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Geologic features of dam sites in the Nehalem, Rogue, and Willamette River basins, Oregon, 1935-37

by

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Contents

Diabase.

Illustrations

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Introduction

The present report comprises brief descriptions of geologic features at 19 potential dam sites in the Nehalem, Rogue, and Willamette River basins in western Oregon. The topography of these sites and of the corresponding reservoir sites was mapped in 1934-36 under an allocation of funds by the Public Works Administration for river-utilization surveys by the Conservation Branch of the United States Geological Survey. The field program in Oregon has been under the immediate charge of R. O. Helland.

The 19 dam sites are distributed as follows: three on the Nehalem River, on the west or Pacific slope of the Oregon Coast Range; four on Little Butte Creek and two on Evans Creek, tributaries of the Rogue River in the eastern part of the Klamath Mountains; four on the South and Middle Santiam Rivers, tributaries of the Willamette River from the west slope of the Cascade Mountains; and six on tributaries of the Willamette River from the east slope of the Coast Range.

Except in the Evans Creek basin, all the rocks in the districts that were studied are of comparatively late geologic age. They include volcanic rocks, crystalline rocks of several types, marine and nonmarine sedimentary rocks, and recent stream deposits.

The study of geologic features has sought to estimate the bearing power and water-tightness of the rocks at each dam site, also to place rather broad limits on the type of dam for which the respective sites seem best suited. It was not considered necessary to study the corresponding reservoir sites in detail for excessive leakage appears to be unlikely. Except at three of the four sites in the Santiam River basin, no test pits have been dug nor exploratory holes drilled, so that geologic features have been interpreted wholly from natural outcrops and from highway and railroad cuts. Because these outcrops and cuts are few, many problems related to the construction and maintenance of dams can not be answered at this time and all critical features of the sites should be thoroughly explored by test pits and drilled holes before any dam is designed. This applies especially to sites in the Nehalem and Willamette River basins where commonly the cover of timber and brush is dense and the rocks are rather deeply weathered.

On the Middle Santiam and South Santiam Rivers, the Cascadia, Greenpeter, and Sweet Home sites have been studied intensively by the United States Engineer Department, whose work included exploration by diamond-drill holes and test pits. Their conclusions as to geologic features are given in a report by McKitrick 1/ and have been reviewed

1/ McKitrick, W. E., Geology of dam sites [on the] North, Middle, and South Santiam Rivers [and the] Calapooya River: War Department, First Portland (Oregon) District, typewritten report, 44 pp., maps and sections, 1936.

by the writer. 2/ Data from this source have been used freely in the

2/ Piper, A. M., Geologic conditions at certain dam sites in the Willamette River Basin, Oregon: U. S. Geol. Survey typewritten report, pp. 173-185, , June 28, 1937.

discussions of the respective sites in this report (pp. 45, 61, 76).

The probability of destructive earthquakes in the region appears to be small but is not negligible. Prudence suggests that any high dam should embody features to assure stability against moderately strong earth motions.

Nehalem River basin

Jewell (Tideport) dam site

At and near the Jewell dam site (pl. 1) the bedrock includes thinly

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Plate 1.– A, Tentative geologic map of the Jewell dam site, Nehalem River; B, Explanation for geologic maps of dam sites along the Nehalem River.

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stratified shale and earthy sandstone, dense non-fragmental volcanic rock (basalt), and fragmental volcanic rocks (basaltic tuff and agglomerate). The shale and sandstone are overlain by and intruded by the volcanic rocks. In general, the rocks dip about 5°–35° from N. 20° W. to N. 20° E. (upstream). At the dam site itself, the exposures of bedrock are few and small so that the geologic features must be interpreted largely from the regional features just described.

At the site the dense volcanic rock is exposed at the base of the right (west) abutment to a height of about 40 feet above the road and for about 350 feet along the road (see pl. 1). There it includes a layer of dense fine-grained basalt about 45 feet thick, another layer of basalt about 40 feet thick which is spotted with small globular masses of secondary non-metallic minerals (amygdule fillings), and fine-grained fragmental material (tuff). These layers appear to be conformable and to have tight contacts. These and others of similar rock are inferred to form the greater part of the thin spur that rises from the exposure to and above the margin of the mapped area, also to be fairly extensive on the opposite or left bank of the river.

Dense non-fragmental volcanic rock such as that exposed at the Jewell dam site has high crushing strength. However, it appears not to afford a rigid and thