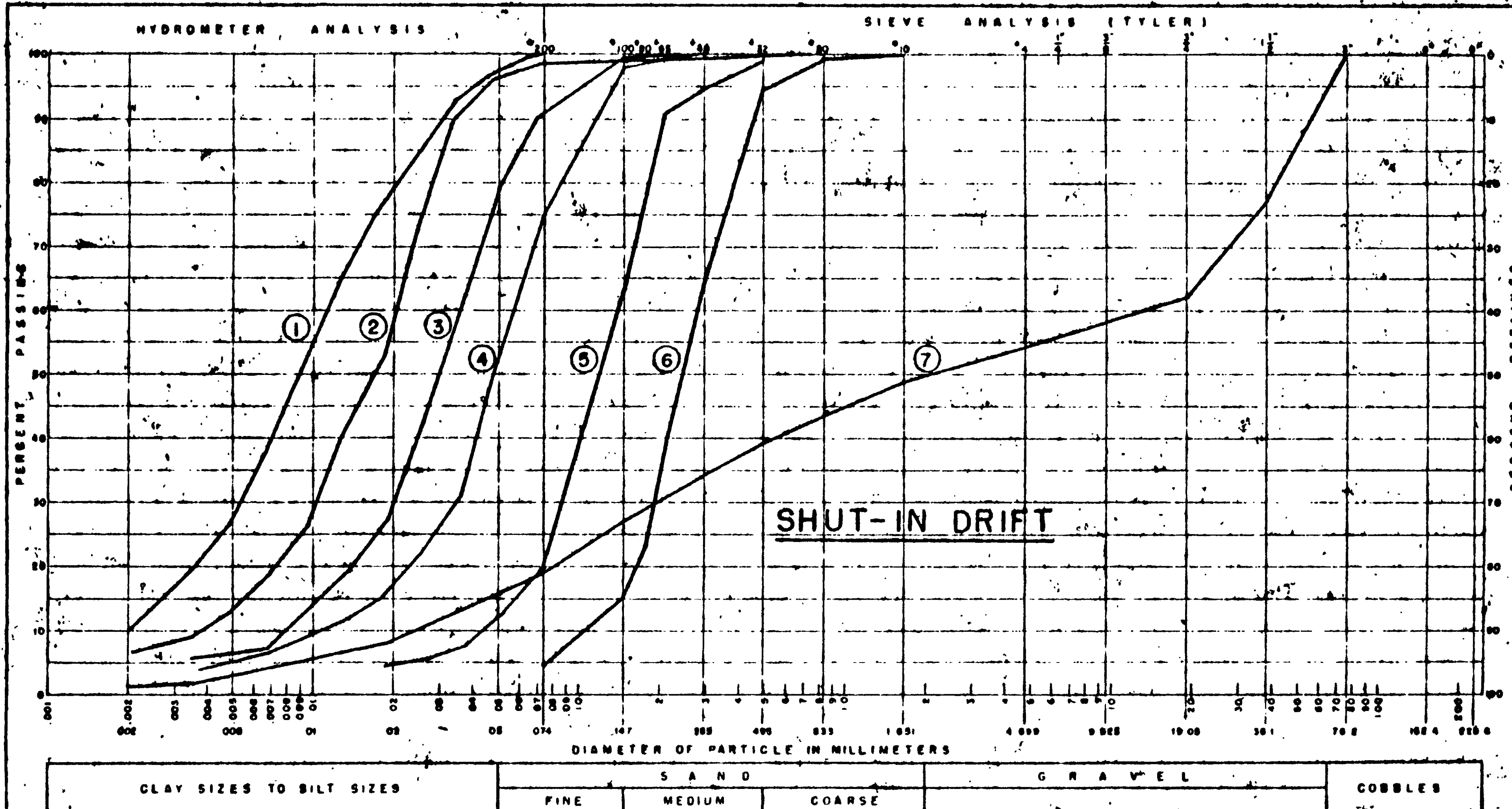
<u>Shut-In Glacial Deposits.</u> - These deposits have been recognized throughout that part of the Cowlitz and Tilton valleys shown on figure 2, at altitudes varying from 240 to 1,080 feet above sea level, and are especially well developed at the head of Shut-In Canyon. They consist

of tills, outwash sands and gravels, and lacustrine clays and silts that are predominantly light bluish-gray in color. Wherever the lower contact has been seen, these deposits are underlain by volcanic rocks of the Keechelus (?) series. However, in a well at Salkum, they are underlain by decomposed gravels that are considered to be Ancient (?) drift:

Section of glacial deposits, DeCoss well, Salkum, Washington. Location is midpoint of south line sec. 12, T. 12 N., R. 1 E., W.M. Surface altitude is 562 feet.

Recent	
Soil	6 feet
Younger drift	
Gravel, cobbles hard and fresh, cemented slightly.	72
Older drift	
Shut-In Glacial Deposits. Silt, light bluish-gray, noncalcareous, slightly plastic, containing some very fine sand and a few small pebbles. Under binocular microscope it appears to be made up entirely of rock flour composed of fine angular quartz grains with minor amounts of a light yellow resinous clay mineral. The lowermost 30 feet contains small pockets of woody coal, and alder wood.	263
Ancient drift (?)	
Gravel, yellowish-gray, decomposed.	2
Total	345 feet

The well was dug by hand to a depth of 116 feet and then continued by drilling. Although the well is over 20 years old, the owner kept a log of materials and retained samples of the silts. Unfortunately, no sample of the decomposed gravels was saved. However, the owner's description fits the gravels of the Ancient drift (?) previously described.



GRADATION TEST

(1) SILT, LEFT BANK COWLITZ RIVER, NEAR MOUTH SULFUR CREEK, SE 1/4, SW 1/4, SEC. 15, T. 12 N., R. 3 E.
(2) SILT, DeGOSS WELL, DEPTH 116 FEET, SE CORNER, SW 1/4, SEC. 12, T. 12 N., R. 1 E.
(3) SANDY SILT, LEFT BANK COWLITZ RIVER, SE 1/4, SE 1/4, SEC. 3, T. 12 N., R. 2 E.
(4) SILTY SAND, RIGHT BANK COWLITZ RIVER, SW CORNER, NW 1/4, SEC. 9, T. 12 N., R. 3 E.
(5) SAND, RIGHT BANK COWLITZ RIVER, NW 1/4, NW 1/4, SEC. 24, T. 12 N., R. 1 E.
(6) SAND, RIGHT BANK COWLITZ RIVER, NW 1/4, NW 1/4, SEC. 24, T. 12 N., R. 1 E.
(7) TILL, RIGHT BANK COWLITZ RIVER, UPPER END SHUT-IN CANYON, NE 1/4, SW 1/4, SW 1/4, SEC. 10, T. 12 N., R. 3 E.

A gradation curve of a silt sample from a depth of 116 feet is shown on figure 4.

It is difficult to obtain an accurate figure as to the depth to which weathering and oxidation of these sediments extends because of the removal of weathered material by later glaciers that advanced down the valleys and their accompanying melt waters. As a result, most exposures, especially those at lower positions with respect to the valley, show materials that are relatively fresh. However, a few scattered exposures show evidence of prolonged weathering, the best of which is in a road cut on State Highway No. 5, one mile east of Ajlune:

Partial section of Shut-In Glacial Deposits, one mile east of Ajlune, Washington, SW¼, SE¼, sec. 15, T. 12 N., R. 3 E., W.M. Altitude of ground surface is 700 feet above sea level. From top down.

Clay, light-gray, loose fluffy structure, lean, silty, with scattered pebbles to ½ inch maximum size. Contains some angular quartz grains, a few fresh-looking crystal fragments of ferromagnesian minerals, a few flakes of brittle mica, and many pebbles of volcanic rocks whose ferromagnesian minerals have been altered to a bright red clayey material.	5.0 feet
Gravel, compact, firm, fairly well-graded, fine, with much coarse silty sand. Pebbles are rounded, coated with rock flour, and composed of andesitic rocks. Maximum size is ½ inch. All pebbles are badly weathered and break easily. Feldspar grains are kaolinized.	2.3
Sand, pale brownish-yellow, fine, slightly silty, poorly graded, thinly laminated, with fine cross-bedding. Some laminae are iron-stained.	2.2

Gravel, ash-gray, except where stained red with iron, compact, fairly well-graded, well-stratified, with cobbles to maximum size of 2 inches and a slightly silty sand matrix. Pebbles are somewhat softened and break with a dull thud. Feldspar grains are kaolinized and ferromagnesian minerals altered to clayey material all way through largest cobbles. Many pebbles are coated with clay and pebble sockets are iron-stained.	3.5
Sand, black, deeply stained with manganese dioxide.	0.05
Sand, deep, brilliant red, weakly cemented, fine-to medium-grained, poorly graded, grains heavily coated with iron-oxide. Scattered pebbles of andesitic rocks, to maximum size of ½ inch. They are weathered all way through with feldspar grains kaolinized.	3.8
Silt and sand, in alternating beds from 1/16 to ¼ inch thick. Sand makes up less than one-fourth of deposit; is stained deep rust-color. The silts are grayish-tan, except in top one foot where they are iron-stained. At top, a 6 inch boulder is softened and weathered all way through.	7.0
Silt, grayish-tan, fine, non-plastic, thinly laminated, with laminae of fine, even-grained, silty sand.	9.2
Sand, light reddish-brown to buff, thinly laminated, fine, even-grained, silty, compact, with many silt laminae and layers up to 2 inches thick.	5.0
Covered	
Total	38.05 feet

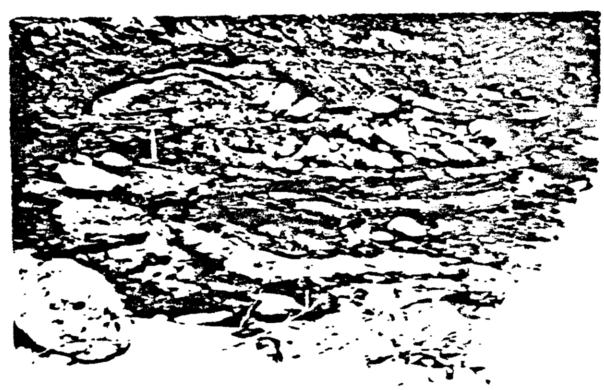
The various materials that make up the Shut-In deposits are as follows:

Till. - Light bluish-gray, very compact till composed of a poorly to fairly well-graded mixture of boulders, cobbles, and pebbles, with a poorly graded silty sand matrix. Gradation of a representative sample is shown on figure 4. The till occurs in beds or masses from a few feet to over 60 feet thick and in small lenses enclosed by the silt and sand phases. The till is usually massive, but some beds show faint stratification. Boulders and cobbles are held tenaciously, and the till is so compact as to make difficult the picking loose of samples. In some exposures, cobbles and boulders make up 30 to 40 percent of the total mass, but in others they may be so rare that the till is composed almost entirely of matrix with small cobbles and pebbles. Maximum size of boulders is about 3 feet. Some of the boulders and cobbles have faceted surfaces, and a few show faint striations and scratches. They are made up almost entirely of volcanic rocks such as occur in the Keechelus formation, but a few are sandstone. The matrix is rock flour or so. ?
It consists chiefly of angular to subrounded particles of quartz with minor amounts of ferromagnesian minerals, pumice, dark brown glass, a light yellowish, resinous clay mineral, small, rounded pebbles of volcanic rocks, and rounded, frosted quartz grains.

Silt. - Light pearl-gray to light bluish-gray, weathering to buff, thinly laminated, even-grained, slightly sandy silts, in beds from a few inches thick to the maximum of 263 feet in the well at Salkum. In some

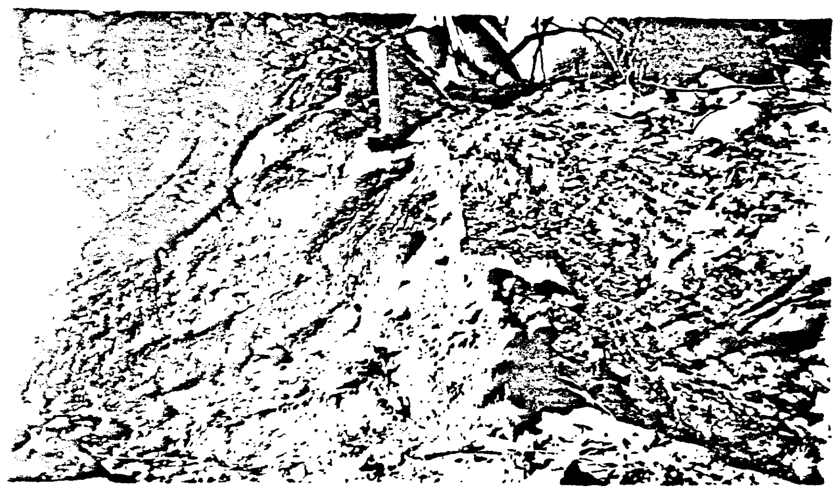
SHUT-IN GLACIAL DEPOSITS STANDING ON EDGE, RIGHT BANK OF COWLITZ RIVER AT HEAD OF SHUT-IN CANYON, 120 FEET UPSTREAM FROM DRILL HOLE C-2.

The silt bed is approximately 12 inches thick. Note that the silt shows considerable intraformational folding and crumpling, but that the overlying till is undisturbed. Photograph by C.E. Erdmann.



SAND PHASE OF THE SHUT-IN GLACIAL DEPOSITS, RIGHT BANK OF COWLITZ RIVER, MILE 64.2
(SEE FIGURE 2)

Fine-grained, minutely laminated, finely ripple-marked, nearly horizontal sand with small lenses of fine silt. Photograph by A.F. Bateman, Jr.



SHUT-IN GLACIAL DEPOSITS, RIGHT BANK OF COWLITZ RIVER AT HEAD OF SHUT-IN CANYON, 70 FEET UPSTREAM FROM DRILL HOLE C-2, FIGURE 13.

Note the vertical fault that cuts deposits. Strike is N 38° W. Material to right of fault is fine sandy silt and to left is coarse sand and fine gravel. Photograph by C.E. Erdmann.

SHUT-IN GLACIAL DEPOSITS, RIGHT BANK OF COWLITZ RIVER AT HEAD OF SHUT-IN CANYON, 70 FEET UPSTREAM FROM DRILL HOLE C-2, FIGURE 13.

Sharp drag folds in coarse sands and fine gravels on left of fault shown in Plate X. Note lens of coarser gravel. Photograph by C.E. Erdmann localities, many beds show intraformational faulting and folding that is highly complicated and intricate. (See pl. VIII.) The crumpled beds are usually overlain by undisturbed beds. Examination under a binocular microscope shows that the silts are typical mo or rock flour. They consist chiefly of angular to subrounded particles of quartz and minor amounts of ferromagnesian minerals, pumice, glass, a light yellow, resinous clay mineral, and small, scattered, rounded pebbles of volcanic rocks. Individual laminae are even-grained. Figure 4 shows grain-size distribution curves of several representative samples. Laminae of fine silty clay and of fine, even-grained sand are common. In places, the material is varved. These silts no doubt accumulated in lakes and ponds dammed by ice or debris.

Sand. - Well-stratified, highly cross-bedded sands, varying from fine to coarse, occur in beds from a few inches thick interbedded with silts up to deposits more than 60 feet thick. These sands are distinguished from those of younger deposits by their high compaction and resistance to picking. Individual laminae tend to be even-grained, as is shown by the grain-size distribution curves, figure 4. Most of the sands are light buff to grayish-tan in color, fine-grained, clean to slightly silty, and composed of angular to subrounded particles of quartz, with a few rounded pebbles of volcanic rocks. They commonly are minutely laminated, finely ripple-marked and contain many layers and lenses of silt. (See pl. IX.) Medium and coarse sands are less common, and tend to be clean. Some contain lenses and layers of gravel and scattered pebbles. (See pls. X and XI.)

Gravel. - Coarse, compact, gravels occur but are less common than other types of sediments. They are usually clean, but may be silty. Because of their high permeability, the gravels are highly iron-stained in many exposures. Pebbles and cobbles are similar in composition to those in the till, but tend to be somewhat more rounded, and slightly more weathered. Matrix is coarse to medium, sometimes silty sand. Fluvial origin is suggested by torrential cross-bedding and shingled structure.

The total thickness of Shut-In sediments is unknown. At the head of Shut-In Canyon, over 1,600 feet of highly tilted and overturned sediments are exposed. However, this thickness may include repetition from faulting and folding. They are:

Partial section of Shut-In glacial deposits at head of Shut-In Canyon, SE¼, SW¼, sec. 10, T. 12 N., R. 3 E., W.M., Lewis County, Washington.

Top concealed	Feet
Silt, light-gray, fine, even-grained, with small masses of till.	30.7
Till	4.1
Silt, with sand zones, and small masses of till up to 2 inches thick.	21.5
Till, massive, stony, boulders to 18 inches.	9.9
Sands and silts, thinly laminated, contorted.	14.1
Covered.	43.9
Till, faintly stratified, fine, small, scattered cobbles, small silt masses.	63.7
Silt	7.1

Till, fine, mostly matrix with scattered cobbles and boulders, and masses of thinly laminated silt, traces of bedding.	15.6
Silt, thinly laminated, highly contorted.	5.2
Till, fine, similar to that immediately above first silt.	26.8
Silt, rather massive, highly sheared.	5.2
Till, massive, boulders to 18 inches.	3.5
Sand, silty, with scattered pebbles, massive, contains lenses of thinly laminated, highly contorted silt.	18.2
Silt, thinly laminated, with sand layers from ½ to 6 inches thick, scattered pebbles.	35.5
Till	4.3
Silt, thinly laminated, some beds contorted.	13.0
Silt and fine sand, thinly interbedded, very dense and firm.	6.9
Till	4.3
Silt, thinly laminated, some beds contorted.	13.0
Silt and fine sands, thinly interbedded, very dense and firm.	6.9
Till	4.3
Silt, thinly laminated, some zones contorted and sheared.	12.1
Silt, massive to weakly stratified, sandy, bluish-gray, weathers buff, sandy layers and scattered pebbles.	12.1
Silt, thinly laminated, thin clay laminae, highly contorted.	1.7
Till, boulders to 18 inches in size.	3.5
Interbedded layers of fine, even-grained, silty, blue-gray sand; and fine, sandy, thinly laminated silts containing thin laminae of silty clay. The	

sands contain scattered cobbles and boulders to 12 inches, as well as small masses of till. There is much minor crumpling in silts.	79.6
Till, very dense and firm, slight stratification; upper part fine with most pebbles under one inch; lower part contains many cobbles and scattered boulders to 18 inches.	59.3
Interbedded layers of gravels, sands, and silts, with small scattered masses of till. Over 50 percent of deposit is fine-to-medium, blue-gray sand.	68.7
Covered.	87.6
Till, massive.	12.0
Covered.	9.2
Till, massive.	15.7
Covered.	25.8
Till, massive.	3.7
Covered.	147.3
Bedrock outcrop, glacial deposits stripped.	57.6
Covered.	144.1
Till, massive, with small lenses of thinly laminated, highly contorted silts from ½ to 24 inches thick.	63.8
Silts, thinly laminated, with interbedded masses of till.	12.9
Till, massive to slight stratification, many lenses and layers of silt.	14.7
Silt, with interbedded masses of till.	9.2
Till, massive, in beds up to two feet thick interbedded with silt beds, some of which are highly contorted.	12.9
Covered.	11.1

Till, massive, with boulders to 18 inches, contain interbedded layers of fine silt near top.	9.8
Covered.	8.1
Till, fine-grained, pebbles to one inch and a few scattered cobbles. Interbedded layers and lenses of silt. Very poorly exposed.	105.2
Till, contains silt layers up to 9 inches thick, scattered cobbles and boulders.	33.0
Silt, in beds up to 6 feet thick with interbedded zones of stratified till and silty gravels. Cut by numerous small faults; many crumpled zones in silt layers.	20.2
Stratified drift, made up of interbedded layers of silt, silty sand, and till. Many cobbles, scattered boulders to 12 inches. Maximum thickness of silt layers 18 inches.	110.8
Silt, thinly laminated, contorted, with fine laminae of sand and of lean clay.	1.0
Stratified drift, as above.	7.3
Silt, as above.	1.3
Stratified drift, as above.	16.3
Silt, as above.	1.0
Stratified drift, as above, silt lenses and layers very numerous, till, fine, most of pebbles under 1 inch, scattered cobbles and boulders.	24.9
Silt, thinly laminated, crumpled, contains thin laminae of fine sand.	4.8
Till, massive, a few silt lenses and layers.	25.4
Stratified drift, as above.	6.2
Till, massive, very dense, compact, boulders to 24 inches.	25.5

Stratified drift, as above.	10.4
Silt, with sandy and pebbly layers.	3.1
Total	1612.4

Bottom of section cut by fault.

Tilton Deposits. - Near the mouth of the Tilton River, a series of sands and gravels outcrops at altitudes from 300 to 480 feet above sea level. (See fig. 2.) This series consists chiefly of grayish-tan, thinly bedded, fine, even-grained, clean to slightly silty sands, with interbedded coarser clean sands, gravels, and silts. These sediments are compact, resistant to picking or erosion, and tend to stand in vertical banks. Cut and fill structure is very common, with gravels and coarse sands filling channels cut into the fine sands. In the center of NE¼ sec. 3, T. 12 N., R. 2 E., W.M., at an altitude from 325 to 350 feet, coarse gravels dipping 37°, S.73° W., make up fore-set beds of a small delta. There is considerable intraformational faulting and some folding.

The Tilton deposits overlie and fill channels cut into the Shut-In glacial deposits. One-fourth mile east of the highway bridge over the Tilton River, fine, blue-gray silts that look like those of the Shut-In deposits along the banks of the Cowlitz River in sections 3 and 10, T. 12 N., R. 2 E., W.M., are interbedded with fine sands of the Tilton. Outwash gravels and sands of the younger drift unconformably overlie and in some places fill channels cut into the Tilton deposits.

Younger drift

Unconsolidated glacial deposits less compact and less weathered than the Older drift overlie it unconformably in both the Cowlitz and Tilton valleys. Distribution in the lower parts of these valleys is shown on figure 2.

In general, the Younger drift appears slightly more weathered than the latest drift in the Puget Sound area. On this basis it is tentatively considered earliest Wisconsin or Iowan in age.

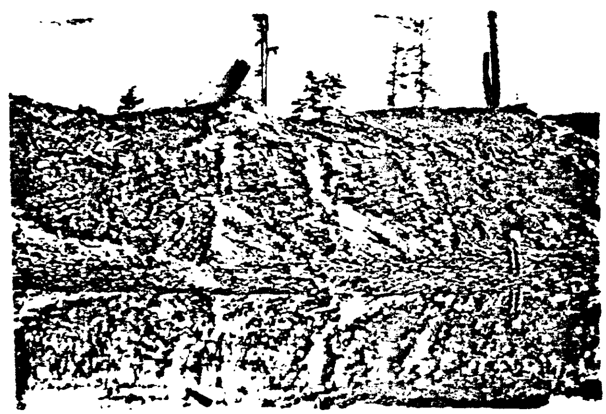
The attitude of the Younger drift is essentially horizontal. Component sediments are:

Till. - Compact, massive deposits of till thinly veneer the Cowlitz valley as far downstream as Mossyrock dam site. Two larger masses form * moraines behind the left abutment of Shut-In dam site (see figure 13), and small masses are interbedded with outwash.

The till is light grayish-buff, massive, unsorted, non-stratified, compact mixture of boulders, cobbles, and gravel tightly held in a lean silty clay matrix. In most exposures the till is fairly well-graded, and in almost all instances is practically impervious. Cobbles and pebbles are almost entirely andesites and basalt derived from the Keechelus (?) series, but there are occasional pebbles of Tertiary sandstone and Mt. Rainier andesite. Many of the cobbles have faceted surfaces and a few show striae.

Last, Puget drift oxidized 4-20"

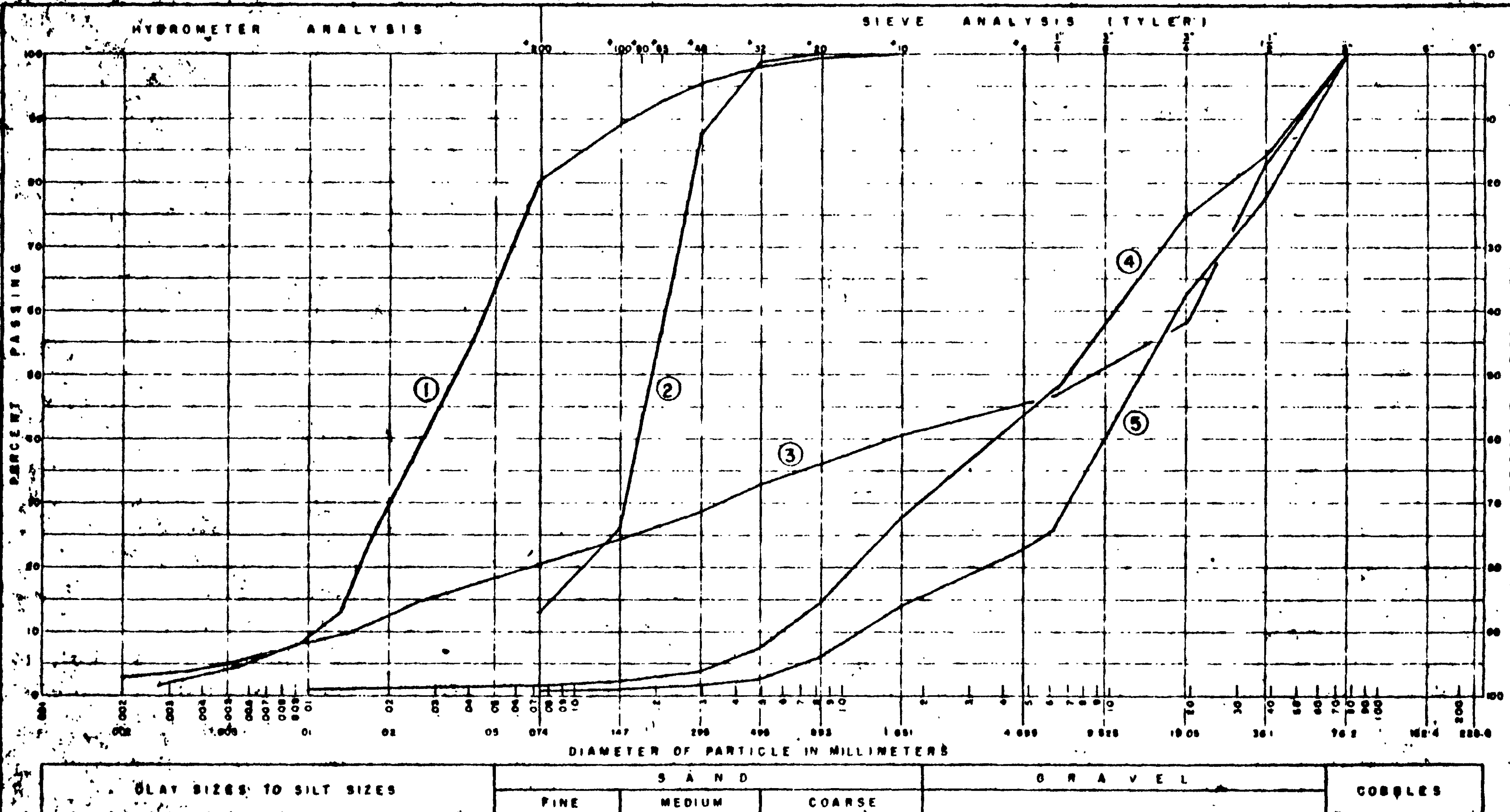
Exposed surfaces of the till have been penetrated by oxidation and weathering to depths of from 4 to 10 inches. Approximately 25 percent of the pebbles less than one inch in diameter found in this zone are softened all of the way through. Other pebbles and cobbles are hard and sound, but



OUTWASH GRAVELS OF THE YOUNGER DRIFT IN GRAVEL PIT ON SILVER CREEK-CINNABAR SCHOOL ROAD, NE$\frac{1}{4}$, SE$\frac{1}{4}$, SEC. 33, T.13 N., R.2 E.

Coarse, slightly silty, sandy gravels interbedded with coarse, clean to slightly silty sands. Note fore-set cross-bedding. Photograph by A.F. Bateman, Jr.

63b



GRADATION TEST

(1) CINEBAR SILT LOAM, SHUT-IN DAM SITE, SW 1/4, SE 1/4, SEC. 9, T. 12 N., R. 3 E.

KEECHELUS (?) ANDESITE SERIES

(2) UNIT B, SANDSTONE, MAYFIELD DAM SITE, STA. I

YOUNGER DRIFT

(3) OUTWASH GRAVEL; PIT BY ROAD FROM SILVER CREEK TO CINNABAR SCHOOL, CENTER E 1/2 SEC. 33, T. 13 N., R. 2 E.
(4) OUTWASH GRAVEL, NW 1/4, NW 1/4, SEC. 24, T. 12 N., R. 1 E.
(5) OUTWASH GRAVEL, SE 1/4, SW 1/4, SEC. 9, T. 12 N., R. [illegible] E.

This sounds like my "find till"

have softened and discolored outer rinds from 1/8 to 5/8 inches thick.

Outwash. - Coarsely stratified outwash gravels underlie extensive bench areas in the Cowlitz basin. (See fig. 2, pl. XII.) In the Cowlitz valley, they are found from below Mayfield dam site upstream at least as far as the village of Riffe at altitudes ranging up to 850 feet. In the Tilton valley similar gravels have been found at the three dam sites examined, at altitudes ranging up to 1,300 feet in the vicinity of Bear Canyon. Between the Tilton and Cowlitz rivers, these gravels underlie high benches up to 1,300 feet in altitude. The broad, flat plain to the south and southwest of Cinnabar school between the Tilton River and Mill Creek and on the right bank of Mill Creek is also underlain by similar gravels.

These outwash deposits consist primarily of light grayish-brown, fairly well-graded, coarsely stratified gravel-sand mixtures. Gradation curves of typical samples are shown on figure 5. Although the gravels contain little fines, the pebbles and cobbles are coated with thin films of rock flour. As a result, the gravels set up to form a compact and rather hard mass. The cobbles and pebbles are subrounded to rounded in shape, and most are less than 10 inches in maximum diameter, although there are occasional boulders up to 18 inches in diameter. Rock types are mostly basalts and andesites from the Keechelus (?) series, but a few cobbles are Tertiary sandstones, Mt. Rainier andesite, and mudballs of the Older till. Most of the cobbles are hard and firm, but nearly all have thin, weathered and discolored outer rinds. Approximately 10 percent, mostly volcanic agglomerate, are completely decayed. The finer materials also consist chiefly of rounded grains of andesitic and basaltic rocks, but contain subangular quartz grains, and scattered bits of pumice.

Stratification is coarse, regular, and lenticular in character. Cross-bedding is common, with dips in a general downvalley direction. Shingle structure is evident in many exposures. The gravels are interbedded with: (1) lenticular beds of coarse, clean sands, in beds up to several feet thick; (2) lenticular beds of fine silty sands; (3) small, irregularly shaped lentils of coarse clean sand and fine gravel, beneath and in the lee of boulders and overlying till masses; (4) cobble and pebble beds, with no sand or fines; (5) thin layers of thinly stratified glacial silt, often mildly contorted; and (6) lenticular masses of till from a few inches to 3 or 4 feet thick and 10 to 30 feet in length.

The upper parts of the outwash show little effect of weathering, although a few gravel layers are iron-stained. This is apparently explained by the fact that most good exposures of the material underlie erosional rather than depositional surfaces, so that an oxidized zone has not had a chance to develop. or has been removed

Although large areas underlain by the outwash have been observed, no kettle and kame type topography has been seen. This, together with the character of the deposits, suggest that the outwash is proglacial in origin.

This is true, but I'd add another sentence to spell out your meaning more clearly.

Loess

Benches and rolling topography in the area between Silver Creek, Cinebar, and Riffe, are blanketed with a light yellowish-brown soil that overlies wide areas of Younger drift and smaller areas of Older drift and bedrock. Locally, it is known as the Cinebar silt loam. It has been observed at altitudes ranging from 400 feet to about 1,400 feet. In thickness it varies greatly from a few inches in some localities to more than 20 feet in others.

In the outcrop this material tends to stand in vertical banks and has the character of loess. It is a lean, silty, noncalcareous to slightly calcareous clay with low plasticity, containing much fine sand and a few scattered pebbles up to one-half inch in diameter. The soil is homogeneous, nonstratified, and has a porous structure with many root holes. It is pervious and absorbs water readily. Examination under a binocular microscope shows that the coarser grains are rounded and are composed of frosted quartz, andesitic and basaltic rocks from the Keechalus (?) series, and occasional fragments of pumice. The finer grains are subangular to subrounded in shape and composed mostly of unfrosted quartz grains, some of which are lightly iron-stained, but with some grains of mica and ferromagnesian minerals. A gradation curve (see fig. 5) shows that the material is well-graded and that 53 percent of the particles lie between the narrow limits of 0.01 to 0.05 mm., the size range of most particles in loess.

The vertical distribution and grain character suggests that much of this material was wind-blown in origin and possibly was originally derived from outwash left in the Chehalis-Centralia area at the southern limit of the Puget lobe of Wisconsin ice. Since deposition, parts of it have been partially reworked by slope wash, introducing larger cobbles and, in places, rude stratification.

RECENT

Pumice deposits

Several square miles of the Cowlitz valley in the vicinity of Kosmos, Randle, and the junction of the Cispus and Cowlitz rivers are covered with either one or two sheets of pumice. The older pumice deposit consists of subangular to rounded grains of a light yellowish-buff, rather weathered pumice, averaging about one-eighth inch in diameter, but with scattered fragments to one inch. Exposures of this bed are numerous along State Highway No. 5 in the Rainy Valley between Kosmos and Randle, where its thickness ranges from 1 to 6 feet. Carithers[22/] describes one pit in which the pumice bed is 13 feet thick.

22/ Carithers, Ward: Pumice and pumicite occurrences of Washington. State of Washington Department of Conservation and Development, Division of Mines and Geology, Report of Investigations No. 15, 1946.

The thickest parts may be due to drifting. Some deposits have been modified and redeposited by water.

The younger sheet is thin and in many places absent. It is made up of fresh, unweathered, light-gray pumice fragments. The two sheets are separated by 6 inches to 3 feet of yellowish-brown, pumiceous, sandy, silty clay. The younger bed is covered with one to 3 inches of soil.

Both deposits are the result of pumice showers from Mt. St. Helens, during postglacial time. The younger bed is very recent. Older trees of the area are rooted either in the separating clay or in the older pumice beds.

cite authority

why not from Mt. [illegible]

Colluvium

Landslides in the Cowlitz and Tilton valleys are few and relatively small. The largest observed slide, on the right bank of the Cowlitz River in Shut-In canyon (see fig. 13), is approximately 400 feet high, and its maximum depth is estimated at not more than 75 feet. A complete description is given in the section on valley fill at Shut-In dam site. Small masses of slumped material consisting either or bedrock or glacial material are fairly common, but none are at any of the proposed dam axes. A block of slumped bedrock may be seen from the highway in SE¼ SE¼ sec. 14, T. 12 N., R. 3 E., W.M.

Talus deposits are thin, superficial, and not very active. Probably few in the lower Cowlitz basin, in which the dam sites are located, approach 50 feet in thickness. The talus consists of angular joint blocks lying below the base of rock outcrops. Voids between blocks are partially or wholly filled with slope wash materials, derived mostly from glacial outwash and till deposits.

Alluvium

Inactive alluvium is used in this report to include alluvium that lies at higher altitudes than the present flood plain. It generally is covered with trees and brush and is not reworked by the stream while in flood stage. In the Cowlitz and Tilton valleys, inactive alluvium underlies low benches, at elevations up to about 30 feet above stream level. Total maximum thickness of inactive alluvium is probably in the neighborhood of 40 feet. Figure 2 shows distribution in lower Cowlitz basin.

Individual exposures are small, ranging from a few hundred square feet to about 80 acres in extent. The inactive alluvium consists of clean, coarse, sandy, fluvial gravels, with occasional large boulders. The gravels are well-stratified, considerably cross-bedded, and show well-developed shingle structure. They are fairly well-graded, and are made up of materials derived from the glacial deposits, with some additions from bedrock exposures. Consequently, included cobbles and pebbles show a wide range (0 to ½-inch) in thickness of weathered rinds. Rarely a cobble is found with a discolored rind as much as one inch thick.

In Shut-In canyon and upstream at least as far as the Riffe bridge, a thin blanket of loose, fine-to-medium, clean, even-grained sand covers glacial deposits to an altitude of about 480 feet, or some 50 feet above stream level. This material apparently has been derived by the reworking Shut-In glacial deposits and redeposition in fairly recent time. The Indians of this area had a legend to the effect that this part of the valley was a lake in their "grandfathers" time, no doubt blocked by a log jam in either Dunn or Harmony canyons.

Active alluvium forms a thin veneer on the base and sides of the present stream channel. Throughout most of the courses of the Cowlitz and Tilton rivers in the area examined, deposits of active alluvium are thin, ranging from 3 to 20 feet in thickness, with an average probably less than 10 feet. However in the rock gorges, alluvium builds up to considerably greater depths during periods of low water. At Mayfield dam site, for example, a maximum thickness of about 40 feet is attained. (See fig. 9.) During periods of high water, however, this alluvium is removed and the rock bottom swept bare.

STRUCTURE

Regional relations?

Mountain structure

upwarps?

The Cascade Mountains and the Coast Range of western Washington are nearly parallel north-south trending [illegible]al upfolds separated by a downfold, the Puget Sound depression and its southward extension. Uplift of these mountains was started in late middle Miocene Epoch, but took place largely at the close of the Pliocene Epoch. Events leading up to their development are outlined in the following brief summary of the Tertiary geologic history of the area based on work by Weaver. 24/25/26/

24/ Weaver, C. E., op. cit.
25/ Weaver, C. E., Eocene of the Lower Cowlitz River Valley, Washington, Calif. Acad. Sci. 4th Series, Vol. VI, No. 1, May, 1916.
26/ Weaver, C. E., Post-Eocene formations of western Washington, Calif. Acad. Sci. 4th Series, Vol. VI, No. 2, May, 1916.

In earliest Tertiary time the present mountains did not exist. Most of the present State of Washington was a plain lying near sea level and drained by westward-flowing streams. During the early Eocene Epoch there was both marine and fresh water deposition in basins resulting from differential subsidence. There followed folding, erosion, and then extensive volcanic activity during which the entire western half of the State to the western foothills of the present Cascade Mountains was covered by submarine lava flows. Further crustal movements consisting of north-south trending upwarps and downwarps formed a long peninsula extending from Vancouver Island southward along the present Washington and Oregon coast. Behind this peninsula a gulf occupied the site of the present Puget Sound lowland and the eastern half of the Coast Range, and connected with the ocean at the south end. Into this gulf, some 8,000 feet of marine sediments, the Cowlitz formation, were deposited. On the east, 8,000 to 14,000 feet of brackish water and fresh water sediments of the Puget Group interfinger with these marine sediments. During the Oligocene Epoch, marine deposition in the gulf continued, giving the sandstones and shales of the Lincoln formation. Minor uplifts in early Miocene forced the sea to regress, but in Middle Miocene subsidence allowed deposition of more than 4,000 feet of marine sands M. M. and shales. Great quantities of lava poured out at this time, blanketing the area now occupied by the southern Cascade Mountains, and interfingering with the sediments.

In late Middle Miocene, western Washington was folded into a series of northwest-southeast trending anticlines and synclines. During the Pliocene Epoch this area was subjected to vigorous erosion, except along the coast where marine deposition was taking place. At the close of the Pliocene, diastrophic movements that affected the entire west coast of North America uplifted the present Cascade Mountains and the Coast Range, producing the intervening Puget lowland. During this disturbance, north-south trending folds were superimposed upon the earlier structures, and the present day topography was largely developed, except as it has since been modified by glaciation. Differential warping, possibly since deposition of the Ancient drift but before the glaciation that deposited the Younger drift, rejuvenated streams and may have renewed uplift along the north-south trending folds.

Early Pleistocene

Cowlitz Basin

Cowlitz basin lies on the west flank of the Cascade Mountains. It is underlain by Miocene volcanic flows, agglomerates and ...as, but small areas are underlain by Eocene continental and Miocene ...e sediments. In general, the regional dip is to the south and west. ...ils of structure are very imperfectly known because of the heavy ...rest cover, the extensive blanket of glacial deposits, and the massive ...aracter of much of the volcanic material that makes difficult the deter- ...mination of its attitude.

Folds. - In the Cowlitz basin, an area extending from Shut-In dam site downstream to below Mayfield dam site is warped into a series of anticlinal folds. Three of these are exposed in the rock canyon of the ...wlitz River extending from mile 50.5 to 54.0 near Mayfield. Axes are located in SE¼ sec. 19, SW¼ sec. 20, and NW¼ sec. 21, T. 12 N., R. 2 E., W.M. (See figure 2). They trend from N. 24° W. to N. 30° W., and plunge to the southeast. Dips on the southwest flanks vary from 30° to 37° SW., and on the northeast flanks from 26° to 39° NE. Weaver 27/ reports a shallow anticline near Vader that trends N. 30° W., and hence appears related to the folds in Mayfield canyon. Because of their axial trends, these folds appear to result from the Late Middle Miocene orogeny.

27/ Weaver, C. E., op. cit. (26)

Cr which flows into the Cowlitz River at

e Keechelus (?) series are folded into an anticline trending
nd plunging southward. Dips on the west flank vary from
°, and on the east flank from 9° to 27°. This fold is shown
res 2 and 13. At the upper end of Shut-In dam site, lava flows
eeply to the east at angles ranging from 19° to 29°, with nearly
-south strikes. (See fig. 13.) On the Tilton River at mile 6.5,
Canyon dam site, and at mile 4.2, Cooper Creek dam site, are small,
allow anticlines with low dips. They have not been mapped in detail,
t their axial trends appear to be nearly north-south. The fact that
the axial trends are nearly north-south suggests that these folds are
related to the diastrophic movement at the close of the Pliocene.

Faults. - Faults are an unimportant feature of the geologic structure of the region. Two faults are described at Mayfield dam site, three faults and a system of shear zones at Mossyrock dam site, and one fault at Shut-In dam site. Details of the faults are discussed under the section on individual dam sites. The faults are small, with displacements ranging from a few inches to about 80 feet. None can be traced for more than a short distance. They make up two systems, one system striking northwest-southeast and the other system striking northeast-southwest. No evidence has been found of movement along any of the faults in recent geologic times.

Earthquakes

Western Washington is an area of considerable seismic activity. However, most of the earthquake shocks are of low intensity. For the most part, these shocks originate in or near Puget Sound. The most severe earthquake shock experienced by this region occured April 13, 1949, with its epicenter in a fault approximately 90 miles southwest of Seattle. It had a maximum intensity of VIII on the modified Mercalli scale. According to Associated Press dispatches, the shock was felt throughout Washington and in adjacent parts of British Columbia, Oregon, and Idaho. Damage was severe throughout western Washington, with eight persons killed and property damage estimated at $6,000,000. In the Chehalis-Centralia area, the shock was of intensity VIII, several buildings collapsed and total damage was estimated at $500,000. Buildings collapsed in a number of towns in the lower Cowlitz valley. Throughout the Cowlitz basin, the shock was of intensity VII to VIII. On the Columbia River near Bonneville dam, several earth slides occurred.

The more important earthquakes from 1856 through 1935 are listed by Heck.[28/] In the Cowlitz Basin and marginal areas he shows no earthquakes from 1856 through 1870, and from 1919 through 1935. From 1871 to 1918 inclusive, eight earthquakes are listed. Of these, the strongest

28/ Heck, N. H., Earthquake history of the United States, Part 1, Continental United States and Alaska, U. S. Department of Commerce, Coast and Geodetic Survey, Serial No. 609, 1938.

...ten y V, and one other was of sufficient intens...
...ck slides at Longmire in Mount Rainier National Park.
...ing in 1935, complete records [29] have been kept, and since then

...ighteen shocks have been felt in this area. Of these, the strongest had epicenters lying outside of the basin. Six with epicenters in the Puget Sound area of intensities V to VII at the epicenter were felt in the basin with intensities varying from IV to VI, and one with epicenter in southeast Washington near Walla Walla was felt with intensity VII. ...f those centering in or near the Cowlitz basin, the strongest was of intensity IV.

From this review of past earthquake activity, in the Cowlitz area, it is evident that a dam and its appurtenant structures will be subject to numerous earthquakes of low intensity, and to occasional shocks of intensities as high as VII or VIII. In general, the intensity of shock seems to be slightly higher in the lower part of Cowlitz basin than in the higher.

29/ United States Earthquakes, 1935 to March 1948, inclusive, ...lished annually for the years 1935 to 1946, inclusive, and quarterly ...ce then by the Coast and Geodetic Survey, U. S. Department of Com- ...rce.

BURIED VALLEYS

General

Both the Cowlitz and Tilton River valleys contain buried channels now filled with glacial sediments. The present streams are superimposed upon the older buried valleys so that their courses intertwine. In some places the present stream intersects the buried channel at an angle, in other places it follows a separate but roughly parallel course, and in still other it occupies the same course and has partly re-excavated the older channel. Hence, a dam located at any point except where the course of the present stream coincides with that of the buried channel will be flanked by a buried gorge filled with glacial debris. In some cases, permeability of the glacial sediments may be sufficient to cause excessive reservoir loss by seepage.

Preglacial valley of the Cowlitz River

Location and description. - Possible routes of the preglacial valley of the Cowlitz are outlined by outcrops of bedrock. Since no Ancient drift has been recognized in the Cowlitz valley upstream from the Silver Creek area, the presence of the Older drift at or near present stream level has been used to delineate the course of the preglacial Cowlitz. Its generalized course from mile 49 to mile 70 as measured on the present stream, together with outcrops of bedrock and of the various glacial sediments, is shown on figure 2. Upstream from mile 70, only a very brief geologic reconnaissance of the valley has been made. However, throughout this upper stretch, the preglacial channel appears to be wide and to coincide with the present stream valley except for about three miles from a point near the mouth of the Cispus River, SE¼ sec. 31, T. 12 N., R. 6 E., W.M., extending down valley to SW¼ sec. 34, T. 12 N., R. 5 E., W.M. The present stream is superimposed upon a rock spur of Tumwater Mountain approximately one mile to the south.

From mile 70 to mile 65.8 at the head of Shut-In Canyon, the preglacial channel coincides with the present stream valley, and is from 0.2 to 0.7 miles wide. Through Shut-In Canyon, the preglacial valley also coincides with the present stream course to near the mouth of Corn Creek. Through this canyon, the preglacial Cowlitz had cut a narrow gorge approximately 200 feet deeper than at present. Its cross profile as outlined by drill holes is shown on figure 15, and consists of a U-shaped valley approximately 300 feet wide at present stream level, with floor at about altitude 355 feet, into which is cut an inner valley approximately 140 feet wide, with floor at altitude 220 feet.

At Corn Creek, the preglacial channel lies to the south of the present stream. A short distance downstream it turns, intersects the present stream at an angle and then continues northwestward behind the right abutment of Mossyrock dam site. A cross profile of the channel as outlined by drill holes and resistivity determinations is shown on cross section J-J', figure 9. In contrast to the narrow canyon a short distance upstream, the preglacial channel is here a broad valley more than 1,600 feet wide at present stream level and 2,700 feet wide at an altitude of 600 feet.

From the SE¼ sec. 6, T. 12 N., R. 3 E., W.M., to the mouth of the Tilton River, there are two possible routes that the preglacial Cowlitz could have followed. The most likely route leaves the present Cowlitz valley and extends southward through the W½ sec. 7, T. 12 N., R. 3 E., W.M., to the village of Mossyrock, then turns to follow a northwest trend until it re-enters the present valley near the mouth of the Tilton River. Factors that point toward this as being the most likely route are: (1) the relatively flat ground surface throughout its length, including the rather extensive "Mossyrock Plain" that comprises all but the NE¼ of sec. 18, T. 12 N., R. 3 E., W.M., the northern two-thirds of secs. 13 and 14 and portions of secs. 10 and 11, T. 12 N., R. 2 E., W.M.; and, (2) the presence of a large mass of Shut-In deposits in SE¼ sec. 6 and NE¼ sec. 7, T. 12 N., R. 3 E., W.M., whose deposition is difficult to explain without such a channel. No deep drill holes or wells have been drilled on the "Mossyrock Plain" to prove or disprove the presence of this channel. In a water well one-half mile south of Mossyrock, the driller reported the following:

0 - 17 feet brown clay and boulders

17 - 39 feet gray clay and boulders

From his description it is concluded that the top 17 feet were in till of the Younger drift and that the underlying material is till from the Older drift. The occurrence of Shut-In deposits at three localities along the river in sec. 1, T. 12 N., R. 2 E., can be explained as having been deposited in tributary valleys that entered the preglacial Cowlitz valley at the extreme northwest corner of sec. 7, T. 12 N., R. 3 E., and in the western part of sec. 2, T. 12 N., R. 2 E.

The second of the two possible routes, from SE¼ sec. 6 to the mouth of the Tilton River, is shown on figure 2 as "Possible Alternate Route." It is shorter and more direct. Bedrock is exposed along the present river bed and in the hill to the south, but most of the area is deeply covered with outwash gravels of the Younger drift. The previously mentioned occurrence of Shut-In drift in sec. 1 indicates a channel in this location, but it may very well have been a tributary rather than the main preglacial Cowlitz valley. Supporting this viewpoint is the narrow gap between bedrock outcrops in the SE¼ sec. 6, T. 12 N., R. 3 E., W.M., through which the main channel would have to pass if it followed this route. Hence, it seems more probable that the Shut-In deposits were made in one or more tributary streams.

At the mouth of the Tilton River, the preglacial Cowlitz channel appears to be more than a mile wide, possibly because this was probably the junction of the preglacial channels of the Cowlitz and Tilton

Rivers and also a tributary stream from the east along the "Possible Alternate Route." Depth to the rock floor of the channel at this point is unknown, but the Older drift is unusually well-exposed. A profile is shown on cross section G-G', figure 6.

For the next three miles below the junction, the Older drift is well-exposed in banks along the Cowlitz River. The left bank of the preglacial channel is outlined by bedrock exposures, but the right bank is deeply covered by outwash gravels of the Younger drift. The channel was at least three-fourths of a mile wide through this stretch.

Near Silver Creek, the channel is constricted between a ridge underlain by bedrock extending northward from Mayfield canyon in E½ sec. 19 and W½ sec. 20, T. 12 N., R. 2 E., W.M., and a hill to the north of Silver Creek that is probably underlain by bedrock although it is heavily covered on the surface. Hence, the main channel appears to lie slightly more than a mile north of Mayfield dam site. Older drift in the right bank of the Cowlitz River, SE¼ sec. 20, T. 12 N., R. 2 E., just upstream from Mayfield dam site, was probably deposited in the channel of a tributary, the preglacial Winston Creek. A small channel behind the right abutment of Mayfield dam site is shown on figure 2. Cross profiles are shown on sections E-E' and F-F', figure 9. It apparently was a relatively short tributary channel because its floor has a gradient to the northeast of more than 300 feet per mile.

Downstream from the constriction at Silver Creek, the preglacial Cowlitz channel widens considerably. Depth to the bedrock floor is unknown. Cross section A-A', figure 6, shows a cross profile through the valley in this area.

From this description it is evident that the preglacial Cowlitz occupied a broad valley throughout its length except for a stretch about one mile in length through the present Shut-In Canyon, in which it flowed through a narrow deep gorge.

Floor. - Portions of the floor of the preglacial Cowlitz channel can be observed at numerous localities near the margin of the channel where it rises to the present ground surface. At Mossyrock and Shut-In dam sites, drill holes have penetrated it. In all cases, it is composed of volcanic rocks of the Keechelus (?) series. Gradient of the bedrock floor is known only in one locality, between cross section P-P' at Shut-In dam site and J-J' at Mossyrock dam site, where it is approximately 23 feet per mile.

Fill. - The glacial debris filling the preglacial channel of the Cowlitz consists in general of Shut-In drift covered by outwash gravels of the Younger drift. Relationships between these deposits are shown on cross sections A-A', G-G', figure 6; E-E', F-F', figure 9; H-H', I-I', J-J', figure 10; L-L', M-M', N-N', O-O', P-P', figure 14; and figure 15.

The various types of sediments comprising the Shut-In drift have been described previously. All types occur in the preglacial Cowlitz channel, with a slight suggestion of arrangement as follows:

1. From the Riffe bridge to the mouth of Sulphur Creek, these sediments consist primarily of thinly laminated glacial clays, some of which are varved, silts, and fine silty sands. Permeability of these sediments is extremely low. They are highly folded into tightly compressed anticlines and synclines, and are considerably faulted. *

2. From the mouth of Sulphur Creek to cross section P-P' in Shut-In Canyon, the Older drift consists of till and pebble clays that appear to be till slightly reworked by water interbedded with many silt layers from a few inches to several feet thick, and occasional beds of outwash gravels. Even the outwash gravels are silty and have low to medium permeability. Other beds have very low permeability. These deposits are standing on end and some are overturned. There is much small scale intraformational faulting in them.

3. Through the remainder of Shut-In Canyon, the sediments are similar in character but tend to be finer. There are more silt beds. Faulting is much less noticeable and the folds are gentle and open.

4. From the mounth of Corn Creek to the head of Dunn Canyon, the sediments are mostly horizontal or gently dipping, fine, even-grained, very compact sands. Permeability of these beds is low.

5. From Mossyrock dam site on downstream, the sediments are mostly thinly bedded glacial clays and silts with minor amount of sand. These beds are in most cases horizontal or with gentle dip. In a few localities, as for example in SW¼ sec. 3, T. 12 N., R. 2 E.,

near the mouth of the Tilton River, there are masses of till, pebble-clays, and outwash gravels. These materials almost always show more complex structures and steeper dips than the silts and clays.

The outwash gravels of the Younger drift are as previously described and in general have medium to high permeability. The boundary between the Older drift and the Younger drift is very irregular. Water moves along the contact, so that springs and seeps are common throughout the Cowlitz valley at the top of the Older drift. As a result, the fines have been washed from a zone at the bottom of the Younger drift that varies from a few inches to a foot in thickness. This zone is highly permeable. Consequently, the altitude of the contact and this overlying permeable zone in various portions of the buried channel may be the controlling elevation for a dam site.

Preglacial valley of the Tilton River

A brief reconnaissance of the Tilton River valley in connection with Bear Canyon, Cooper Creek, and Tilton dam sites has revealed a preglacial channel that probably extends to considerably below the present stream bed of the river. Exposures of Older drift indistinguishable from the Shut-In glacial deposits occurs from the mouth of the river at least as far upstream as Morton. Data are as yet insufficient to outline the course of the preglacial channel, but it is believed to lie behind the right abutments of Bear Canyon and Cooper Creek dam sites, and probably entered the preglacial Cowlitz near the mouth of the present stream.

Glacial diversion channel

Behind the left abutment of Shut-In dam site is a filled channel. Its relationship to the present stream and to the preglacial channel is shown on cross section P-P', figure 14, and its course is outlined on figure 2. The channel leaves the preglacial channel in SE¼ SE¼ sec. 15, extends through S½ sec. 15, follows a northwestward course across NE¼ sec. 16, and re-enters the preglacial channel in SW¼ sec. 9. All sections in T. 12 N., R. 3 E., W.M. A detailed profile of the channel, cross section P-P', figure 16, shows a channel excavated into the volcanic rocks of the Keechelus (?) series with a maximum width of about 1,900 feet. Floor of the channel is at altitude 538 feet or 110 feet above the present river bed and 317 feet above the floor of the preglacial channel in Shut-In Canyon. Some of the diamond drill cores taken from the rock foundation give the impression of considerable weathering. The material filling the channel below altitude 717 feet is interpreted from samples as Shut-In glacial deposits of the Older drift. In character, this material is very similar to the pebble-clays, tills, and sands of these deposits at the head of Shut-In Canyon. Overlying these sediments are outwash gravels and sands of the Younger drift, which in turn are covered with from 5 to 20 feet of the Cinebar silt loam.

Remarks previously made regarding the permeability of these sediments and the contact zone between them where they fill the preglacial channel apply equally well to the present case where they fill a diversion channel.

MATERIALS FOR CONSTRUCTION

Many of the materials required for dam construction in the Cowlitz basin would have to be imported. Access to the various sites by rail and truck transportation is discussed in the section on dam sites.

Cement

No limestone suitable for the manufacture of Portland cement is found in the Cowlitz basin. However, Portland cement is readily available by a comparatively short rail haul from plants operating at Seattle and Grotto in King County, Bellingham in Whatcom County, and Concrete in Skagit County.

Clay and clay products

Clays and shales suitable for the manufacture of brick, drain tile, and other structural wares, is provided by the Puget Group and by Pleistocene aqueoglacial clays. Buff and gray-burning clays suitable for high quality structural wares and buff-colored facing brick occur in the Buswell farm on the east side of the Cowlitz River, NW¼ sec. 25, T. 11 N., R. 2 W., W.M. Deposits of clays suitable for red and brown structural wares are found at many localities in the lower Cowlitz basin in the vicinity of Vader, Winlock, Napavine, and Centralia. One plant at Chehalis manufactures common brick and drain tile.

Coal

Coal, varying in rank from sub-bituminous to anthracite, occurs in the Eocene Puget Group at several localities in and adjacent to the Cowlitz basin. Anthracite coal is found near the headwaters of the Cowlitz River in a triangular-shaped area extending from Packwood to Carlton Pass to Cowlitz Pass. Outcrops are especially numerous along Summit Creek. This coal is mined near Packwood. Bituminous coal is mined at several localities in an area in the upper reaches of the Tilton River extending from Morton northward to Mineral. Sub-bituminous coal occurs in a belt extending along the lower Cowlitz valley from Vader to Kelso. It is mined at Castle Rock. Sub-bituminous coal also underlies an area in the Chehalis River basin extending from Chehalis to Tenino, and is mined at many localities. Near Bucoda, coal is taken from an open pit.

Concrete aggregate

Materials for concrete aggregate probably can be obtained locally at any one of the proposed dam sites from the active or inactive alluvium or from the outwash deposits of the younger drift. Figure 2 shows the areal extent of these deposits in the vicinity of all dam site areas, with the exception of Cowlitz Falls. Gravels from any of these sources would be composed almost entirely of andesitic and basaltic rocks from the Keechelus (?) series. Of these, only the fragments of volcanic agglomerate and tuff would be particularly weak. Gradation of these materials is similar and ranges from poorly graded to fairly well-graded. All are probably lacking in fine and medium sand sizes, and hence would require processing. Gravels from the Younger drift would require washing. The active alluvium would furnish the soundest material with the smallest percent of weathered and decomposed grains, but tends to occur in small, irregularly shaped deposits, the largest volume of which is below ground-water level. Gravel pits would be most easily developed in the Younger drift. Active alluvium has no overburden, the inactive alluvium from a few inches to a few feet of silty, sandy soil overburden, and the outwash deposits from 1 to 10 feet of soil overburden, for the most part Cinebar silt loam. Because of the lenticular character of these deposits, especially those of the Younger drift, extensive exploration and testing will be required for the location of aggregate pits.

Electric Power

There are three small developed power sites, but no developed storage sites in the Cowlitz basin. On the Nisqually River, approximately 20 miles north of the Cowlitz River, the City of Tacoma Light Division has a power development consisting of one storage reservoir, two dams, and two power plants. Data on these power sites are summarized in the following table:

Company Name	Plant Name	Stream	Installed Capacity H.P.
Packwood Electric Co.	-	Hagar Creek	225
Rainier National Park Co.	Paradise River	Paradise River	1,200
Washington Gas & Electric Co.	Morton	Highland Creek	125
Tacoma City Light	La Grande	Nisqually River	53,600
Tacoma City Light	Alder	Nisqually River	67,000

The Bonneville Power Administration Mossyrock to Morton, 69 KV, single circuit transmission line crosses behind the left abutments of both Mossyrock and Shut-In dam sites.

Embankment material

Embankment materials of various types are locally available within comparatively short haul distances of each of the dam sites. Good quality impervious materials can be obtained from the Older drift, especially the till and the clayey, silty, sandy, stratified drift facies. These materials are fairly well-graded (see No. 7, figure 4), and have high shear strength and relatively low permeability. The chief difficulty in utilizing these materials would be finding borrow pit locations where sufficient quantities were available. The silts and silty clays of the Shut-In deposits, although more abundant, would make poor impervious embankment material because of their poor gradation and lower shear strength. Furthermore, with silty material of this type, it is often difficult to secure adequate compaction when placed in the embankment. Till from the Younger drift would also make excellent impervious embankment material, but only in a few localities does it occur in deposits of sufficient volume. (See figure 13.) Satisfactory impervious embankment material could be made by excavating outwash gravels of the Younger drift together with the overlying Cinebar silt loam in shovel cuts adjusted so as to take the proper amounts of each to give a well-graded mixture. Large volumes of these materials are available in both the Tilton and Cowlitz valleys. (See figure 2.)

Large quantities of excellent semipervious and pervious embankment materials are available in the outwash gravels of the Younger drift. Gradation curves of three samples are shown on figure 5. Active and inactive alluvium would also provide pervious embankment materials. Extensive field exploration and testing would be necessary to outline borrow pits from which materials could be obtained that would be satisfactory for each type of embankment.

Natural gas

There is no source of natural gas in the Cowlitz basin or nearby areas.

Pozzuolanic materials

No pozzuolanic materials occur in the region.

Pumice

Two pumice sheets occur in the upper Cowlitz valley above the village of Kosmos. They are described on page 67. The younger sheet is too erratic in outcrop and too thin to be of value, but the older sheet is continuous over fairly large areas. Carithers measured 26 stratigraphic section in which the older sheet varied from 4 to 156 inches, and averaged 47 inches in thickness. The thickest deposit located in the center of sec. 5, T. 11 N., R. 6 E., W.M., contains material that has been reworked by stream action and redeposited along the edge of an abandoned channel of the Cispus River.[30] This pit is now being worked by the Western Sales and Manufacturing Company, Seattle, to obtain aggregate for light weight concrete building blocks. When ground, this pumice would be suitable to add to concrete as an admixture to increase workability.

30/ Carithers, Ward, op. cit., p. 19.

Rock

Many of the basalt and andesite beds of the Keechelus (?) series are sufficiently hard, dense, and resistant to weathering to be satisfactory sources for rubble, riprap, and masonry. Other rocks in the

Keechelus (?) series, including volcanic agglomerate, flow breccia, and tuff beds, would not be sufficiently durable and resistant to weathering for these uses. Adequate supplies of satisfactory rock should be available in the vicinity of each of the dam sites. Exploration for a quarry site should include studies of the joint systems and spacings of the rock under investigation to insure obtaining materials of the required dimensions.

Sand

Sand deposits are numerous throughout the Cowlitz and Tilton valleys. In general, the sands are poorly graded and would not be satisfactory for the use in manufacture of concrete without some processing. Both the active and inactive alluvium contain small, erratic, lenticular beds of sand. These sands are generally medium-to coarse-grained, clean, and poorly graded to even-grained. The outwash deposits of the Younger drift also contain small, scattered, lenticular beds of sand, usually slightly silty and in most cases poorly graded. The Older drift contains large quantities of fine, even-grained sands, that are usually clean but sometimes slightly silty. Near the mouth of the Tilton River in NE¼ sec. 3 and center N½ sec. 2, T. 12 N., R. 2 E., W.M., in the Tilton deposits, fine sands with thin silt strata and gravel lenses have a thickness of more than 50 feet. On the left bank of the Cowlitz River just upstream from Mossyrock dam site in E½ SE¼ sec. 8, T. 12 N., R. 3 E., W.M., fine, even-grained, clean sands occur in a bed that is estimated to be 40 feet thick. Below Mayfield dam site in bluffs along the right bank of the Cowlitz River in $N\frac{1}{2}$ sec. 24, T. 12 N., R. 1 E., 70 to 80 feet of fine, even-grained, clean sand underlie 20 to 30 feet of gravels of the Younger drift that cap the bench.

Timber

Douglas fir, hemlock, and other timber is available locally in abundance. Several sawmills are operating in the Cowlitz basin.

Water Supply

Water supply at all of the sites is abundant and good.

EXPLANATION

C—C' LINE OF CROSS SECTION

② LOCALITY NUMBER

×346 PLANE TABLE BENCH MARK

×407 USEFUL ELEVATION

×W240.0 ALTITUDE WATER SURFACE

32° DIP AND STRIKE OF FORMATION

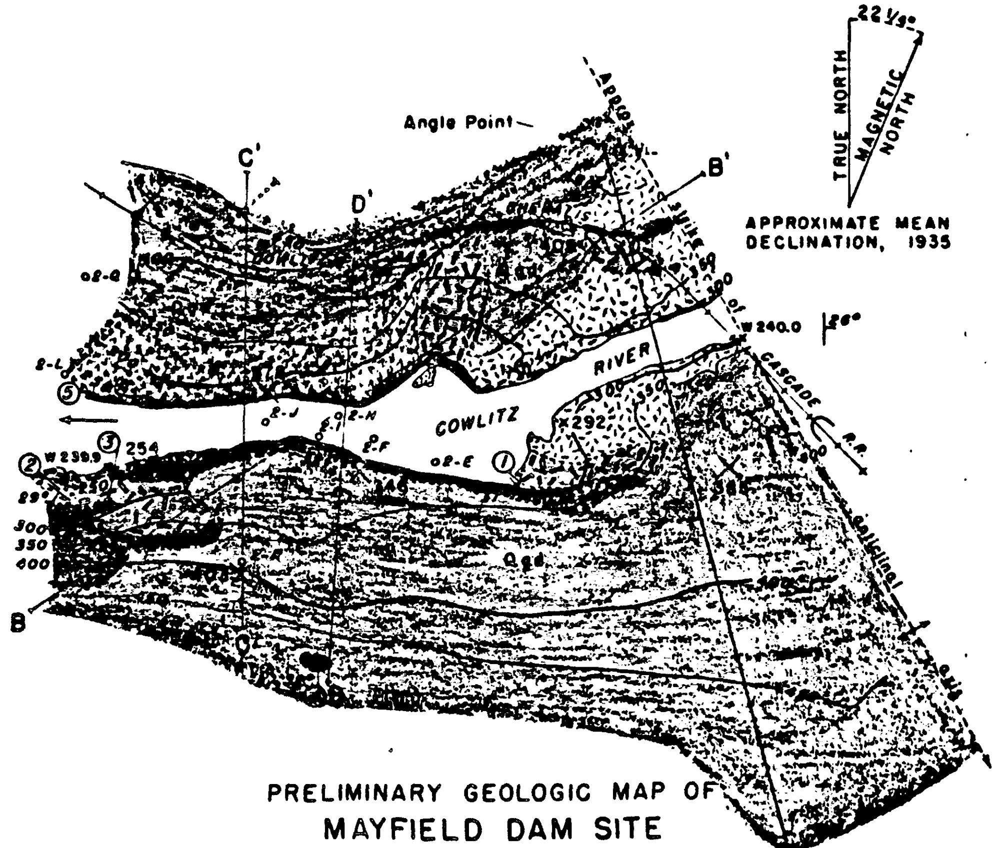
AXIS OF PITCHING ANTICLINE

FAULT

○ Ω-H DIAMOND DRILL HOLES

Ω-O HORIZONTAL D.D. HOLE

NOTE: ONLY THE LOCATIONS OF THE D.D. HOLES USED IN FIG. 9 OR THAT ARE MENTIONED IN THE TEXT OF THE ACCOMPANYING REPORT ARE SHOWN. ALL OTHER EXPLORATION WORK, INCLUDING TEST-PITS AND TRENCHES ARE OMITTED.



PRELIMINARY GEOLOGIC MAP OF
MAYFIELD DAM SITE
SECTIONS 20 AND 29, T.12N., R.2E.W.M.
LEWIS COUNTY, WASHINGTON

SCALE
0 200 400 600 800 FEET

CONTOUR INTERVAL 50 FT.
1936

EXPLANATION

RECENT
- ACTIVE ALLUVIUM
- BASALT TALUS

PLEISTOCENE
- GLACIAL DRIFT

KEECHELUS (?) ANDESITE SERIES

TERTIARY, MIOCENE
- ANDESITE AND TUFFS, UNIT G
- TUFF, UNIT F
- BASALT, UNIT E
- FRAGMENTAL TUFF, UNIT D
- BASALT AND AGGLOMERATE, UNIT C
- SANDSTONE-SHALE, UNIT B CONCEALED IN MAP AREA
- BASALT, UNIT A

LETTERING OF UNITS HAS ONLY LOCAL SIGNIFICANCE, AND DOES NOT INDICATE CORRELATIONS WITH BEDS SIMILARLY LETTERED AT OTHER DAM SITES ON COWLITZ RIVER.

GEOLOGY BY W. WARREN

MAYFIELD DAM SITE

12 NK 3

(Figures 7, 8, and 9)

Location

This prospective dam site is situated in the vicinity of mile 51.9 on Cowlitz River in S½ SW¼ sec. 20, and N½ NW¼ sec. 29, T. 12 N., R. 2 E., Willamette Meridian, Lewis County, Washington.31/

31/ Plan and Profile of Cowlitz River, Mile 42 to Mile 97, Cispus River to Mile 32, and Tilton River to Mile 19, Washington Dam Sites. Sheet 1. U. S. Geological Survey. In preparation.

The special dam site survey32/ is on a scale of 1:2,400 (1 inch =

32/ Op. cit. Sheet 7.

200 feet), with 5-foot contours on land, and covers an area of about 20 acres. The accompanying geologic map, figure 7, has been prepared from this special survey, but for the sake of clarity only the 50-foot contours are shown. Mayfield dam site takes its name form the village of Mayfield, about a mile to the east on the right bank of the river.

Accessibility

State Highway No. 5 crosses Cowlitz River at Mayfield, the nearest settlement. This road is surfaced and open throughout the year. The river is bridged just above the dam site by the Cowlitz, Chehalis and

Cascade Railroad, and access to both banks is easy. Nearest accommodations are at Mary's Corner on U. S. Highway No. 99, 12 miles west of Mayfield. Centralia and Chehalis are about 25 miles by road from Mayfield, and Olympia is 30 miles farther north.

Purpose of project

Development of water power is the primary purpose of a dam at this locality. Storage for flood control is a secondary feature.

In their report on the Cowlitz River,[33] the Corps of Engineers

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33/ Op. cit.

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describe the project in the following words:

> "115. - - - At this point the river flows in a box canyon in basalt rock, with nearly vertical walls about 100 feet in height. A dam 130 feet high would raise the pool to the elevation of tail-water for site 12 NK 2 (Mossy Rock) above. Such a dam would be 50 feet long at the water surface and 225 feet long at its crest 130 feet above. The total height from bed rock to crest would be about 150 feet."

> "117. The elevation at low-water surface at the dam is 250 feet. At crest elevation 380 the flooded area would be about 1,440 acres, and the total storage capacity would be 70,250 acre-feet. Considering this dam as an independent unit its economic drawdown would be 80 feet and the power producible with the mean head of 90 feet would be 4,000,000 kilowatt-hours from the 65,000 acre-feet of live storage. Much greater power is obtainable by using this dam wholly to create power head, utilizing storage from reservoirs above."

"138. - - - A pressure conduit would be required from the dam 5,000 feet to power house at the foot of Mayfield Canyon, in section 19, township 12 north, range 2 east, Willamette meridian."

"At this site maximum power development would be secured by the use of all of the head without drawdown. Flow regulation would be secured with storage at sites above. The elevation at low water is 250, and at the crest of the dam is 380. The head available for power would be 130 feet."

"139. Estimates of the water available for site 12 NK 3 are:

Drainage area, 1,396 sq. miles	Total for basin	Per sq. mile
Runoff, average rate	5,960 second-feet	4.27 second-feet
Runoff, average annual total	4,300,000 acre-feet	
Natural flow 90 per cent of the time	1,810 second-feet	1.30 second-feet
Natural flow 50 per cent of the time	4,700 second-feet	3.37 second-feet

Regulation of the flow at the site could be accomplished with storage of 1,235,000 acre-feet at six sites above.

Such storage could produce flow as shown under regulated flow in the table below. With an operating head of 130 feet power could be developed as follows:

	With natural flow		With regulated flow	
	Second feet	Kilowatts	Second feet	Kilowat[ts]
90 per cent of the time	1,810	14,100	3,980	31,000
50 per cent of the time	4,700	36,700	4,760	37,100

at. 4/1/
plant 73%

Previous exploration

During the Summer of 1926, the late Ira A. Williams,[34] consulting

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[34] Williams, Ira A., Report on Geolgic Conditions at Dam Site No. 2, Mayfield Canyon, Cowlitz River, Washington. Portland, Oregon. September, 1926. Exhibit "A", Vol. II of Report on Proposed Hydro-Electric Development, Cowlitz River, Washington, unpublished report by Ralph D. Thomas, Consulting Engineer to the Backus-Brooks Company, Minneapolis, Minnesota, December, 1928.

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geologist of Portland, Oregon, explored and described the geology of the lower part of Mayfield dam site in considerable detail for the Backus-Brooks Company of Minneapolis. The area mapped was somewhat larger than that included in the present survey, and extends about 600 feet farther downstream. Physical exploration included 31 test pits, 19 diamond drill holes and 8 trenches. With the exception of the diamond drill holes mentioned in this report, none of this work is shown on figure 7, because most of the localities have been obliterated and no longer contribute to the surface geology. However, all drill holes are shown on figure 8.

Field work

A detailed geologic map of the dam site (fig. 7), was made by Walter C. Warren, September 1936. During the field seasons of 1947 and 1948, 59 drill holes were put down by the Light Department, City of Tacoma. Locations of these holes are shown on figure 8. Examination of cores and samples from the drill holes was made by A. F. Bateman, Jr., April 19 to 23, 1948 and August 3 and 4, 1948.

Catchment basin

The drainage basin of Cowlitz River above Mayfield dam site has an area of 1,347 square miles, or about 54 per cent of the total area of the basin of Cowlitz River. Within the watershed of Mayfield dam site, 438 square miles are occupied by the basin of Cispus River, the principal tributary of the upper part of Cowlitz River, and 154 square miles lie in the basin of Tilton River. Hence, the trunk stream of the Cowlitz drains about 755 square miles, and 594 square miles of this area lie above the mouth of the Cispus. The country drained is roughly rectangular, extending eastward from the crest of the Cascade Range. Stream pattern is dendritic and relatively simple. Most of the country is heavily forested, and precipitation is in the form of rain. Some of the upper basins of the trunk Cowlitz and the Cispus include portions of the flanks of Mount Rainier and Mount Adams, high, rugged, inaccessible terrain occupied in part by glaciers. Their melt water, however, makes a negligible volume of the river, and the glacial characteristics of some of the headwaters has disappeared at Mayfield dam site.

Stream gradient

Gradients on Cowlitz River in the vicinity of Mayfield dam site average about 8 feet per mile.[35/] Through the dam site, however, for a

35/ Plan and Profile of Cowlitz River. Op. cit. Sheet 8.

distance of about 1,100 feet, the gradient is only 0.1 foot. Just below the dam site, where the swift current through the gorges drops its load, there is a gravel bar that causes a local increase in gradient during low water.

wall rises continuously as a slope of about 1 on 1 to the terrace level where it flattens to about 3 on 6, and continues at this rate to the level of the upland surface. This topography results in an asymmetric profile for the inner gorge, and a convex profile for the north bank as a whole. (See fig. 9.) The inner gorge, however, is not an unrelieved box canyon. Its middle portion is broken on either side by the passage across the valley of a sandstone-shale member intercalated between the lava flows, and so lacking in strength that the high, sheer walls are breached from top to bottom. The topographic expression of this non-resistant member, modified as it is by a mantle of basalt talus, is well shown on the dam site map, and furnishes an important clue to one of the deficient features of this site. Some 600 feet downstream another weak unit cuts diagonally across the gorge and the wall is breached again. The northwest extension falls outside of the map area, but the southeast extension enters the map at the southwest corner, near P.T.B.M. 254. Unfortunately, the topography in this area is slightly inaccurate, with consequent loss of expression of the weak element.

Apparent possible height of dam

Topographic conditions suggest two prospective dam axes: (1) the gorge beneath the railroad bridge, figure 9, G-H; and (2) the second gorge about 600 feet downstream, figure 9, C-D, E-F. Hereafter they will be referred to as the Upper and Lower or No. 1 and No. 2 sections.

The Upper section appears to be suitable for a comparatively low masonry dam. Crest elevation would stand near the level of the old rock-cut bench, or at about altitude 340. Such a structure would stand about 100 feet above mean water level, and about 160 feet above foundation. Crest length would be about 170 feet. Backwater from a dam of this elevation would extend 11.0 miles upstream into Dunn Canyon (Mossy Rock dam site).

The Lower section also appears suitable for a masonry dam. Altitude of crest would be about 400 feet. At this elevation height above foundation is about 200 feet, and apparent length of crest is around 500 feet. Backwater from such a dam would extend about 12.0 miles upstream through Dunn Canyon.

Character and depth of valley fill

Active alluvium in the stream bed through the dam site is comparatively thin. It consist chiefly of sand, gravel, and boulders, with an average thickness of about 20 feet, and a maximum thickness of around 40 feet. All of this material is in active transport, and the quantity present varies with the stage of the stream. During times of flood scour may penetrate to the bedrock floor of the channel, which is probably swept clean except for occasional large boulders.

A light mantle of glacial drift covers the terrace and upper slopes of the valley. Greatest thicknesses are on the bench on the south side where known depths of 30 feet are present, and locally it may approach

50 feet. The amount of cover on the north bank seldom exceeds 20 feet, and the average is around 10 feet. Most of this drift consists of sand and gravel, and is evidently outwash debris. Much of it includes fragments of andesite and basalt, which may have been introduced as talus. Cementation of the outwash by calcium carbonate is of local occurrence.

Slopes of active talus mantle the re-entrants caused by the non-resistant bedrock layer that passes through the central part of the map area. On the north bank the slide extends from the level of the railroad to the river surface, an elevation of at least 165 feet. The corresponding slide on the south bank is only 125 feet high. Another fairly large area of basalt talus occupies the southwest corner of the map area above B.M. 254; and a smaller area occurs on the right bank just below the railroad at B.M. 405. None of these talus slides occupy prospective dam sections.

Country rock

Bedrock at Mayfield dam site is thought to be assignable to the Keechelus andesite series of Miocene age. More than 800 feet of strata are present, but their stratigraphic position within the Keechelus series is not known. Owing to the direction of dip, the youngest rocks crop out at the west end of the dam site and one goes down in the section, or into older rocks, as one moves upstream. The lithology of the various beds is summarized in the following partial section, and more detailed descriptions of each unit are then given with particular reference to their effect on the dam site.

Partial section of the Keechelus Andesite Series at Mayfield dam site:

Unit	Lithology	Thickness (Feet)
	Top not seen.	
G	Andesite, interbedded with tuff and agglomerate	150±
F	Tuff	20-25
E	Basalt	50-60
D	Tuff	60
C	Basalt and agglomerate	240-250
B	Sandstone-shale	35-80
A	Basalt, base not seen	200±
	Total	755-825

Unit A. - The lowest member of the Keechelus series cropping out at Mayfield dam site is a thick, massive flow of basalt. Color varies from dark gray to nearly black, with a greenish or brownish tinge. All of the rock is unusually dense, and close examination is necessary to distinguish an occasional lath-shaped crystal of plagioclase. Microscopic examination reveals a porphyritic texture, the phenocrysts being plagioclase and augite in a densely felted matrix of the same minerals. Some of the augite shows thin rims of greenish hornblende, but the rock as a whole is very fresh. Cellular or scoriaceous structure is absent except in a thin layer at the top where a scattering of small, irregular vesicles have been drawn out by flowage parallel to the surface of the mass. A thickness of at least 175-200 feet of this body is visible in the gorge of Cowlitz River below the railroad bridge, and the base is not exposed. Total thickness is therefore unknown, and this appears to be the principal unknown element of this unit. The considerable thickness, the character of the jointing and the minor development of vesicular texture suggest that it might be an intrusive body, and hence likely to be very thick. However, the fineness of grain, the absence of contact metamorphism in the overlying beds and the nature of the contact suggest that it is a single and unusually heavy flow of lava. Surface indications are that it has every qualification for a strong, firm dam foundation with abutments of equal bearing power. However, if the river has cut nearly through the base of the flow, and if it is underlain at shallow depth by weak thin-bedded formations similar to those cropping out downstream, then its value as a dam site will be reduced seriously.

Unit B. - The basalt of Unit A is separated from that of Unit C by a topographically weak bed whose passage across the river breaches the steep, close walls of the inner gorge. (See topographic map of Mayfield dam site,[36] and fig. 7.) Most of the surface of these re-entrants is

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36/ Plan and profile of Cowlitz River. Sheet 7.

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covered with basalt talus from the adjacent lava flows, but at Sta. 1, under the cliff-face of Unit C, just above the river surface there is a small exposure of sedimentary rock. Close inspection reveals a two-foot thickness of soft, friable, poorly consolidated grayish-buff sandstone containing small balls of basaltic clay. Estimates based upon the topography and the attitude of the enclosing lavas indicate the total thickness of this non-resistant layer to be about 35 feet. Porosity and permeability are high, and the rock appears to wet through almost at once. Cementing material is clay, which softens quickly in water and the rock crumbles soon after immersion.

A mechanical analysis of a small hand specimen gave the gradation curve shown on figure 5.

Microscopic examination shows the grains to be angular, some with crystal faces, and water-worn fragments are only occasional. Quartz is the predominant mineral, and is roughly estimated at 60-65 per cent; aluminum silicates, or feldspar, makes about 25 per cent; ferromagnesian minerals, chiefly biotite, make around 8 or 9 per cent; and these may be 1 or 2 per cent of muscovite. Many of the mineral grains adhere to one another, especially biotite to feldspar. This, together with the angularity of the material, suggests that it was derived locally from the disintegration of some granitic rock.

The effect of these characteristics makes the inclusion of this bed in a dam site a most critical matter, and it was explored quite thoroughly with a diamond drill. Seven holes were drilled through the bed: 2-E, 2-F, 2-H, 2-I, 2-J, 2-L and 2-O; and 6 other holes of series 2 penetrate the upper and middle parts of the bed. These borings furnish much information that cannot be ascertained by study of the surface. Perhaps first among the things they show is that sandstone at the top of the bed, as found at Sta. 1, is not the normal field condition. The top of the unit is commonly a bed of shale several feet thick, and its upper surface is "often reddened, variegated, and hardened by the thermal effect of overlying lava." Another important feature revealed by drilling is the abrupt and apparently irregular variation in thickness. Bore holes put down in the middle of the river, 2-F, 2-I, and

2-J, show a progressive increase in thickness westward from 15 to 30 feet. Two holes on the right bank, 2-O and 2-L, show thicknesses of 50 and 90 feet, respectively. The group of holes: 2-P, 2-Q, and 2-L, suggest a sharp increase in thickness beginning just west of hole 2-P. Hole 2-L was drilled horizontally into the right bank, and revealed the following section. The thicknesses given are not those logged, but are stratigraphic and have been taken from a cross-section of the bed compiled from a combination of structural and stratigraphic data.

Description	Thickness (Feet)
Shale, black and variegated	25
Sandstone, containing thin layers and lentils of clay	20
Shale	20
Sandstone, with thin layers and lentils of clay	25
Total	90

Much of the sandstone in the thicker part of the bed is coarser in grain and less well-cemented than on the outcrop. Core recovery was difficult because of a caving hole.

It is interesting, and possibly significant to note that the minimum thicknesses discovered appear to be situated toward the axial region of a small anticline that plunges south just off the east end of the dam site map, and that the maximum thicknesses are down on the west flank of the fold. Information for the east flank is lacking. The borings also show that shale does not occur in the bed where thicknesses are minimum. These relationships suggest that the variation in thickness is the result of deformation rather than conditions of sedimentation, such as deposition over irregularities on the surface of the underlying basalt. According to this hypothesis, the shale of the incompetent layer was squeezed from the crest of the fold and passed into the flanks by flowage. A bit of confirmatory evidence may be that the sand in contact with the basalt at Sta. 1 shows no thermal effect of the overlying lava flow, the implication being that the overlying shale that received the heat of the lava was squeezed out during the period of folding. Opposed to this idea is the fact that the thickness of the overlying basalt (Unit C) is greatest where the sandstone-shale bed is thinnest.

Regardless of this problem, which is essentially academic, it is evident that the sandstone-shale bed (Unit B) is one of the critical geologic features of Mayfield dam site. Other factors contingent upon its presence will be considered under the subsequent headings of Ground-water Conditions and Foundation.

Unit C. - Standing above the soft sandstone just described are high, massive cliffs of basalt and flow-agglomerate whose total stratigraphic thickness amounts to about 240-250 feet. Contacts are tight and indistinct, and opinion differs as to the number of flows. Williams counted three, but Warren thought there were five or six. The lava sheets vary in thickness from 10 to 30 feet, and are separated by the flow agglomerates that carry thinner and smaller lentils of basalt. Individual flows are very similar in composition and appearance, and no effort was made to differentiate them, the entire mass being mapped as a unit. Most of the thicker flows exhibit columnar jointing. The columns are rudely hexagonal, five or six feet in diameter and sometimes about 30 feet in length with the longer axis normal to the flow surface. Vesicular lava is characteristic of the upper parts of the flows. These portions and the intervening flow agglomerates are more weathered than the non-cellular rock; and although slightly younger, the entire group is more weathered in appearance than the massive basalt below the sandstone-shale bed.

The freshest rock is dark greenish-gray, with small phenocrysts of augite, and it is tough and dense, and impermeable except along the joints. Microscopic examination shows abundant augite in comparatively large euhedral grains in a very fine matrix of needles of basic plagioclase and basalt. All of the rock is well dusted with small opaque grains of iron oxide that give it the dark color.

The facies called flow agglomerate is dark grayish-brown to nearly black, with a dull lusterless, weathered look, and it is seemingly softer and more elastic than the columnar basalts. It includes and cements rudely-rounded fragments and boulders of basalt that may represent engulfed portions of the crust of the flow or debris from the surface over which the lava moved. Microscopic examination of the matrix of the flow agglomerate shows no evidence of pyroclastic structure. Phenocrysts are inconspicuous, and have either been replaced or broken out. Most of them were probably augite. The ground mass consists of a finely felted mass of plagioclase and augite, much of which is altered to uralite. Some of the larger grains of augite may have changed to serpentine. Amygdaloidal minerals are common and consist of calcite, a greenish radiating and fibrous mineral in thin crusts that may be chlorite, and brown amorphous substances with colloform structures that are probably one of the hydrous iron oxides. The rock is in great contrast to the fresh character of the columnar basalt, and its alteration is probably due to hydrothermal action accompanying the flow rather than to weathering.

All of the flow agglomerate is very massive and contains but few fractures. Pockets and nodules of fairly large radiate masses of brown calcite are common and suggest a previous permeability. At Sta. 1 the base of the group is characterized by large cavities, now occupied by secondary minerals that may have originated from steam arising from moist ground over which the flow poured.

Taken as a whole this unit seems to be entirely dependable for the location of a dam. The rock has ample strength, the individual flows being welded together so that the entire mass will react to stress as a unit. Permeability is low. Whatever fluid movement there may be through the rock will occur on the joints rather than through the fabric or texture. Vesicular structures are non-continuous and will offer little avenue for seepage. Its chief defect is that it is both overlain and underlain by comparatively weak rocks, and that it is too thin to serve alone as a foundation for a dam of the size required by the topographic characteristics of Cowlitz River valley at this place.

Unit D. - The beds of this topographically weak unit consist of fragmental tuff, and have also been called "graywacke" and "tuff-shale." Stratification is distinct, and results from differences in color and texture, but it is doubtful if the beds are wholly waterlain. The following layers or sub-units were recognized in the southwest corner of the map area:

		Feet
5.	Tuff, thinly bedded (1/2 inch)	10
4.	Tuff, single massive layer	3
3.	Tuff, thinly bedded	3
2.	Tuff, massive	10
1.	Tuff, largely concealed by talus. Becomes increasingly sandy toward base. Color brownish. Serves as matrix for slabs and boulders of basalt at base. Contact with underlying bed firm and tight.	25
	Total thickness	60

Colors vary from reddish-brown, olive-green, to blue-black. Close inspection shows a clayey and sandy matrix containing small fragments ($\leq$ 0.25 inch) of red scoria and gray basalt; broken grains of weathered chalky feldspar, up to 3 mm. diameter; black ferromagnesian minerals, a few angular fragments of clear quartz, occasional small (0.125 inch) subrounded stream-worn pebbles, and so on. The matrix has a granular structure (0.25-0.50 inch), which spalls thin concentric shells when wet, and these break into small, sharp pyramidal fragments; ultimately the mass disintegrates into a gritty clay. On the surface induration is only fair, and porosity and permeability appear to be high. The clayey parts can be cut easily with a knife, and the entire mass can be dug with a pick. With cold dilute HCl there is strong but short-lived effervescence. After effervescence the acid leaves a yellow stain, and upon washing the rock appears gray. Color and surface-structure appear to be a function of weathering.

Microscopic examination reveals this rock to have many other significant characteristics. The matrix is seen to consist of a greenish, partially devitrified basic glass with an index of refraction of about 1.55. Many original glassy structures are still visible, such as microlites, spherulites, and vestiges of perlitic structure. Much of the glass is isotropic, but a minutely crystalline structure indicates incipient devitrification. It is possible that the tendency of the rock to swell when wet is due in part to absorption of water by the glass. Some of the fragments are seen to be other kinds of glass. Mineral fragments consist of biotite, quartz, and basic plagioclase (bytownite). Much of the plagioclase has been replaced by calcite, and pseudomorphs are rather common. The bulk of the rock fragments consists of a very fine-textured olivine basalt heavily dusted with magnetite (?), whose plagioclase is largely replaced by calcite.

Although tough and elastic where fresh, and of good bearing power where properly confined, the rock of this unit must be regarded as dangerously weak from the viewpoint of engineering construction. This conclusion results from its softness, its partial solubility in mass can be dug with a pick. With cold dilute HCl there is strong but short-lived effervescence. After effervescence the acid leaves a yellow stain, and upon washing the rock appears gray. Color and surface-structure appear to be a function of weathering.

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Although tough and elastic where fresh, and of good bearing power where properly confined, the rock of this unit must be regarded as dangerously weak from the viewpoint of engineering construction. This conclusion results from its softness, its partial solubility in water, and its tendency to absorb water and further soften and swell when wet. Finally, it disintegrates into a soft gritty clay. Hence, its occurrence in the Lower section at Mayfield dam site must be considered as a serious geologic defect.

Unit E. - This unit appears to be a single flow of basalt 50 to 60 feet thick, closely resembling the basalt of Unit C below. Freshly broken surfaces are very dark gray with a tinge of greenish-brown. Small phenocrysts of dark, lath-shaped plagioclase with bright cleavage faces relieve the dense aphanitic texture of the rock, and there are also some inconspicuous lusterless grains of a brown mineral that may be pseudomorphs of iddingsite after olivine. Microscopic examination reveals more or less complete alteration of the ferromagnesian minerals, but a few grains of augite still remain fresh and untouched. With the exception of the altered phenocrysts of augite, most of the alteration is confined to the groundmass, which consists of a felted mass of small needles of plagioclase, uralite, and a sprinkling of black, opaque grains of magnetite (?). Some of the larger areas of brown mineral may be limonite occupying vesicles, and other cavities are filled with calcite.

Gas cavities are prevalent near the base of the flow, and the larger ones are 6 or 8 inches in diameter. Fillings are chiefly calcite. Continuity of the openings is lacking or incomplete, and there is less possibility of percolation through them than through the joints, which are numerous and destroy the massiveness of the flow by cutting it into blocks about 2 feet square. The entire thickness of this flow is exposed in the southwest corner of the map area, and it makes a rather large portion of the upper part of the left abutment of the lower dam section. In spite of the fact that most the rock is hard and tough, the rather complete jointing and its position between two structurally weak tuffs decrease its total strength so effectively that it must be regarded as a potentially weak unit.

Unit F. - This unit consists of a massive 20-to 25-foot bed of light olive-drab volcanic tuff. The rock is firm when dry, but not very hard, and can be cut easily with a knife. It is also notable for its light weight. Treatment with cold dilute HCl produces a slight effervescence, and leaves a pale yellow stain, suggesting easy solution of some ferrous iron. When placed in water the rock softens rapidly into a mass of crudely spherical particles that disintegrate further by spalling off thin concentric shells. These granules vary in size from 0.25 to 0.50 inch, and are probably a weathering structure, although they may be inherited from perlitic structure in the original tuff. The bulk of the material is fine-grained, much of it of silt size or finer, and small discrete fragments of various other volcanic rocks and minerals are numerous. Among these may be listed: basalt, red and black scoria, glassy quartz, chalky weathered feldspar, and others, that give a gritty feel to the finer, softer clay. Exposures occur in the southwest corner of the map area, and the bed is involved in the upper left abutment of the Lower dam section where it is unquestionably a weak element.

Unit C. - Unit C consists of undifferentiated flows of andesitic lava, agglomerates, and tuffs, varying in thickness from 10 to 60 feet. It crops out in the extreme southwest corner of the map area, and the lowest bed of tuff is the youngest member of the Keechelus series at Mayfield dam site. Lava flows in this group resemble the basalts of Unit C, but are not separated by as great thicknesses of tuff or agglomerate. Where not so separated the top of each is marked by red scoriaceous lava, usually saturated with water.

A 30-to 40-foot andesite flow has been selected arbitrarily as the basal member of this unit, and it is overlain by a 10-foot layer of tuff. Weathered surfaces of the andesite are brownish-gray to nearly black, and show a tinge of greenish color. Broken surfaces reveal a subconchoidal fracture on a hard, dense, tough rock that exhibits only a few small platy phenocrysts of plagioclase feldspar and a sprinkling of minute flakes of sericite (?) that make the surface glisten. Under the microscope the groundmass is seen to consist of a densely felted mass of plagioclase needles, and an abundant sprinkling of opaque black grains that are probably magnetite, give the rock its grayish tone. Phenocrysts of pyroxene are fewer and smaller than those of feldspar. On the whole, the rock is fairly fresh. Alteration products, in addition to sericite, are minor amounts of chlorite and saussurite.

Taken by itself, this rock is eminently suited for the foundation or abutments of a dam, but the flow in which it occurs is too thin to warrant such usage, and this defect is accentuated by its position between two structurally weak and incompetent layers of volcanic tuff. Fortunately, it is not involved in either of the two possible dam sections.

Structural features

Folds. - An anticlinal axis, striking and plunging about S. 30° E., passes along the east side of the map area and crosses the gorge of the Cowlitz about 20 feet upstream from the railroad bridge. The rock exposed at water-level below the bridge is therefore the lowest and oldest stratigraphic horizon within the dam site. No attempt was made to trace the fold back from the banks of the river, but this should be done in order to determine its characteristics more fully. One of its most critical features is the plunge to the southeast, for this condition makes the permeable sandstone bed, Unit B, cross the anticlinal axis somewhere southeast of P.T.B.M. 385, outside of the map area. If the bed persists over the axis a short and highly permeable path for seepage exists around the left abutment of the Upper dam section.

Dip of beds. - On the west limb of the fold, downstream from the bridge, the rocks have an average dip of 33°, S., 46° W. Amount of dip varies from 32 to 37 degrees, and direction varies from S. 33° W., to S. 60° W. Dip cannot be observed on geologic boundaries east of the bridge, but "bedding" joints within the basalt of Unit A, presumed to be parallel to the flow surface, are inclined 26° E.

Faults. - The east dip terminates against a normal fault that crosses the river about 2,000 feet upstream from the anticlinal axis. The downthrown side of the fault is on the west. Amount of displacement is not known definitely, but is not large.

Within the dam site there is no evidence of large scale rock movement. At Sta. 2 one small reverse fault with a stratigraphic throw of about 6 inches was observed within Unit D striking N. 30° W., with a 65° dip to the southwest. The strike is essentially that of the strata, but the amount of dip is about twice as great. This fault was not observed to cut the enclosing units, and it is apparently confined to the tuff in which it originated by differential movement as the incompetent beds adjusted themselves during the period of folding. Near Sta. 3 two large blocks of basalt have slipped down the slope from Unit E.

Joints. - Jointing, or the tendency of rocks to part along planes on which there has been little or no movement, is of considerable importance in a dam site in hard rocks because they are usually more permeable along the fractures than through the texture of the rock.

Most of the rocks at Mayfield dam site are thoroughly jointed. Since they are largely of volcanic origin, it is often difficult to distinguish between primary fractures resulting from contraction during cooling, and fractures resulting from deformation or stress. Many times the former have exerted some control over the latter. Furthermore, rocks with different physical properties react individually to different kinds of stress and the various ways in which it may be applied. Hence, there is much variation in the attitude and spacing of the joints, and too detailed descriptions of the joints at each locality where observations were made is unsatisfactory. Some of this confusion, however, is more apparent than real. This is brought out by considering separately the joints within each unit of rock.

Wherever observed the massive basalt of Unit A appears to be cut by at least three set of joints. Over the crest of the anticline, below the railway bridge, the flow is thought to be approximately horizontal for a distance of about 50 feet. This condition provides a locality where the existing joints may therefore be referred to an apparently normal or undisturbed plane of reference. Examination of the north wall of the gorge at the water surface shows a set (I) of horizontal joints spaced at intervals of about 6 feet, here called "bedding" joints because they are approximately parallel and related to the surface of the flow. Their ends are inclined downward paralleling the dip of the limbs of the fold. At the axis of the fold there are three vertical joints (II) striking N. 30° E., spaced about 4 inches apart. Apparently they have no relationship to the axial plane, but are vertical diagonal joints related to the regional stress that caused the fold. Their conjugate set was observed about 60 feet west, vertical, striking N. 70° W., and spaced about 3 feet apart over a distance of 15 feet. Then, there is a third set (III) of irregular hackly fractures, poorly represented, that are obviously tentional, but their structural relationship is obscure.

With few exceptions all other fractures within Unit A can be referred to these joint sets regardless of their different attitudes, if the limbs of the fold are rotated into normal horizontal position. For example, in the north wall of the gorge about 100 feet downstream from the bridge three sets of joints are exposed: (1) a horizontal set, poorly developed, spaced at intervals of about 2 feet; (2) a set dipping 33°, S. 45° W., spaced at intervals of about 3 feet; and (3) a set dipping 57°, N. 45° E., spaced at 2 inches, and cutting the rock into thin sheets. Upon tilting the rock back to the horizontal, set (2) becomes horizontal and equivalent to the "bedding" joints (I); set (3) appears to be equivalent to set (II); and set (1) equivalent to set (III). This suggests that the anticline developed after the joints.

It also appears that Unit A is cut by only three joint sets of major importance, and two sets of lesser significance. These are as follows:

"Bedding" joints. These fractures parallel the flow surface and are probably the result of contraction during cooling. Although extensively developed, they are not continuous, the ends overlapping by various amounts. The surfaces are smooth and gently curved. At the top of the flow they are spaced at intervals of 2 to 3 inches, but spread rapidly downward so that an average spacing of about 8 inches would hold for the upper 5 feet. Within the body of the flow, 50 feet or more below the surface, they are spaced from 4 to 6 feet, the distance between them becoming greater with depth below the flow surface. Except at the top of the flow, there is small possibility that they could serve as avenues of percolation. Hence, there is no need to estimate their average spacing.

Diagonal joints. These fractures are of mechanical origin, occur in two conjugate sets, and appear to cut the flow from top to bottom. The most numerous set strikes northeast with a variation of about 30 degrees, the range being from N. 20° E., to N. 50° E. Most of them trend N. 30°- 35° E. Dips are high, either vertical, or never less than 80° to the southeast. Their development is extensive, and often they are spaced at short intervals of 2 or 3 inches, 6 inches, and seldom exceed 1 foot.

Their complementary set has a general stike of about N. 70° W., dips are usually vertical, but are sometimes as low as 60° northeast, the amount depending upon the tilt of the rock. Development is not extensive. In some places they may be spaced at intervals of 3 feet for several yards, and often they are absent. At the top of the flow, however, in the neighborhood of B.M. 405, both sets are spaced at intervals of only a few inches. Hence, in conjunction with the "bedding" joints, the upper 5 or 6 feet of the flow is cut into small rhombohedral blocks.

One of the less conspicuous sets consists of short, irregular fractures that strike east and dip 78° south. Frequently they extend only between northeast trending joints of the conjugate set. Sometimes they are open, and they may be of tensional origin. They are infrequent in occurrence. The remaining set consists of discontinuous, hackly fractures that are so irregular in character and distribution that they are difficult to describe. They were noted chiefly in the lower exposures of the flow, and may be due to some cooling effect of the lower surface. Perhaps the most surprising feature of this mass is the lack of normal columnar jointing, ordinarily so characteristic of lava flows. Its absence, together with the thickness of the mass, has led some geologists to regard the body as a laccolith or sill rather than a flow.

Unit B is so poorly exposed that joints cannot be observed. Owing to its poorly consolidated character, it is doubtful if the joints in Unit A carry through it.

Unit C consists of an alternating series of lava flows separated by flow agglomerates. The thickest individual flows are at the base, and the upper one-third to one-half consist chiefly of small lentils of basalt in agglomerate. Because of this lack of homogeneity, and the clastic nature of the matrix of the flow-agglomerate, the unit does not exhibit very systematic jointing. Most of the basalt shows characteristic columnar jointing into hexagonal or prismatic columns whose size is apparently a function of the thickness of the flow. The greatest columns are found in the basal part and may be 30 feet long and 5 feet in diameter.

"Bedding" joints are also typical of these flows, and some of them show a zone at the top 10 feet thick that carries joints spaced at about 6 inches.

Mechanical or deformational joints are also characteristic of the thicker flows, but since they follow to some extent the earlier cooling cracks, they are difficult to recognize in the thinner sheets where the contraction joints are usually closely spaced. At least four sets have been recognized:

Strike	Dip	Spacing
N. 60° E.	Vertical	2 feet
N. 40° W.	55° NE.	3 feet
North	47° W.	1 foot
N. 25° E.	Vertical	3 feet

When the beds are restored to their normal horizontal position, it develops that the first two correspond to the conjugate set of diagonal joints found in Unit A. Rotation produces no change in the northeast diagonal, but the northwest diagonal shows an increase in dip from 55° to vertical. This latter set has been observed to cut through the flow agglomerate separating the basalts. Considering the unit as a whole, jointing cuts the more brittle basalts into blocks usually not exceeding 2 feet on a side. The more elastic flow agglomerates are but little affected.

Unit D, the stratified fragmental tuff, is cut by two sets of joints. One set is vertical, with a strike of N. 27° E., and is spaced at intervals of about 2 inches. The other set strikes N. 50° W., dips 60° NE., and is spaced at intervals of 4 inches. They appear to belong to the system of diagonal conjugate joints observed in Units A and C. Both sets are tight, and probably impermeable.

The basalt of Unit E is cut by a set of joints that strike N. 53° W., and dip 30° SW. This is essentially the attitude of the flow, and the fractures probably are to be classified as "bedding" joints. They are spaced at about 3 feet, and each extends for about 50 feet. Other irregular fractures are present, and cut the flow into blocks about 2 feet in diameter, but do not appear to belong to a recognizable system.

Fractures were not reported from the tuff of Unit F, but if present they probably somewhat resemble those of Unit D.

Jointing in Unit G was observed only in the andesite flow at Sta. 4, probably the basal flow of the group. Platy joints dip 32°, S. 47° W., probably the attitude of the flow. They are spaced at intervals of about 1/2 inch, and are usually tight; however, some at intervals of about 3 feet are open, and persist for short distances, usually between the deformational joints. Where tight their presence is indicated by differential etching due to weathering. The open fractures are evidently of later tensional origin, and were guided by the primary cooling joints.

The deformational joints at this locality consist of a conjugate pair that apparently belong to the same system as the master joints previously described, although their orientation is somewhat different with respect to the attitude of the flow. One set is vertical, and strikes N. 75° E., with strong persistent fractures spaced at intervals of 3 feet. The complementary set strikes N. 15° W., and dips 55° E., with equal persistence and spacing.

Ground-water conditions

Surface indications of ground water are negligible, and are confined to a few small springs and seeps that are largely seasonal. Chief among these are the scoriaceous zones at the top of the andesite flows in Unit G, in the southwest corner of the map area. Across the river at Sta. 5 there is a small spring estimated to flow about 40 gallons per minute from a hole in a small lentil of columnar basalt in the upper part of Unit C. Local reports are that formerly the water was sulphurous.

This spring is probably one of the group that Williams observed along the right bank of the river about 170 feet downstream from Sta. 5. After the sandstone-shale bed (Unit B) had been penetrated by a series of bore holes into the right bank and the hydraulic head reduced, these lower springs ceased to flow.

Surface exposures of Unit B are dry throughout the dam site. Most of the holes drilled to it in the channel found water. This occasioned no surprise for the bed crops out in the channel bottom a short distance upstream from the drill locations. (See fig. 9, B-B'.) In hole 2-J, figure 9, C-C', for example, water was found under an artesian head of about 157 feet, just flowing over the collar of the drill pipe, and indicating the equilibrium of the system with the river. It also shows a very high coefficient of permeability for the sandstone of Unit B, and illustrates how readily uplift pressure of a head of water impounded behind a dam would be transmitted to the base of any dam sited above this bed.

However, the discovery of water under pressure in the bed above river level was something of a surprise, and is evidently related to another hydraulic system. Two of these holes are within the dam site area as mapped by the Geological Survey. Hole 2-L, at altitude 248, or about 8 feet above the elevation of the adjusted river profile, was drilled horizontally in the direction N. 50° E. The top of the bed (shale) was found 145 feet in from the surface, and the first sandstone was drilled at 195 feet. A "heavy flow of water," volume not stated, was found at this point, and after the bore was completed to a total length of 450 feet, measurements showed a water pressure of 38 pounds per square inch. This is equivalent to a hydrostatic head of about 68 feet, or approximately half of the normal hydrostatic head for the locality. Angle hole 2-Q, 180 feet north, found the top of the sand at altitude 267, but it was dry. Horizontal hole 2-O at altitude 250 was drilled N. 65° E., for 430 feet. The top of the bed (shale) was found 320 feet in from the surface and the top of the sand was found at 340 feet, with water under a pressure of 4.5 pounds per square inch. This is equivalent to a hydrostatic head of only 10 feet, whereas the expected hydrostatic head should be about 125 feet. Vertical hole 2-P, to the north, found the top of the sand dry at about altitude 256. These erratic water conditions in the bed above the level of the river show that it is incompletely saturated, and suggest that the water is of meteoric origin. Some of the irregularity, however, may be due to lentils of sand cut off or enclosed by the clay or shale. The rapidity of pressure-drop after the sand was penetrated indicates that the rate of recharge is slow, and under existing topographic conditions it is doubtful if the upper part can ever be saturated completely.

There is no data on ground water in Unit B from the left bank, but structural conditions favor drainage into the bed rather than from it. For these reasons it may be expected to contain somewhat more water than in the right bank, and under the same erratic conditions.

Permeability

In the rock formations at Mayfield dam site permeability is largely a function of their jointing, which has been described briefly in a foregoing section from the viewpoint of origin, attitude, and orientation. Under the present heading they will be considered again, bed by bed, with regard to their capacity to transmit water.

Unit A, the thick, massive basal flow of basalt, may be considered as essentially impermeable except for the upper 8 or 10 feet where closely-spaced joints in conjunction with vesicular texture make feasible the passage of water. Within the body of the flow the non-persistent "bedding" joints are not expected to contribute to the permeability. Of the remaining sets, the more closely-spaced northeast diagonal fractures will contribute more to the permeability than the relatively widely-spaced northwest-trending set, particularly since some of the group parallel the direction of stream flow. Without going into detail, previous estimates of the permeability of rock of this type suggest that the coefficient of permeability (K) will probably not be more than 10×10^{-8} feet per second.

The permeability of Unit B is dangerously high. Some of the basic data have been described under the topic of Ground-water conditions, but considerably more information is needed before any K-value can be assigned. In this unit the permeability is through the texture of the sandstone rather than fractures, and the irregularity of the clay and shale make any field estimate very uncertain.

Field observations suggest that the permeability of Unit C is about twice that of Unit A. That the rock is permeable is indicated by the presence of springs that apparently originate from artesian conditions in Unit B. Conditions are locally highly variable. Where unfractured the flow agglomerate is very impermeable, but some of the thicker flows with well-developed columnar jointing are very permeable. The K value of 20×10^{-8} feet per second is therefore a very rough over-all estimate.

Although the fragmental tuff of Unit D is bedded as well as jointed, the rock is probably practically impermeable. This condition results from the tendency of the devitrified glass to swell when wet, thus automatically sealing any fractures that might carry water.

Jointing in the basalt flow of Unit E is rather complete, the fractures cutting the rocks into blocks about 2 feet on a side. The coefficient of permeability is at least 20×10^{-8} feet per second, and very probably higher.

Permeability in the tuff of Unit F is negligible, and for the same reasons given for Unit D.

Permeability in Unit G is variable, but the over-all coefficient is estimated to be about that for Unit C, 20×10^{-8} feet per second. The value of the coefficient for the tuff beds will be less, and that for the andesite flows higher, particularly if they have both prismatic and deformational jointing.

Dam sections

The Upper or No. 1 section, figure 9, E-E', has been mentioned briefly by the Corps of Engineers in their report on Cowlitz River,[37/] and extensive quotations from it have been made in a preceding section of this report. The Lower or No. 2 section, figure 9, C-C', D-D', has been described by Williams,[38/] who also refers to it as the No. 2 Mayfield site. References to the location of Williams's No. 1 Mayfield site have not been found, but presumably he considered another else the one he explored so thoroughly would not be designated No. 2. It is possible that it is the Upper site, as the term is used in this report.

Figure 9, E-E', illustrates the major geologic features of the Upper or No. 1 site. At altitude 400 the width of open valley is about 580 feet, but the distance between the bedrock walls is about 620 feet. This additional length is through a superficial fill of glacial outwash and drift. Cross-sectional area of the open valley below altitude 400 is about 18,800 square feet, and the total cross-sectional area of the valley is about 39,600 square feet. The difference of some 20,800 is occupied chiefly by glacial drift above the gorge section on the left bank, but about 3,200 square feet is submerged in the bottom. Below altitude 340 the gorge section has an

37/ Op. cit. pars. 115-117. p. 29.

38/ Op. cit.

area of about 12,000 square feet, including the fill of alluvium and water.

Insofar as surface geologic observations extend, the gorge appears to have been cut entirely in the basalt of Unit A. Bearing power of the abutments is great and substantially equal, and the short distance between them suggests an ideal situation for an arch dam. Unfortunately, the total thickness of Unit A is unknown, and uncertainty exists as to the nature of the underlying rock, for borings have not been made in this part of the channel. If any considerable thickness of the basalt of Unit A is present, the situation is favorable, and even if a weaker rock is present much of the load upon it could be relieved by arch-action within the narrow confines of the gorge. However, in the absence of specific information, in order to secure the greatest possible thickness of basalt in the foundation, it appears advisable to shift the dam axis either up or down stream from the anticlinal axis that approximately parallels section E-E' only 100 feet upstream (fig. 7) because, regardless of the true or total thickness of Unit A, the amount of basalt is at a minimum where the river cuts the crest of the fold. Owing to the comparatively steep dips of the limbs of the anticline, it is only necessary to move the dam axis 250 or 300 feet in order to place about 200 feet of basalt in the foundation.

The disadvantages of such a shift are that, due to the curvature of the top of the flow, the height of the basalt walls of the gorge decrease as one moves along the river either way from the anticlinal axis where they are highest. Since the east boundary of the map more or less coincides with the anticlinal axis, the consequences of an upstream move cannot be considered in detail because it falls without the map area. Downstream, as one approaches the top of Unit A, there is an added disadvantage of increasing proximity to the highly permeable and structurally weak sandstone of Unit B. The combination of this condition, which results in the progressive deterioration of the left abutment, and the decrease in depth of the gorge, which reduces the economy of the section, restrict the most favorable dam axis to approximately that of E-E', figure 9. Even here, however, the plunge of the anticline to the southeast causes Unit B, if it persists or has not been squeezed out completely, to cross the anticlinal axis, and the topography makes it climb high upon the left bank. This combination of geologic structure and land forms results in the appearance of the bed high on the south abutment, as shown in E-E', figure 9. Its presence at this elevation is somewhat unfavorable to the consideration of the section for a high dam because it produces a lowering of the bearing power of the upper part of the left abutment, weakening much of the overlying Unit C, and because it introduces a highly permeable element into a situation structurally weak. It may be argued that the hydraulic head on Unit B at this place will be small. This is true, but the hydraulic gradient in the bed to the open valley at Sta. 1 would be about 2.5 on 1, wich is dangerously high considering the unconsolidated character of the rock. Furthermore, the longer path of seepage around the end of the anticline is also involved.

Even though these adverse conditions can be rectified by grouting and cut-off walls, it seems prudent to restrict contemplation of any dam on section E-E' to the gorge section with the flow line not exceeding altitude 350, until further high-level exploration of the south abutment has been carried out. Under this restriction the rock-cut bench now buried by glacial drift might make a logical spillway section, and the smaller, shallower niche on the right abutment offers an alternative section at a slightly higher elevation. Stream diversion for any dam contemplated would have to be by tunnel through Unit A, preferably under the right abutment. This construction should offer no unusual difficulties.

The Lower or No. 2 dam section at Hayfield dam site is analogous to No. 1 in that the gorge has resulted from the down-cutting of the river in a thick, massive bed of volcanic rock, Unit C. Topographic conditions indicate two possible dam axes, C-C' and D-D', figure 7. For C-C', at altitude 400 the width of open valley is about 460 feet, but the distance between the bedrock walls is about 570 feet. The additional length is through a thin mantle of glacial deposits. Cross-sectional area of the open valley below altitude 400 is about 33,700 square feet, and the total cross-sectional area of the valley is about 40,200 square feet. Only 2,000 square feet are submerged in the valley bottom, but the gorge section is confined to 6,600 feet below altitude 300. For D-D', at altitude 400, the width of open valley is about 490, and the distance between bedrock walls 530 feet. Cross-sectional area of open valley below altitude 400 is about 33,700 square feet, the same as for section C-C', and the total cross-sectional area is around 41,600 square feet. The gorge section below altitude 340 has an area of 15,000 square feet, and the submerged portion totals about 3,200 square feet. Section C-C' is, therefore, slightly the more favored from the standpoint of minimum amounts of fill and submergence.

In geologic features, however, each section appears to have certain advantages over its neighbor, but usually these are offset by local defects. Thus, since Unit C, through which the river is cut, dips southwest about 32 degrees, the foundation of the downstream section, C-C', is thicker and heavier than that of D-D'. To some extent this offsets the weakness and potential hydraulic uplift inherent in the permeable underlying bed, Unit B, but it would be a very strong unbalanced force for a dam on section D-D'. On the other hand, the advantage is with D-D' for a structure attaining altitude 400 in that only one bed of tuff, Unit D, is fully involved in the upper left abutment whereas section C-C' includes two, Units D and F. In other respects these sections are much alike, as in the unequal bearing power of their abutments that is caused by the diagonal course of the river across the strata. For each, the entire right abutment is in the thick, strong, massive flows of Unit C, but the upper part of the left abutment consists of thin, soft, weak beds of volcanic tuff intercalated between comparatively thin flows of basalt and andesite.

Choice of dam sections

For low dams, or those with crest not exceeding altitude 340, all sections are comparable. However, the gorge section is better at D-D' and E-E' than at C-C', and the abutments and foundations are within a single rock unit. These conditions, together with their upstream location, give them a slight advantage over C-C'. The gorge section at E-E' is slightly superior to that at D-D'. Amounts of submergence, attitude of rock, and abutment conditions bearing power are essentially equal. The rock at D-D' is thought to have twice the permeability of E-E'. However, the foundation is comparatively thin and subject to uplift due to the occurrence at shallow depth of permeable bed B. Foundation conditions at E-E' are really unknown; that is, the thickness of Unit A is unknown, and information on the underlying stratum is not available, but a dam could be placed in such a position in the gorge so that it would be underlain by a considerable thickness of sound rock. If it were placed upstream from the bridge it would have the advantage of an upstream dip. In general, the foundation at E-E' appears to be stronger than at D-D', in spite of the lack of information.

Geology of reservoir area

Mayfield reservoir site is comparatively long and narrow and is confined to the gorge of Cowlitz River. For this reason its capacity is not large. Area in acres and capacity in acre-feet have been computed by Johnson,[39] who points out that the flow line is limited

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39/ Op. cit. p. 9.

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to about altitude 380 feet by Mossy Rock dam site, or to about altitude 420 by Shut-In dam site. It will be recalled, however, the most favorable section for a low dam at the Mayfield site has a crest altitude of only about 340 feet. A pool with level at this altitude would have an area of 626 acres and a capacity of 19,060 acre-feet. Its backwater would not inundate Mossy Rock dam site. The most favorable section for a high dam does not exceed altitude 400. A pool with this level would have an area of 1,510 acres and a capacity of 80,120 acre-feet. Backwater from such a dam would inundate the Mossy Rock site but Shut-In dam site would not be affected.

Comparatively little is known about the geology of the area, but conditions are thought not to differ greatly, if at all, from those described at Mossy Rock dam site. In general, bedrock is made by the andesites of the Keechelus series, and is overlain by Pleistocene silt and outwash.

Leakage from Mayfield reservoir through sediments filling the preglacial course of the Cowlitz River is a possibility that must be considered. From a point approximately two miles upstream from the dam site to a point about 1½ miles below the dam site, the Cowlitz flows in rock-walled canyons of its recent superimposed course. (See fig. 2.) However, both upstream and downstream from this stretch, the present course coincides with the preglacial course. From approximately two to six miles upstream from the dam site, the left bank of the preglacial valley is outlined clearly in sections 9, 10, and 16, T. 12 N., R. 2 E., figure 2. From 1½ to 3½ miles downstream from the dam site, evidence of the preglacial valley occurs in sections 23 and 24, T. 12 N., R. 1 E. Between these two localities, the exact course of the preglacial valley is not known, but is believed to follow approximately the course sketched on figure 2.

Sediments of the Older drift do occur near stream level in the superimposed stretch at the mouth of Winston Creek. Distribution of these exposures suggests that these materials were deposited in a preglacial tributary stream, possibly ancestral to Winston Creek. Another small tributary behind the right abutment in SE¼ sec. 20, T. 12 N., R. 2 E., was outlined by drill holes put down by the City of Tacoma (see figs. 2, 8, and cross sections E-E' and F-F', fig. 9). Drill hole samples of materials filling this tributary channel were all highly impervious and were interpreted as belonging to sediments of the Older drift. These materials appeared to be very similar in the various holes, and the following condensed log of drill hole No. M-12 is submitted as typical:

Log of Drill Hole No. M-12

Location: 425 feet south and 734 feet west of center sec. 20, T. 12 N., R. 2 E., W. M., Lewis County, Washington

Surface elevation: 573 | Operator: City of Tacoma, Light Department

All measurements are in feet | Examination of samples by: A. F. Bateman, Jr.

Description	From	To	Thickness
Clay, deep yellowish-brown, fine-grained, medium plasticity, tough at plastic limit. Contains some fine sand and scattered pebbles to one-eighth inch. Some pebbles are softened and decayed.	0	10	10
Gravel and sand with silty clay matrix, yellowish-brownish gray, fairly well-graded, with cobbles to 1½ inches. Many cobbles have decayed, discolored rinds up to one-eighth inch thick; but are otherwise hard and sound.	10	15	5
Gravel and sand with silty clay matrix, light yellowish-gray, fairly well-graded, with cobbles to 1½ inches. Cobbles are hard and sound. Driller's log reports occasional boulders.	15	37	22
Gravel and sand with silty clay matrix, light bluish-gray, fine, fairly well-graded. Maximum pebble size three-fourths inch.	37	67	30

Gravel and sand with silty clay matrix, gray to light bluish-gray, fairly well-graded, cobbles to 3 inches. Driller's log reports occasional boulders.	67	92	25
Sand with silty clay matrix, light yellowish to brownish gray, fairly well-graded, pebbles to one-fourth inch.	92	97	5
Gravel and sand with silty clay matrix, light bluish to brownish-gray, fairly well-graded, cobbles to 1½ inches, occasional boulders.	97	132	30
Gravel and sand with silty clay matrix, light bluish gray, well-graded, fine, maximum pebbles size three-fourths inch.	132	142	10
Gravel and sand with silty clay matrix, light bluish-gray, well-graded except at top where it is very sandy and poorly graded. Cobbles to 1½ inches and an occasional boulder to 6 inches. Some of material recovered at 175 feet was in large chunk. It resembled very closely the till phase of the Shut-In glacial deposits exposed at the bed of Shut-In Canyon.	142	182	40
Sand with silty clay matrix, yellowish to brownish-gray, coarse to fine, fairly well-graded, maximum size three-sixteenths inch, scattered pebbles to three-fourths inch. Particles subangular to subround. Composed mostly of andesitic rocks, but some quartz and amorphous silica.	182	192	10
Gravel and sand with silty clay matrix, light bluish-gray, fairly well-graded, cobbles to 3 inches.	192	202	10

Sand with silty clay matrix, yellowish-brown, fairly well-graded, contains many pebbles to one-fourth inch.	202	205	3
Gravel and sand with clay matrix, yellowish-brown, with cobbles to 1½ inches. Matrix is tough, plastic clay.	205	210	5
Clay, light bluish-gray, lean, silty, weak at plastic limit, contains some fine sand, scattered pebbles to one-fourth inch, and an occasional cobbles to 3 inches.	210	260	50
Gravel and coarse sand, with lean silty clay matrix, light bluish-gray.	260	265	5
Sand with bluish-gray, clay matrix and a few scattered pebbles, fairly well-graded.	265	275	10
Clay, light bluish-gray, lean, silty, contains an occasional pebble to three-fourths inch.	275	300	25
Gravel, sand, and clay, bluish-gray, pebbles to 1 inch.	300	315	15
Sand and clay, bluish-gray.	315	320	5
Sand with a slightly clayey silt matrix, fairly well-graded, one-eighth inch maximum size.	320	330	10
Sand, medium to fine, poorly graded, matrix of fine sand and silt. Top few feet contain fragments of hard, compressed and flattened, partly carbonized wood.	330	337	7
Gravel and sand, with an over-abundance of silty clay matrix, poorly graded, light bluish-gray, maximum size 1 inch.	337	345	8

Sand and clay, with pebbles to one-fourth inch, and an occasional cobble to 1½ inches.	345	352	7
Basalt (bedrock), medium-gray, dense, fine-grained, hard.	352	365	13

The preglacial channel is partially filled with sediments of the Older drift overlain by outwash gravels of the Younger drift. Since the outwash gravels have rather high permeability, seepage would readily take place through them, and the altitude of the contact between these two deposits filling the preglacial valley is highly important. However, since Older drift extends to altitudes higher than the proposed pool levels both in the material filling the tributary valley in SE¼ sec. 20 and exposed along the present stream bank in section 9 and 16, it may be inferred that the contact in the preglacial valley is probably higher than the proposed pool levels. The path of percolation for water entering the fill materials of the preglacial valley in sections 9 and 16, T. 12 N., R. 2 E., to an outlet in sections 23 and 24, T. 12 N., R. 1 E., is slightly in excess of three miles.

Summary. - It is concluded that seepage losses from the reservoir through glacial deposits filling either the buried preglacial channel of the Cowlitz River or the tributary channel behind the right abutment will be slight. Reasons are: (1) the probability that only sediments of the Older drift are involved; (2) the impervious character of these sediments; and (3) the length of the percolation path through the preglacial channel.

Summary and Recommendations

Geologic conditions are probably suitable for a high dam somewhere between C–C' and D–D', figure 7. Exact location of the axis would be influenced by two weaknesses: (1) the highly permeable sandstone-shale bed, B, covered by only a thin thickness of basalt below the river channel at D–D'; and (2) the tuff bed, F, in the left abutment. Maximum pool level is altitude 400 to 420 feet. A dam to 400 feet would be 500 feet long, and would stand 160 feet above mean water level and about 200 feet above rock foundation. Storage would be 80,120 acre-feet. Maximum power could be secured by use of the total head without drawdown. Flow regulation would be obtained by storage at sites upstream.

D–D' is probably the best section for a low dam with crest not exceeding 340 feet, in spite of the sandstone in the foundation.

The permeable sandstone, bed B, in swinging over the south end of the plunging anticline provides an avenue for seepage around the left abutment. Studies of this bed should be made to determine if it can be grouted so as to effectively prevent seepage. Detailed studies should be made of the physical properties of tuff beds D and F to determine whether or not they can be incorporated in the abutments of a high dam.

The dam site is by-passed by the preglacial channel of Cowlitz River and by a small tributary, figure 2. Exploratory drilling by the City of Tacoma shows that the tributary valley is filled with relatively impermeable glacial deposits. Not much is known of the materials filling the main channel. Hence, their character should be determined, probably by drilling, to provide a means for assessing the danger of seepage loss through these sediments. Narrowest cross section of the preglacial channel is probably about on the line between sections 17 and 18, T. 12 N., R. 2 E.

MOSSY ROCK DAM SITE

12 MK 2

(Figures 10, 11, and 12)

Location

Mossy Rock dam site is on Cowlitz River at mile 63.4. The special dam site survey covers about 44 acres in the south-central part of sec. 8, T. 12 N., R. 3 E., Willamette Meridian, Lewis County, Washington, 40/ and

40/ Plan and profile of the Cowlitz River. Op. cit. Sheets 2 and 7.

is on a scale of 1:2,400 (1 inch = 200 feet), with 5-foot contours. This map was used as a base for the accompanying geologic map, figure 11, but for the sake of clarity only the 50-foot contours are shown.

The canyon in which the dam site is located is known locally by various names, depending upon which side of the river inquiry is made. Inhabitants of the right bank, where the Dunn ranch is located, call the gorge "Dunn Canyon," and this name has been accepted by the Geological Survey for use on the Eatonville quadrangle, and on Sheet 2 of the Plan and Profile of the Cowlitz River. Nevertheless, the inhabitants of the left bank, where the Young ranch is located, prefer to call the gorge "Young's Canyon." This name has been used by the Corps of Engineers and private interests who have reported on the dam site, and thus is not without local prestige. Fortunately, the name of the dam site has been taken from the little village of Mossyrock, on the high terrace a mile to the southwest of the site, and besides giving focus to its geographic location, avoids the local controversy over the name of the canyon.

Accessibility

Mossyrock, in sec. 18, T. 12 N., R. 3 E., is the nearest settlement to the dam site. State Highway No. 5, surfaced and open throughout the year, passes through this village. Mayfield, 5 miles west, is the nearest railroad point. Nearest hotel accommodations are at Morton, 13 miles northeast, and also a railroad point.

A road running north from Mossyrock leads to the Harmony bridge, C SE¼ sec. 1, T. 12 N., R. 2 E.; thence northwest to Harmony, and a branch to the east leads to the Dunn ranch through which access may be had to the right bank of Cowlitz River at the dam site. Local trails are shown on the special topographic map of the dam site.

Purpose of project

Water power development and storage are the primary purposes of a dam at this site. In their report on the Cowlitz River,[41] the Corps of Engineers describe the project in the following words:

41/ Op. cit. pp. 28-29; 32-33.

> "111. - - - The Mossy Rock Reservoir dam site is located on the main Cowlitz near the head of Young's Canyon in section 8, township 12 north, range 3 east, Willamette meridian. The rock walls of the canyon at this point are 40 feet apart at the water surface and about 40 feet in height. The hillsides above the cliffs are steep, until a wide bench on the south side is reached. A dam 300 feet high would reach this bench, and would have a crest length of 1,000 feet."

"137. Estimates on the water available for site 12 MK 2 are:

Drainage area, 1,170 sq. miles	Total for basin	Per square mile
Runoff, average rate	5,300 second-feet	4.53 second-feet
Runoff, average annual total	3,800,000 acre-feet	
Natural flow 90 per cent of the time	1,610 second-feet	1.38 second-feet
Natural flow 50 per cent of the time	4,180 second-feet	3.57 second-feet

"Regulation of the flow at the site could be accomplished with storage of 570,000 acre-feet at this site and 665,000 acre-feet above, mentioned in paragraph 135."

"Such storage could produce flow as shown under regulated flow in the table below. With an operating head of 250 feet power could be developed as follows:

	With natural flow		With regulated flow	
	Second-feet	Kilowatts	Second-feet	Kilowatts
90 per cent of the time	1,610	29,000	3,780	56,700
50 per cent of the time	4,180	75,000	4,240	63,600

Previous exploration

The late Ira A. Williams, consulting geologist of Portland, Oregon, explored and described the geology of Mossy Rock dam site in considerable detail for the Backus-Brooks Lumber Company of Minneapolis, Minnesota. His findings are outlined in a series of three comprehensive reports, excellently illustrated with maps, cross sections and photographs. The first 42/ compares two alternative dam sections in Young's

42/ Williams, Ira A., Preliminary Presentation of the Comparative Merits of Two Prospective Dam Sites in Young's Canyon, Cowlitz River, Washington. Portland, Oregon. July, 1927. Exhibit "C", Vol. III of Report on Proposed Hydro-Electric Development, Cowlitz River, Washington, unpublished report by Ralph D. Thomas, Consulting Engineer to the Backus-Brooks Company, Minneapolis, Minnesota, December, 1928.

Canyon, Cowlitz River, and the downstream or No. 2 site is indicated as the most feasible. This is essentially the site mapped by the Geological Survey, 43/ except that the Survey mapping extends up and downstream for

43/ Plan and Profile of the Cowlitz River. Op. cit. Sheet 7.

about 200 feet from the limits of the No. 2 site as defined by Williams, and is somewhat more extensive on the north or right bank. The center of the No. 1 site is about 1,200 feet upstream from the center of the No. 2 site. A fault along the left bank of the river was the chief reason for its rejection. The second report [44] outlines geologic factors

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44/ Williams, Ira A., Report on Geologic Conditions Beneath Dunn Flat, Young's Canyon, Cowlitz River, Washington. Portland, Oregon. January, 1928. Exhibit "B", Vol. II of Report on Proposed Hydro-Electric Development, Cowlitz River, Washington, unpublished report by Ralph D. Thomas, Consulting Engineer to the Backus-Brooks Company, Minneapolis, Minnesota, December, 1928.

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conditioning percolation of reservoir water through the fill of the pre-glacial gorge of Cowlitz River that by-passes the dam site, and the third report [45] describes the geology of the favored dam section at

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45/ Williams, Ira A., Report on Geologic Conditions at Dam Site No. 2, Young's Canyon, Cowlitz River, Washington, Portland, Oregon. July, 1928, Exhibit "D". Vol. III of Report on Proposed Hydro-Electric Development, Cowlitz River, Washington, unpublished report by Ralph D. Thomas, Consulting Engineer to the Backus-Brooks Company, Minneapolis, Minnesota, December, 1928.

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greater length. All of these reports have been studied in detail, and some of the factual data, such as logs of bore holes, have been used to supplement and interpret observations made in course of the present investigation.

Catchment basin

The drainage basin of Cowlitz River above Mossy Rock dam site has an area of about 1,170 square miles. Inasmuch as Mossy Rock dam site is only 11.4 miles above Mayfield dam site, their catchment basins are practically identical, the chief difference being the exclusion of the Tilton River basin from the drainage tributary to Mossy Rock dam site. Indeed, the difference in area between the two can be accounted for largely by the extent of the Tilton River basin. Since otherwise they coincide, reference is made to the catchment basin of Mayfield dam site (p. 97).

Stream gradient

Cowlitz River is ungraded in the vicinity of Mossy Rock dam site from the mouth of Tilton River, mile 57.5, to Sulphur Creek, mile 66. Over this distance of 8.5 miles, the total fall is about 121 feet, making the average gradient a little more than 18 feet per mile. However, the gradient through Young's Canyon or Mossy Rock Canyon is only about 3.5 feet per mile.[46]

46/ Plan and Profile of Cowlitz River. Op. cit. Sheet 8.

See Carrol?

Valley profile

Cowlitz River valley at Mossy Rock dam site is not the original consequent valley of the stream. The relationship of the active, superimposed gorges of the river to its preglacial valley is shown in figure 2 and figure 10, J-J'. Only the present-day topography is considered in the description that follows. The ancient topography and the character of its cover will be referred to in the section of the report that deals with the geology of the reservoir area.

Cross-section J-J', figure 10, is typical, and shows the river occupying a sharp, narrow slot in the bottom of a U-shaped valley that has been superimposed upon a thick succession of massive flows of andesitic lava that make a broad, north-trending spur into the valley of the preglacial Cowlitz. Superimposition must have taken place late in Pleistocene time, probably during the Vachon (Wisconsin) glacial epoch, upon a broad aggradational sheet of outwash that completely submerged the lower elevations of the older landscape. The width of this surface in the neighborhood of Mossy Rock is about 2 miles, and its present altitude is around 700 to 750 feet. Slopes to the regional summit level begin at these elevations and rise to 1,500 feet on the south and to about 2,300 feet on the north. Due to recent uplift and rejuvenation the country must now stand about 100 feet higher than it did when superimposition began.

The general form of the valley, figure 11, J-J', and the presence in the walls of well-compacted masses of till is indisputable evidence that alpine glaciers played a part in its development. Before rejuvenation and the initiation of canyon-cutting this valley was about 600 feet across from rim to rim and at least 200 feet deep. The old bottom now stands at altitudes of 435 to 450 feet, and its gradient to the corresponding feature at Mayfield dam site, downvalley 8 miles, is about 10 feet per mile.

Cowlitz River is still busily entrenching itself into the floor of its late or postglacial valley and has now cut a gorge about 95 feet deep. Remnants of the old bottoms remain on the left bank as rock-cut benches at altitude 435, and on both banks at altitude 450. Foundation, or channel bottom, is at altitude 330. The total relief of the valley is thus about 370 feet. Within the gorge, owing to the depth of the water, the height of the walls usually appears to be about 60 feet. Width at the lower terrace level is also about 60 feet, and at mean water level it is sometimes as narrow as 40 feet. In such places width of channel and depth of water are essentially equal. Usually, though, the walls drop vertically from the terrace levels, making an almost perfect box canyon. Its length through the massive rock spur into the preglacial valley of the Cowlitz is about 6,500 feet, but the length of the dam site, figure 11, is only about 900 feet. Even though the precipitous inner walls are nearly sheer, they are by no means smooth plane surfaces.

Differential erosion has taken place along joints; shear zones or small faults on which there has been movement with resultant shattering and weakening of the rocks, and hard, thick resistant dikes. These features yield sharp, narrow V-shaped re-entrants, the crush zones make coves, and the dikes stand out in relief buttressing the walls.

Apparent possible height of dam

The controlling altitude for a dam at this site is 700 feet, the approximate level of the outwash plain. Higher altitudes are out of question because of the length of section involved, if for no other reason. A dam to altitude 700 would stand 370 feet above foundation. However, economical sections with bedrock in both abutments do not occur above altitude 620. A dam to this level would rise 290 feet above foundation, and length of crest would be about 600 feet. It will be noted that such a structure is about 60 feet lower than that considered in the Corps of Engineers report. Raising the crest line to higher altitudes depends upon the depth of cover over the upper part of the right abutment. This problem will be considered under the next topic.

Character and depth of valley fill

The valley fill at Mossy Rock dam site may be classified as glacial deposits, talus, and alluvium.

The alluvium is all active and submerged in the gorge. Most of the material is completely unconsolidated sand and gravel, with occasional large boulders. Transport is vigorous, and probably only the larger boulders are to be regarded as relatively stationary. These deposits are wholly surficial and of negligible volume. Thickness is highly variable, depending upon the stage of the river. During low water when the current is at a minimum, accumulations may amount to 10 or 15 feet, but when the river is in flood the channel bottom is probably swept bare except for the rolling load.

Talus is also surficial, and not especially active. The larger pieces consist of angular joint blocks, and the spaces between them are occupied by sand and gravel from the disintegrating till and outwash higher up the slope. Thickness of the talus seldom approaches 50 feet, and the average is probably 20 or 25 feet.

Glacial deposits exposed in the dam site area belong to the Younger drift. They consist of till overlain by outwash that mantles the valley plain. Exposures of well-compacted till stand in low banks on the south (left) wall of the valley, just below the rim, in the vicinity of Sta. 1 (altitude 725). Cobbles and pebbles of igneous rocks are abundant in a matrix of gray-buff silty clay, making a typical boulder clay. The thickness of the deposit is not known, but it cannot be great, and probably does not exceed 20 feet. Resting upon it are beds of brown, bouldery loam, containing layers of lime-cemented gravel, that extend up to the top of the bench. These materials are of outwash origin. The formation was penetrated and carefully logged in Test Pit No. 2 on the right bank, from which the following record was taken:

Section of Outwash Gravel in Test Pit No. 2

Surface elevation 722.0

Description	Thickness (Feet)
Soil	10
Gravel, fine	13
Boulders and gravel	4
Boulder and gravel, cemented	14
Gravel and clay, cemented	8
Gravel and sand, hard	9
Gravel, cemented, hard	5
Gravel and clay, soft	3
Clay, blue, sandy	9
Basalt	
	75

The character and permeability of the outwash on the right bank is of particular concern if the flow line of a dam is to be higher than altitude 630, for this would require a long cut-off wall through the outwash. Permeability tests by Williams on the "cement gravels" show that the coefficient of permeability, K, varies from 6×10^{-6} to 38×10^{-6} feet per second, and that the coefficient for the formation as a whole is about 28×10^{-6} feet per second.

Country rock

Bedrock at Mossy Rock dam site consists of about 800 feet of basic andesite lava flows and flow-agglomerate that are cut by thin dikes of andesite and basalt. The extrusive rocks are assigned tentatively to the Keechelus andesite series (?) of the Miocene, but their stratigraphic position within the series is unknown. The lavas at the dam site strike almost due west and have a moderate south dip. Consequently, the youngest rocks are exposed at the top of the left wall of the canyon.

Keechelus andesite series (?). - Throughout the exposed section the formation exhibits great similarity, and it is difficult to separate the flows on the basis of lithology, as can be done at Mayfield and Cowlitz Falls. Where flow contacts can be recognized they cannot be traced for any considerable distance because of the erratic distribution of cover. Again, some of the thicker flows are composite in character and consist of flow-agglomerate and fore-set sheets of lava, so that the internal structure is very confusing. Hence, although flow contacts are indicated tentatively on the cross-section J-J', figure 11, no attempt was made to map individual flows or beds in the field.

The andesites vary in color from dark-gray to black, and when fresh their surfaces glisten with minute crystals of plagioclase. Vesicular lava is of common occurrence in their upper parts, and where the top can be identified it is often scoriaceous and shaly. Evidently sufficient time elapsed between the major units for the accumulation of thin layers of soil or ashy clays, and when these beds were over-ridden by another lava sheet the thermal metamorphism baked them into brick-like material varying in color from pink to dull red. These contact zones vary in thickness from a few inches to 2 or 3 feet. Although fairly well indurated, they are much softer than the enclosing lavas, and are usually etched out by weathering and erosion to depths equalling their thickness.

Cellular rock at the top of the major extrusive units often carries abundant amygdules of quartz and calcite. Fresh material is bluish-gray, but where weathered the color is pinkish-gray to dull red. The facies called flow-agglomerate appears to be in much greater quantity than the normal andesitic lava. This may be because of its greater ability to stand forth in massive exposures, due to wider separation of joints. The dikes are similar petrologically to the lavas, although more closely related to basalt. Some of them are very fresh, and they may be a good deal younger than the flows they cut.

The lowest flow is massive and of composite character. Bore hole data suggests that its total thickness is about 210 feet. Naturally, this makes an excellent foundation for a dam. The top crops out on the right bank at about altitude 465, and is marked by a layer of vesicular lava about 10 feet thick that yields numerous seeps of water. In the vicinity of B.M. 431, just below the top of the flow, there is a sheet of hard, dense lava about 20 feet thick that is the freshest flow rock in the dam site, and typical of all the andesites. Across the river, at B.M. 427, there are two 5-foot sheets of similar lava separated by 10 feet of flow-agglomerate. The lateral extent of these flows is about 200 feet, and probably represents the width of an individual lobe or tongue of lava. Viewed in cross-section in the wall of the gorge the "bedding" is wavy and undulating. One hundred feet downstream from B.M. 427 the upper sheet lenses out.

In hand specimen the typical andesite from B.M. 431 is a dark gray, massive rock, breaking with a rough sub-conchoidal fracture. Texture is porphyritic, and is developed by countless small needles of plagioclase feldspar with an occasional larger tabular grain, whose cleavage faces glisten and relieve the dull luster of the groundmass. This portion of the rock is aphanitic, and aside from the phenocrysts, is broken only by occasional blebs, 3 to 5 mm. long, of a dark-green mineral that may be amygdaloidal.

Under low power microscopic examination the rock is definitely porphyritic. Phenocrysts make about 75 percent of the rock, and consist chiefly of clear grains of labradorite (60 percent) with average length of 0.9 mm., and an occasional grain 2.0 mm. long. The other phenocrysts are predominantly serpentine (antigorite) pseudomorphorous after pyroxene, with occasional unaltered or partially altered grains of pyroxene (augite). The groundmass is a much finer grained, granular, intergrowth of plagioclase and pyroxene, averaging about 0.03 mm., with some opaque iron oxides and other accessory minerals. The only secondary alteration product noticed was amygdaloidal chlorite filling an occasional small cavity. On the whole this rock is as strong and fresh as its appearance indicates.

The rock here called flow-agglomerate is exposed typically in the same lower flow in the vicinity of B.M. 450. In hand specimen the weathered surface is brown, mottled by dark gray and dull green splotches where amygdaloidal minerals have broken out. Freshly broken surfaces are a lighter grayish-brown, and close inspection reveals a porphyritic texture, with dull chalky phenocrysts of plagioclase. The groundmass is aphanitic, and embeds numerous shot-like blebs of a brownish substance with a sub-resinous luster. Vesicular structure is well developed, with most of the cavities occupied by greenish and brownish amygdaloidal minerals.

Microscopic examination shows that fundamentally it is much the same as the compact andesite from B.M. 431, but it is moderately altered and contains a good deal of clear, fresh, light-brown volcanic glass in the form of rounded and irregular masses, with thin, narrow, connecting veinlets. The rock is, therefore, intermediate in character between a vitreous tuff and a normal andesitic lava, and evidently represents a more explosive phase of volcanic activity than that resulting in the compact non-glassy andesite. Quite possibly glassy pyroclastic material settled upon an active lava stream and was admixed. The field term flow-agglomerate recognizes this, but is not completely descriptive in a petrographic sense, and it seems best to name the rock an andesite-vitrophyre-agglomerate.

Glass is estimated roughly to make 15 to 20 percent of the rock. When in rounded or oval form the blebs seldom exceed 3.0 mm. in length, and have sharply defined outlines. Larger, irregular masses, up to 8.0 mm. in length have transitional boundaries, and pass insensibly into the groundmass, but angular fragments of some of the larger, first-generation plagioclase phenocrysts, which are zoned, are embedded along the margins. This type of glass body usually exhibits aphyophyses or is connected with another mass by thin veinlets. This is considered as further evidence of mechanical mixing. With the exception of minor stains of red iron oxide, none of the alteration products observed are the result of weathering. Among the changes noted are the replacement of plagioclase by epidote, sericite and chlorite, pyroxene by serpentine, and glass by serpentine. None of these changes weaken the strength of the rock so much as does the presence of the glass. In small bodies this material contributes a certain softness to the rock, and its tendency to absorb water accentuates this condition, and is probably responsible for the soft, weathered appearance of some of the exposures. Vesicular structure furthers the weathering process, and much of this rock is now stained by hematite to pinkish-gray or dull red. Nevertheless, where fresh the andesite-vitrophyre-agglomerate or flow-agglomerate has ample strength to support a dam.

Overlying the thick, composite lower flow is a thin sheet of vesicular and agglomeratic or tuffaceous lava that probably does not exceed 35 feet in thickness. There is reason to believe that this bed decreases in thickness to 21 feet in drill hole 2A, and it may lense out completely within the left bank. See figure 11, J-J'.

The remaining, or upper part, of the right bank consists of a composite lava mass much like that in the gorge, and a flow contact high on the left bank suggests that its total thickness may be about 180 feet. A specimen of basic andesite porphyry from B.M. 548 is from the lower part of this unit. The rock is medium brown in color and differs from the black andesite at B.M. 431 in that the ratio of phenocrysts (20 percent) to groundmass (80 percent) is approximately reversed.

On the left bank still higher flows crop out in the floor of Young's Creek up to altitude 720, and show the same composite character of overlapping and interfingering lobes of andesite and andesite-vitrophyre-agglomerate, with the latter predominant.

Intrusive rocks. - Five dikes cut the lava flows in the dam site area, and a swarm of 10 or 12 crop out in the gorge between the east margin of the dam site map and the head of Young's Canyon. Strike varies from N. 35° to 65° W., and width from 5 to 25 feet.

The largest and thickest dike in the dam site area, known locally as the "Big Dike," crops out on the bench on the left bank about 100 feet northwest of B.M. 437. Strike is about N. 50° W., and dip is vertical. The maximum width exposed is about 20 feet, but diamond drilling has revealed greater thicknesses, and across the river downstream it is wider and more prominent. Freshly broken surfaces of the rock are almost jet black in color, with a glistening subvitreous luster; weathered surfaces are olive drab and very thin. The texture is very dense, but is relieved by a sprinkling of small grains of platy plagioclase whose cleavage faces mirror the light. Toward the margins the rock is even more dense and glassy, and is so thoroughly welded to the walls that the boundaries are difficult to locate. The best criteria are its darker color, finer grain, and superior hardness that sometimes causes it to stand out in relief.

Another characteristic of the rock is its thorough jointing, closely spaced, and normal to the walls, so that it breaks into small columns a few inches square. Cross fracture normal to these joints is subconcheidal.

Microscopic examination shows the rock to have porphyritic texture, but the larger phenocrysts (0.4 to 1.4 mm.) are comparative few in number and only make about 5 percent of the rock. Plagioclase (labradorite) is the predominant mineral, and there are a few widely scattered grains of pyroxene. The groundmass consists of smaller crystals (0.05 mm.), with fluxion structure or parallel arrangement, and minute needles of plagioclase in a mesostasis of light-brown basic glass (index of refraction about 1.555). The parallel fractures mentioned previously have been healed by fillings of clearer glass. This dike rock is a basic andesite vitrophyre, closely related to basalt.

A five-foot dike crops out across the river, 15 feet west of B.M. 450. Strike is N. 35° W.; dip is about 80° NE., but there is some variation in these data due to irregularity of the walls. The rock is a dense, dark-gray vesicular basalt, with irregular vesicles paralleling the walls. Cooling has developed columnar structure perpendicular to the walls. One of the features of this dike is a median joint. On the left bank of the river its southeast extension cuts the wall of the gorge about 300 feet downstream from B.M. 427. This apparent deviation in strike results from small offsets on joints trending northeast.

The other dikes were not examined in detail. One poorly exposed, except in test pits crops out high on the left abutment north of test pit 18 and 19. It appears to be about 10 feet thick. Two other small dikes are poorly exposed northeast of B.M. 431, but may be seen to better advantage in the walls of the gorge 300 and 450 feet, respectively, upstream.

Structural features

Dip of beds. - On account of the thickness and massive character of the lava beds, observations on their attitude are difficult to secure. A further complication is the composite character of the flows, for dips upon individual lobes or tongues of lava may embody some element of the gradient of the flow. Dips upon these components may be as deceptive as dips upon false-bedding in a sedimentary rock.

The most reliable dip in the dam site area is 19°, S. 12° W., and was taken upon a rather extensive surface of agglomerate at B.M. 427. The attitude of a thin (5-foot) sheet of andesite within the agglomerate at the same locality is 25°, S. 25° W., and the flow also carries closely-spaced "bedding" joints of identical attitude. "Bedding" joints with similar spacing and attitude were also observed in stratigraphically higher flows at Sta. 2 on the left bank. Several other dips were observed in Young's Canyon outside of the dam site area, as follows: right bank at foot of canyon, 12°, S. 20° W.; left bank at head of canyon, 15° S.; and right bank, 1,000 feet upstream from head of canyon, 15°, S. 20° W.

Excluding the steep dip on the andesite sheet at B.M. 427, and the attitudes inferred from "bedding" joints, the arithmetical average of the surface observations of dip is 15°, S. 13° W.

Determination of dip from the bore holes is also troublesome because of the difficulty of recognizing and correlating flow contacts in the cores or logs, and because an insufficient number of holes penetrate the same horizon. What data there are, however, suggest a dip component of 8° south.

Joints. - Joints in the lava flows at Mossy Rock dam site may be classified as cooling joints and tectonic joints. The cooling joints may further be separated into "bedding" joints and columnar jointing perpendicular to the walls of the dikes. The "bedding" joints are confined to the thin, hard, brittle andesite sheets, and do not seem to affect the thicker, massive layers of flow agglomerate. Hexagonal, or columnar jointing has not been recognized in the lava sheets. Since the rocks in which they occur are of comparatively small volume at the dam site, cooling joints, although usually closely spaced, are not likely to be persistent or to contribute to the permeability of the small rock units in which they occur.

The tectonic joints at Mossy Rock dam site are conspicuous because of their topographic effect. Two sets of complementary master joints are easily recognizable because of their strong development and persistence.

They are noticeable chiefly in [illegible] agglomerate facies of the lava, and of course are also present in the normal andesitic facies, but are somewhat obscured by their closer spacing in the harder and more brittle rock. One set trends northwest and varies in strike from N. 35° to 62° W., and is easily identified because of its control over the direction of dike intrusion. Most of these joints dip northeast at angles of 75° to 80°, and are spaced anywhere from 20 to 50 feet apart in the softer, more elastic flow agglomerate. Occasionally when dips are as low as 45° to 50°, the fractures are less well developed. There is also a variant high angle dip to the southwest in some members of this set, and the dip of some of the dikes that are under joint control is vertical. Variation in strength and spacing is illustrated by a strong shear zone striking N. 62° W., through B.M. 437. At the B.M. it consists of but one fracture that appears to be dying out to the southeast, but on the right bank it consists of a series of fractures spaced about 2 feet apart over a width of 30 feet. Some of these features are expressed topographically by small re-entrants or chimneys in the canyon wall.

To the southeast joints of this particular group enter the basalt dike that crops out just south of B.M. 437, and then parallel the north wall a few feet within the margin as a single fracture along which there is evidence of movement. A median joint also cuts the thin dike across the river. This is evidence of the renewal of the stress that developed the northwest set of master joints, and suggests that the complementary joints trending northeast make a cognate system with the younger fractures of the northwest set.

The master joints trending northeast strike N. 45° to 55° E., and dip 75° SE., or may be vertical. Spacing varies from 5 to 25 feet. Differential movement has taken place along some of them, and erosion along the crush zones has emphasized their topographic expression. This is shown in excellent detail at the east end of the dam site map between B.M. 427 and B.M. 431. Another member of this set is inferred to strike through the soil-filled ravine separating the two massive exposures of bedrock just south of drill hole 2-A, and it is also thought to be responsible for the offset in strike of the two dikes in the bottom of the gorge, especially the narrow one trending southeast from B.M. 450. Another important element of this set is the Young's Creek fault at the west end of the dam site area (see Faults).

In summary, the hard, brittle, andesitic facies of the lavas are usually so jointed that they form blocks that will probably average in the neighborhood of 1 foot by 2 feet by 2 feet. On the other hand, the softer but more massive flow-agglomerate facies is cut into blocks that probably are not less than 6 feet on an edge.

Faults. - A few faults are present at Mossy Rock dam site, but their displacements are small, and would be very difficult to detect in the thick massive lava flows if it were not for the offset of an occasional thin basalt dike or flow contact. Most of them occur along the lines of the master joints and are evidently related to the same stress.

The fault within the Big Dike was studied in considerable detail by Williams[47] who found conflicting evidence of the direction of movement.

47/ Op. cit. July, 1928. p. 46.

Some excavations show diagonal striae dipping 45°, N. 53° W., and other striae dipping 75° to 80° S. 53° E. The movement appears to have been largely vertical, with a downthrow of about 25 feet on the north side. The magnitude of this displacement has been estimated from the apparent offset of the top of the basal lava flow. Within the dike the walls of the fracture are only a fraction of an inch apart, and are separated by a thin film of gouge clay, and crusts and veinlets of secondary minerals are also occasionally present.

The Big Dike, and presumably the set of northwest fractures to the north of it, is itself offset by another fault striking N. 55° E., in the vicinity of Sta. 3 on the left bank about 150 feet west of B.M. 437. This feature is known as the Young's Creek fault, as it cuts the left wall of the canyon at the mouth of Young's Creek. Dip is vertical or about 85° W. On the right bank the fault zone is about a foot wide, and at Sta. 3 there appears to be a "horse" about 10 feet wide. The east wall, or foot-wall, is smooth and persistent with well-developed slickensides. Gouge clay and breccia rests upon this wall and shows considerable evidence of weathering and ferruginous stain due to the movement of water through the fault zone. Offset, as measured by the displacement of the Big Dike, is about 40 feet, and the character of the dislocation suggests that the relative movement of the east side was to the northeast.

Reference has been made to differential movement on the fractures trending northeast between B.M. 431 and B.M. 427. Eight or ten of these features occur within a horizontal distance of about 100 feet. Usually they are developed in pairs with rather well-defined walls that are separated by zones of crushed rock. Their width varies from 2 to 14 feet, and the breccia sometimes contains blocks 3 feet long in a matrix of soft clay. The easy erosion of this material is responsible for their topographic expression as alternate re-entrants or coves and massive buttresses. Despite this evidence of considerable strain, the displacement along these fractures does not appear to have been great, and is probably of the order of that on the Young's Creek fault. On the basis of strike these fractures may be classified with that fault, but it should be noted that they dip in opposite directions.

Indian Creek fault. This fault does not crop out within the dam site area, but is exposed along the left bank of the river in the vicinity of the mouth of Indian Creek, 800 feet N., and 800 feet W., of SE. cor. sec. 8. (See figure 2.) For 600 feet downstream from Indian Creek it is largely in the river, although close to the left bank, controlling the course of the canyon, and it enters the left bank in a sharp re-entrant about 600 feet upstream from B.M. 427. In general, the strike along this portion is about S. 62° W., and this trend carries it 800 to 1200 feet south of the left abutment of the dam site. Horizontal offset determined by the shift of dikes, is 70 to 80 feet, and the relative movement of the southeast block was toward the northeast, and Williams[48/] noted that the downthrown side of the fault was on the southeast with a dip slip of about 50 feet. However, elsewhere in his report (photograph YC 30) he states that the fault surface dips northwest toward the river "3° to 5° from upright," that is 85° to 87° from the horizontal. Under these conditions, if the southeast block moved down dip relatively, then it is a reverse fault. The width of the fault zone varies from 5 to 8 feet, and the slickensided walls are separated by a breccia of andesite blocks in a matrix of blue and yellowish clay. Most of the fragments have been softened by weathering. Considerations of attitude indicate that this fault is also related to the northeast-trending set of master joints.

48/ Op. cit., July, 1927. Photograph YC 58-63, explanation.

Although in a geologic sense these faults are not old, being probably late Miocene or post-Miocene in age, there is no evidence of movement during Recent geologic time, or even since the latest epoch of uplift and rejuvenation. If such movements had taken place one would expect to find some evidence in the ungraded character of the stream, for the throw of the northeast-trending faults is sufficient to produce a waterfall where they cross the river. Hence, in evaluating the probabilities of future activity along these faults it seems safe to conclude that the antecedent conditions that culminated in their movement no longer exist, and that they are inactive. However, immunity from future movement cannot be guaranteed for any fault.

Ground-water conditions

Surface indications of ground water are negligible, and are confined to a few small seeps and springs that for the most part are seasonal. Probably most of the fluid movement is riverward along the shallow contact between the overburden and the bedrock surface.

There is one series of springs that may be of more complex origin. Numerous seeps of water occur along the right bank at the top of the rock bench in the vicinity of B.M. 431, and are thought to mark either the pervious horizon at the top of the lower major flow unit or the thin zone of vesicular and agglomeratic lavas immediately above it. In a preceding paragraph it was shown that the average dip of the flows is 15°, S. 13° W. If this dip is projected northward from the spring zone it will be found to carry through the south flank of the massive lava ridge that separates the preglacial and postglacial valleys of Cowlitz River, and emerge upon the bevelled top under a fairly heavy cover of outwash gravel. (See J-J', figure 11.) The flat ridge top has a slight inclination toward the south, and water percolating through the gravels may enter the permeable zone, where its progress to the open valley will be accelerated by reason of the steeper gradient. This hydraulic system is admittedly conjectural, but it is well within the realm of possibility because each separate physical element can be shown to exist. Even more significant is the fact that it is a reversible system. Hence if water ever raised over the seeps to altitude 640 or higher, springs may appear under the capping of outwash gravel. The consequences of this event are considered briefly in the description of the right abutment in the discussion of the Dam Section. Fortunately, the situation lends itself to remedial measures, for the outcrop of the permeable zone probably can be grouted or blanketed for such a distance upstream from the prospective dam axis as to prevent entrance of water to it.

Years ago a sulphur spring was reported on the left bank of the river about 1,070 feet west and 620 feet north of the southeast corner of section 8. The water flowed from an open joint, near a basalt dike, at a rate of about 10 gallons per minute. This locality is about 1,400 feet upstream from the prospective dam axis, and is believed to represent a deep, non-reversible system, and therefore of no potential danger.

Permeability

The considerations of permeability outlined here concern bedrock only. Possibilities of percolation through glacial deposits are considered under the heading of Leakage from the reservoir. The only features of the lavas that have any capacity to transmit water are: (1) contacts between the major extrusive units, (2) zones of cellular lava just below such contacts, (3) joints, and (4) dikes.

Owing to the thickness of the major extrusive lava units flow contacts showing weathering, erosion, or thermal metamorphism of accumulated soil are few, but they are permeable. The probabilities are that there are only 2 or 3 such contacts in the right bank, and 3 or 4 in the left bank. However, they are amenable to grouting, as are the cellular zones that usually underlie them.

Some percolation may also occur along the joints. As explained in the description of these features, they are spaced fairly closely in the andesitic facies of the lava, but these masses are usually thin, of small volume and more or less enclosed in the andesite-vitrophyre-agglomerate. Joints in this facies are usually widely spaced. Many, especially those trending northeast, have been sealed by the development of gouge clay, but others, such as the Young's Creek fault give evidence of fluid movement. The thinner cracks may be self-sealing to some extent due to the tendency of the glass to swell upon contact with moisture. Hence, although certain parts of each composite flow are permeable, the units as a whole are relatively impervious. Indeed, insofar as percolation through joints is concerned, the coefficient of permeability is so low that it is difficult to evaluate. In my opinion, based upon comparison with lavas for which coefficients have been given, K is probably of the order of 3×10^{-8} feet per second.

Aside from the major flow contacts, the most permeable features of the bedrock are the dikes, especially the larger, wider ones. Although few in number at the dam site, they are controlled by the northwest set of master joints, and thus, striking more or less normal to the axis of the prospective dam, lead directly from the reservoir into the open valley downstream. Their permeability appears to be largely a function of their jointing, which is columnar (square or rectangular), and closely spaced. Usually one lateral or medial joint is also present. Williams 49/ noted some water when drilling the Big Dike. The walls of the dikes, however, are tight and fused into their wall rock. All of them can be rendered impervious by simple pressure grouting.

49/ Op. cit. July, 1928.

In summary: the main body of bedrock is very impervious to seepage. Its permeable features, the major contacts, zones of vesicular lava, and dikes are few in number and can be made impervious by pressure grouting. Seepage through bedrock under or around a dam at this site should be of negligible amount and easily subject to control.

Dam section

The most economical section at Mossy Rock dam site is illustrated by cross-section J-J', figure 11. Conditions are essentially similar for 100 feet downstream and 200 feet upstream. Topography appears to permit a dam to be raised to altitude 700, and a structure to this elevation was considered in Williams' reports to R. D. Thomas for the Backus-Brooks Company. The highest structure contemplated in the Corps of Engineers report is to 680 feet. Such a dam would stand 350 feet above foundation. These considerations have been developed from the height and strength of the left abutment. However, investigation of the right abutment favors limiting the height of pool level to altitude 620 feet. A dam to this elevation would rise 290 feet above foundation. Width of open valley is near 590 feet, and length of crest for a full gravity section would be about 610 feet. This additional distance is largely through a thin, slumped superficial cover of outwash gravel. Cross-section of the open valley below altitude 620 is about 72,800 square feet, and the total cross-sectional area of the valley is about 77,600 square feet. The difference of 4,800 square feet may be classified as 3,200 square feet of mixed soil and talus, 1,200 square feet of water, and about 400 square feet of active alluvium. The valley at this section is therefore remarkably free from fill.

Insofar as surface geologic observations extend, the foundation or gorge section appears to be cut entirely in the lower composite flow unit, and approximately 100 feet of rock of the same flow underlies the bottom of the river bed. There is thus good continuity of structure through the foundation, and conditions are geologically simple. The lavas have ample strength to support a full gravity section, and their homogeneity argues for small possibility of downstream erosion, sliding or other foundation defects.

Actually, the only geologically weak element in the site is the thin, permeable layer or vesicular and agglomeratic lava that rests upon the basal unit. This bed appears to thin rapidly southward, and it may wedge out completely in the left abutment. Little or nothing is added to the strength of the foundation by the basalt dikes, but so tightly are they fused into the wall rock that they do not detract from it either. They are harder and more brittle than the enclosing rock, and more closely jointed. Hence they are permeable elements, but their small size makes this easily remediable by grouting. Two small faults are spaced about equally from the river on either bank. Dips are nearly vertical, offsets are small, and the displacement does not materially alter the lithology of the foundation. The Young's Creek fault is permeable and will require grouting. Moving the section upstream tends to shift the Big Dike southward into the left abutment, the small dike also moves southward toward the channel, and the Young's Creek fault moves northward up the right abutment. The Indian Creek fault is about 1,300 feet south in the left abutment. As explained previously, the antecedent conditions for these faults no longer exist, but if ever they should be reactivated along their present lines, the block between them would be tilted slightly to the south.

The bearing power of the abutments is approximately equal, but the left is considered to be somewhat stronger than the right because of the inward dip of the beds, the greater number of thick, massive flow units, and the probable lensing out of the thin zone of permeable lava that is so conspicuous in the right abutment. This unit separates two massive elements, and all dip into the valley. As explained in the discussion on ground water, if water is impounded in the valley by a dam, it will become saturated to pool level, and if water is raised to altitude 640 springs might erupt under the outwash gravels and cause slides into the valley and possibly onto the dam. The left abutment is also higher, its summit standing approximately at altitude 700, whereas rock in the right abutment probably does not stand much higher than altitude 640.

In order to utilize the full elevation of the left abutment, it would be necessary to make a cutoff wall so long and so deep, and without anchorage in the poorly consolidated outwash gravels, that it would constitute a separate project in itself, and its feasibility merits very serious consideration. Obviously such a feature would develop very unequal bearing power between the upper parts of the two abutments. Aside from the lack of strength of the outwash gravels, such construction might also be menaced by the possibility of reversal of flow through the permeable lava bed, as outlined above.

Another group of conditions to be weighed before considering such an undertaking is that some 700 feet upvalley from the top of the right abutment, just northwest of the 670-foot knob in the NW corner of the SE¼ SE¼ sec. 8, exploration has revealed a saddle with bedrock at altitude 600 feet or less in the lava ridge separating the active river gorge from the filled preglacial valley. But the contingency of seepage through this gap is academic for water heading against the fill of the preglacial valley in the elbow in the NE corner of the NW¼ SE¼ sec. 8, would have an equal or better opportunity to by-pass the north extremity of any feasible cutoff wall over the top of the right abutment.

For these reasons, the altitude of pool level recommended in this report is 620 feet. With a cutoff wall some 200 feet long on the top of the right abutment it could go to altitude 640, as a maximum. Construction to higher elevations faces the contingencies enumerated in the preceding paragraphs.

Mossy Rock reservoir area

At altitude 700 the surface of the Mossy Rock reservoir will cover 8,680 acres, or about 13.5 square miles, and the capacity will be about 976,000 acre-feet; but at the 620-foot pool level thus far favored in this report the area is reduced to 5,220 acres, or about 8.1 square miles, and the capacity to 416,000 acre-feet.[50] The difference in capacity between the 620 and 700-foot levels is thus about 134 percent of the volume below 620. This is a serious reduction, and an important reason for striving to develop a pool level as high as possible above altitude 620. Backwater from a dam to the 620 level would extend upvalley for 15.3 miles or to mile 78.7 on the river in the NE¼ sec. 6, T. 11 N., R. 5 E., and that at the 700-foot level would continue on for 5.25 miles to mile 83.95 in the southwest corner of sec. 34, T. 12 N., R. 5 E. This locality is near the village of Kosmos, and only about 4.5 miles downvalley from Cowlitz Falls dam site.

Geology. - Comparatively little is known about the geology of this basin, but reconnaissance along the river up to the Riffe bridge near mile 69, sec. 13, T. 12 N., R. 3 E., indicates that to this point conditions are much the same as at Dunn and Shut-In canyons. Bedrock consists of the same thick series of basic andesitic lavas that have been referred

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50/ Johnson, Arthur. Op. cit. p. 10.

provisionally to the lower part of the Keechelus series, and these flows are cut by thin dikes of basic andesite and basalt. The formations dip to the south and southwest at moderate angles, and the same fracture pattern probably prevails over most of the area. It is interesting to note, however, that in the lower part of the reservoir the dikes are controlled by the northwest-trending set of master joints, but that toward the east end of the basin, as at Cowlitz Falls, they are controlled by the northeast set.

These formations are overlain unconformably by Pleistocene deposits consisting of till or boulder-clay, glacio-lacustrine silt and outwash gravels, that may be of considerable thickness, and by the active alluvium in the river bed.

Leakage from the reservoir. - The chief geologic feature of this reservoir is the preglacial valley of Cowlitz River, figures 2, 10, 11, and 13. Inasmuch as it by-passes Dunn Canyon and Mossy Rock dam site to the north, the problem arising from this relationship is whether or not it will provide an outlet for water from the reservoir. Indeed, until assurance can be given that serious leakage from the reservoir will not occur, the gorge in Dunn Canyon cannot rightfully be considered as a dam site.

A somewhat generalized cross-section of the buried valley is shown on figure 10, I-I'. The width at altitude 650, the top of the buried ridge making the left bank, is about 24,500 feet, and the depth from this

cost of dam at this site cannot be evaluated level to bedrock is about 475 feet. The maximum depth of fill, as revealed by drill hole 17, figure 10, J-J', and figure 12, is 557 feet, but since good abutments are not available on the right bank of Dunn Canyon above altitude 640, the fill above the highest possible pool-level does not enter into this discussion. Cross-sectional area of the valley below altitude 650, and therefore of the fill, amounts to about 8,250,000 square feet, and this may be broken down roughly into 3,125,000 square feet of silt, with average summit level at 475 feet, and 5,125,000 square feet of undifferentiated outwash.

The length of the fill is shown in figure 10, H-H', from which the following measurements have been taken: At river level, 4,950 feet; at altitude 475, average for the top of the silt, 4,650 feet; at the 620 pool level, 3,800 feet; and at the top of the fill, altitude 700, 3,300 feet.

Its general character is represented typically by the accompanying driller's log of drill hole 17:

Log of Drill Hole No. 17

Location: 2,330 feet west and 1,200 feet south of NW cor. sec. 8, T. 12 N., R. 3 W., W.M., Lewis County.

Surface elevation: 737 Operator: A. and M. Co.
Authority: N. C. Jannsen Collector: W. Warren
Date: 7-1-27

Description	From Ft.	From In.	To Ft.	To In.	Thickness Ft.	Thickness In.
Soil, boulders and gravel	0		12		12	
Gravel and boulders mixed with clay	12		37		25	
Boulders	37		39	6	2	6
Hard pan	39	6	42		2	6

	Description	From Ft.	From In.	To Ft.	To In.	Thickness Ft.	Thickness In.
	Gravel, cemented	42		60		18	
	Boulders	60		64		4	
	Sand and gravel, cemented	64		67		3	
	Gravel and boulders, cemented	67		86		19	
	Sand and gravel, cemented	86		101		15	
	Gravel, cemented. Water sand at 107	101		111		10	
	Gravel, loose	111		116		5	
	Gravel, cemented	116		120		4	
	Sand, loose, with coarse gravel. Lost all water	120		122		2	
	Gravel and sand, cemented	122		136		14	
	Sand	136		137		1	
	Boulders, loose	137		146		9	
	Boulders, loose, small. Takes away all water	146		152		6	
	Boulders and some sand, loose	152		154		2	
	Gravel and boulders, loose; water goes out	154		159		5	
	Boulders, loose	159		163		4	
	Gravel, sand and boulders, loose, takes all water	163		168		5	
	Boulders, loose	168		173		5	
	Sand, gravel and boulders, loose; takes water away	173		178		5	
	Boulders and sand, loose	178		182		4	
	Sand, cemented	182		183	6	1	6
	Boulders, and sand, loose	183	6	186	6	3	
	Sand, gravel, and boulders, loose; takes all water	186	6	191		4	6
	Boulders and some gravel, loose	191		196		5	
	Sand and gravel, loose	196		198		2	
	Boulders and some sand, loose	198		216		18	
	Sand, hard	216		225		9	
	Gravel, loose	225		226		1	
	Clay, sandy	226		235		9	
	Clay and sand	235		270		35	
	Sand, gravel, and clay, loose	270		292		22	
	Sand, running, water	292		294		2	
Top silt	Sand, blue, heaving	294		303		9	
	Sand, black	303		338		35	
	Sand, blue, mixed with clay	338		383		45	
	Sand, and clay	383		405		22	
	Sand, gravel and boulders	405		410		5	
	Sand, black, running	410		415		5	
	Sand, and gravel, blue, loose	415		421		6	

Description	From Ft.	From In.	To Ft.	To In.	Thickness Ft.	Thickness In.
Boulders and gravel, loose	421		424		3	
Sand and gravel	424		425		1	
Boulders	425		427		2	
Sand and clay	427		453		26	
Clay, blue, some "shale" (silt?)	453		469		16	
Sand, loose	469		471		2	
Gravel, coarse	471		474	6	3	6
Gravel and sand	474	6	480		5	6
Clay and sand	480		486		6	
Gravel	486		489		3	
Clay, and loose "shale" (silt)	489		490		1	
Sand, and quicksand	490		502	6	12	6
Gravel, and sand, loose	502	6	506	6	4	
Sand, loose	506	6	513		6	6
Gravel	513		514	6	1	6
Sand, loose	514	6	532		17	6
Boulders	532		535		3	
Sand, black, loose	535		539		4	
Boulders, loose	539		540		1	
Sand, black and gravel, fine	540		546		6	
Sand, loose	546		549		3	
Sand and some clay	549		554		5	
Sand and boulders, loose, of "Eocene" basic flows	554		557		3	
Rock, black	557		566		9	
Rock, black and gray	566		582		16	
Rock, black, gray and brown. Water went down 75 feet from the top; you can hear the water running. Can't keep water in well.	582		585		3	
Total depth			585			

Examination of this log reveals three formations: glacial outwash; glacio-lacustrine silt, and andesites of the Keechelus formation as bedrock, in order as drilled. Bedrock was topped at a depth of 557 feet, and was penetrated for 31 feet to the total depth of the hole at 585 feet. It has been described in connection with the dam site, and further reference to its lithology is unnecessary here. That it was found to be dry is significant evidence of the effectiveness of the silt as an impermeable blanket. The highly permeable zone drilled from 582 to 585 feet, where 75 feet of head of drilling water was lost and could not be regained, is probably a scoriaceous flow contact.

Blue-gray silt assigned to the Shut-In deposits of the Older drift was drilled from 294 to 532 feet, or for 238 feet, and the interbedded boulders and gravels, especially the pebble clays, are probably of glacial or fluvioglacial origin. The 25 feet of boulders and sand, from 532 to 557 feet, may also be of glacial origin. The top of the silt has been logged at a depth of 200 feet, but interpretation of resistivity depth curves indicates homogeneous material of low resistivity, the characteristics of the silt, only below the depth of 294 feet. Both resistivity and lithology have been used in picking this point.

Besides being encountered in this borehole, the silt formation crops out conspicuously along the river banks (see figs. 2 and 10) where the stream has removed its overburden. Resemblance to the Faber silt on the Skagit River in northwestern Washington is very striking[51/] and both formations were evidently accumulated in a similar

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51/ Preliminary report on the geology of miscellaneous dam sites on the Skagit River near Rockport, the Sauk River below the mouth of the Suiattle, and the Sauk-Stillaguamish divide near Darrington, Skagit, and Snohomish Counties, Washington. Report in preparation.

environment. This is interpreted as a ponded river basin into which melt water from abrading Cascade glaciers carried their rock flour. Bedding is mainly horizontal, and consists of laminae and layers up to 2 inches thick that are marked by variations in texture and permeability rather than color, which is monotonous. Clay or fine silt, commonly dark due to retained moisture, at the base of a layer grades upward into sandy silt and sand at the top. A mechanical analysis of a representative specimen showed only 2.06 percent passing a 100 mesh and remaining upon a 200 mesh screen, and 97.93 percent passing the 200 mesh screen. The particles are fresh, sharp, angular fragments of Tertiary and Quaternary volcanic rocks. Although sufficiently firm and compact to stand in nearly vertical walls when being eroded rapidly, and to develop sharp, persistent joints and small faults when stressed, dry lumps of silt slough rapidly in water. Plasticity is low, and the total clay content is obviously low. Some layers of fine silt carry calcareous concretions of varying shapes and size parallel to the bedding. The largest observed were of circular cross-section, 2 inches in diameter and about 2 feet long; others are flat and oval.

In some places the bedding of the silt shows evidence of disturbance, and local dips vary from 5 to 15 degrees. These conditions may have resulted from several causes: initial dip on the walls of the buried valley, subaqueous slumping, or possibly to secondary causes such as slumping due to undercutting by the river or to entrainment of material or piping by ground-water movement. One locality where the last-mentioned cause may have operated is the creek valley in the NE corner of sec. 7, and the NW corner of sec. 8. The gradient is much steeper on the silt than on the overlying outwash, and the beds dip 5 to 10 degrees downstream. Mr. Warren thought this deformation suggested that a strong flow of ground-water might have been eroding silt from the base of the formation, and that even if not now active, the head of water raised by the proposed dam might reactivate the flow.

Williams 52/ made several porosity and permeability tests upon this silt.

52/ Op. cit. January, 1928. Table V.

Sample J was taken from the mouth of Dunn Creek in the NW corner of sec. 7 at altitude 380. The natural porosity was found to be 43.3 percent, and the same material in a permeameter gave a value of 49.4 percent. K, the coefficient of permeability, was 13×10^{-6} feet per second. The average K value for all of the silt is given as 3×10^{-4} feet per second. Because of its fine grain, and retention of moisture the apparent resistivity values of the silt are low, the ordinary range being from 7,000 to 11,000 ohms/cm^3. Sometimes even lower values occur. This is also the approximate range of the resistivity of the andesite bedrock, and the similarity is strengthened because of the igneous derivation of the silt. Because of this lack of contrast in resistivity between the two formations, they are very difficult to separate, and thick bodies of silt produce a screening effect that makes it virtually impossible to recognize the bedrock.

Fluvioglacial outwash of the Younger drift is a widely prevalent surface formation in the dam site area and on Dunn Flat, where it makes the bulk of the fill of the buried valley. Thickness changes rapidly from place to place, and the 294 feet penetrated by drill hole 17 is the greatest recorded thus far. Composition and thickness of the individual units is likewise highly variable. Sheets of sand, gravel, or boulders are interlaced with beds of till and thin layers of lacustrine clay and silt. It is doubtful if more than a few of them are persistent for any great distance, due to the cut-and-fill action attending their deposition. Sorting within the beds is generally poor. Much of the material is river or terrace gravel reworked by glacial ice. The larger cobbles and pebbles are stream-worn with shapes varying from rounded to subrounded. Most of them have been derived from Tertiary and Quaternary igneous rocks. Very little coarse, angular material is present, and what there is probably represents reworked talus. Pumice and tuffaceous material from the Pleistocene volcanoes makes a good deal of the matrix, and locally there may be thin beds of volcanic ash. Color of the finer material is usually brownish-buff.

Williams [53/] investigated and logged the outwash formation with considerable detail in his study of the "Geologic Conditions Beneath Dunn Flat," and the serious student of Mossy Rock dam site should review the data he presents with care. Numerous tests were made on the porosity and

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53/ Op. cit. January, 1928.

permeability of the different facies of the fill. Values of the coefficient of permeability, K, for the outwash were found to vary from 3×10^{-4} feet per second to 6×10^{-6} feet per second. The possibility of percolation along the walls of the buried valley, as well as along the contact between the outwash and the silt were also considered. After summing up all of the factors, he concludes:

> "Judicious application of the results of the percolation tests to the two formations (outwash and silt) that will be exposed to prospective heads of water by storage against the upstream side of this fill indicates a possible total loss by seepage beneath Dunn Flat of a little over 9 acre-feet per year under a flow-line elevation of 685 feet. Under a flow-line height of 650, the loss figures somewhat short of 7 acre-feet per year."

In comparison with the loss from the reservoir by evaporation this amount of seepage is negligible, and insofar as it represents percolation through the fill, it is probably correct. In Erdmann's opinion, however, it is only the smaller element of the total possible leakage.

The greater element consists of direct leakage along the contact between the outwash and the silt, N O Q, figure 10, H-H'. This boundary is an erosional unconformity with considerable local relief and irregularity; and it is the only continuous feature through the fill. Springs and seeps are of common occurrence along it wherever it is exposed in the river valley. Usually they are small and seasonal, for their water supply is dependent on meteoric water from the overlying outwash. Nevertheless, they demonstrate effectively the permeability of this zone. The westerly springs now functioning along the contact. Hence, M.O P will be deflected to M O Q. Since N Q is essentially an open conduit, the resistance to flow at O is but little more than at Q, and as the line of saturation shifts down as it passes from a less permeable to a more permeable medium, the net result will be for O to move toward N, as at O', thus steepening the gradient within the fill to M O'. Percolation through the segment of outwash M N O' will therefore be accelerated. This is the portion of the seepage whose evaluation was attempted by Williams, and it is obvious that it is an addition to that flowing directly along the contact from N to Q. Conditions along this conduit are difficult to evaluate, but it can probably be treated as a horizontal crack. It also appears that the contact N O' is analogous to a graded filter in an earth dam, for its effect is to keep the line of saturation deeper within the fill, thus increasing its stability.

Now, all of this is very diagrammatic and hypothetical, and is intended for illustrative purposes only, but it suggests that the problem of leakage from the prospective Mossy Rock reservoir may be more involved and more serious than was imagined heretofore. Engineers will want to review the entire problem thoroughly in the light of revised geologic opinion as to the character of the contact between the outwash and the silt, and recent advances in soil mechanics and theory of seepage phenomena. Sufficient information is probably available now to make a model of the buried valley beneath Dunn Flat and, treating the fill as a natural earth dam, its percolation problems should be investigated by the method of electrical analogy.

Fortunately, the necessary measures to reduce the probability of seepage through the fill are not difficult although they may be expensive because of the size of the area to be treated. Briefly, the east face of the fill should be treated as though it were the upstream face of an earth dam. The upstream face of the fill in the NE¼ sec. 8 should be cut down until a stable slope is developed, and the contact between the outwash and the silt exposed. This surface must then be blanketed with such a thickness of clay or silt that seepage will be prevented effectively. The blanket and upper surface of the slope should then be riprapped with blocks of andesite to hold the fill in place, and to prevent wave erosion. A short cutoff through the north side of the fill to the old valley wall will reduce considerably the area to be excavated.

These measures will reduce percolation through the fill for any dam up to altitude 640, the maximum height of bedrock in the right abutment. For dams of greater height, the bearing power of the upper right abutment is weak and unbalanced. Such a structure would require a long, deep cutoff wall over the right abutment, blanketing the entire upstream face of the fill, and such other additional safety measures that the project would probably be economically unfeasible. Some of these considerations have been referred to in the description of the dam site under the headings of Groundwater and Dam section.

Summary and conclusions

Provided effective measures be taken to prevent seepage through the buried preglacial valley of Cowlitz River north of the right abutment, Mossy Rock dam site is feasible for a masonry dam with pool level at altitude 620.

The problem of leakage from Mossy Rock reservoir is probably more serious and more involved than heretofore imagined, and it should be reviewed thoroughly in the light of revised geologic opinion as to the effectiveness of the permeable contact between the outwash and silt filling the buried valley as a conduit for leakage. Remedial measures to prevent this seepage should consist of treating the east face of the fill as though it were the upstream face of an earth dam.

A masonry dam in the gorge section will stand about 290 feet above foundation, and have a crest length of about 610 feet. Storage capacity at this elevation will be about 416,400 acre-feet. Further exploration of the right abutment may indicate the feasibility of a pool level at altitude 640, and this appears to be the maximum possible for the site. Storage at this level amounts to 531,000 acre-feet, or about half of the potential capacity of the reservoir site.

SHUT-IN DAM SITE

Location

The proposed site is in Shut-In Canyon on the Cowlitz River at mile 65.5, measured from the mouth. The special dam site map 55/

55/ Plan and profile of Cowlitz River, mile 42 to mile 97, Cispus River to mile 32, and Tilton River to mile 19, Washington, sheet 7, dam sites.

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covers an area of about 271.5 acres in the SE¼ sec. 9, and the SW¼SW¼ sec. 10, T. 12 N., R. 3 E., W.M., Lewis County, Washington, and is on a scale of 1:4,800 (1 inch equals 400 feet), with 10-foot contour intervals on land and 1-foot contour intervals on the river surface. This map was used as a base for the accompanying geologic map, figure 13, but for the sake of clarity, only the 50-foot contours are shown. The map was extended along its southern border to include parts of the NW¼ sec. 15 and the NE¼ sec. 16, T. 12 N., R. 3 E., W.M., in which are located drill holes, resistivity lines, and seismic determinations.

Accessibility

The left or south abutment is about 1.35 miles north and slightly east of the village of Ajlune. From a point on State Highway No. 5 about 0.2 miles east of Ajlune, one can drive northward 0.7 miles over a graveled road to within 0.65 miles of the dam site. The easiest approach to the right or north abutment is over a logging road that extends from its junction with State Highway No. 5L (Riffe to Morton) for about 3 miles downstream to the general vicinity of the dam site. Personnel can cross the Cowlitz River near the dam site on a cable car constructed by the Light Division of the City of Tacoma Department of Public Utilities.

State Highway No. 5 extends through the reservoir area. From Riffe to Nesika, 6.15 miles upstream, the road lies on the south side of the river, and above Nesika on the north side. The river can be crossed 0.8 miles north of Riffe on Highway No. 5L and at Nesika.

Purpose of project

Water power development and storage for flood control are the primary purposes for a dam at this site. Originally, Mr. Arthur Johnson, hydraulic engineer, U. S. Geological Survey, selected Shut-In site as an alternate for Mossyrock site, when detailed field work revealed certain defects in it.

Water available for this site is the same as for Mossyrock site, which is only two miles downstream. No tributaries of any size join the river in this stretch.

Field work

Mr. C. E. Erdmann, regional geologist of the U. S. Geological Survey, accompanied by Mr. Arthur Johnson, made a geologic reconnaissance of the site[56] April 11, 12, and 13, 1942.

56/ Erdmann, C. E., Report on geologic reconnaissance of Shut-In dam site, Cowlitz River, Lewis County, Washington, U. S. Geological Survey, unpublished report, May 1942.

Geophysical investigations were carried on during August 1943, under the supervision of Mr. B. E. Jones,[57] Chief, Water and Power Branch, U. S. Geological Survey, at the dam site and on either abutment where the existence of older buried stream channels was suspected. Electrical resistivity depth determinations were made by Mr. Jones and Mr. H. C. Spicer. Refraction seismograph determinations were made by Mr. E. R. Shepard of the Bureau of Public Roads.

57/ Jones, B. E., Report on geophysical measurements, Cowlitz River, Washington, U. S. Geological Survey, unpublished report, August 1943.

Further geologic field work was done by Mr. F. A. McMillin. Detailed geologic mapping of the dam site was done by A. F. Bateman, Jr., September 24 to October 11, 1946, and September 19 to October 2, 1947. Examination of samples from drill holes was made by Bateman, April 19 to 23, 1948 and August 3 and 4, 1948.

Catchment area

Since no tributary streams discharge an appreciable flow into the Cowlitz River between Shut-In and Mossyrock dam sites, the drainage basin is the same for each. It has an area of about 1,170 square miles.

Maximum reported discharge 58/ at Harmony Bridge, one mile north of Mossyrock village, was 81,000 second-feet, December 22, 1933. Average discharge over a fourteen year period is 5,142 second-feet.

58 58/ Johnson, Arthur, Op. cit., October 1940.

Stream gradients

Average gradient of the Cowlitz River through the stretch shown on the special dam site map, figure 13, is 21.5 feet per mile. The 1,000 feet immediately upstream from the proposed dam axis has a gradient of 27.2 feet per mile. The gradient of the Cowlitz River through Shut-In Canyon is higher than through any other stretch between Cowlitz Falls, mile 88.7, and the lower limit of the river survey, mile 42.5, approximately 10.7 miles downstream from Mayfield. In the reservoir area, the stream gradient is 14.7 feet per mile to a point 18.2 miles above the proposed dam axis at which the water surface in the river is at an altitude of 700 feet, and 15.0 feet per mile to a point 20.5 miles above the proposed dam axis where the water surface is at an altitude of 740 feet.

Valley profile

Shut-In Canyon is a narrow, v-shaped trough about 1½ miles long that lies within the main Cowlitz valley. (See plate II.) Five cross profiles of this inner trough are shown on figure 14. As can be seen from them, the Cowlitz River flows on glacial debris about 200 feet above the rock floor of a buried gorge whose cross section is composite in character. A detailed profile as outlined by drill holes, figure 15, shows that this gorge consists of a U-shaped valley about 300 feet wide with its floor at an altitude of 355 feet, into which is cut a smaller U-shaped valley about 175 feet wide with rock bottom at an altitude of 220 feet. Remains of the floor of the larger valley form a distinct rock bench on the right wall of the smaller one (see figure 15).

The walls of the trough extend upward from river level at steep angles, especially on the left bank at the head of the canyon where there are several vertical rock cliffs. Rock also crops out on the right bank in the upper part of the canyon, but through the downstream two-thirds of the canyon rock exposures are few, and the walls are largely underlain by fill materials. The steep slopes of the walls are interrupted by several benches cut into the glacial deposits.

The lowest of these, designated as No. 8 on page 36, is particularly well developed on the left bank opposite the mouth of Corn Creek at altitudes varying from 510 feet next to the river to 550 feet on its inner margin. This is 100 to 140 feet above the river. On the right bank, this bench is present in the vicinity of the line between sections 9 and 10 at altitudes from 475 to 520 feet. Farther downstream, slope-wash and alluvial cones have built the surface to altitudes of from 500 to 550 feet. This bench is cut into outwash gravels of the Younger drift except for a small area on the right bank at the head of the canyon where it has bevelled bedrock. A narrow bench, No. 5 page 36, varying in altitude from 750 feet on its river side to 800 feet on its valley side, is cut into glacial sediments about 20 feet below the fill surface on the right bank throughout most of the length of the dam site. At its upper end in SW¼ sec. 10, this bench bevels a small area of bedrock. On the left bank of the river, bench No. 5 covers most of the SE¼ sec. 9 where it is cut into outwash gravels of the Younger drift.

The right bank continues to rise at a steep angle. At an altitude of 1,180 feet near the line between sections 9 and 10, a small rock-cut bench remnant, No. 2 page 34, is indented. A high bench, No. 1 page 32, covers large areas in the southern parts of sections 3 and 4, the extreme northeast corner of section 9, and the northern half of section 10, at altitudes ranging from 1,390 to 1,410 feet. Behind this broad bench the valley wall rises to the top of an elongate ridge at an altitude of about 2,300 feet that separates the Cowlitz and Tilton drainage systems.

South of the river, Bench No. 5 merges gradually with the broad rolling fill surface (see page 30) which covers most of the dam site area behind the right abutment at altitudes ranging from 760 to 800 feet. At the upstream edge of the dam site area, an elongated, southward-trending, morainal ridge projects above its surface to an altitude of 880 feet. Just downstream from the dam site is another similar and parallel morainal ridge.

The fill surface extends southward beyond the dam site area to the left margin of the valley wall. A steep slope separates it from several small bench remnants at an altitude of approximately 1,000 feet in S½S½ sec. 21, T. 12 N., R. 3 E., W.M. Steep slopes rise from these benches to the summit of a ridge approximately 1,400 to 1,500 feet in height that separates the Cowlitz valley from Winston Creek drainage.

Behind the left abutment of the dam site, a buried channel extends through sections 15 and 16 on a northwest trending course, and enters the preglacial valley in SW¼ section 9. The course of this channel is sketched on figure 2, and its relationship to Shut-In Canyon is shown on cross section P-P[4], figure 14. An enlarged cross section as outlined by drill holes, figure 16, shows a broad, rather shallow valley approximately 1,700 feet wide at an altitude of 700 feet and about 235 feet deep. Altitude of the bedrock floor in the deepest part is 538 feet.

Apparent possible height of dam

The maximum height of dam in Shut-In Canyon is controlled topographically by the altitude of the divide in S½SW¼ sec. 15, T. 12 N., R. 3 E., W.M. This divide separates the reservoir area from a broad, shallow topographic depression that is the surface expression of the buried channel extending northwestward through sections 15 and 16. It is drained by a small creek that enters the Cowlitz River in the S½ of section 9 about 1,500 feet downstream from the mouth of Corn Creek. Altitude of the divide is approximately 775 feet. A dam in Shut-In Canyon with crest at this altitude would stand approximately 355 feet above stream bed.

Character and depth of valley fill

Unconsolidated glacial and postglacial deposits cover most of the dam site area. Their classification and areal distribution are shown on figure 13, and their thicknesses and relationships to bedrock and to the present valley are shown on the cross sections of figure 14.

Older drift. - Shut-In glacial deposits fill the preglacial gorge in the bottom of Shut-In Canyon. They also crop out in the stream bed, along both banks, and along the walls of the inner trough to altitudes as high as 625 feet. From examination of churn drill samples, it is believed that these deposits also fill the buried channel behind the left abutment.

Character of the Shut-In deposits varies considerably. At the head of Shut-In Canyon approximately 1,600 feet of tills interbedded with poorly stratified layers of pebble clays and sand clays, thinly laminated silts, and occasional beds of clean sand are exposed. The silt beds show much intraformational crumpling and faulting. (See pls. VIII, X, and XI.) The entire series dips eastward at high angles, except in places where it is overturned slightly to the west. Bottom of the series is cut off by a small fault that can be seen on the right bank about 50 feet upstream from cross section P-P[4]. A detailed description of these beds is given in the measured section, page 58. Only the lower 740 feet of beds crop out within the dam site area. From the fault downstream along the right bank for a distance of about 2,000 feet, Shut-In deposits are exposed in a narrow, discontinuous band extending 15 to 20 feet above stream level. In this stretch they consist of a thick gravel bed at the top underlain in turn by a thinly stratified bed of sandy silt at least 10 feet thick, a bed of coarse gravel, a bed of coarse sand, and finally by a bed of coarse gravel. No stratigraphic section could be measured, since exposures are limited in siz, and the beds are folded into a complicated series of anticlines and synclines. At the downstream end of this exposed band, till overlies the gravels and sands. From this point to the mouth of Corn Creek, exposures on both banks are small and scattered, but all consist of till. Downstream from the dam site area, Shut-In deposits can be traced on both banks for about 3,000 feet. For this entire distance, they consist of horizontal to gently dipping beds of sand with thin interbedded, often crumpled, silts. The sands vary from clean to silty, are thinly stratified and sometimes cross-bedded. In texture they vary from coarse to fine, but individual laminae tend to be even-grained. (See pl. IX.)

Shut-In sediments filling the buried channel behind the left abutment consist primarily of sands similar to those exposed along the river downstream from Corn Creek. Gravels, pebble-clays, silty clays, and probably till, are interbedded with the sand. These deposits are shown on the enlarged cross section of the channel, figure 16.

Younger drift. - Glacial deposits of the Younger drift overlie Shut-In deposits and bedrock unconformably. They are exposed over large areas of the dam site, and include several types of deposits.

Light grayish-buff, compact, massive till occurs as layers and small masses interbedded with outwash. Behind the left bank on the fill surface, both upstream and downstream margins of the dam site area

UNCONSOLIDATED FLUVIO-GLACIAL OUTWASH OF THE YOUNGER DRIFT, LEFT BANK OF COWLITZ RIVER OPPOSITE MOUTH OF CORN CREEK, CENTER SEC. 9, T.12 N., R.3 E.

Compact, horizontally stratified, poorly graded gravels and coarse sands with boulders up to 12 inches in diameter. Matrix sand is pumiceous. Contact with silts and pebble-clays of the Shut-In Glacial Deposits is visible in middle view at Mr. Johnson's waistline. Photograph by C.E. Erdmann.

are bounded by morainal ridges composed largely of till (see fig. 13).

By far the greatest part of the Younger drift is outwash consisting of compact, horizontally stratified, cross-bedded, poorly graded gravels and coarse sands, containing boulders up to 12 inches in diameter and occasional lenses of till. (See pl. XIII.) Along the right bank, the outwash is exposed in a narrow band underlying bench No. 8 at altitudes ranging from 430 to 500 feet. Thickness of this deposit is estimated to vary from 20 to 40 feet. Patches of the outwash too small to show on the geologic map veneer the left bank upstream from cross section O-O'. Between cross sections O-O' and M-M', the left wall of the inner trough above bedrock is made up entirely of outwash that ranges in altitude from 450 to 750 feet. Greatest total thickness at any point is probably in the neighborhood of 100 feet. Downstream from cross section M-M', the outwash underlies the left wall of the inner trough at altitudes from 430 to 500 feet, bench No. 8, bench No. 5, and the steep slope separating the two benches. Maximum thickness of outwash probably approaches 250 feet under bench No. 5. Continuing southward, the sheet of outwash covers the entire dam site area between the morainal ridges and continues to the main valley wall. However, the gravels are considerably thinner, varying from 15 to 45 feet in the drill holes penetrating materials filling the buried channel.

VIEW UPSTREAM INTO SHUT-IN CANYON FROM A POINT ON RIGHT BANK 100 FEET UPSTREAM FROM CROSS SECTION M-M', FIGURE 13, NW$\frac{1}{4}$, SE$\frac{1}{4}$ SEC. 9, T.12 N., R.3 E.

Note large boulders along both banks. These boulders were derived from a small landslide on the right canyon wall. Photograph by A.F. Bateman, Jr.

Behind the left valley wall much of the ground surface is underlain by a massive, nonlaminated, light yellowish-brown, lean, silty clay, the Cinebar silt loam, described on page 66. It covers bench surfaces from No. 8 bench to the fill surface and overlies the outwash gravels of the Younger drift.

The walls of Shut-In Canyon are largely covered by talus and slope wash. Downslope from rock outcrops are slightly active accumulations of talus estimated to be from 5 to 25 feet thick. Over most of the area, however, the ground surface is covered with vegetation, accumulated evergreen needles, and soil that masks the underlying deposits consisting of small joint blocks of rock mixed with ground moraine.

A small landslide at least 400 feet high, about 300 feet wide and probably not more than 75 feet thick, has moved down the right bank of Shut-In Canyon near cross section N-N'. (See fig. 13.) The slide consists of an unsorted, heterogeneous mass of glacial deposits, slopewash, and angular blocks of rock varying in size from a few inches to more than 15 feet. From the toe of the slide, downstream for a distance of about 1,400 feet, both banks of the river are covered with large, angular to slightly rounded, boulders, some of which are as much as 4 to 5 cubic yards in volume. (See pl. XIV.)

About 1,200 feet downstream from the slide along the east side of a small creek is a slumped block of glacial materials about 100 feet long and probably 20 to 30 feet thick.

Inactive alluvium includes several types of deposits: (a) Unconsolidated gravels and sands very similar to active alluvium except for its position; (b) Loose, unconsolidated, horizontally stratified, fine sand that covers all types of deposits other than active alluvium as a thin veneer up to an altitude of about 480 feet. This sand has been derived from the Shut-In glacial deposits of the Older drift. After some reworking, it has been redeposited by the Cowlitz River; (c) An alluvial cone is built on the lowest terrace of the right bank just downstream from cross section M-M' (see fig. 13), where a small stream debauches from a course cut into the steep valley wall onto the bench surface. Another cone is built at the mouth of Corn Creek. Deposits making up the cones consist of boulders, cobbles, and coarse, clean, poorly graded, highly permeable gravels interbedded with coarse, clean sands.

Active alluvium consists of unconsolidated sand and gravel with occasional boulders. In the canyon, deposits are small, and are confined to the bottom and banks of the stream channel. Thickness varies with the stage of the stream. During low water when the current is slight, beds may be built up to thicknesses of 10 to 15 feet, but during high water when the current is very swift, these beds probably are swept away completely. At the head of the canyon and farther upstream in the reservoir area, active alluvium covers wide areas of the flood plain and is no doubt somewhat thicker.

Country rock

Bedrock at Shut-In dam site consists of a series of basic lava flows and flow agglomerates cut by thin basalt dikes. The series is more than 1,000 feet thick. Tentatively, these rocks are assigned to the Keechelus Andesite Series, but their stratigraphic position within the series is unknown. It is believed that the upper flows correspond to those exposed at Mossyrock dam site in Dunn canyon.

Thick forest and heavy cover of surficial deposits makes it impossible to trace individual flows for more than a few hundred feet. Since the flows are very massive and quite similar in appearance throughout thick portions of the stratigraphic section, it is difficult to distinguish between them on the basis of lithology.

Since the beds are dipping upstream, the youngest rocks crop out at the head of Shut-In canyon. Proceeding downstream, older flows are exposed successively along the river banks to a point about 400 feet below cross section M-M', figure 13. Further downstream, somewhat younger rocks are brought down to river level by folding and are exposed on both sides of the river at the mouth of Corn Creek. Partial section of the Keechelus Andesite Series(?) at Shut-In dam site is as follows:

Unit	Lithology	Approximate thickness in feet
E	Andesite	200±
D	Andesite and basalts	200 - 250
C	Basalt	75 - 80
B	Agglomerate and basalts	145 - 150
A	Basalt	435±
	Total	1055 - 1115±

Unit A. - All rocks stratigraphically beneath the flow agglomerates of Unit B are lumped together into Unit A. Probably more than 435 feet of basalt flows are involved. These rocks are exposed along the river banks in the vicinity of cross sections M-M' and N-N', figure 13, to a maximum altitude of 630 feet. Top of this series is represented by the bottom 4 feet in drill hole No. L-2 (hole 16 degrees from vertical). In these holes it is a dark gray, very fine-grained, glassy basalt with small white feldspar phenocrysts, rounded masses of what appear to be green glass, and small spheroidal amygdules ~~filled~~ of ~~with~~ a black, greasy, clay-like material, probably chlorophaeite. In both drill holes, there seems to be a gradual change to the overlying agglomerates rather than a sharp contact. Those rocks exposed along the banks of the river are made up of a number of massive lava flows of rather similar appearance with inconspicuous flow contacts. Where flow contacts could be distinguished, the flows were from 12 to 20 feet thick. Rocks making up the flows are dark gray to dark greenish-gray, fine-grained basalts with small light-colored phenocrysts of plagioclase feldspar (labradorite), and a few scattered, dark-colored phenocrysts of ferromagnesian minerals (augite (?) and olivine). Many irregularly shaped vesicles are present, especially in the zones immediately beneath flow contacts. These vesicles vary in size from a fraction of an inch to a maximum of about two inches. Many are filled with silica, but some are filled with a soft, greasy, dark green to black, amorphous, clay-like material that may be chlorophaeite, and a few are filled with zeolite (stilbite). Often a crystal makes up the center of the filling and is surrounded by the black, greasy material. Contacts between flows, observed only in a few places, showed little or no alteration and were marked only by concentrations of vesicles at the top of the lower flow. In some instances, the flow contact was marked by an almost continuous layer of silica from one-half to three-fourths inch thick.

The thick massive character of the flows, with their tight, unaltered contacts, moderate jointing, and their composition of hard, fine-grained basalts, indicate a strong rock that would be satisfactory for a dam foundation or abutment.

(hole inclined 16 degrees from vertical) where Unit B extends from a depth of 133.7 feet to 294 feet. The following log was made from a field examination of the cores with the aid of a hand lens.

Description of rock	Depth in feet From	To
Flow agglomerate, coarse fragments up to 4 inches. Both fragments and matrix altered to bright red.	133.7	138.0
Flow agglomerate, coarse dark greenish-gray, with a few red fragments. Silica ~~filled~~ amygdules in both fragments and matrix. Moderately jointed. Joints filled with calcite.	138.0	146.5
Basalt, dark gray, fine-grained, massive.	146.5	149.0
Flow agglomerate, coarse, angular fragments up to 3 inches; both fragments and matrix red; many small, rounded, calcite-~~filled~~ amygdules in the fragments, inclusions of basalt up to 12 inches in size; jointing very inconspicuous.	149.0	160.0
Flow agglomerate, coarse, dull reddish-gray, many small calcite-~~filled~~ amygdules, basalt inclusions near top, much jointed, calcite filling joints.	160.0	165.0
Basalt, dark gray, fine-grained, dense, glassy. Includes some agglomeratic material. Moderately jointed. Calcite fills joints.	165.0	173.8
Flow agglomerate, coarse; both fragments and matrix bright red; many fragments partly melted; many small calcite-~~filled~~ amygdules; two sets of joints, one filled with calcite, second with quartz.	173.8	185.8
Flow agglomerate, fine, dark bluish to greenish-gray, with red fragments in the top 6 inches; inconspicuous jointing; small silica-~~filled~~ amygdules in bottom 18 inches.	185.8	190.0

Flow agglomerate (?), transition zone in which above flow agglomerate changes to basalt. Medium-gray with mottlings of dull red. Many small feldspar phenocrysts.	190.0	200.0
Basalt, medium-gray; fine-grained; ~~dense.~~ Altered to dull red from 208.8 to 211 feet; and contains masses of burned material between 215 and 220 feet. Contains small, rounded mass of green glass; joints at 6 to 12 inch intervals, tight, calcite-filled.	200.0	220.0
Flow agglomerate, coarse, both fragments and matrix bright red, large amygdules ~~filled~~ of calcite, and small ones ~~filled~~ of black, greasy, clay-like material.	220.0	223.0
Flow agglomerate (?), fine-grained, dark-gray, contains small masses of glass and a few small, silica-~~filled~~ amygdules.	223.0	230.0
Flow agglomerate (?), fine-grained, dark-gray; contains many fedlspar phenocrysts. Small masses of material altered to red color. Contains amygdules ~~filled~~ of soft, greasy, green, clay-like material and a few ~~filled~~ of calcite. Inclusions of a dark-gray, fine-grained basalt in bottom 5 feet.	230.0	240.0
Flow agglomerate, fine, with angular fragments from microscopic size to one-fourth inch. A few of fragments burned bright red, but most of rock is dark-gray. Matrix is very fine, contains small masses of amygdaloidal silica and calcite. Moderate jointing. Contact with underlying rock missing.	240.0	245.3
Flow agglomerate, coarse fragments in a groundmass made up mostly of glass that is green from 245.3 to 255 feet, dark-gray from 255 to 268 feet, and reddish-gray from 268 to 275. A few large calcite-~~filled~~ amygdules are present. There are three sets of moderately developed joints, many of which are slickensided.	245.3	275.0

Flow agglomerate, fine fragments in a dark brownish-gray ground containing small masses of brownish-gray to greenish-gray glass and many small phenocrysts of plagioclase.	275.0	294.0

The sequence of flow agglomerate burned and altered by gases, unaltered flow agglomerate, and basalt is repeated three times from depth 133.7 to 200 feet. Each sequence probably represents an individual flow. The agglomerates from 220 to 294 feet probably include several more flows. The transition from flow agglomerate to basalt is usually so gradual that it is often difficult to differentiate between the two. The relative amounts of flow agglomerate to basalt appears to vary greatly from one locality to another as is shown on figure 15, but the general character of the series remains essentially the same throughout the dam site area. In drill holes L-2 and R2-1, there is a sharp break between the burned and altered flow agglomerate at the top of Unit B to the basalt of Unit C. On the ground surface relationship between the two is not so clear. In Corn Creek valley, agglomerate appears above the lowest bed of Unit C, either as a result of interbedding or repetition by faulting. Exposures are not good enough to determine which is the explanation.

In general, the flows making up Unit B are thick and massive. Agglomerates make up more than 50 percent by volume of the series. Since the agglomerates probably have less strength and are considerably more pervious than the basalts, Unit B as a whole is less desirable than those made up entirely of basalts or andesites, but is probably adequate to serve as the foundation or abutments of a dam.

above the base of the unit in drill hole L-2 (16 degrees from vertical) is a thin zone of fragments about one inch thick. The overlying material is dull and lusterless for 10 to 12 inches, and for three feet underlying the fragments there are many small spheroidal amygdules ~~filled with~~ of soft, black, greasy, clay-like material and a few larger, silica-~~filled~~ amygdules. All of the amygdules are arranged in rude bands roughly paralleling the contact. In hole L-2 (20 degrees from vertical) a zone made up of flow agglomerate enclosing small blocks of the basalt extends from 30 to 37 feet above the base of the unit. In drill hole R-2, about 7 feet above the base, is 9 inches of bright red, fragmental flow agglomerate.

This is a strong rock only moderately jointed, that should be sufficiently strong for a dam foundation or abutments. Its permeability should be comparatively low.

Unit D. - A series of basalt flows crop out on both banks of the Cowlitz River in the vicinity of cross section P-P4. These flows were penetrated by drill holes L-2 and R2-3. Total stratigraphic thickness of the unit is approximately 200 feet. This series is made up of not less than five individual flows, all very similar in appearance. Rocks composing the flows are hard, tough, fine-grained basalts that are medium-to dark-gray to brownish-gray in color, speckled with small white feldspar phenocrysts. They weather to an olive-gray. Small rounded masses of black glass are present. Amygdules are not common except in zones beneath flow contacts. Small amygdules ~~filled with~~ of black, greasy, clay-like material (chlorophaeite) are common in these zones; larger ones ~~filled~~ with silica are more scattered; and large calcite~~-filled~~ amygdules are found occasionally.

In thin section the basalts are composed of small, scattered, brick-shaped phenocrysts of labradorite and small yellowish-green phenocrysts, probably olivine, in a ground composed of microlites of labradorite, small unidentifiable grains of ferromagnesian minerals, and much dark-colored glass.

On the ground surface contacts between the flows are inconspicuous and rather difficult to distinguish, but in drill hole L-2 they are marked by from 1 to 3 feet of red coarse, fragmental flow agglomerate.

Joints are only moderately developed, usually in three sets, although in one locality columnar jointing was observed. Joint spacing varies from 6 inches to 3 feet. On the surface many of the joints are open to about one-sixteenth inch, but in the drill holes they tend to be tight. Many of them are filled with silica and a few with calcite.

This unit would be involved in the lower part of each abutment and in the foundation of a dam at cross section P-P4. However, because of the thick massive character of the flows, thin contact zones, and tough, hard rock, this is a strong unit adequate to serve as the foundation or abutment for any type of dam.

Unit E. - This unit, consisting of a series of undifferentiated flows of andesitic lava, crops out on both banks of the river upstream from cross section O-O', figure 13. Exposed rocks have a stratigraphic thickness of about 200 feet, but since the top of this unit is covered, the total thickness is unknown. The unit is no doubt made up of several flows, but the number is unknown since no exposed contacts were found.

In color, the weathered surface of the lava is brownish-gray, often with a slightly greenish or olive tone. On a fresh surface, the rock is fine-grained, hard, tough, medium-gray to brownish-gray in color, with small, scattered white plagioclase feldspar phenocrysts, small grains of biotite, and small phenocrysts of pyroxene. Under the microscope the groundmass is seen to be crystalline. Feldspar microlites make up 80 to 90 percent of the ground with minor amounts of pyroxene and magnetite. The feldspar microlites exhibit a slight tendency toward parallel orientation.

Small amygdules ~~filled with~~ of soft, greasy, greenish-brown mineral, probably chlorophaeite, and larger less common silica-filled amygdules are found scattered throughout the lava, but are more numerous in certain zones, probably underlying flow contacts. In several of these zones feldspar phenocrysts are unusually numerous and tend to be arranged in parallel alignment.

Since jointing is moderate and the rocks tough, hard, and relatively impermeable except along joints, this unit should be well

COMPOSITE DIKE CUTTING COUNTRY ROCK, LEFT BANK COWLITZ RIVER, SHUT-IN DAM SITE AT CROSS SECTION N-N', FIGURE 13
SE¼, SE¼ SEC. 9, T.12 N., R.3 E.

The composite dike consists of two parallel dikes about 6 feet wide separated by approximately 10 feet of country rock. Photograph by A.F. Bateman, Jr.

suited for a dam foundation or abutments. At Shut-In site, it would be involved in the upper part of the abutments for a dam at cross-section P-P'.

Intrusive rocks. - Four dikes cutting the lava flows were observed in Shut-In canyon. These dikes are exposed near the center of the dam site area on the left bank of the river at cross-section N-N', figure 13.

The most conspicuous dike is approximately parallel to the "Big Dike" at Mossy Rock dam site, (see pl. X7). Strike determinations on it varied from N. 47° W. to N. 50° W., and dips from 70° northward to vertical. Although it appears to be a single large dike it actually consists of two dikes, each approximately 6 feet wide separated by 6 to 10 feet of country rock. In general, the two parts are parallel, but locally the dip of one may vary as much as 15 degrees from that of the other. The rock is a hard, fine-grained, fresh-appearing basalt. Color varies from dark-gray with a subvitreous luster on a fresh surface to a lighter and duller gray or olive-gray on a weathered surface. Microscopic examination shows the rock to consist of a dense mat of plagioclase feldspar microlites with small irregular masses of glass enclosing small, scattered plagioclase phenocrysts, occasional small pyroxene phenocrysts, and a few small, silica-~~filled~~ amygdules. Closely spaced cooling joints perpendicular to the wall of the dike break the rock into small columns a few inches on a side. Fractures are subconchoidal.

In the vicinity of cross section N-N', this dike can be traced on the ground for about 400 feet. A small exposure of similar dike material about 1,000 feet upstream near B.M. 576 is interpreted as being part of the same dike. About 2,000 feet downstream similar material veneers the water-side of a rock exposure on the north bank near the mouth of Corn Creek. The dike probably once occupied the gap between this exposure and a rock island in the center of the stream, since the width and alignment of the gap agrees with the width and strike of the dike. The nearly horizontal and well-developed columnar jointing of the dike rock would permit much more rapid removal by stream corrasion than would the enclosing country rock.

A two-foot dike of similar material is exposed about 50 feet north of the composite dike on cross section N-N'. Strike of this dike is N. 38° W., and dip is vertical except for a small fold. About 10 feet farther north is a one-foot dike of similar material that strikes N. 50° W., and whose dip is vertical.

A fourth dike approximately two feet wide cuts the first three dikes diagonally. Its strike is S. 58° W., and its attitude is about vertical. The rock is a dense, fine-grained basalt, olive-gray in color on a fresh surface and deep olive to brownish-gray on a weathered surface. Under the petrographic microscope the ground appears as a mat of extremely fine plagioclase microlites with scattered, very small crystals of pyroxene, and some brown glass filling fine cracks. A few scattered needle-shaped plagioclase phenocrysts are embedded in the ground. Jointing is not as well-developed as in the other dikes. A median joint is present throughout its observed length. For a short distance this joint is filled with crystalline quartz approximately one-fourth inch thick.

The contacts between all of the dikes and the country rock are so tight that it is often difficult to pick the exact boundary between them.

Structural features

<u>Dip of beds</u>. - Attitude of the lava is difficult to determine because of the thick, massive character of the flows, the similarity in appearance of the rocks making up the various flows, the thick forest cover, and the paucity and small size of rock outcrops. Such determinations of dip and strike as could be obtained are shown on figure 13.

The regional dip at Mossyrock dam site, approximately 0.7 miles west of the downstream edge of the Shut-In dam site area is 19°, S. 12° W., and near Ajlune in SE¼NE¼ sec. 21, T. 12 N., R. 3 E., about 0.6 miles south of the dam site area, is 21°, S. 23° W. On the right bank of Corn Creek in the northwest corner of the dam site area, the flows dip more nearly westward with determinations as follows: 18°, S. 82° W.; 20°, S. 36° W.; and 37°, S. 60° W. Throughout the remainder of the dam site area the flows dip eastward. At the upper end of Corn Creek, the dip is 9°, N. 50° E., and slightly lower is 27°, N. 55° E. Upstream from Corn Creek, on both banks of the river, the flows dip eastward at angles ranging from 19° to 35° with strikes varying from N. 37° E. to N. 40° W. One exception is discussed in the paragraph on folds.

<u>Folds</u>. - An anticlinal axis striking and plunging approximately S. 8° E. crosses the Cowlitz Valley near the west edge of the map area (see figure 13). This fold is exposed in the valley of Corn Creek about 650 feet from its mouth at altitudes of from 530 to 570 feet. It brings

LOCAL FLEXURE IN LAVA FLOWS, LEFT BANK OF COWLITZ RIVER,
SHUT-IN DAM SITE AT CROSS SECTION N-N', FIGURE 13.
SE$\frac{1}{4}$, SE$\frac{1}{4}$ SEC. 9, T.12 N., R.3 E.

View is upstream with Mr. Johnson for scale. Flows in upstream flank dip approximately eastward at an angle of 27°. Photograph by C.E. Erdmann.

comparatively permeable volcanic agglomerate to a maximum altitude of 675 feet. Along the river bottom and on the left bank of the Cowlitz the anticline is entirely covered by glacial deposits and alluvium.

Twenty-five hundred feet upstream from the mouth of Corn Creek an anticlinal fold striking approximately north-south can be observed in a cliff along the left bank of the Cowlitz River that projects about 30 feet above the water surface. Beds in the upstream flank dip eastward at an angle of 27°. The west flank is poorly exposed and no satisfactory determinations of dip and strike were obtained, but the beds appear about horizontal. This fold is believed to be a minor flexure on the flank of the Corn Creek anticline. (See pl. XVI.)

Faults. - No faults of any size were observed. In Corn Creek Valley at an altitude of 640 feet, a slickensided surface dips 85°, S. 57° W. Both walls are composed of lavas of Unit C, but the southwest side appears downthrown about 6 inches.

Joints. - Because of their effect on strength and permeability, joints are one of the most important mechanical features of the lava flows. Consequently, a rather thorough examination of jointing in the dam site area was made. Seventy-nine determinations of joint directions and dip were made at 30 localities on the ground surface. Observations were also made on joints in diamond drill cores, especially those taken from drill holes L-2, R2-1, and R2-2. From 2 to 4 sets were observed at each locality, but more than 4 sets are present. In general, there are two types: (1) joints related to cooling stresses in the rock whose directions and dips vary with the strike and dip of the lava flows; and (2) those related to tectonic stress whose directions and dip appear to be largely independant of the attitude of the beds. In the field joints of the two types cannot ordinarily be distinguished from one another on the basis of their physical character except in the case of clearly defined "bedding" joints and hexagonal cooling joints.

"Bedding" joints were observed throughout the dam site area in all of the rock units and in the drill holes. Strikes of these joint surfaces were essentially parallel to the strike of the bedding at the particular locality. Dips vary from the dip of the beds by not more than 10 to 15 degrees. Spacing varies considerably, not only from one unit to another but even within the same unit. In the agglomerate beds of Unit B, spacing is from 1 foot to 2 or 3 feet. In the lavas, spacing tends to be less, especially near flow contacts where it may be only an inch or two. On the ground surface, these joints are either tight or else open only a small fraction of an inch. In the drill holes, they are tight and occasionally healed with either calcite or silica.

Two conjugate sets of joints strike roughly parallel to the strike of the bedding, but dip at angles that are usually about 45 degrees from the flow surfaces, although in some cases this angle is nearer 90 degrees than 45 degrees. These joints were observed in Units A, C, D, and E, throughout the dam site except for the right abutment upstream from the section line. On exposed rock surfaces, these joints are open from a small fraction of an inch to about one-fourth inch. Spacing ranges from one to four feet. In the drill holes these joints are tight. Many are filled with calcite and a few with silica.

Two sets of master joints occur in the Cowlitz Valley, one set striking NW-SE and the other set NE-SW. Joints of both sets are vertical or nearly so. These two sets control the minor topographic features found throughout this part of the Cowlitz Valley. In the dam site area, the NW-SE set is more noticeable because several are occupied by dikes. Since these two sets of joints appear to be more or less independent of the attitude of the flows and of the individual rock units, they probably have resulted from tectonic stress. Joints belonging to the NW-SE set were observed throughout the dam site. Strikes range from N. 15° W. to N. 50° W., and dips vary from 70° NE to 62° SW., although most are vertical or nearly so. Spacing is rather wide, varying from 1 to 6 feet. Some joints are open as much as three-fourths inch on the surface, but are probably fairly tight at depth. Joints belonging to the NE-SW set were also observed throughout the dam site. Strikes of these joints vary from N. 60° E. to N. 90° E. Dips are either vertical or at high angles to the northwest or southeast. Invervals between dikes vary from 1 to 4 feet. Most joints are open from a fraction of an inch to one-fourth inch on the surface.

In addition, there were 7 joint determinations observed that, on the basis of their direction and dip, did not appear to belong to any of the above sets nor to form another set.

Ground water conditions

Surface indications of ground water in Shut-In Canyon consist of small springs and seeps fed by precipitation in the form of rain and snow. Movement of water is down the valley walls toward the river. At the time field observations were made during the dry weather of September and October, no individual seep had a flow as great as one cubic foot per second. Flow was from the following types of water-bearing structures:

1. Contact between bedrock and overburden. The largest seeps observed were of this type. On the right bank they occur at the top of a rock outcrop southeast of B.M. 503, at the top of a rock cliff underlying the alluvial cone just downstream from cross section M-M', and at the top of several rock cliffs in Corn Creek Valley. On the left bank these springs are numerous, especially at the top of the rock outcrops extending from a point about 300 feet upstream from B.M. 437 to a point about 600 feet downstream.

2. Contact between the Older drift and Younger drift. Flow is on top the impervious sediments of the Older drift and through the lowermost 6 to 12 inches of gravels and sands making up the Younger drift, from which the fines have been washed. Seeps of this type are small but occur along the entire length of the ~~right~~ left bank in Shut-In Canyon wherever Older drift is exposed. They are from a few feet to 25 feet above the stream surface. On the right bank, seeps of this type are very small, few, and scattered.

3. Joints and flow contacts in bedrock. Seeps of this type occur at many localities within the dam site area, but quantity of flow is extremely small. They are located near the tops of rock outcrops where surface water moving down the valley wall along the bedrock surface has an opportunity to enter the joints.

4. Permeable layers in the Older drift. In the elongated exposure of Older drift extending upstream along the right bank of the river from B.M. 452, water issue from gravels and sands along the tops of thin layers of glacial silts. Total quantity of flow is minute.

Two wells located near a farmhouse not far from drill hole S-2 obtained water from outwash gravels of the Younger drift at depths of 18 and 24 feet. This water is probably perched on impervious beds in the Younger drift.

No data is available with respect to hydraulic conditions found in the drill holes.

Permeability

Percolation through the rocks making up the foundation and abutments of the dam site must take place either through the fabric of the rock or along openings provided by flow contacts, joints, faults, or dikes.

Both field examination and microscopic study indicate that the porosity of the basalt and andesite lavas of the various units is low. Hence these rocks must be practically impervious, and percolation through their fabric would be negligible. However, the flow agglomerates that make up more than 50 percent by volume of Unit B are much more permeable and would permit appreciable percolation through the fabric of the rock. Fortunately, in the vicinity of the proposed axis, P^1-P^4, the flow agglomerates lie beneath the relatively impervious beds of Units C and D. In the preglacial channel the overlying beds have been removed, but the agglomerates are covered by glacial deposits of the Older drift that have rather low permeability.

The tight and relatively unaltered flow contacts of Units A and C would no doubt have low permeability. The flow contacts in Unit B, however, consist of zones of coarse, burned, fragmental agglomerate several feet in thickness and highly permeable. Those in Unit D are similar but thinner. No flow contacts were seen in Unit E. In the vicinity of the proposed axis, P^1-P^4, the flows dip upstream at an angle of 29 degrees, an attitude that limits considerably the effectiveness of the flow contacts as percolation channels.

Some percolation channels may occur along joints. They tend to be rather closely spaced in the lavas, but are more widely spaced in the agglomerates. In surface exposures, joints gape open from 1/32 to ½ inch, but those observed in diamond drill cores were either tight or else open only a very small fraction of an inch. Many were filled with either silica or calcite. It is concluded that percolation along joint surfaces would be small.

Consideration of seepage along faults can be eliminated since none were found in the vicinity of the proposed axis.

Dikes in the Shut-In area strike about normal to the proposed axis and lead directly from the reservoir to the open valley downstream. The dike rocks are tightly welded to country rock, so flow along the contact surfaces would be minute. Chief danger of leakage is through the well-developed and closely spaced columnar jointing.

In summary, it is concluded that the main body of bedrock is relatively impermeable. Permeable members are buried beneath more impermeable units. Seepage through permeable features such as flow contacts, joints, and dikes will occur, but can be controlled by grouting.

Dam section

The most economical section in Shut-In Canyon for a high dam is illustrated by cross section P-P', figure 14. Topography would permit a dam to be raised to altitude 750 feet and possibly a few feet higher, but other considerations limit the maximum height to about 740 feet. A dam to this altitude would stand 324 feet above stream bed and 516 feet above the bedrock floor of the valley. At this height the width of open valley is about 1,240 feet. Conditions are about the same 200 feet upstream. Downstream the valley flares slightly, but conditions do not change a great deal for slightly more than 600 feet to cross section O-O'. Further downstream between cross sections O-O' and M-M', the section is only slightly less favorable from the standpoint of topography, but geologic conditions in the abutments make this portion of the canyon much less favorable for a dam.

Abutments

The term abutments includes the valley walls above river surface. Geologic conditions in the abutments of Shut-In Canyon are not uniform throughout its length, so for this discussion the canyon will be divided into three parts:

Upper end. - For about 1,500 feet at the upper end of the canyon, abutment conditions are comparatively uniform. This includes the area upstream from cross section O-O', figure 13. Exposed rock consists of thick, massive lava flows of the Keechelus andesite series (?). (See figs. 13 and 14.) Units D and E make up the abutments for the most part, but Unit C is exposed along the left bank of the river at the lower end. Bearing capacity of these rocks is believed sufficient for any type of dam. The flows dip upstream at angles varying from 19 to 29 degrees with a component dip of about 5½ degrees into the right abutment and about 12 degrees into the left abutment. Hence, the two abutments are about equal in strength. Bedrock is at or near the ground surface on the right abutment from an altitude of about 480 feet to well over 800 feet, and on the left abutment from river level to the top of an outcrop of Unit E that because of the attitude of the beds rises from about altitude 450 feet at the east edge of the dam site area to a maximum of 760 feet about 300 feet downstream from section P-P'. What cover is present consists of talus, slope wash, and glacial drift that probably never exceeds 15 to 20 feet in thickness.

From river level to 480 feet on the right abutment, the ground surface is underlain by outwash sands and gravels of the Younger drift except for a narrow band of pebble-clays, sand clays, fine sandy gravels, sands, and silts of the Older drift exposed ~~in a~~

~~narrow band~~ along the river bank. Relationship of these deposits and their approximate thicknesses are shown on the enlarged cross section P^2-P^3, figure 15.

Above exposed rock, the left abutment is blanketed by heavy forest cover, soil, and slope wash, underlain by deposits of the Younger drift. Below altitude 810 feet these deposits appear to be mostly outwash gravels, and at this altitude a compact till associated with an elongated morainal ridge extending southwestward from the rim of the canyon. Configuration of the bedrock surface beneath these deposits is unknown through a distance of more than 1,000 feet between the highest rock outcrops on the canyon wall and bedrock in drill hole S-7 at an altitude of 710 feet.

Center. - For a distance of about 1,200 feet between cross sections O-O' and M-M', no bedrock is exposed on the right abutment except for a small outcrop near the lower end. Cover is rather thick, as is shown by sections N-N', M-M', figure 14, and consists of soil, slope wash, landslide debris, talus, and glacial deposits. On the left bank, Units A, B, and C are exposed near the river up to a maximum altitude of 600 feet. Above that level, everything is covered by outwash gravels of the Younger drift.

Lower end. - From cross section M-M' to L-L' at the mouth of Corn Creek, the downstream end of the map area, is a distance of about 1,500 feet. Bedrock is exposed on the right bank just downstream from section M-M' in a cliff extending from river level to an altitude of 490 feet, where it disappears under an alluvial cone built up by a small tributary stream. In the valley of this stream above the alluvial cone, rock is again exposed at altitudes from 626 to 664 feet. Undifferentiated glacial drift covers the remainder of the right abutment except in the valley of Corn Creek where rocks of Units B and C are exposed from river level to 433 feet and from 480 feet to more than 900 feet. On the left bank, rock exposed in the central section extends down into the lower section for about 200 feet, where it disappears under glacial deposits. Top of this exposure is at 620 feet. The remainder of the left abutment is underlain by outwash gravels of the Younger drift, except for small exposures of Older drift along the river's edge.

Foundation

Active alluvium in the stream bed is thin and probably does not exceed 10 to 15 feet in thickness at any point in Shut-In canyon. The alluvium is underlain by either bedrock or sediments of the Older drift that fill the preglacial channel. The course of this channel is outlined by drill holes at section P-P⁴, and for 1,100 feet downstream. Beyond that point, its position must be inferred from surface outcrops. At P-P⁴, the channel directly underlies the present stream bed, but downstream from this line, it swings to the north and underlies the right bank for a distance of at least 2,000 feet. In the vicinity of cross section M-M', there are two possible routes: (1) The channel may coincide with the present course of the stream; or (2) The channel may swing wide to the right. If the channel follows the first course, it must pass between rock outcrops on either side of the river only 200 feet apart. Outcrops of Older drift were not found along the river in this stretch. If the channel follows the second course, there is a space of about 300 feet through which it may pass. Downstream from this stretch the channel swings left under the bench opposite the mouth of Corn Creek.

An enlarged profile of the channel at cross section $P-P^4$ is shown on cross section P^2-P^3, figure 15. The channel floor lies 203 feet below stream level at an altitude of 224 feet. For 800 feet downstream from this point the floor rises gradually to a rock divide at altitude of 250 feet, and then drops to 240 feet, 1,100 feet downstream from section $P-P^4$. Presumably, it continues to drop throughout the rest of Shut-In canyon.

Sediments filling the channel, as disclosed by drill holes C-2, R-2, R2-1, consist of pebble-clays, sand clays, fine sands, and silts of the Older drift. These sediments are very compact and dense, and should have ample strength to support a flexible dam of earth embankment. Permeability is no doubt comparatively low. Farther downstream through Shut-In canyon, outcrops along the river banks suggest that the fill materials contain less of the till phase and more gravels and sands. However, even these deposits appear to have low permeability.

In the upper end of Shut-In canyon, the preglacial channel is cut into the massive basalt flows of Unit C, and the flow agglomerates and basalts of Unit B. Farther downstream, basalts of Unit A and possibly rocks underlying this unit that have not been observed either on the ground surface or in drill holes are involved. These rocks all have ample strength to support a dam. Some of the agglomerates, especially at flow contacts, are rather permeable.

Choice of section

Since a dam in Shut-In canyon would be used for flood control and power development, it is desirable to obtain maximum storage. Present knowledge of abutment conditions limits the location of a site for a high dam to that portion of the canyon upstream from cross section O-O', figure 13. Downstream from this limit, bedrock is exposed in the left abutment only to altitudes of slightly more than 600 feet and probably does not extend much higher in the divide between Shut-In canyon and the glacial diversion channel. (See fig. 13, and cross sections M-M' and N-N', fig. 14.) Drill holes or test pits are needed to establish the altitude and configuration of the bedrock surface behind the left abutment in this area. The overlying outwash gravels appear to be too permeable to serve as part of the abutment for an earth-fill dam, although they probably have sufficient strength for the job.

Upstream from section O-O', a tentative dam axis has been selected at section P-P'. This choice is a compromise brought about by several conditions:

1. Bedrock is near the surface over most of the right abutment, but in the left abutment, top of exposed bedrock descends from approximately 750 feet near section O-O' to 450 feet at the upper end of the dam site area. Topography suggests that rock probably does not extend much higher under its cover of glacial deposits. Hence, the farther downstream the location of the dam axis within this stretch of the canyon, the higher bedrock will extend in the left abutment.

2. As has previously been stated, it is possible that bedrock does not reach much above altitudes of 600 to 650 feet in the left abutment downstream from section O-O'. If this condition actually exists, the left abutment is a narrow rock ridge, only about 1,000 feet thick at an altitude of 650 feet. To make the paths of percolation for reservoir waters seeping through the abutment as long as possible, the dam axis should be moved upstream as far as other conditions permit.

3. The flow contact zones and agglomerate beds of Unit B tend to be permeable. Hence, it would be desirable to keep them covered by the more impervious beds of Units C and D and the glacial deposits of the Older drift. This can be accomplished by keeping the dam axis

as far upstream as possible. (See section Q-Q', fig. 14.)

Height and length of possible dam

Width of valley for various heights of dam at section P-P' are as follows:

Altitude of crest - feet	Height above stream bed - feet	Height above rock foundation - feet	Length - feet
740	324	516	1,240
730	314	506	1,205
725	309	501	1,190
720	304	496	1,170
710	294	486	1,130
700	284	476	1,100

LOOKING UP COWLITZ FROM NORTH BANK OF RIVER ABOVE UPPER END SHUT-IN DAM SITE, NW$\frac{1}{4}$, SE$\frac{1}{4}$ SEC. 10, T.12 N., R.3 E. APPROXIMATE ALTITUDE 1000 FEET

View shows lower end of reservoir area from river mile 66 to mile 68, Figure 2. A portion of the fill terrace can be seen in the right middle ground, and Swofford Valley in the center middle ground. The long ridge against the skyline is Green Mountain, and the cone-shaped peak is Winters Mountain. Photograph by A.F. Bateman, Jr.

Reservoir area

Shut-In reservoir area lies in a flat-bottomed, steep-walled valley, from half a mile to one mile wide (see pls. I and XVII). Storage capacity, area, and length of reservoir for various pool levels are as follows:

Pool level - feet	Length - miles	Area - acres	Storage capacity - acre-feet
740	20.8	9,790	1,277,000
730	20.2	9,430	1,180,600
720	19.7	9,080	1,008,300
710	18.8	8,720	999,300
700	18.4	8,300	914,200

Reservoir waters would inundate the village of Riffe, with a population of 175 people (1940 census), and two or three dozen small farms that cover most of the bottom land. Merchantable timber has been removed for the most part, but brush and second growth that is too small to be of economic value cover several square miles. No minerals of economic value are known within the reservoir area.

Approximately 13 miles of State Highway No. 5 that extends longitudinally through the reservoir area with one bridge across the Cowlitz River would be flooded. The southernmost 1.5 miles of State Highway No. 5L, between Morton and Riffe, together with one bridge across the Cowlitz River, would also be flooded.

Geology. - Geologic conditions in the reservoir area are known only in a very general way. Brief reconnaissance was made along the highway and the river. Bedrock consists of basic lava flows similar to those at the dam site cut by occasional dikes. Accurate determinations of dip and strike were very difficult to obtain because of the small size of exposure and the massive character of the flows. Dip is to the southeast and southwest at angles varying from 20 to 30 degrees. Determinations obtained in the reservoir area for 3 miles immediately above the dam site are shown on figure 2.

Throughout the reservoir area, the preglacial channel of the Cowlitz River lies within the wide flat-bottomed valley now occupied by the stream. Sediments of the Older drift, exposed at various localities along the banks of the river, probably fill the channel. These deposits are overlain by Younger drift and alluvium.

Leakage from the reservoir. - Chief danger of leakage from the reservoir, other than at the dam site, is through sediments filling the glacial diversion channel that by-passes Shut-In canyon to the south.

The approximate course of this channel is shown on figure 2, and its relationship to the dam site is shown on cross section P-P[4], figure 14. Shape and size of the channel and the character of the fill as determined by six drill holes is shown on the generalized cross section, figure 16. Approximate dimensions of the channel are as follows:

Altitude - feet	Width - feet	Maximum depth to bedrock - feet	Cross-sectional area - sq. feet
740	1,920	202	186,800
720	1,825	182	222,100
700	1,700	162	259,000

"Drive" samples of the fill were taken at five foot intervals. From the examination of these samples and the driller's logs, a sample log was prepared for each hole. However, many samples showed evidence of washing, so that the original content of fines in these samples is problematical. The fill materials appeared to be very similar in the various holes, and the following condensed log of drill hole No. S-3 is submitted as typical since it penetrated the maximum depth of fill, 233 feet.

Log of Drill Hole No. S-3

Surface elevation: 771.5

All measurements are in feet.

Description	From	To	Thickness
Clay, light yellowish-brown, silty, sandy, tough, plastic, with occasional pebbles.	0	14	14.0
Gravel and sand, with a small amount of clayey silt matrix and occasional boulders, light brownish-gray. Cobbles hard and sound.	14	47.5	33.5
Gravel and sand, clean, many iron-stained pebbles. Cobbles and pebbles hard and sound.	47.5	52.5	5.0
Sand, light brownish-gray, medium-to fine-grained, with poorly graded silt matrix having a trace of plasticity. A few interbedded layers of coarse sand and fine gravel.	52.5	102.5	50.0
Sand, light brownish-to bluish-gray, medium and fine, with scattered pebbles to one-eighth inch, and much slightly plastic silty matrix.	102.5	127.5	25.0
Sand, as from 102.5 to 127.5, except with barely enough matrix to fill void spaces between grains.	127.5	132.5	5.0
Sand, coarse and medium, clean.	132.5	137.5	5.0
Sand, fine, even-grained, with a few grains of coarse sand. A trace of silt matrix.	137.5	142.5	5.0
Sand, same as from 137.5 to 142.5, except that it has much silt matrix.	142.5	162.5	20.0

Sand, medium and fine, poorly graded, scattered pebbles, trace of silt matrix.	162.5	167.5	5.0
Sand, medium and fine, poorly graded, clean.	167.5	177.5	10.0
Sand, fine, even-grained, silty.	177.5	182.5	5.0
Sand, medium and fine, poorly graded, trace of silt matrix.	182.5	192.5	10.0
Sand, fine, even-grained, silty.	192.5	212.5	20.0
Sand, bluish-gray, fine, even-grained, very silty.	212.5	217.5	5.0
Sand, light brownish-gray, medium and fine, poorly graded, silty.	217.5	222.5	5.0
Sand, dark gray, fine, even-grained, trace of silt	222.5	227.5	5.0
Sand and fine gravel, light brownish-gray, silty matrix.	227.5	233.0	5.5
Basalt, dark gray, fine-grained, conspicuous white labradorite phenocrysts and many small irregularly shaped amygdules filled with black, greasy, clay-like material. No phenocrysts in bottom 2.0 feet.	233.0	244.0	10.0
Total depth		244.0	

The light yellowish-brown sandy silty clay that makes up the top 14 feet in drill hole No. S-3 is Cinebar silt loam. This material forms a blanket over the channel varying from 8 to 18 feet in thickness. No field permeability tests have been made on the channel fill, but from the character of this clay it is estimated that it has a rather low permeability in the order of 3×10^{-7} to 3×10^{-6} feet per second.

Underlying the yellow-brown clay are 39 feet of rather silty gravels interbedded with clean gravels and coarse sands, interpreted as outwash gravels of the Younger drift. Thickness of these materials varies from a maximum of 58 feet in drill holes S-1 and S-2 to zero in drill hole S-6. Cross sectional areas of these gravels below water level are estimated at only 30,000 square feet and 4,000 square feet, respectively, for pool levels of 740 and 720 feet. None occurs below pool level 700 feet. These beds are lenticular in character, and permeability varies with each bed. However, the coefficient of permeability is probably rather high for all and is estimated to be within the limits of 3×10^{-4} to 3×10^{-2} feet per second.

The next 180 feet in drill hole No. S-3 is made up of sands. Some are medium-to fine-grained, poorly graded, and silty, and others are fine, even-grained, and silty. Small amounts of coarse clean sands, clean gravels, and fine sandy gravel with a little silty clay matrix are interbedded with the fine sands. Similar materials were found in the other drill holes. Drillers' logs give the impression that these materials are very compact and hard. In fact, some fine sands with only scattered pebbles (as determined from samples) were logged as "cement gravel." As can be seen, these materials largely fill the channel, and make up 88, 98, and 100 per cent of the cross sectional area of the channel for reservoir water levels of 740, 720, and 700 feet, respectively. Average permeability coefficient of these beds is estimated at from $3X10^{-7}$ to $3X10^{-5}$ feet per second.

If these estimates of the permeability coefficients of the various materials are of the correct order, seepage through the channel should be negligible. However, before a dam is constructed, extensive field permeability tests should be made on the various fill materials.

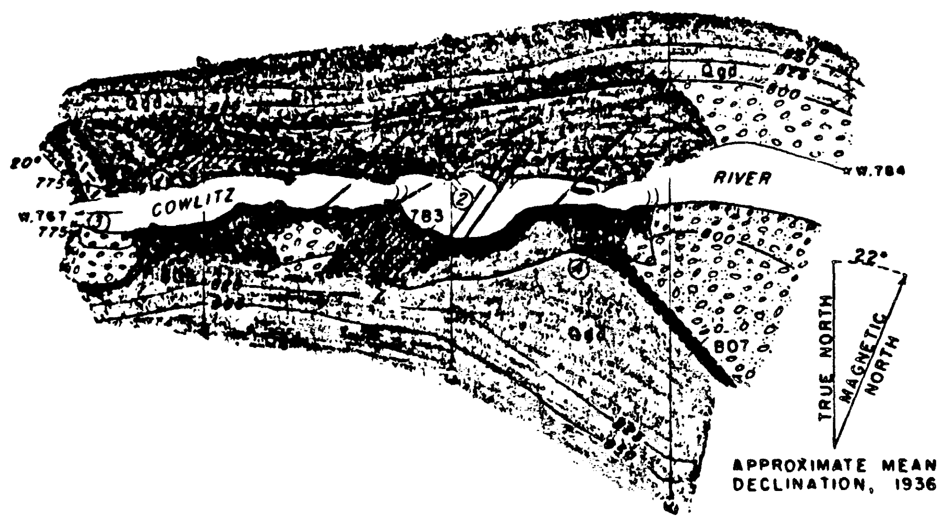
Summary and Conclusions

Geologic conditions in Shut-In canyon are probably suitable for a dam in the vicinity of cross section P-P^4, figure 13, but further investigations are necessary before the type and height of dam is determined. Rock is present in the right abutment to over 800 feet altitude, and in the left abutment to about 700 feet altitude. The preglacial channel of the Cowlitz River is cut into rock foundation at the dam site to a maximum depth of 192 feet. It is filled with sediments of the Older drift, having high bearing capacity and comparatively low permeability. Leakage from the reservoir might take place through glacial sediments filling a diversion channel nearly 2,000 feet wide and 233 feet deep that by-passes Shut-In canyon behind the left abutment of the dam site. Bottom of this channel is at 538 feet.

A dam to top of rock in the left abutment at altitude 700 feet would stand 284 feet above stream bed and 476 feet above rock foundation. It would be 1,100 feet long and would provide 914,200 acre-feet of storage. However, for regulation of stream flow for power purposes, more storage is desirable. A dam with pool level at 740 feet altitude might be feasible. Such a dam would stand 324 feet above stream bed and 516 feet above rock foundation. It would be about 1,240 feet long and would store 1,277,000 acre-feet of water. However, before a high dam, even to altitude 700 feet, is considered, additional information should be obtained by drilling and other means into regard to:

1. Conditions in and behind the left abutment above altitude 700 feet, extending from the canyon wall as far back as drill hole S-7, and from several hundred feet upstream from cross section P-P' to at least as far downstream as cross section O-O'.

2. Permeability of the glacial sediments filling the glacial diversion channel.



APPROXIMATE MEAN DECLINATION, 1936

EXPLANATION

- LINE OF CROSS SECTION
- LOCALITY NUMBER
- 807 PLANE TABLE BENCH MARK
- W.784 ALTITUDE WATER SURFACE
- 20° DIP AND STRIKE OF FORMATION

PRELIMINARY GEOLOGIC MAP OF COWLITZ FALLS DAM SITE

SECTION 6, T.11N., R.6E.W.M.
LEWIS COUNTY, WASHINGTON

SCALE

0 200 400 600 800 FEET

CONTOUR INTERVAL 25 FT.

1936

EXPLANATION

RECENT
- ALLUVIUM, LARGELY INACTIVE. MINOR AMOUNTS ACTIVE ALLUVIUM IN STEAM CHANNEL.
- TALUS

PLEISTOCENE
- GLACIAL OUTWASH GRAVEL

KEECHELUS (?) ANDESITE SERIES

TERTIARY, MIOCENE

INTRUSIVE ROCKS
- DIKES, ANDESITE

EXTRUSIVE ROCKS
- ANDESITE, UNIT F
- ANDESITE PORPHYRY, UNIT E
- ANDESITE, AGGLOMERATE AT BASE, UNIT D
- ANDESITE, UNIT C
- TUFF AND AGGLOMERATE, UNIT B
- ANDESITE, UNIT A

LETTERING OF UNITS HAS ONLY LOCAL SIGNIFICANCE, AND DOES NOT INDICATE CORRELATIONS WITH BEDS SIMILARLY LETTERED AT OTHER DAM SITES ON COWLITZ RIVER.

GEOLOGY BY C.E.ERDMANN

DIF

241a

COWLITZ FALLS DAM SITE

12 NK 1

(Figures 17 and 18)

Location

This prospective dam site is located at mile 86.7 on Cowlitz River, just south of the center of sec. 6, T. 11 N., R. 6 E., Willamette Meridian, Lewis County, Washington.59/ The special dam site survey is on a scale of 1:2,400 (1 inch equals 200 feet), with 5-foot contours on land, and covers an area of about 11 acres. This map was used as a base for the accompanying geologic map, figure 17, but for the sake of clarity only the 25-foot contours are shown. The site takes its name from Cowlitz Falls, a two-step waterfall with a total drop of about 15 feet over a distance of about 1,000 feet.

59/ Plan and profile of the Cowlitz River. Op. cit. Sheets 1 and 7.

Accessibility

Although Cowlitz Falls is off from the beaten path, the river below the falls is a well-known fishing place, and two good woodland trails suitable for automobile travel lead to it on the north bank. One runs southeast from the village of Kosmos, on State Highway No. 5, to Cispus, and a branch turns south a mile south of Cispus and terminates on the right bank at Kelly's bridge. Another runs southwest from Randle, also on State Highway No. 5, to Cispus, and thence to the bridge by the route just mentioned. Kelly's bridge is a foot-bridge suitable for saddle horses and pack animals, and it crosses the river at the mouth of Tumwater Creek, about half a mile west of the dam site. Foot or horse trails extend from either end of the bridge to the falls.

Nearest accommodations are at Randle about 11 miles northeast, but more comfortable lodgings are to be found at Morton, about the same distance northwest.

Catchment basin

Cowlitz Falls occur about 1.2 miles below the mouth of Cispus River. The drainage basin of the Cowlitz above the Cispus occupies about 594 square miles and that of the Cispus about 438 square miles. These areas total 1,032 square miles, and not much more than 1 square mile is drained by the trunk Cowlitz between the dam site and the mouth of the Cispus, making the total area of the catchment basin about 1,033 square miles. Details of the topography, precipitation, forest cover and culture of these basins is given in reports previously cited.

Purpose of project

In their report on Cowlitz River the Corps of Engineers[60/] make

[60/] Op. cit. pp. 24, 31, 32.

brief reference to Cowlitz Falls in the following words:

"76. A low dam in this section is feasible and is incorporated in the power considerations below in this report as a diversion dam. No storage of consequence would be developed."

"133. A dam 40 feet in height above bed rock would raise the water level to elevation 800 and back the water to the mouth of Cispus River. It is not considered desirable to raise the water level above that elevation because of the effect on flood heights through Big Bottom. Storage capacity at site 12 NK 1 would be small, but would provide sufficient pondage for efficient operation of a power plant. Development would include diversion at elevation 800, with a 4-mile conduit to a point in section 33, township 12 north, range 5 east, Willamette meridian, at elevation 680. The available head for power would be 120 feet."

"134. Estimates on the water available for site 12 NK 1 are:

Drainage area, 1,032 sq. miles	Total for basin	Per square mile
Run-off, average rate [61/]	4,870 sec.-ft.	4.72 sec.-ft.
Run-off, average annual total	3,525,000 acre-feet	
Natural flow, 90 per cent of the time	1,400 sec.-ft.	1.21 sec.-ft.
Natural flow, 50 per cent of the time	3,480 sec.-ft.	3.37 sec.-ft.

[61/] Annual refers to the run-off season Oct. 1 to Sept. 30.

"135. Regulation of the flow at the site could be accomplished with storage described above, as follows:

	Acre-feet storage
Site 12 NK 4	35,000
Site 12 NK 6	50,000
Site 12 NK 7	75,000
Site 12 NK 8	90,000
Site 12 NK 9	415,000
Total:	665,000

"Such storage could produce flows shown under regulated flow in the table below. With an operating head of 120 feet in site 12 NK 1 power could be developed as follows:

	With natural flow		With regulated flow	
	Second-ft.	Kilowatts	Second-ft.	Kilowatts
90 per cent of the time	1,400	10,100	2,760	19,900
50 per cent of the time	3,480	25,000	3,540	25,500

Stream gradient

Cowlitz River is ungraded at the falls due to the plunge of the stream over several resistant layers of rock. Below the falls for about half a mile the gradient is about 10 feet per mile. The falls consist of two steps totalling 15 feet over a distance of about 0.20 mile, or about 75 feet per mile. Upstream the gradient averages 26 feet per mile for 2.3 miles to mile 91, where it flattens to 3 feet per mile for 5 miles.[62] Unfortunately,

62/ Plan and Profile of Cowlitz River. Op. cit. Sheet 9.

due to unfavorable topographic conditions, very little of this stretch can be utilized in the reservoir of Cowlitz Falls dam site.

Valley profile

As at so many other localities downstream, Cowlitz River valley at Cowlitz Falls dam site probably does not occupy its original consequent valley. Consideration of the regional topography [63/] indicates

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63/ Mount St. Helens Quadrangle, U. S. Geological Survey.

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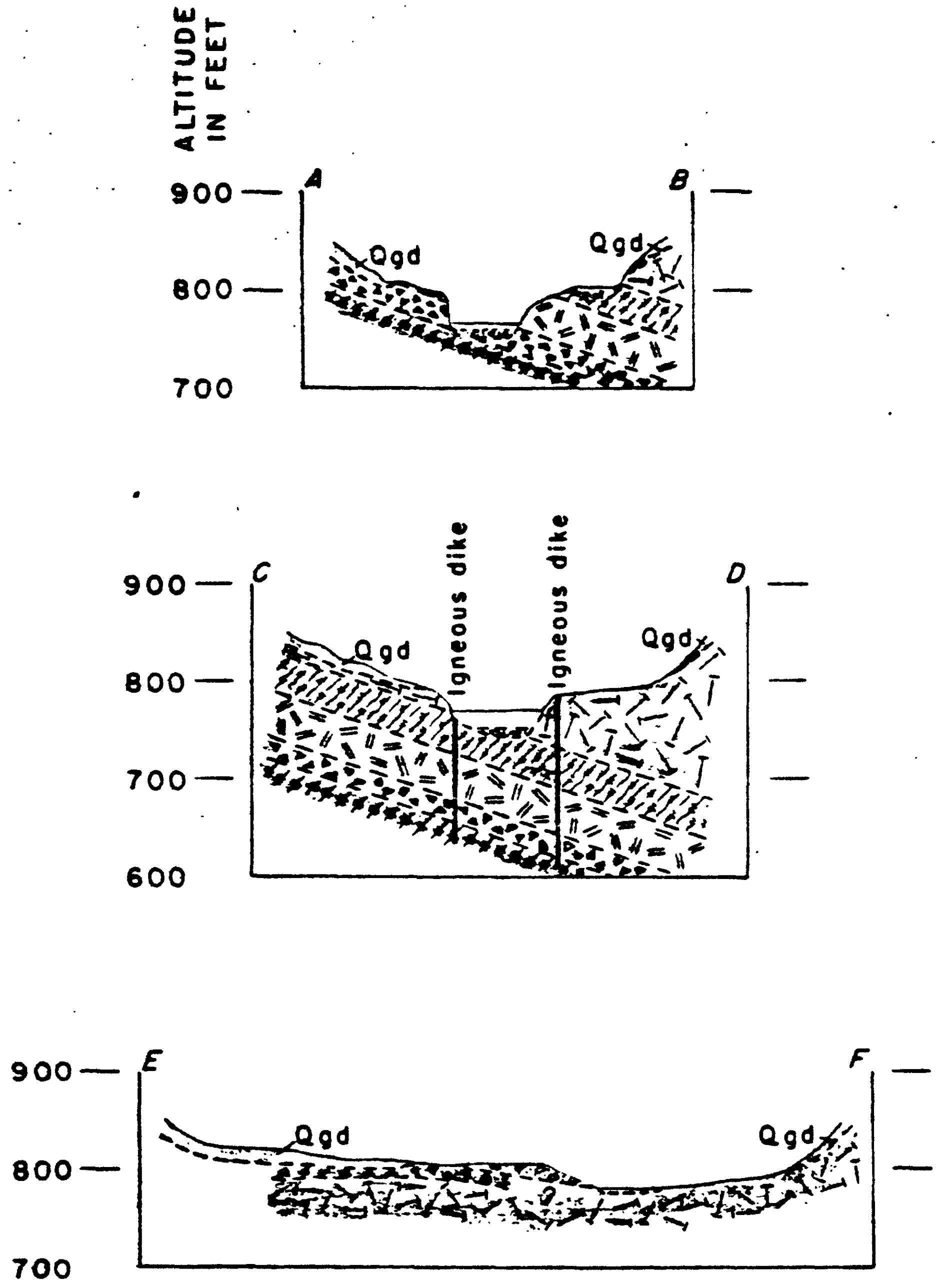
that it is superimposed upon a low, narrow, north-projecting spur of Tumwater Mountain that terminates in a high, isolated hill occupying most of the north half of sec. 6, T. 11 N., R. 6 E. This section has a length of about half a mile, and a profile along the spur at altitude 1,000 shows a shallow U-shaped valley about 1,400 feet wide and 250 feet deep, with a very narrow, shallow, ungraded gorge now being cut in the bottom. The old, buried valley lies about a mile north. Cispus River probably originally joined the ancient Cowlitz near the present confluence of the two streams. Downstream from this locality the original trunk valley of the Cowlitz extended westward from the center of sec. 31, T. 12 N., R. 6 E., along the south boundary of the township to the SW¼ sec. 34, where the active stream re-enters its ancient valley.



ALL VIEWS DOWNSTREAM
FOR EXPLANATION SEE FIG. 8

GEOLOGIC CROSS SECTIONS
COWLITZ FALLS DAM SITE

SECTION 6, T. 11 N., R. 6 E. W. M.
LEWIS COUNTY, WASHINGTON

SCALE

0 200 400 600 800 FEET

GEOLOGY BY C.E. ERDMANN

D.I.F.

Apparent possible height of dam

The controlling altitude for any dam at Cowlitz Falls is 900 feet, and occurs in a topographic saddle about a mile north of the dam site in SW¼ sec. 31, T. 12 N., R. 6 E. If a dam were to be built up to this altitude its height for the middle section C-D, figure 18, would be about 150 feet above foundation. However, construction to this altitude is impracticable for the physical reason that considerable seepage would probably take place through the ridge making the saddle, for its thickness at this elevation is only about 1,000 feet; and for the economic and social reasons that it is inadvisable to flood extensively the broad flat at the junction of Cowlitz and Cispus Rivers that is known locally as "The Big Bottom." These objections are reduced considerably by contemplating construction to altitude 850, probably the maximum allowable for this side. A dam to this altitude would stand about 100 feet above foundation.

Considerations of economy of height of dam favor a section at the head of Cowlitz Falls, figure 18, E-F, but regard for a minimum cross-sectional area indicates a section downstream where the valley is narrower, A-B or C-D. Since the total difference in elevation on the river surface for a dam above or below the falls is only about 13 feet, the economy of the downstream sections is evident for their length is approximately half that of E-F atthe head of the falls.

Character and depth of valley fill

Active alluvium in the stream bed through the dam site is thin and superficial, and consists of sand and gravels in transit.

Inactive alluvium consists of very coarse boulders in a matrix of coarse sand and gravel, and upstream from the dam site caps the bench above the river in beds up to 20 feet thick. Locally these beds rest upon unsorted silt, sand, and gravel, with only an occasional boulder, that appear to be reworked deposits of glacial outwash.

For the most part, however, the glacial outwash, consisting chiefly of gravels, occupies the higher portions of the dam site. A good deal of pumiceous material is mixed with the drift, and imparts a lightness to the soil that is probably responsible for its rather permeable character.

Country rock

Bedrock at Cowlitz Falls consists of lava flows and tuff thought to be assignable to the Keechelus andesite series of Miocene age. Only about 200-300 feet of beds are represented, and their stratigraphic position within the Keechelus series is not known. Owing to the direction of dip, the oldest rocks crop out at the west end of the dam site and one goes upward stratigraphically, or into younger rocks, as one moves upstream. With few exceptions, all of the beds are cut by a series of andesite dikes. The lithology of the various layers is summarized in the following partial section, and more complete descriptions of each unit are then given with reference to their effect on the locality as a dam site. The alphabetical designation of the units has only local significance, and does not indicate any correlation or relationship with beds similarly lettered at other dam sites on Cowlitz River.

Partial section of the Keechelus andesite series at Cowlitz Falls dam site

Unit	Lithology	Thickness (Feet)
	Top not seen	
F	Andesite, drab gray	10-15+
E	Andesite porphyry, gray-green	40-150+
D	Andesite, drab green	35-70
C	Andesite, bluish-gray	48
B	Tuff and agglomerate, bentonitic, gray-green to buff	20
A	Andesite, gray	20+
	Total	172-317

Unit A. - The lowest member of the Keechelus series to crop out at Cowlitz Falls dam site is a thick, massive flow of dense, gray andesite. In many respects it is much like Unit D, but grayer. Exposures occur at the west end of the dam site, just beyond the boundary of the map, and for this reason the rock will not be described in detail. The partial thickness given in the composite section is only 20 feet, but the total thickness of the flow may be two or three times as great.

Unit B. - Immediately east of Unit A, Cowlitz River is crossed by a comparatively thin, nonresistant layer that is expressed topographically by shallow re-entrants in the low but steep banks of the river. Exposures are incomplete, the most extensive being on the right bank under a rubble of large, angular talus blocks that have descended from the enclosing slopes of hard lavas that flank the trough. South, on the left bank, the depression is almost wholly covered with rounded stream cobbles residual from the older, inactive alluvium. Search through the debris on the north bank reveals soft, thinly-bedded, poorly consolidated tuff and agglomerate, with some bentonite resting sharply but conformably upon a local area of dip slope on the basal andesite. Colors vary from bright green, gray-green to buff, with the somber shades predominant. The agglomeratic facies is confined to the lower part of the unit, and consists of subrounded cobbles of reddish andesite, 1 to 3 inches in diameter, in a dull-green matrix of finer grain. Thickness estimates of the bed based upon width of outcrop and amount of dip indicate a total of about 20 feet.

Unit B must be regarded as a weak element, both from the viewpoint of geology and construction engineering. The crushing strength of the material is variable, being higher for the agglomerate than for the tuff, and the latter, together with the bentonite, will soften and disintegrate, or swell, when wet. Fortunately, it is not involved in any prospective dam section, but it may affect some of the appurtenant works if care is not exercisedto site them properly.

Unit C. - This unit consists of an andesite flow of somewhat variable composition in that within its limits masses of soft rock appear to be enclosed by harder facies, giving rise to an elliptical structure that is sometimes developed upon a comparatively large scale. The hard rock is illustrated typically by a specimen taken from near the top of the flow at Sta. 1. At this place the rock is a very dense, dark gray to bluish-gray lava that weathers dark limonitic brown. Except for the thin (1/8 to 1/4 inch) crusts of weathered rock, all of this facies is hard and tough and apparently fresh, and breaks with a hackly conchoidal fracture. Close examination of freshly broken surfaces shows only occasional cleavage faces of a dark mineral that is probably feldspar. Some of the rock is cut by very thin, widely-spaced quartz veinlets, and cavity fillings of red iron oxide and a dull green mineral seem to be associated with these veinlets. Small blebs of bluish-white chalcedony are also present.

Under the microscope this rock appears definitely porphyritic in texture, and nowhere near so fresh or unaltered as field study indicates. Small phenocrysts of plagioclase, seldom exceeding 1.0 mm. in length, and of intermediate composition, make 30-35 percent of the rock. Most of them are dusty with minute decomposition products, probably minerals of the epidote group, and some have been replaced partially by calcite. No large phenocrysts of ferromagnesian minerals were observed, but pseudomorphs of chlorite and calcite after pyroxene are undoubtedly present. The groundmass consists of numerous but much smaller plagioclase needles, seldom exceeding lengths of 0.15 mm., that are intergrown with scaly aggregates of greenish-yellow minerals that probably include both epidote and serpentine. Some rude parallelism or alignment of the needles is discernible, but there is no well-developed trachitic structure. Small opaque grains of iron oxide are scattered heavily throughout the groundmass, and contribute to the dark color of the rock.

The groundmass also contains numerous grains of secondary calcite, some intergrown with chlorite and chalcedony in cavities. Other grains, and by far the larger part, apparently have replaced some of the ferromagnesian minerals of the groundmass. Crude estimates by eye indicate that between 5 and 10 percent of the rock may be calcite. After observing calcite in thin section, tests on hand specimens with 10 percent HCl yielded vigorous effervescence. Although a readily soluble mineral, very little or none of the calcite is so arranged as to develop connected porosity or permeability, if it should happen to be dissolved. Hence, the chief effect of the calcite is to contribute an element of softness to the rock. Other than this, the hard andesite has no defects that make it unsuitable for inclusion in a dam site.

At the top of the flow this hard rock grades upward through an irregular contact into a 6-foot layer of agglomerate whose top is marked by the smooth plane of the base of Unit D. This agglomerate is softer than the enclosing lavas, and has a rough, hackly surface, dull green in color where fresh and dull red where weathered. The matrix is granular but dense and embeds small angular fragments of red-weathering andesite. Chalcedony is present in accessory amounts. In the left bank of the river opposite Sta. 1 is a good exposure of an apparently similar mass of agglomerate wholly enclosed by hard lava. This body has a length of about 80 feet and a thickness of 20 feet, and the sheeting of the enclosing rock conforms to its boundaries. Such a feature occupies approximately half of the thickness of the unit, whose thickness at Sta. 1, including the upper agglomerate, is about 48 feet.

Unit D. - The lower step of Cowlitz Falls is made by the middle portion of an andesite flow that crosses the river near the center of the dam site area. In the sequence of rock units studied at this locality this flow comes fourth from the bottom, which makes it Unit D. This rock is a fairly hard, tough, dark gray to bluish-or greenish-gray andesite, with an earthy lusterless surface. This somber aspect is relieved along some of the joints by thin bands of bright red weathered rock, and throughout the mass there are numerous bluish-white amygdaloidal blebs of finely banded chalcedony, white to flesh-colored calcite, and close inspection shows gray-green blebs of some green mineral, probably chlorite. Evidently the rock once possessed a considerable degree of vesicularity, but most of the cavities are now occupied by amygdaloidal minerals.

Width of outcrop and amount of dip indicates that Unit D has a thickness of about 70 feet at the west end of the map area, and only about 40 feet near its passage of the river near the lower falls. The base is well exposed at Sta. 1, and the top portion is exposed equally well at Sta. 2, a short distance upstream. At this place the upper surface appears to be rather uniform or plane, but occasionally it is undulating. Upon it, separating it from the overlying flow, is a lenticular layer of agglomerate about 4½ feet thick. Locally it is absent, but whether this due to erosion or to depositional irregularities is unknown. The rock is soft and locally the bed above it may be undercut for 5 or 6 feet. Texture is fine-grained and bedding is thin and laminated. The finer parts are tuffaceous, with only an occasional angular block parallel to the bedding. Originally the color was gray or gray-green, but weathering has produced some red color. In several respects the relations of this bed to Units D and E are similar to the agglomerate at the top of Unit C. Contacts with the enclosing flows are tight.

Microscopic examination of specimens from the middle part of Unit D shows a very fine-grained porphyritic rock with vesicular structure that has undergone moderate alteration. Phenocrysts of plagioclse, rarely exceeding 1.0 mm. in length, make about 25-30 percent of the mass. Most of the grains are of intermediate composition - andesine, labradorite - and are so thoroughly dusted with decomposition products that they are more easily visible in plain than polarised light. The alteration products are chiefly saussurite and calcite. Phenocrysts of fresh ferromagnesian minerals do not occur, all of them apparently having been replaced by serpentine. Groundmass material consists of a closely felted mass of very small (0.10-0.15 mm.) needles of plagioclase intergrown with scaly aggregates of yellowish-green to green minerals that include epidote, chlorite and possibly serpentine (antigorite), and the whole is heavily peppered with small opaque grains of iron oxides. Small grains of calcite are also present.

One of the most interesting features of the rock are the vesicles and the amygdaloidal minerals that fill them. Roughly, the cavities occupy about 10 percent of the area of any surface. Most of them are small; none observed exceeded 1.5 by 4.0 mm., and they occur separately so that connected porosity or permeability will not develop if their fillings should be dissolved. In general, the sequence of the filling is: (1) a thin outer layer of calcite. Occasionally, however, calcite deposition continued after the other minerals had been deposited and flamboyant crystals burst through them toward the center of the vesicle, (2) a somewhat wider band of brownish-green mineral with finely banded botryoidal structures. These become smaller toward the base of the layer, and with decrease in size of particle the substance tends to become isotropic. Where interference colors can be seen, however, the birefringence is of medium order. Exact identification of this mineral has not been made, but it may be chlorophaeite, a member of the chlorite group that occurs as cavity fillings in basic igneous rocks. In the smaller vesicles this mineral occupies the remaining volume of the cavity, (3) quartz occupies the central part of the larger cavities, and may be intergrown with calcite if the latter has broken through the band of chlorophaeite (?).

In summary, although somewhat softer than the enclosing flows and containing possibly 5 to 10 percent of calcite, the rock of Unit D is strong and tough and fully capable of supporting any structure that may be built upon it at this site.

Unit E. - More than half of the area of the dam site, the central and east end in particular, is occupied by a thick, massive flow of gray-green andesite porphyry that makes the upper bench of Cowlitz Falls, and is referred to as Unit E. The base is well exposed at Sta. 2, and consists of an agglomerate 4 or 5 feet thick. Its matrix is a soft, dense, red-weathering material that embeds rounded boulders, usually not exceeding 6 to 8 inches in diameter, of a harder rock. The main body of the flow consists of hard, homogeneous porphyry that yields uniformly to river scour, and many potholes have been cut into it. Perhaps the most conspicuous feature of the rock is the numerous large, grey, glassy phenocrysts of zoned plagioclase. Some of them are 8.0 mm. long, and they may make about 40 percent of the rock. Their matrix is a dense aphanitic material, gray to gray-green in color, with a dull luster, and breaking with a rough fracture. It is less resistant to weathering than the phenocrysts, and the latter frequently stand in relief on surfaces stained with hematite.

Under the microscope the porphyritic character of the rock is as apparent as in hand specimen. Some of the large phenocrysts have rounded outlines due to resorbtion by the matrix, but corrosion has not proceeded far. In comparison with the underlying flows the plagioclase is remarkably fresh, only the outer margins showing decomposition into calcite, sericite, and so on. Most of it appears to be labradorite. In great contrast to the phenocrysts is the plagioclse of the groundmass. Innumerable small needles averaging about 0.15 mm. in length are intergrown to make a densely felted mass that is only relieved by the chlorite, sericite that gives the rock its greenish color, and minor amounts of calcite.

On the left bank of the river, south of the upper falls and extending southeast toward B.M. 807, Unit E appears to be overlain by another flow of distinctly different character. If this be the top of the flow, dip components projected east from B.M. 783 indicate a thickness of only 40 feet. However, if the dip at the upper falls is the same as in the middle of the map area, the higher flow, Unit F, should go under the river; and, if it is less, Unit F should crop out on the right bank. However, it was not observed there. North of B.M. 786 Unit E appears to have a thickness of at least 150 feet, with the top concealed by glacial outwash. These anomalous conditions may result from a change in dip, original variations in thickness, variations in thickness due to erosion, or to any combination of these conditions. The area examined was too limited to determine the prevailing factor.

In spite of these irregularities, Unit E will make a strong firm foundation for a dam.

Unit F. - At Sta. 4 and vicinity a finely granular drab gray andesite carrying a few small crystals of pyroxene rests sharply upon Unit E. The contact is exposed only over a length of about 10 feet, but is very distinct because Unit E maintains its characteristic coarse porphyritic texture up to the boundary. There is no intervening bed of agglomerate. However, the lower 3 feet of the overlying andesite is brecciated and fractured into a tightly bound mass of angular and subangular blocks. Between Sta. 4 and B.M. 807 the surface of this flow has been scoured thoroughly by some higher stage of the river. Relief upon it amounts to 2 or 3 feet, and the rock is very rough, jagged and irregular due to the emergence of many small closely spaced joints. Numerous small closed depressions capable of holding water are dry, suggesting high permeability through the fractures.

The base of this flow crops out at altitude 795 and the highest altitude at which it was observed is 815, with the top not visible. Some of this apparent thickness may be due to dip, but it is at least 15 feet thick. Its anomalous relations with Unit E have been referred to under the description of that unit. Appearances at Sta. 4 suggest that it is the highest stratigraphic unit in the dam site, but structural conditions indicate that much of Unit E in the right bank occurs at higher altitudes. Fortunately, Unit F is not involved in the sections likely to be considered for a dam.

Intrusive rocks. - A series of dikes with a general northeast trend cut units C, D, and E, at Cowlitz Falls. Six of them are indicated with somewhat exaggerated width in figure 17, and more may be present, for they are difficult to see because of their lack of color contrast with the rocks they cut. Most thicknesses are between 2 and 3 feet. Attitude is vertical, and contacts are usually sharp and tight.

The group in the vicinity of B.K. 786 is fairly typical. In hand specimen the rock is gray to dull greenish-gray, weathering brownish, with dull luster. Some surfaces show a tendency toward a satiny finish due to innumerable small crystal faces too small to identify. The texture is dense, but close inspection with a hand lens shows numerous small stubby black grains, and there are also a few rounded amygdaloidal minerals.

Microscopic examination shows a very fine-grained rock with a pronounced trachitic structure and numerous vesicles whose longer axes parallel the mineral grains. The bulk of the rock consists of plagioclase needles seldom exceeding 0.30 mm. long intergrown with chlorite and secondary calcite. Phenocrysts are few and consist of plagioclase 2.50 mm. long so thoroughly replaced by calcite, sericite, and chlorite that they are difficult to distinguish under polarized light. Phenocrysts of ferromagnesian minerals were not observed, but are probably represented by calcite pseudomorphs. Amygdaloidal minerals make up about 10 percent of the rock and consist chiefly of radiating and fibrous crusts of chlorite, with minor calcite and quartz. Considering the rock as a whole, plagioclase makes about 50-55 percent, chlorite 30-35 percent, calcite 10 percent, accessory minerals 5 percent.

The dike through Sta. 1 strikes more to the east than those upstream but is similar in attitude and thickness. In hand specimen the rock is a hard, dark gray aphanite that appears rather fresh. Weathered surfaces are thin and brown, while freshly broken surfaces glisten with a few small crystal faces. Fracture is splintery and subconchoidal. Under the microscope the porphyritic texture is conspicuous, with relatively large phenocrysts of fresh, clear plagioclase making about 25 percent of the rock, with a few small scattered grains of pyroxene and epidote. The groundmass is a felted mass of plagioclase and pyroxene with few alteration products.

These dike rocks are as strong and fresh as the flows, and do not detract from their strength. On the contrary, they add to it by binding the layers of the flows into a single structural unit.

Structural features

Dip of beds. - A dip of about 20°, N. 45° E., was observed on Unit A on the right bank of the river. Mapping on the top of Unit C indicates a dip of 20° 28' NE, with a strike of N. 72° 30' W. At Sta. 2 a dip of about 35°, N. 45° E., was observed on top of the agglomerate separating flows D and E, but is not regarded as reliable because of the irregularity of the agglomerate. Dips could not be observed within the dam site area east of B.M. 786. However, about 1,100 feet upstream from B.M. 786 exposures of andesite and agglomerate have an apparently horizontal attitude, and a short distance farther upstream (southeast) the dip is apparently 4° or 5° southeast, but this may be a component of the northeast dip at the dam site.

Joints. - General considerations of the joint problem in volcanic rocks at dam sites have been discussed in preceding sections of this report (pp. 115-122). The procedure of describing joints bed by bed was also applied at Cowlitz Falls.

Unit C appears to be cut by at least five sets of joints. Of these the "bedding" joints are the most prominent and result in a rude sheeting spaced at intervals of about 6 feet, that parallels the top and base of the flow. They are the only type of cooling joint observed. All of the others are of tectonic origin. One well-developed set strikes N. 52° W., and dips 60° SW. These fractures are persistent and are usually spaced at intervals of about 3 feet. Another set of sharp, clean persistent fractures strikes N. 28° E., and dips 65° NW. In the vicinity of Sta. 1 this set has been cut by the joints that control the line of dike intrusion, N. 66° E., vertical. More infrequent than any of these are clean, sharp nonpersistent joints striking N. 15° W., with a dip of 45° NE.

Unit D is cut by three sets of joints. All of them are tightly closed, irregular and nonpersistent. Locally individual surfaces are smooth, but on the whole, they are rough and hackly. The principal set in this bed is vertical and strikes N. 52° E., paralleling the dikes. Spacing is about 2 feet. Their conjugate set, cutting the dikes, strikes N. 65° - 70° W., and dips 85° SW. Spacing is at intervals of about 6 feet. Less well-developed, to the point of being indistinct, are a poorly developed set striking N. 3° E., with dip to the west.

The relationships of joints to dikes are best displayed in Unit E, in the vicinity of B.M. 786. The dikes here vary in strike from N. 55° - 65° E., to N. 35° E., and are vertical. On some of the joints the strike is undulatory. Paralleling those striking more to the east are nonpersistent fractures spaced at intervals of 4 to 6 feet. All of them are tightly closed, and some have been sealed with thin veinlets of chalcedony. Complementary with these is another strong, sharp, persistent set striking N. 50° W. Dip varies from 85° SW through vertical to 75° NE. Spacing averages about 2 feet. Movements of small but variable amounts have taken place along some of these joints, and are particularly noticeable where the dikes have been offset. Usually the horizontal displacement does not exceed 3 feet. A few dikes exhibit evidence of tensional stress along their strike before they were offset. A third set of infrequent occurrence strikes N. 74° W., dips 85° S., and cuts the set that offsets the dikes.

At Sta. 3, on the left bank near the west margin of the map, a small vertical fault strikes N. 35° E. The maximum displacement observable is about 7 feet, with downthrow to the southeast. This fault does not appear to cross the river, and since on the basis of strike it seems to fall into the joint set controlling the trend of the dikes it is mentioned here rather than separately under the heading of Faults.

In summary, the master joints at Cowlitz Falls are a conjugate pair, one trending N. 35° - 65° E., and controlling the dike intrusions, and the other striking N. 50° - 52° W., and sometimes offsetting the dikes by a few feet. These, in conjunction with the others, cut the rocks into rhombohedral blocks of variable dimensions, but probably averaging 3 or 4 feet on a side.

Ground-water conditions

Surface indications of ground water were negligible at the time the dam site was visited, and were confined to a few small seeps from detrital materials where in contact with bedrock.

Permeability

Most of the flow contacts, vesicularity and joints in the rocks at Cowlitz Falls dam site have had a previous permeability, but are now sealed thoroughly by chalcedony or other secondary or amygdaloidal minerals. The only flow observed to have a high permeability is Unit A, which is not involved in any dam section. Hence, under the conditions of a low-head dam, permeability of bedrock will be a minor factor. The coefficient of permeability (K) for the site as a whole will probably be between 5×10^{-8} and 10×10^{-8} feet per second.

Dam sections

Three cross-sectional profiles of Cowlitz Falls dam site are shown on figure 18. Section A-B may be passed over because of the weak foundation condition resulting from the presence of agglomerate bed B, and the unknown character of the section below Unit A. Section E-F may be condemned on geologic grounds because of the unsatisfactory character of Unit A. By this process of elimination, section C-D remains as the best section available at this site.

At altitude 800 the width of open valley on section C-D is about 265 feet, but the distance between the bedrock walls, or the length of crest of dam would be about 280 feet. The additional length is through a thin mantle of glacial outwash on the left bank. Maximum height of dam above foundation to altitude 800 will be 55 or 60 feet. Cross-sectional area of the open valley is about 4,100 square feet, and the total cross-sectional area, including the filled and submerged portions, is about 6,400 square feet.

For a dam with crest at altitude 850 the width of open valley is about 430 feet, and the distance between the rock walls about 475 feet. This additional length is through glacial outwash on both banks. Cross-sectional area of the open valley is about 21,200 square feet, and the total cross-sectional area about 24,200 square feet.

Foundation consists of the tough, partially altered andesite of Unit D; and there is at least 80 feet of sound rock to the structurally weak agglomerate of Unit B. Unit D, overlain by the thin agglomeratic base of Unit E, makes the left abutment; but all of the right abutment is in the andesite porphyry of Unit E. Because of the thickness and attitude of this flow (or flows) the right abutment is considered to have somewhat greater bearing power than the left abutment, which consists of thinner beds and dips into the valley. In all probability the agglomerate at the base of Unit E will have to be removed from the left abutment.

For a high dam, crest altitude 850, the most economical spillway section will probably be over the left abutment; but for a dam with crest at altitude 800, the best spillway is probably over the right abutment.

Geology of reservoir area

The reservoir of Cowlitz Falls dam site is comparatively small, and its capacity is very limited. Since the dam is intended for diversion rather than storage this lack is not a critical matter. With pool level at altitude 800 water will back up only about 2,500 feet, or to mile 89.15. Within this small area geologic problems are essentially the same as those within the dam site, and there is no possibility of seepage from the reservoir. This condition prevails up to about altitude 820. However, with pool level at altitude 850, probably the maximum possible, water will back up Cowlitz River for about 4.4 miles or to mile 93.1, and up Cispus River to mile 1.2.

Comparatively little is known about the geology of this basin. Andesites of the Keechelus series make up the bedrock, and they are probably cut by numerous dikes, as they are at the dam site and other localities downstream. Heavy deposits of Pleistocene drift and outwash rest unconformably upon the Tertiary lavas and intrusives.

In the preceding section describing Cowlitz River valley at Cowlitz Falls (p. 246) the statement was made that the original trunk valley of Cowlitz River extended westward from the center of sec. 31, T. 12 N., R. 6 E., and that this ancient valley, now buried, lies about a mile north of Cowlitz Falls dam site. The upstream extension of this old, deeply filled valley underlies the enlarged reservoir area of Cowlitz Falls dam site, and perhaps is its most critical geologic feature.

Reference to Sheet No. 3, Plan and Profile of the Cowlitz River, suggests that there is a possibility for seepage from the reservoir through the permeable surficial fill of the buried valley unless there is some impermeable condition extending northward from Hill 1502 to the south-projecting spur capped by a small mound rising just above altitude 980. The argument for the existence of the buried valley precludes the existence of a buried rock ridge under the narrow, flat-topped saddle so well defined by the opposed 900-foot contours. Hence, if an impermeable barrier exists it must be of sedimentary origin and related to the valley fill. Reservoir waters will have access to the fill materials as they will be raised approximately 15 feet higher than the present stream surface against the bluff cut into glacial sediments that extends in a N-S direction through the south half of section 31.

If seepage can occur beneath this saddle when water is raised against it to altitude 850, topographic and hydraulic conditions suggest that its outlet might be under the saddle in the ridge on the right bank of the river near W¼ cor. sec. 6, T. 11 N., R. 6 E. River altitude just south of this locality is about 767. Ground surface in the saddle above the river stands slightly higher than altitude 880 feet. One seismic measurement was made in this area. Exact location was 250 feet east and 2,100 feet south of the northwest corner of section 6. From the results, Mr. Shepard calculated that bedrock is 96 feet below the ground surface or about altitude 785 feet. Consequently, with pool level at 850 feet, the hydraulic gradient through the outwash deposits would be about 1 on 77. Even though only 15 feet of water were raised against the fill, seepage could take place through a permeable fill on this gradient for the path of percolation is only 5,000 feet in length.

The remaining possibility of leakage is that percolation might occur along the axis of the buried valley, the water re-entering the river somewhere in the vicinity of the elbow in SE¼ sec. 34, T. 12 N., R. 5 E., where the altitude of the river surface is 695, or near mile 85, near the center of sec. 3, T. 11 N., R. 5 E., where the altitude of the river surface is 715. In either case, the length of the path of percolation is about 17,000 feet, and the hydraulic gradient to the locality first mentioned is about 1 on 110. Seepage along this route, however, will probably be negligible, because the width of the divide at pool level elevation of 850 feet is approximately 7,000 feet.

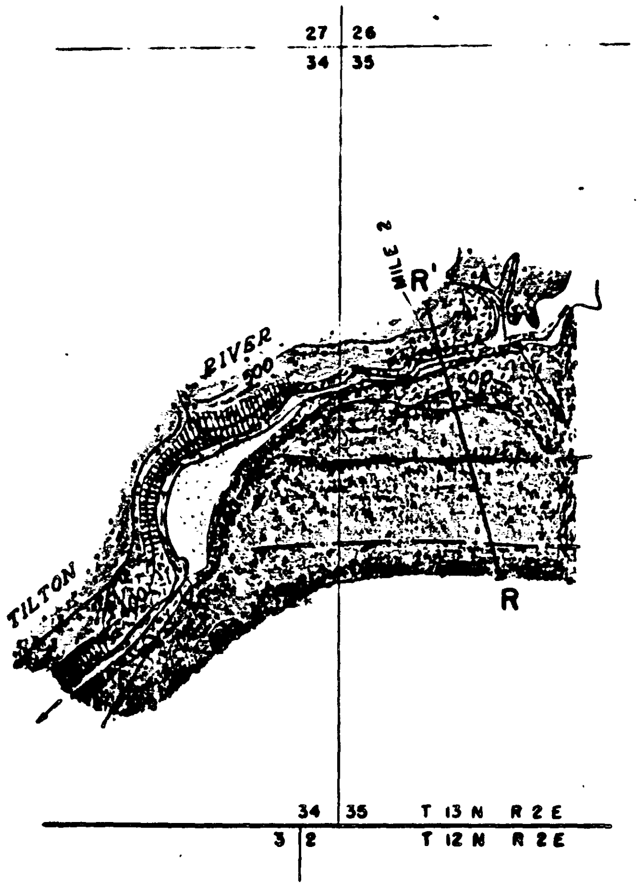
Summary and Recommendations

Cowlitz Falls dam site is suitable in every way for a relatively low diversion dam. Choice of section is C-D, figure 17. Rock foundation is at shallow depth.

If the pool level is restricted to altitude 800 feet, all conditions affecting construction are comparatively simple, and the problem of leakage from the reservoir does not exist. Such a dam would stand about 50 feet above rock foundation and would have a crest length of about 290 feet.

If social and economic conditions permit, the pool level might be raised to altitude 850 feet. The dam would stand 100 feet above rock foundation and would have a crest length of about 475 feet.

Under these conditions there would undoubtedly be leakage from the reservoir through alluvium and glacial deposits filling the preglacial valley of Cowlitz River. Hence, if the enlarged project is ever seriously considered, sufficient data should be obtained to estimate the quantity of seepage loss and the seepage velocities developed in the more permeable beds. This would involve exploration, probably by drilling, of the saddle in section 31, T. 12 N., R. 6 E., to determine the depth to bedrock in the preglacial valley and the character and arrangement of the fill materials. The saddle near the W¼ corner of section 6, T. 11 N., R. 6 E., should also be drilled to determine the character and arrangement of the glacial deposits overlying bedrock.



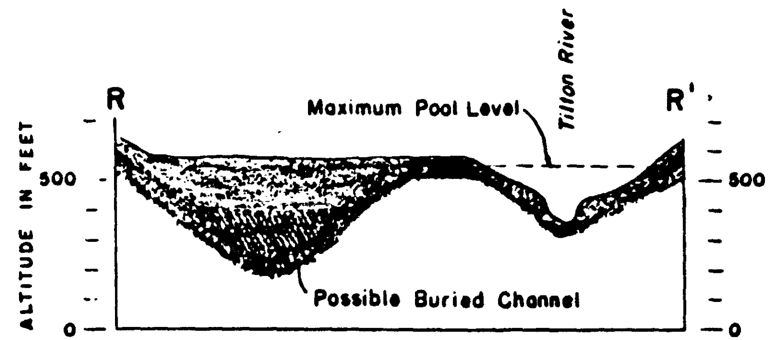
RECONNAISSANCE GEOLOGIC MAP

SCALE: 1/12,000

250 0 1000 2000 3000 FEET

TILTON DAM SITE

W. SEC. 35, T. 13 N., R. 2 E.
LEWIS COUNTY, WASHINGTON



GEOLOGIC CROSS SECTION

SCALE: 1/6,000

250 0 500 1000 1500 2000 FEET

EXPLANATION

RECENT — ALLUVIUM, ACTIVE

PLEISTOCENE — YOUNGER DRIFT, OUTWASH, GRAVELS AND SANDS

OLDER DRIFT, UNDIFFERENTIATED; TILL, OUTWASH SANDS AND GRAVELS, LACUSTRINE SILTS AND SANDS

MIOCENE — KEECHELUS (?) ANDESITE SERIES, UNDIFFERENTIATED

R R' — LINE OF CROSS SECTION

GLACIAL OR PRE-GLACIAL VALLEY

GEOLOGY BY A. F. BATEMAN, JR.

J.M.S.

270a

TILTON DAM SITE

Location

The proposed dam site is in a box-like rock canyon on the Tilton River, 2.0 miles above its mouth, in NE¼SE¼ sec. 34 and SW¼NW¼ sec. 35, T. 13 N., R. 2 E., W.M., Lewis County, Washington. A portion of the river map, 64/ which is on a scale of 1:24,000 with a 20-foot contour interval, was enlarged to a scale of 1:12,000 (1 inch equals 1,000 feet) for use as a base for the accompanying geologic map, figure 19. For the sake of clarity only 100 foot contours are shown.

64/ Plan and profile of Cowlitz River, mile 42 to mile 97, Cispus River to mile 32, and Tilton River to mile 19, Washington, Sheet 1.

Accessibility

A graveled road leaves State Highway No. 5 at Silver Creek, runs eastward along the north bank of the Cowlitz River to Harmony bridge and thence southward to Mossyrock where it rejoins State Highway No. 5. Near the left abutment of a bridge over which this road crosses the Tilton River, is a logging road that follows up the left bank of the Tilton River for 1.17 miles and ends at the lower margin of the area covered by the dam site map. The right abutment of the dam site can be reached only on foot. It is a distance of about 1¼ miles from the graveled road to the proposed axis.

Purpose of project

Water power development is the primary purpose for a dam at this site. Estimates of water available are:

Drainage area, 158 sq. mi.	Total for basin	Per sq. mi.
Runoff, average rate	782 second-feet	4.95 second-feet
Runoff, average annual total	566,300 acre-feet	

A high dam at Mayfield site would back water over this site, thus reducing the head available for the production of power. If the pool level in Mayfield reservoir stood at an altitude of 400 feet, backwater over Tilton site would have a depth of approximately 25 feet.

Field work

A. F. Bateman, Jr., made a geologic reconnaissance of the left abutment of this site on April 21, 1948. The right abutment was not visited, but was observed at short range from the opposite bank. Rock exposed in the box canyon could not be examined because of high water.

Catchment area

Drainage area of the Tilton River basin above this site is approximately 158 sq. mi. Average discharge at a gaging station in SW¼ sec. 26, T. 13 N., R. 2 E., W.M., about three-fourths of a mile upstream from the dam site and about 1,000 feet downstream from the mouth of Cinnabar Creek, for the years 1942 to 1946 inclusive is 782 second-feet. Maximum discharge of 9,850 second-feet for this period was recorded on November 23, 1942, and a minimum discharge of 66 second-feet on September 11, 12, 1944. No tributaries of any size enter the Tilton River between the gaging station and the dam site.

Stream gradient

Average gradient of the river through the dam site, as determined from sheet 1 of the river survey, is 14.5 feet per mile. In the reservoir, the stream gradient is 54 feet per mile for 3.5 miles to the point where stream bed reaches an altitude of 550 feet.

Valley profile

The Tilton River flows in a narrow, vertical-walled box canyon that has been cut into the bottom of a glaciated valley that has a typical rounded profile. A cross profile is shown on cross section R-R', figure 19. However, the river map from which the profile was made is on too small a scale to show clearly the narrow, box-like character of the inner gorge. From stream level, the rock walls rise vertically to narrow benches on either side at altitudes of 485 to 500 feet (Bar.). From this level, the left wall rises somewhat more gently to a flat bench about 1,000 feet wide at an altitude of 570 feet (Bar.). On its inner margin, the bench is 580 feet (Bar.), from which point the valley wall rises steeply to the top of a small conical hill about 800 feet in altitude. At the upstream margin of the bench, relationships between bedrock outcrops and outwash gravels of the Younger drift suggest that a buried channel lies beneath the bench. This channel has been sketched on cross section R-R', although drill holes will be required to prove its presence, to determine the altitude of its rock floor, and to establish the character of the materials filling it. The right bank slopes steeply from the narrow bench at 500 feet to a broad bench at about 650 feet that covers several square miles between the Tilton River and Mill Creek. A buried channel, possibly the preglacial channel of the Tilton River, may lie behind this abutment. Detailed geologic field work will be necessary to locate the course of this channel, if it is present, and drilling will no doubt be required to outline its cross sectional form and determine the character of materials filling it.

Apparent possible height of dam

On topographic ground, the maximum possible height of dam is limited by the bench behind the left abutment. Surface of this bench on its river side is at an altitude of 575 feet, or approximately 200 feet above stream level.

Character and depth of valley fill

At the dam site, the Tilton River flows on bedrock. Active alluvium consisting of boulders, gravel, and sand is thin, and during periods of high water is probably swept away except for the larger boulders. Above bedrock, the ground surface of both abutments is underlain by outwash gravels and sands of the Younger drift. Composition and arrangement of the materials filling the one or more buried gorges are unknown. However, the relationships of the various glacial deposits to the buried gorges of the Cowlitz River and the numerous occurrences of Shut-In glacial deposits throughout the Tilton River valley, suggest that the gorges are at least in part filled with Shut-In glacial deposits of the Older drift. About 1,000 feet downstream from cross section R-R', figure 19, these deposits are exposed along both banks of the Tilton River, ~~(See pl.)~~. Here they consist chiefly of glacial clays and silts with interbedded sands and occasional beds or masses of till.

Country rock

Bedrock at Tilton dam site is thought to belong to the Keechelus (?) andesite series, but its stratigraphic position within the Keechelus is unknown. About 190 feet of strata are exposed. Since high water prevented entrance into the canyon at river level, and time was insufficient and equipment inadequate to attempt scaling the canyon walls, rock in the box canyon was observed from the south rim only. From this vantage point, it appeared to be made up of a number of andesite or basalt flows. Agglomerate and tuff beds were not seen, but may be present. The flows appeared thick and massive. In the 110 foot cliff forming the right wall of the box canyon, only two flow contacts, separated by a massive flow about 25 feet thick, could be made out. Rock along these contacts was altered to a bright red. At the rim of the canyon, a hard, massive, dark greenish-gray andesite is exposed. In general, the rocks appear sufficiently hard and firm and the flows sufficiently thick and massive to furnish adequate foundation and abutments for a dam.

Structural features

Dip of beds. – Component dip on the flow contacts exposed in the box canyon is 14°, S. 75° W. To obtain a true dip, entrance must be made into the canyon.

Ground water conditions

Surface indications of ground water are confined to small seeps at the contact between bedrock and the overlying glacial deposits of the Younger drift. Movement of water is toward the river.

Permeability

For all practical purposes, bedrock is impermeable to seepage except along flow contacts, through vesicular zones in the lava, and along joints. A detailed examination of the rock exposed in both abutments would be necessary in order to make an estimate of the quantity of seepage through these features. Although the flow contacts were not examined at close range, one could see that a zone from one to two feet thick at the top of the underlying flow had been baked, oxidized and altered. In color, these zones are bright red to reddish-gray. They are probably rather permeable. On exposed rock surfaces, joints are spaced at intervals varying from a few inches to several feet. Most of them are tight, but some are open from 1/32 to 1/16 inches. At a short depth below the surface the joint openings are probably less, and seepage is probably rather small. The permeability of all of these features could be greatly reduced by pressure grouting.

Dam section

Detailed topography of the dam site area is needed to select the most economical dam section. However, from inspection in the field, it appears that a choice of section is limited to a short stretch of the canyon extending about 200 feet in either direction from cross section R-R', figure 19.

Abutments

The abutments, consisting of those portions of the valley wall above river surface, are characterized by massive flows of the Keechelus (?) andesite series. In the left abutment they are exposed from river surface to an altitude of 568 feet, and in the right abutment to a slightly higher altitude. At least two flow contacts have been distinguished in the right abutment. Their true dip is not known, but a component of the dip is downstream at a gentle angle. Bearing capacity of the two abutments is essentially equal, and probably adequate for a masonry dam of either gravity or arch type. However, before any conclusions are made, the thickness of rock supporting each abutment must be determined. Therefore it is imperative that the courses of the preglacial Tilton River and any other buried valleys in the vicinity of the dam site be established. Thickness of rock behind each abutment will also affect its permeability.

Foundation

The stream bed is relatively free of sand and gravel deposits, so their stripping will be a minor construction item. Rock in the valley floor is essentially the same as that exposed in the abutments.

Height and length of possible dam

Accurate figures on the height and length of a possible dam cannot be obtained without more detailed topography. However, data available indicates that the maximum reservoir elevation at an altitude of 575 feet can be obtained by a dam 200 feet above stream bed. Both abutments, however, would rest in part upon glacial deposits. Width of valley at this altitude is approximately 650 feet. Maximum height for a dam with both abutments on bedrock is about 175 feet above stream bed at an altitude of 550 feet. Width of valley at this altitude is about 575 feet, but after stripping, the length of dam would be 650 to 750 feet in length. Width of the box canyon whose rims are at 485 feet is estimated at 150 feet. The maximum reservoir level very likely will depend upon the character and arrangement of glacial deposits filling the buried valleys.

Reservoir area

The reservoir area is confined to a narrow valley. Backwater behind a dam 175 feet high would extend upstream for 3.4 miles. Area of the reservoir is estimated at 130 acres, and capacity from 7,500 to 10,000 acre-feet.

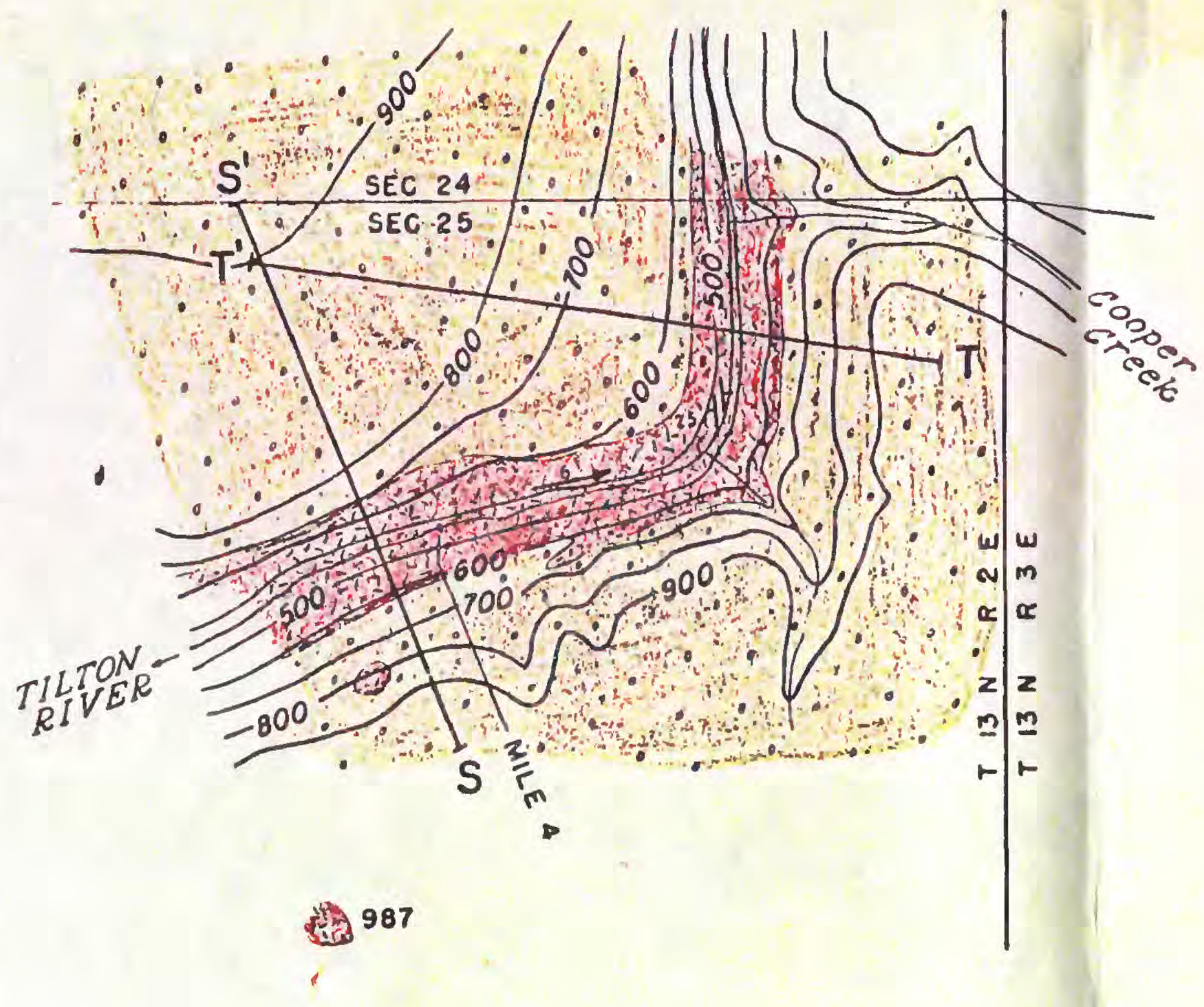
Little is known concerning the geology of the reservoir area, except that the lower three-fourths of a mile appears to be entirely underlain by outwash gravels and sands of the Younger drift. The preglacial Tilton valley, and possibly other filled valleys that are younger in age, no doubt intersect the present valley wall somewhere within this stretch. Hence, opportunities for leakage from the reservoir would be abundant. However, conclusions as to whether leakage would be of sufficient quantity to cause excessive reservoir loss or to result in conditions that are dangerous from the standpoint of stability must await further, more detailed geologic investigations, supplemented by drilling and permeability tests.

Conclusions

Geologic reconnaissance indicates that Tilton site is probably suitable for a masonry dam about 175 feet high. This would require a crest length of approximately 650 feet. The most critical factor, with respect to the safety and utility of a dam at this location, is leakage from the reservoir. It will require further, more detailed geologic investigation.

Storage capacity will be negligible. A dam at this site might well be considered as a supplemental power project, in case a dam is constructed at Bear Canyon site with sufficient reservoir capacity to control the stream. A dam at this site would flood Cooper Creek dam site, so that both could not be constructed.

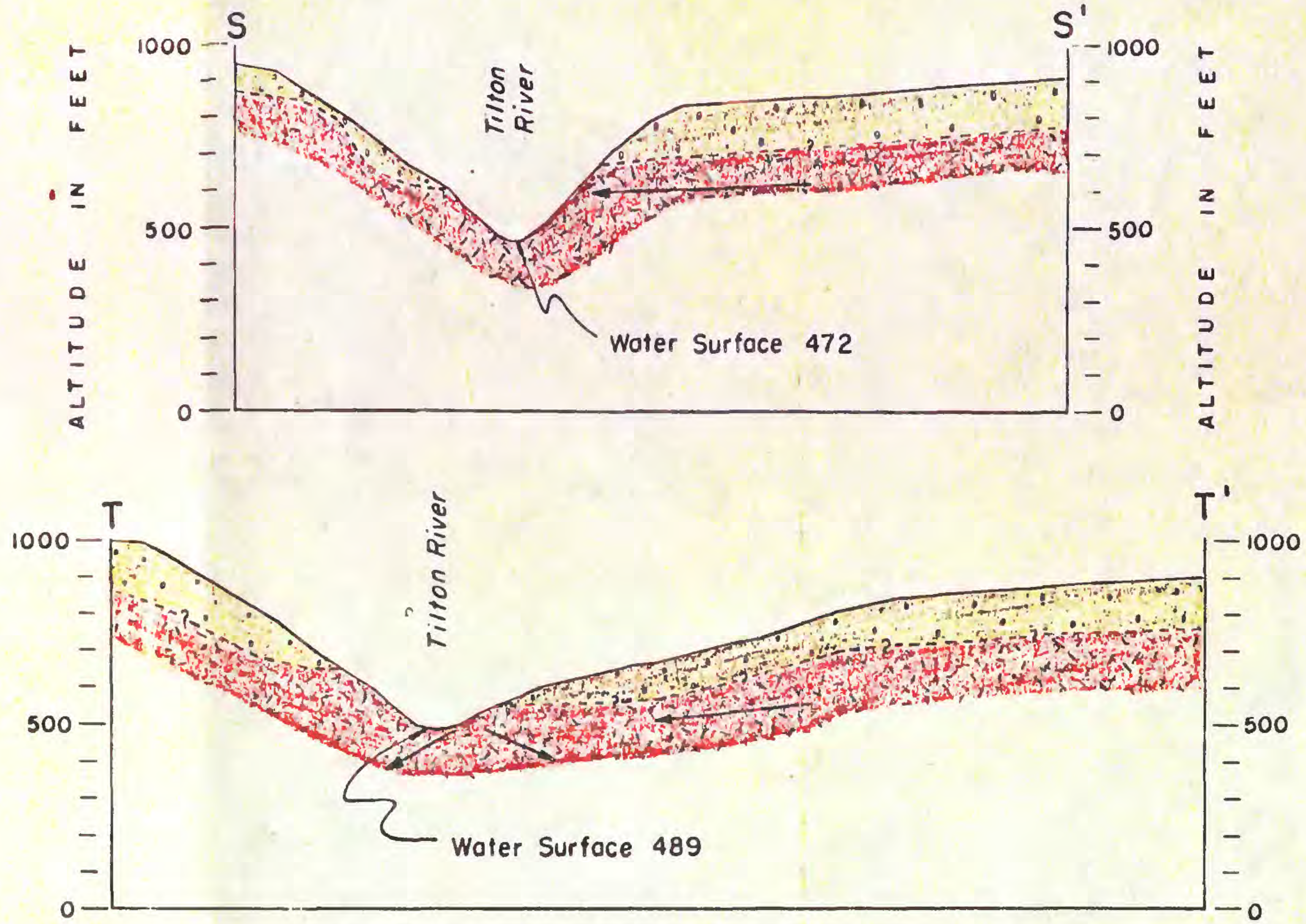
If a dam is built at Mayfield site on the Cowlitz River with pool level at an altitude of 420 feet, Tilton site will be flooded to a depth of about 45 feet, leaving a usable head for generating electric power of 130 feet.



RECONNAISSANCE GEOLOGIC MAP

SCALE: 1/12,000

250 0 1000 2000 3000 FEET



GEOLOGIC CROSS SECTIONS

SCALE: 1/6,000

250 0 500 1000 1500 2000 FEET

COOPER CREEK DAM SITE

NE 1/4 SEC. 25, T. 13 N., R. 2 E.
LEWIS COUNTY, WASHINGTON

EXPLANATION

PLEISTOCENE — YOUNGER DRIFT, OUTWASH, GRAVELS AND SANDS

MIOCENE — KEECHELUS (?) ANDESITE SERIES, UNDIFFERENTIATED

S — S' LINE OF CROSS SECTION

25 DIP AND STRIKE OF FORMATION

6 COMPONENT DIP OF FORMATION

GEOLOGY BY A. F. BATEMAN, JR.

J. M. S.

COOPER CREEK DAM SITE

Location

The proposed dam site is in a deep, narrow canyon on the Tilton River, 4.0 miles above its mouth, in NE¼ sec. 25, T. 13 N., R. 2 E., W.M., Lewis County, Washington. A section of the river map, 65/ scale 1:24,000 with 20-foot contour interval was photostatically enlarged to a scale of 1:12,000 (1 inch equals 1,000 feet) to serve as a base for the accompanying geologic map, figure 20. For the sake of clarity, only 100-foot contours are shown.

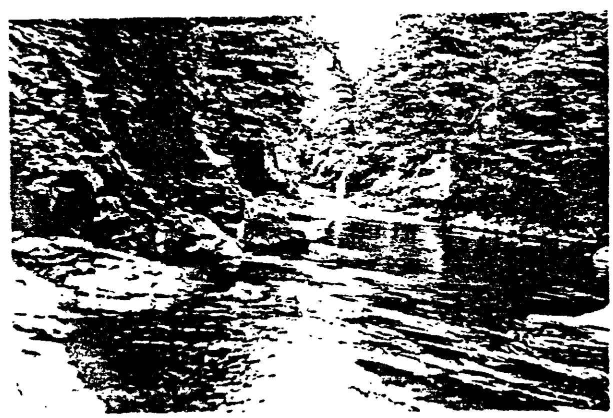
65/ Plan and profile of Cowlitz River, mile 42 to mile 97, Cispus River to mile 32, and Tilton River to mile 19, Washington, sheet 6.

Accessibility

State Highway No. 5K is an all weather, surfaced highway that runs from its junction with U. S. Highway No. 99 nine miles southeast of Chehalis to Morton. From a point on this highway 1.5 miles east of Cinnabar School, a logging road extends southward for 1.0 miles to an old sawmill setting on the brink of a canyon through which the Tilton River flows. From the sawmill, it is a hike of about a quarter of a mile to the upper end of the dam site area. The precipitous rock wall of the canyon makes descent to the river level rather difficult. The left abutment can be approached by auto over a graveled road that runs from the village of Harmony to the Kjesbu farm in NW¼SW¼ sec. 30, T. 13 N., R. 3 E., W.M. From the end of the road, a hike of about one mile brings one to the rim of the canyon overlooking the dam site. Descent to stream level is impossible on the left bank throughout most of the dam site area because of the vertical canyon wall. However, one can climb down to river level at the downstream edge of the area shown on the geologic map, figure 20 , and then make his way along the stream upstream as far as the right-angle bend in the river.

Purpose of project

Water-power development is the primary purpose of a dam at this site. Storage for flood control is a secondary or additional feature. Water available is slightly less than at Tilton dam site because Cinnabar Creek enters the Tilton River between the two sites. Discharge of Cinnabar Creek is unknown.



LOOKING UP ROCK CANYON AT COOPER CREEK DAM SITE FROM RIGHT BANK OF TILTON RIVER JUST UPSTREAM FROM RIGHT ANGLE BEND IN COURSE OF STREAM, FIGURE 20. NE$\frac{1}{4}$, NE$\frac{1}{4}$, SEC. 25, T.13 N.,R.2 E.

Cooper Creek enters Tilton River as waterfall on left wall of canyon. Rock extends approximately 200 feet above stream on left bank and 70 feet on right bank. Photograph by A.F. Bateman, Jr.

LOOKING UP CANYON AT COOPER CREEK DAM SITE FROM RIGHT BANK
OF TILTON RIVER AT WEST EDGE OF DAM SITE AREA
SE¼, NW¼ SEC. 25, T.13 N., R.2 E.

Photograph by A.F. Bateman, Jr.

Field work

A geologic reconnaissance of the right abutment of the site was made by A. F. Bateman, Jr., on August 2, 1948, and of the left abutment on August 5, 1948.

Catchment area

Drainage area of the Tilton River basin above this site is 150 square miles.

Stream gradient

Average gradient through the dam site is 44 feet per mile. In the reservoir area, the stream gradient is 31 feet per mile for 12 miles above the dam site, at which point the stream bed is at an altitude of 840 feet. The downstream portion of the reservoir that lies between the dam site and Bear Canyon dam site has the rather high gradient of 45 feet per mile.

Valley profile

Through Cooper Creek dam site for a distance of slightly more than half a mile, the Tilton River flows in a deep, narrow, rock-walled canyon (see pls. XVIII and IX). Profiles are shown on cross sections S-S' and T-T', figure 20. These profiles were made from the river map which is on too small a scale to show the box-like character of the canyon. From stream level, the right bank rises at a very steep angle for nearly 200 feet to a small bench cut into outwash gravels of the Younger drift at an altitude of 680 feet (Bar.). Top of bedrock exposed in the canyon wall is about 576 feet. Another small bench cut in gravel is at 800 feet and a considerably more extensive bench at 890 to 900 feet. (Bar. altitudes.) From this upper bench a morainal hill rises to about 1,040 feet. This hill is seperated from the valley wall by a flat bench area about three-quarters of a mile wide at an altitude of 940 to 980 feet. From this, the valley wall rises steeply to a high bench at 1,400 to 1,500 feet altitude, and from there, to the regional summit level of around 3,500 feet.

Between Cooper Creek and a point about 600 feet downstream from the right angle bend in the river, hereafter referred to as the "elbow", the left bank rises about 150 feet above the river in an almost vertical rock wall. Above this, the ground surface is underlain by glacial deposits and slopes steeply to an extensive bench at an altitude of 1,000 feet. Farther downstream the canyon wall is not so steep and is broken by a small bench at an altitude of 670 feet. The high bench at top of the canyon wall is at altitude 920.

Several hundred yards behind the canyon rim, a steep slope extends to a high bench at an altitude of 1,200 feet, underlain by outwash gravels.

Apparent possible height of dam

On the basis of topography, the maximum altitude to which a dam could be built is about 900 feet. Height above stream level is approximately 425 feet at cross section S-S', figure 20, and 410 feet at cross section T-T'.

Character and depth of valley fill

Throughout the dam site area, the Tilton River flows on rock. Active alluvium is confined to the stream channel and consists of scattered boulders, and small, isolated patches of gravels and sands varying in thickness from a few inches to a few feet. During high water stages of the stream, most of this alluvium is washed away, and new material deposited as flow decreases, thus lessening the load-carrying capacity of the stream.

Above bedrock on either side of the canyon, outwash gravels and sands of the Younger drift completely cover the area. The buried gorge behind the right abutment is no doubt filled in part by Shut-In glacial deposits of the Older drift. The local character of this material is unknown. Altitude of the contact between the Shut-In deposits and the overlying outwash gravels is also unknown. The character of this contact, however, would be much the same as in the Shut-In area, and has been discussed in the section on Shut-In dam site.

Country rock

Bedrock at Cooper Creek dam site is thought to belong to the Keechelus (?) andesite series. About 350 feet of strata consisting of andesitic and basaltic lava flows, with interbedded flow contact agglomerates, are present. Their stratigraphic position within the Keechelus (?) series is unknown. No detailed stratigraphic section was measured. The youngest rocks crop out at the east end of the dam site and progressively older rocks are exposed as one proceeds downstream. Lack of time, and the precipitous character of the canyon wall prevented more than a cursory examination of these rocks. There appeared to be three types separated by conspicuous flow contact zones.

Unit A. - The lowest unit is exposed along the floor of the canyon from the vicinity of cross section S-S', figure 20, upstream for about 1,000 feet. This unit is composed of a thick, massive, basalt flow or flows. Color of the rock is dark-gray with small flecks of white and colorless materials. The rock is hard, tough, and has a fresh appearance. Examination with a hand lens shows a very fine, dense, groundmass, enclosing small lath-shaped phenocrysts of plagioclase feldspar, small, rounded, colorless masses probably glass, and occasional dark-green to black, minute phenocrysts of a ferromagnesian mineral. At the top is a zone several feet thick that is vesicular and agglomeratic in character, and that is much broken and jointed. This zone has been softened somewhat and altered in color to a reddish-gray. Total thickness of Unit A is not known, but is probably in excess of 100 feet. Joints are rather widely spaced and on the surface are comparatively tight. This member is a strong unit with adequate bearing capacity for a dam foundation and abutments.

This rock has a rather distinctive appearance, and for this reason, it is believed to correspond to Unit C at Shut-In dam site.

Unit B. - Overlying Unit A is a flow, or series of flows, estimated to be 60 to 70 feet thick, that crops out along the stream bed in the vicinity of the elbow. Color of the rock is olive-gray to brownish-gray. It is tough and fairly hard. Under a hand lens, the groundmass appears fine-grained, but crystalline. It encloses many small brick-shaped to lath-shaped phenocrysts of plagioclase feldspar from one-sixteenth to one-eighth inch in length, occasional short, stubby phenocrysts of a dark-green ferromagnesian mineral up to one-fourth of an inch in length, and small blebs of glass. This unit may contain more than one flow, but no flow contacts were observed. Joints are rather closely spaced, but appear fairly tight. At the top is an agglomeratic zone about 2 feet thick that is considerably jointed and broken. This zone is somewhat softened, and in color has been altered to a reddish-gray. Bearing capacity of this unit is adequate for it to serve as a foundation and abutments for a dam, but its close jointing prevent its being considered strong from a structural standpoint.

Unit C. - Overlying Unit B is a ~~dark-gray, aphanitic~~ basalt that crops out along the stream bed starting at a point 200 feet upstream from the "elbow" and continuing for at least 400 feet farther. This rock has also been found in the left wall of the canyon at a maximum altitude of 670 feet in the bed of the small stream that enters the Tilton River at the "elbow". Consequently, this member has a total thickness of not less than 175 feet. Wherever seen, this rock has had a remarkably fresh and homogeneous appearance. It is very hard, dense, and breaks with a conchoidal fracture. Under a hand lens, no individual mineral grains can be distinguished except for a few minute, lath-shaped phenocrysts of plagioclase feldspar. Jointing is rather closely spaced, with intervals ranging from 6 to 18 inches. On the surface, joints are open one-sixteenth of an inch or less. Unit C has high bearing capacity, but because of its jointing could not be classed as strong structurally. However, it should be adequate as a foundation and abutments for a masonry dam.

Structural features

Dip of beds. - Downstream from the "elbow", the lava flows exposed in the walls of the canyon have a component dip of 6 to 10 degrees upstream in an approximate direction of N. 77° E. A true dip and strike have not been determined.

Folds. - About 200 feet upstream from the "elbow" on the right bank is a small anticline whose axis trends slightly west of north, figure 20. Beds in the west limb dip 25°, S. 85° W., and in the east limb, at a slightly steeper angle, approximately east. An accurate determination could not be obtained.

Joints. - Time was not sufficient for a study of the joints in the lava flows. However, in general, there appear to be 3 or 4 systems. One system roughly parallels the flow structure in the rock, and two to three diagonal systems intersect the first at high angles. Spacing of the joints varies with the rock. In the hard, brittle, fine-grained basalt, joint spacing is as close as 4 to 6 inches, forming blocks as small as 6 inches by 1 foot by 1 foot. In the other flows, spacing is greater, giving blocks of considerably greater volume. Most of the joints are open a fraction of an inch on the surface.

Ground water conditions

Surface indications of ground water consist of a series of small seeps at the contact between bedrock and the overlying glacial deposits. Movement of ground water appears to be from the valley walls toward the river.

Permeability

Since the rock composing the lava flows in the foundation and abutments of a dam at this site is practically impermeable, seepage will take place through joints, flow contacts, and vesicular zones at the top of individual flows. Upstream from the "elbow", stream flow is approximately parallel to the strike of the flows. Hence, maximum opportunity will be afforded for entrance of water into the flow contact zones and bedding joints of the right abutment. Downstream from the "elbow", stream flow is probably almost perpendicular to the strike of the bedding.

Data available on the spacing and width of joints are not sufficient to permit an estimate of permeability of the various rock units. In general, however, permeability due to joints will probably be considerably higher for Unit C than for Units A and B. Joint openings appear to be of sufficient size to permit pressure grouting.

During the reconnaissance, only two flow contacts were observed, namely, those between the three rock units. Each of these contacts, together with the vesicular lava at the top of the lower flow, forms a permeable zone from 2 to 4 feet thick. The lower zone passes beneath the floor of the valley downstream from the "elbow", but the upper zone is at or near stream level for several hundred feet above the "elbow." Hence, if this portion of the canyon is flooded, conditions will be created in the right abutment favorable for a hydraulic system whereby water could enter this pervious flow contact zone along an extensive outcrop near river level; rise along this zone to the surface of bedrock; and then continue along the contact between rock and the overlying glacial deposits. Top of rock exposed in the right bank of the river in the lower part of the dam site area is at an altitude of about 680 feet. If the rock surface continues northward behind the right abutment at this altitude, the pervious flow contact zone would intersect it approximately 1,000 to 1,200 feet downstream from the intake area. Percolation path along the top of rock from this point into Cinnabar Creek would be about 3,500 feet. A slightly shorter distance would take it back into the Tilton River.

More detailed geologic investigations may show that the major units are composed of a number of individual flows. However, if this is true, the flow contacts are probably thin and relatively tight, as they were too inconspicuous to be noticed during the reconnaissance.

Dam section

Detailed topography of the dam site area is needed to select the most economical dam section. However, from the field reconnaissance, it appears that the narrowest part of the gorge lies between the mouth of Cooper Creek and a point about 700 feet downstream from the "elbow".

Abutments

The term abutment is used to include the valley wall above the river surface. At Cooper Creek dam site, the abutments are composed of massive basalt or andesite flows of the Keechelus (?) andesite series, that are of sufficient strength to insure an adequate bearing surface for any type of dam. The slope of both abutments is very steep, and the amount of talus is small. Rock is exposed on the right abutment in steep cliffs from river level to altitudes varying from 550 feet at the upper end of the dam site area to 680 feet at the lower end. In the left abutment, rock is exposed in a nearly vertical cliff extending from river level to an altitude of 635 feet at the mouth of Cooper Creek, 670 feet at the "elbow", and 670 feet about 700 feet downstream from the "elbow". From this point on downstream, the top of exposed rock is slightly over 600 feet. However, isolated exposures at altitudes of 800 feet and 987 feet (see fig. 20) suggest that rock extends to considerably higher altitudes all along the left abutment, although it is covered with an unknown thickness of Younger drift.

Foundation

Active alluvium in the stream bed occurs in thin, isolated patches. In the upstream half of the dam site, bedrock in the foundation is essentially the same as that exposed in the abutments. In the downstream half of the dam site area, Unit A is exposed along the river bed. If: (1) the correlation of this unit with Unit C at Shut-In dam site is correct, and (2) the stratigraphic column remains essentially unchanged over the intervening distance of approximately five miles; Unit A is underlain by a series of coarse volcanic agglomerates.

Height and length of possible dam

Sufficient storage capacity to control the Tilton River and provide the maximum average flow through the powerhouse would require the highest dam possible at this site that was physically safe and economically feasible. Accurate data on the lengths of dam required for various heights cannot be determined without a detailed topographic map of the dam site area. The following data, although taken from the river map which is on too small a scale for accuracy, is the best available:

Altitude of Crest	Cross section S-S'			Cross section T-T'	
	Height above stream bed	Length	Estimated length after stripping	Height above stream bed	Length
feet	feet	feet	feet	feet	feet
900	428	1600		411	2150
850	378	850		361	1480
800	328	670		311	1230
750	278	570	620	261	1060
680	208	430	520	-	-
550	-	-	-	61	225

So far as is now known, the maximum altitude of crest for a dam anchored in rock on both abutments is 680 feet at cross section S-S' and 550 feet at cross section T-T'. The right abutment is the critical area. Bedrock in it may rise to higher levels under its cover of Younger drift, but further, more detailed geologic investigation, possibly supplemented by drilling, will be necessary to make certain of this point.

Reservoir area

For the first three miles above the dam site, the reservoir area is confined to a narrow, steep-walled canyon, but for the remainder of its length lies in a flat-bottomed, steep-walled valley from 0.25 to 0.6 miles in width. Storage capacity and length of reservoir for various pool levels are as follows:

Pool level - feet	Length - miles	Area - acres	Storage capacity - acre-feet
900	14.25	3,750	479,600
850	12.7	2,860	317,400
800	10.4	2,150	192,200
750	8.5	1,450	102,300
680	6.0	629	29,100
550	1.4	50	1,640

Upstream from mile No. 7, a few farms on the river bottom would be inundated by the reservoir. Timber has been pretty well cut off, except for a few small patches on the steep valley walls. No mineral deposits of economic value are known. State Highway No. 5K would have to be relocated through part of the reservoir area. Two miles of road would be flooded by a pool level at an altitude of 680 feet and slightly more than 10 miles by a pool level at an altitude of 900 feet.

Geology of the reservoir area is known only in a very general way. Lava flows and flow agglomerates of the Keechelus (?) andesite series underlies the entire reservoir area. From the dam site to mile No. 7, the river flows in a course superimposed upon the left bank of its preglacial valley. Throughout most of this stretch, the river has cut narrow, steep-walled canyons into bedrock. Upstream from mile No. 7, the present valley coincides with the preglacial valley, and the stream flows on the flat surface of glacial debris that partly fills the old valley. Depth to bedrock throughout this stretch is unknown.

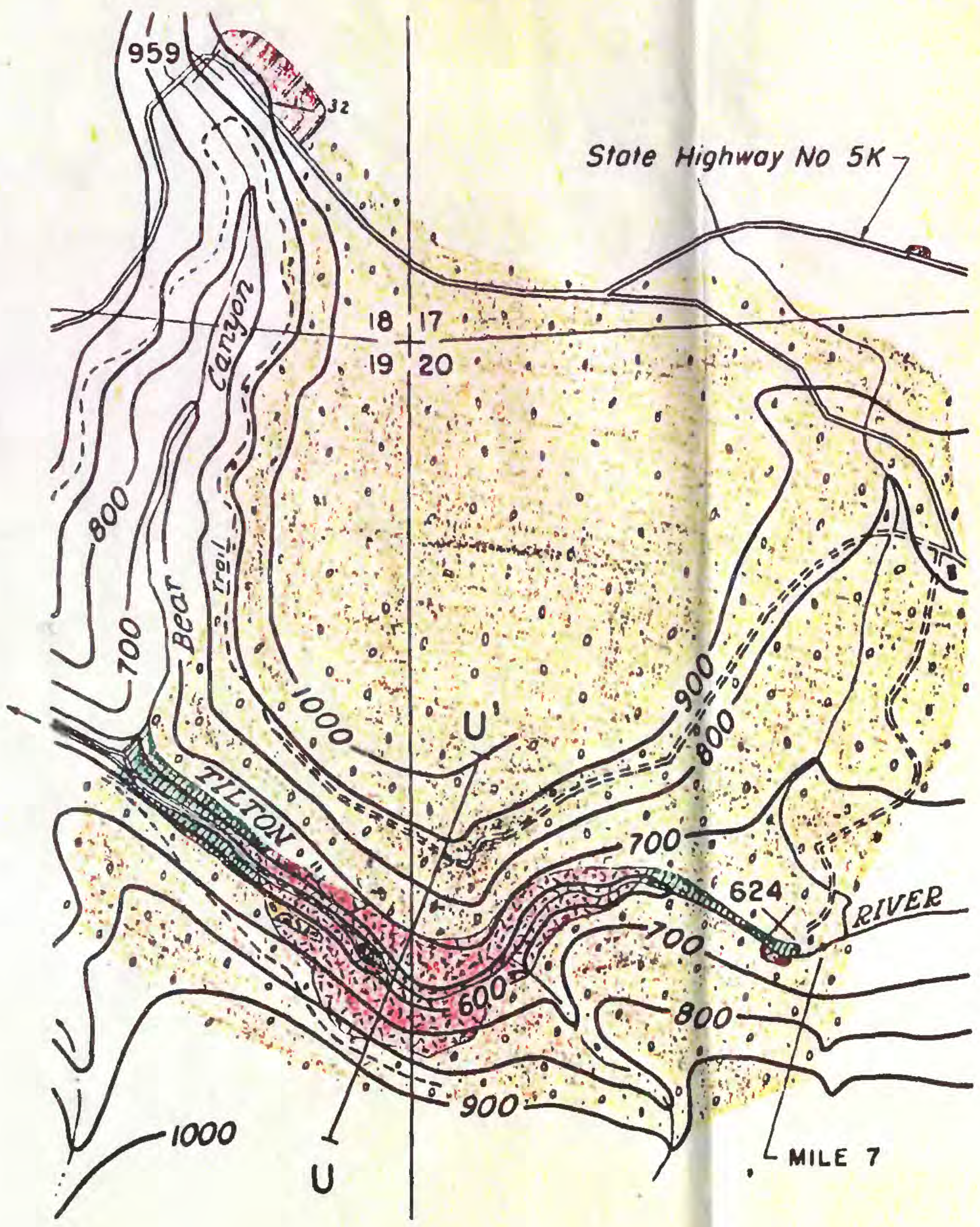
Danger of leakage from the reservoir is through the outwash gravels and sands of the Younger drift overlying bedrock behind the right abutment and through the sediments filling the preglacial valley. The amount of seepage depends on the permeability of these sediments, the cross-sectional area through which seepage can take place, the hydraulic head, and the length of the path of percolation. At present, the exact location, size, altitude of bedrock floor, and character of materials filling the preglacial valley are unknown. However, an estimate of the altitude of the rock floor can be made by projection from the confluence of the preglacial Tilton and Cowlitz Rivers thought to be at about the same location as the junction of the present streams. By this means it is estimated that the floor of the valley behind the right abutment of Cooper Creek dam site is between the altitudes of 200 and 250 feet or more than 200 feet below present stream level. Materials filling much of the channel are probably Shut-In glacial deposits of the Older drift overlain by outwash sands and gravels of the Younger drift. From experience and from comparison of these sediments with others whose permeability has been determined by laboratory and field tests, it is estimated that the Shut-In deposits have relatively low coefficients of permeability ranging from 3×10^{-6} to 3×10^{-9} feet per second, whereas the outwash has medium permeability ranging from 3×10^{-4} to 3×10^{-2} feet per second, although some individual beds may have a permeability as high as 0.5 to 3 feet per second. Reservoir waters will have access to the preglacial valley fill in the valleys of Alder Creek, Bear Canyon, and possibly Sherman Creek (see river map). The path of percolation from Sherman Creek to an outlet in Cinnabar Creek is about one mile and from Bear Canyon to the same outlet about two miles. Consequently, before a decision is made as to the maximum possible reservoir level, it is imperative that: (1), the altitude of the contact between the Older drift and Younger drift be determined; and (2), a profile on bedrock extending from the river to the main north wall of the valley be made. Detailed geologic work may suffice, or supplementary drilling may be required.

Conclusions

Geologic reconnaissance indicates that Cooper Creek dam site is suitable for a masonry dam. Maximum reservoir level depends upon the altitude of bedrock in the right abutment, and on seepage through the preglacial Tilton valley that lies behind the right abutment. For purposes of flood control and maintenance of an adequate flow for power production, a pool level as near an altitude of 900 feet as possible is desirable. However, bedrock in the right abutment is covered by outwash gravels above an altitude of 680 feet. A dam with a pool level at this level would be 430 feet long, but would impound only 29,100 acre-feet of water. Detailed geologic work, perhaps supplemented by drilling, will be necessary to decide the maximum feasible height of dam.

U S GEOLOGICAL SURVEY

51-27 299a FIGURE 21



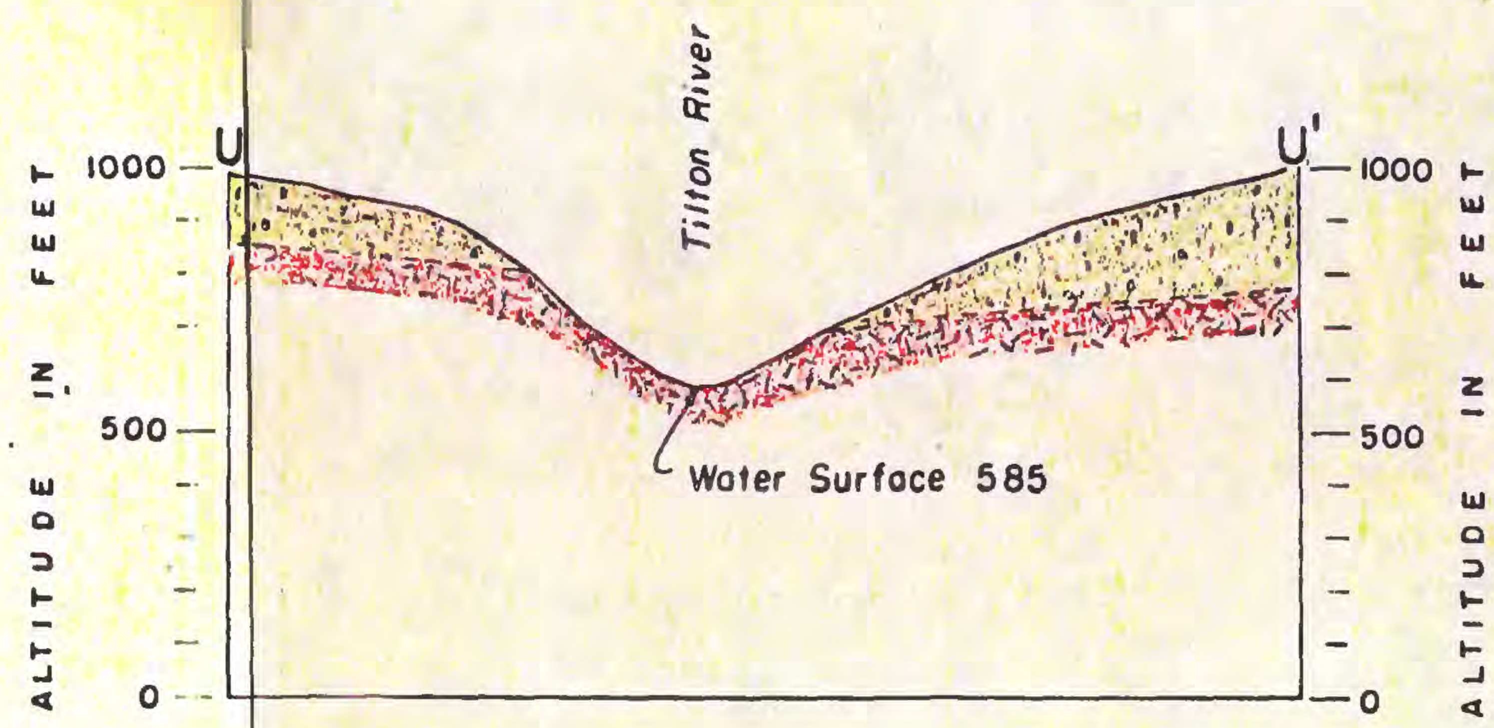
RECONNAISSANCE GEOLOGIC MAP

SCALE : 1/12,000

250 0 1000 2000 3000 FEET

BEAR CANYON DAM SITE

SEC. 19 & 20, T. 13 N., R. 3 E.
LEWIS COUNTY, WASHINGTON



GEOLOGIC CROSS SECTION

SCALE : 1/6,000

250 0 500 1000 1500 2000 FEET

EXPLANATION

RECENT	TALUS
PLEISTOCENE	YOUNGER DRIFT, OUTWASH, GRAVELS AND SANDS
	OLDER DRIFT, UNDIFFERENTIATED; TILL, OUTWASH SANDS AND GRAVELS, LACUSTRINE SILTS AND SANDS
MIOCENE	KEECHELUS (?) ANDESITE SERIES, UNDIFFERENTIATED
EOCENE	PUGET GROUP, SANDSTONE AND SHALE
U—U'	LINE OF CROSS SECTION
9	DIP AND STRIKE OF FORMATION

GEOLOGY BY A. F. BATEMAN, JR.

J M S

BEAR CANYON DAM SITE

Location

The proposed dam site is on the Tilton River, 6.5 miles above its mouth, in NE¼SE¼ and SE¼NE¼ sec. 19, and SW¼NW¼ and NW¼SW¼ sec. 20, T. 13 N., R. 3 E., W.M., Lewis County, Washington. As a base for the accompanying geologic map, figure 21, a portion of the river map,[66/] scale 1:24,000 with a contour interval of 20 feet, was photostatically enlarged to a scale of 1:12,000 (1 inch equals 1,000 feet). For the sake of clarity, only 100 foot contours are shown on the geologic map.

Accessibility

State Highway No. 5K, an all weather, surfaced road, which runs from its junction with U. S. Highway No. 99 nine miles southeast of Chehalis to Morton, skirts the right abutment of the dam site. An auto can be driven from the highway down a side road to the farm house shown on the dam site map, figure 21. In dry weather, an auto

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66/ Plan and profile of Cowlitz River, mile 42 to mile 97, Cispus River to mile 32, and Tilton River to mile 19, Washington, sheet 6.

can be driven southward from the farm house over a truck trail to the north bank of the Tilton River near B.M. 624. Extending south-westward from the farm house is an abandoned road, no longer passable to autos, that makes an excellent trail along the upper edge of the right abutment and on up Bear Canyon. Near the proposed dam axis, cross section U-U', figure 21, a trail descends from this road to the river. In 1948, one could cross to the left abutment on a large log during low stages of the river. Otherwise, the left abutment can be reached only by a hike of about 1½ miles across country from the upper reaches of Cooper Creek in NE¼NE¼ sec. 31, T. 13 N., R. 3 E., W.M., which are accessible by auto from Harmony.

Purpose of project

Water-power development is the primary purpose, and storage for flood control a secondary reason for a dam at this locality. Water available is slightly less than at Cooper Creek dam site, since Cooper Creek, Sherman Creek, and Bear Canyon enter the Tilton River between the two sites.

Field work

A geologic reconnaissance of this site was made by A. F. Bateman, Jr., on August 1, 1948.

Catchment area

Drainage area of the Tilton River basin above this site is approximately 142 square miles.

Stream gradient

Average gradient of the stream through the dam site is 30 feet per mile. In the reservoir area, the stream gradient is 27 feet per mile to the head of the reservoir where stream bed is at an altitude of 840 feet, a distance of 9.5 miles.

Valley profile

From Morton downstream to Alder Creek, the Tilton River flows in an open, wide-bottomed valley from one-half to three-fourths of a mile wide. (See Eatonville quadrangle.) Between Alder Creek and Bear Canyon, the valley is blocked by a mass of glacial debris which has forced the river into a rock canyon at the southern edge of the valley. The left wall of this canyon rises steeply to the top of exposed bedrock at altitudes varying from 775 to 800 feet, and from there on a more gentle slope to a high bench at 1,300 feet that forms the regional summit on the south side of the river. The right bank also rises steeply to the top of exposed bedrock at an altitude of about 700 feet where there is a narrow bench. Above this, it rises on a more gentle slope to the rounded summit of the mass of glacial debris at about 1,300 feet. A low saddle separates this hill from the main wall of the valley which rises steeply to the regional summit level of over 3,000 feet. Downstream from the dam site at the mouth of Bear Canyon, a bench underlain by outwash gravels of the Younger drift and the Older drift is developed on both sides of the river at altitudes from 620 to 630 feet.

The preglacial channel of the Tilton River almost certainly lies behind the right abutment of the dam site and beneath the mass of glacial debris. Its exact location, width, depth, and the character of fill materials is unknown.

Apparent possible height of dam

On topographic grounds alone, the maximum possible height of dam is in excess of 400 feet.

Character and depth of valley fill

Through the dam site the Tilton River flows on bedrock except for a thin and rather patchy veneer of active alluvium made up of large boulders, gravels, and sands. Probably the greatest thickness of alluvium is less than 10 feet. The slopes and benches above the rock walls of the canyon are underlain by outwash gravels of the Younger drift, as is shown on cross section U-U' and the geologic map, figure 21.

Shut-In glacial deposits of the Older drift partially fill the preglacial channel of the Tilton River that lies behind the right abutment. Altitude of the bedrock floor and altitude of the contact between the Older drift and Younger drift are unknown. However, about 1,000 feet downstream from cross section U-U' where the preglacial valley intersects the present valley of the Tilton River, the Older drift is found on both sides of the river up to an altitude of about 615 feet. For the most part, it is made up of outwash gravels and sands that are very hard, dense, and compact. The gravels are a fairly well-graded mixture of rounded, stream-worn boulders, cobbles, and pebbles in a matrix of silty, slightly clayey sand. Weathering is about the same as in similar deposits in the Cowlitz valley. Similar deposits occur in the right bank of the river about 1,500 feet upstream from cross section U-U', where the preglacial valley again intersects the present valley.

Country rock

Bedrock at Bear Canyon dam site consists of lava flows belonging to what is thought to be the Keechelus (?) andesite series. About 250 feet of strata are present, but no detailed stratigraphic section has been measured. The rocks are essentially the same as at Cooper Creek dam site and are thought to correspond to part of the strata exposed at Shut-In dam site. About 3,500 feet up Bear Canyon from its mouth at the east abutment of a bridge over which State Highway No. 5 crosses this stream, sandstones and shales of the Eocene Puget group are exposed. The exact location and the character of the contact between these sediments and the Miocene volcanics is unknown. The nearest exposure of the volcanic rocks is 0.7 miles eastward along the highway (see figure 21). Time was sufficient for only a cursory examination of the volcanic rocks. The following types were observed:

Unit A. - The oldest unit is exposed along the bed of the Tilton River downstream from cross section U-U', figure 21. Top of the flow is from 3 to 8 feet above stream level at an altitude of about 590 feet. It is a massive, hard, tough, dark-gray basalt. Examination with a hand lens shows small lath-shaped phenocrysts of plagioclase feldspar, rounded, colorless masses of glass, and scattered, dark-green, extremely small phenocrysts of a ferromagnesian mineral embedded in a dense ground. At the top of Unit A is a burned and reddened flow contact zone from one to two feet thick. This is a strong unit, only moderately jointed, with adequate bearing capacity to serve as the foundation for a dam. Unit A is tentatively correlated with Unit A at Cooper Creek dam site and with Unit C at Shut-In dam site.

Unit B. - Overlying Unit A along the right bank of the river are 6 to 8 feet of light-to medium-gray volcanic agglomerates that vary in texture from fine to very coarse. All phases contain many small ~~amygdules~~ vesicles, some of which are empty, and others partly or wholly filled with silica. Because of the steep cliffy character of the north bank, the top of the agglomerates was not seen.

Unit C. - A tough, fairly hard, medium-gray basalt or andesite, with a distinct brownish shade and a resinous appearance, crops out along the south bank in a cliff about 20 feet high with its top at an altitude of 700 feet. Neither top nor bottom of this unit was observed, but it is stratigraphically higher than Unit B. Under a hand lens one sees many brick-shaped plagioclase feldspar phenocrysts up to one-fourth of an inch long set in a fine but crystalline matrix. Bearing capacity of this unit is adequate for it to serve as abutments for a masonry dam, although it is somewhat more jointed than Unit A. This unit is believed to correspond to Unit B at Cooper Creek dam site.

Unit D. - Overlying Unit C is a medium-to dark-gray, hard, brittle, highly jointed basalt that has a faint suggestion of flow structure. Neither the top nor bottom of this unit was seen. Highest observed outcrop was on the south bank at an altitude of 833 feet. Under a hand lens the groundmass appears dense with a few scattered, minute, lath-shaped phenocrysts of plagioclase feldspar. Jointing reduces the strength of Unit D, but even so, it has a high bearing capacity and should serve adequately as abutments for a masonry dam. Unit D is believed to correspond to Unit C at Cooper Creek dam site.

Structural features

Dip of beds. - No accurate determinations of the strike and dip of the lava flows were obtained. However, the strata appear to be about horizontal or else dipping downstream at a very small angle. The Eocene sediments in Bear Canyon dip 32°, N. 10° E.

Folds. - A small syncline was observed on the right or north bank of the river about 400 feet downstream from cross section U-U'. Beds in the east limb dip 9°, N. 22° W., and in the west limb 11°, N. 61° E.

Joints. - Jointing appears to be about the same as at Cooper Creek dam site. Time was not sufficient to permit a study of the joint systems.

Ground-water conditions

A few small seeps were observed on both banks of the stream at the contact between bedrock and the overlying glacial deposits. Movement of ground water appears to be toward the river.

Permeability

Units A, C, and D are practically impervious, but Unit B is slightly more permeable so that a small amount of seepage might take place through the body of the rock. Most of the seepage, however, will take place along joints and through flow contact zones. The flow contact zone between Units A and B is from one to two feet thick and has the appearance of being permeable. No doubt similar flow contact zones separate Units B from C and C from D, although they were not seen during the reconnaissance. Since the flows are approximately horizontal, a maximum intake area is presented to the reservoir waters by the pervious zones. Water percolating through the flow contact zone between Units A and B and through Unit B will be subject to the full hydrostatic head of the reservoir. Pressure grouting should reduce the permeability of these zones and of the joints considerably.

Dam section

A detailed topographic map of the dam site area is needed to select the most economical dam section. However, the character of the topography is fairly accurately reflected by the river map, even though it is on a small scale. It appears that the best section would lie within a stretch of the river valley extending from 500 feet upstream to 400 feet downstream from cross section U-U', figure 21.

Abutments

The abutments, which include the valley walls above stream level, are composed of the flow agglomerate of Unit B at the base overlain by the massive flows of Units C and D. All are of sufficient strength to furnish adequate bearing for a dam. Rock in the right abutment forms a steep cliff extending from stream level to an altitude of about 700 feet. On the left bank rock extends to a maximum height of 833 feet. This bank is steep and the higher slopes are cliffy. The amount of talus and slope wash is relatively small. Although the rocks are considerably jointed, especially those of Unit D, there is not much loose rock that will require scaling down.

Foundation

Active alluvium in the stream bed is thin and discontinuous. Unit A makes up the rock floor of the valley. It is a strong unit with adequate bearing capacity to serve as the foundation for a dam of any type.

Height and length of possible dam

To provide maximum average flow for power production and maximum control of the stream would require a high dam at this site. However, bedrock is covered by outwash gravels of the Younger drift above an altitude of 700 feet on the right abutment and 833 feet on the left abutment. Whether or not bedrock extends to higher altitudes under cover can only be determined by drilling. In the following table is shown the width of valley for various heights of dam:

Altitude of Crest — feet	Height above stream bed — feet	Length — feet	Remarks
900	315	1,200	Top both abutments in outwash gravels
850	248	1,000	Top both abutments in outwash gravels
800	215	800	South abutment in rock
750	165	650	South abutment in rock
700	115	500	Both abutments in rock

Reservoir area

The reservoir includes the same area as Cooper Creek reservoir upstream from mile No. 7. Storage capacity, area, and length of reservoir for various pool levels are as follows:

Pool level — feet	Length — miles	Area — acres	Storage capacity — acre-feet
900	11.75	3,240	391,200
850	10.2	2,440	252,100
800	7.9	1,820	145,600
750	6.0	1,185	70,450
700	4.2	669	24,200

Economic factors and general geologic conditions influencing a reservoir at this location are discussed under Cooper Creek Reservoir area.

The relationship of bedrock to exposures of the Older drift at Bear Canyon dam site suggest that the dam site is located in a superimposed valley cut by the Tilton River across a bedrock spur extending northward into the preglacial valley. If this is true, the preglacial valley probably lies only a short distance behind the right abutment of the dam site. Sufficient detailed geologic field work has not been done to outline the course of the preglacial channel or to determine its size. By projection upstream from Cooper Creek site, the altitude of its rock floor is estimated to be between 250 and 300 feet or about 300 feet below present stream level. Glacial debris filling the channel consists of Shut-In glacial deposits of the Older drift overlain by outwash of the Younger drift. Altitude of the contact between them is unknown, but probably not less than 615 feet since this is the top of the Older drift exposed at the mouth of Bear Canyon. At this locality, Shut-In deposits consist of very dense and compact outwash gravels and sands whose coefficient of permeability probably is not more than 3×10^{-4} feet per second. Farther upstream, the Shut-In deposits consist mainly of glacial silts and clays whose permeability is somewhat less. The much more

mittent

outwash of the Younger drift is much less compact and much more permeable. It is well-exposed in the bed of a small, intermittent stream about 400 feet upstream from Bear Canyon where it consists of medium-to coarse-grained, clean sands interbedded with many layers of fine, clean, sandy gravel, a few layers of coarse, clean, sandy gravel, and a few thin beds of glacial silt. An average coefficient of permeability of the mass would probably lie within the ranges of 3×10^{-5} to 3×10^{-2} feet per second. Hence, seepage from the reservoir will be most apt to take place along the contact zone between the Older and Younger drift and through the lower part of the Younger drift. Reservoir water can enter these sediments along the valley of the small creek at the eastern edge of the dam site, which is underlain by Younger drift. Path of percolation from this intake to an outlet in Bear Canyon is approximately 3,500 feet.

Conclusions

Geologic reconnaissance of Bear Canyon dam site indicates that it is suitable for a masonry dam. Rock is present in both abutments to an altitude of 700 feet. A dam to this altitude would be 115 feet in height above stream level, 500 feet long, and would provide 24,000 acre-feet of storage. For stream control and regulation of flow for power purposes, much more storage is desirable. However, before a higher pool level is considered, information must be obtained in regard to the following items:

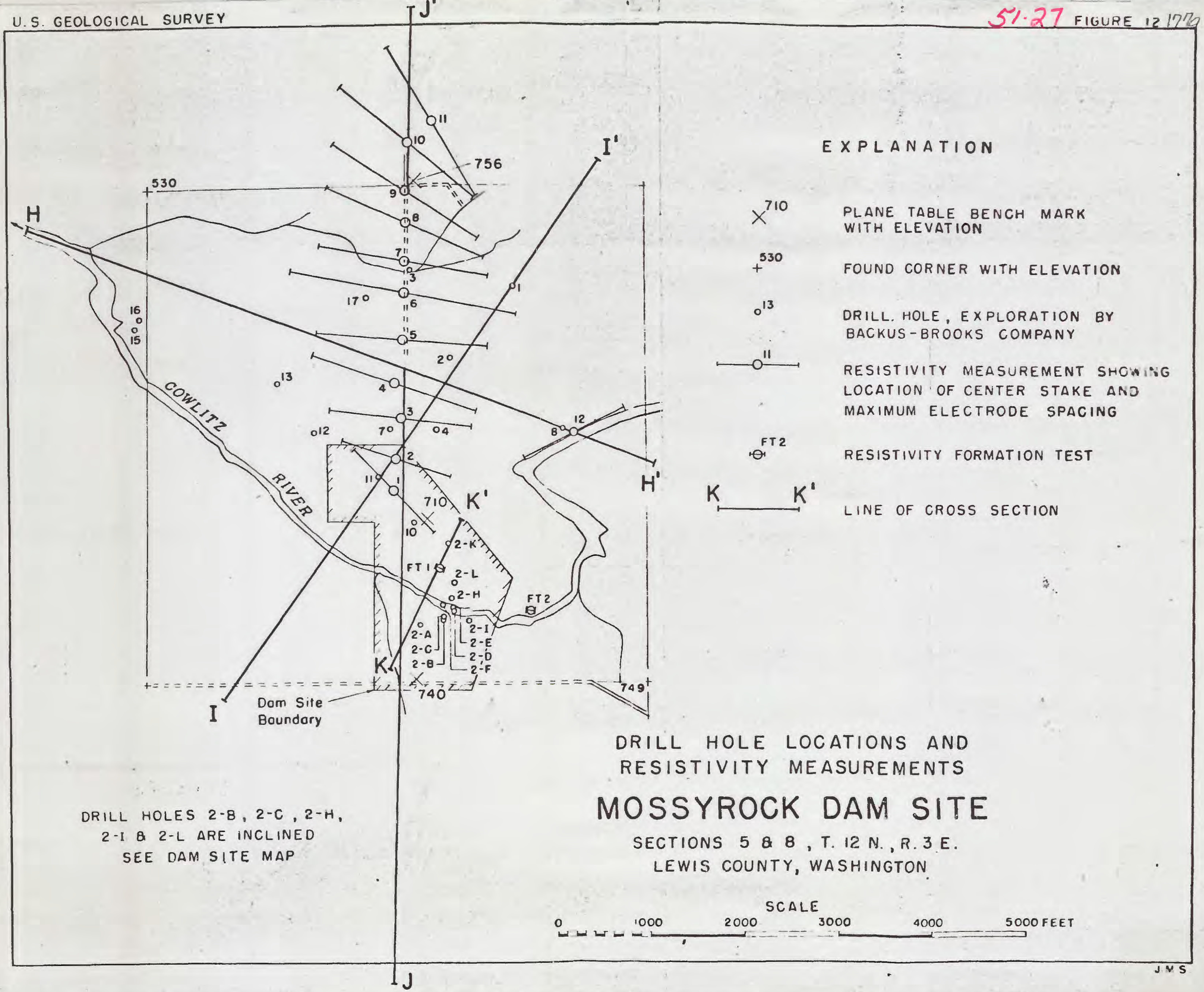
a. Profile on the bedrock surface in and behind the right abutment.

b. Physical characteristics, especially permeability of the outwash deposits overlying bedrock in the right abutment.

c. Location and size of the preglacial valley of the Tilton River.

d. Physical characteristics, especially permeability of the materials filling the preglacial valley.

This information can be obtained by a detailed geologic examination of the right abutment from the river to the main rock wall of the valley, and a reconnaissance of Bear Canyon and the valley of Alder Creek. Drilling, no doubt, will be required. Permeabilities of the various sediments can be determined by field tests in connection with drilling and supplemental laboratory tests.


EXPLANATION
PLANE TABLE BENCH MARK WITH ELEVATION
FOUND CORNER WITH ELEVATION
DRILL HOLE, EXPLORATION BY BACKUS-BROOKS COMPANY
RESISTIVITY MEASUREMENT SHOWING LOCATION OF CENTER STAKE AND MAXIMUM ELECTRODE SPACING
RESISTIVITY FORMATION TEST
LINE OF CROSS SECTION
COWLITZ RIVER
Dam Site Boundary
DRILL HOLES 2-B, 2-C, 2-H, 2-I & 2-L ARE INCLINED SEE DAM SITE MAP
DRILL HOLE LOCATIONS AND RESISTIVITY MEASUREMENTS
MOSSYROCK DAM SITE
SECTIONS 5 & 8, T. 12 N., R. 3 E.
LEWIS COUNTY, WASHINGTON
SCALE
0 1000 2000 3000 4000 5000 FEET
J.M.S.

5127

FIGURE 15

ENLARGED GEOLOGIC CROSS SECTION

SHUT-IN DAM SITE

SHOWING FILLED PRE-GLACIAL CHANNEL

GEOLOGY BY A. F. BATEMAN, JR.

J.M.S.

ENLARGED GEOLOGIC CROSS SECTION OF

SHUT-IN DAM SITE

SHOWING MATERIAL FILLING CHANNEL BEHIND LEFT ABUTMENT

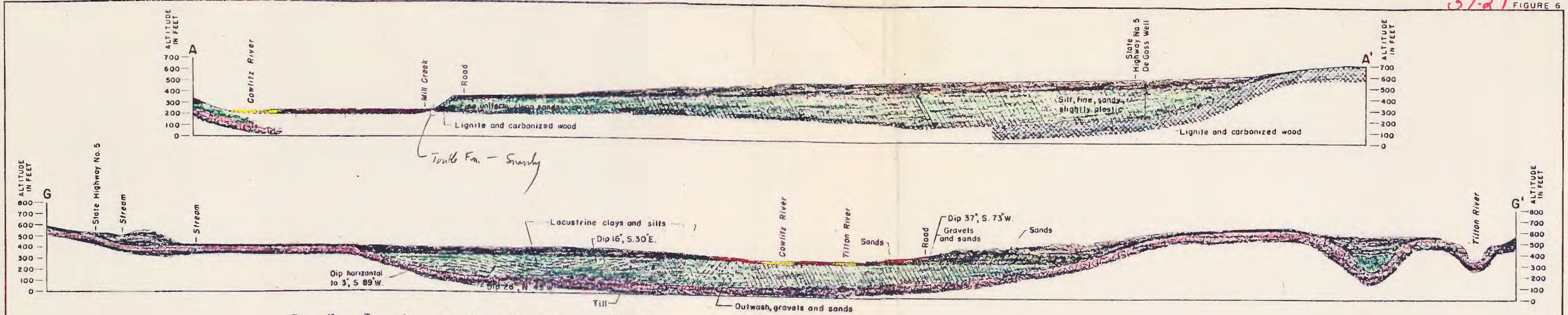
SCALE

100 0 100 200 300 400 500 FEET

GEOLOGY BY A. F. BATEMAN, JR.

J.M.S.

51-27 FIGURE 6



E X P L A N A T I O N

QUATERNARY — RECENT — ALLUVIUM
- ACTIVE
- INACTIVE

QUATERNARY — PLEISTOCENE

YOUNGER DRIFT
- OUTWASH, GRAVELS AND SANDS

OLDER DRIFT
- TILTON RIVER DEPOSITS SANDS, SILTS AND GRAVELS
- SHUT-IN GLACIAL DEPOSITS, UNDIFFERENTIATED PATTERN DOES NOT INDICATE DIP
- SHUT-IN LACUSTRINE CLAYS AND SILTS
- SHUT-IN TILL
- SHUT-IN OUTWASH, GRAVELS AND SANDS

QUATERNARY — PLEISTOCENE (?)

ANCIENT DRIFT
- GRAVELS, HIGHLY WEATHERED AND DECOMPOSED

TERTIARY — MIOCENE
- KEECHELUS (?) ANDESITE SERIES
- KEECHELUS, UNDIFFERENTIATED

GEOLOGIC CROSS SECTIONS
OF
COWLITZ RIVER VALLEY
SHOWING BURIED PRE-GLACIAL VALLEY

SCALE
500 0 500 1000 1500 2000 2500 FEET

GEOLOGY BY A F BATEMAN, JR.
J.M.S.

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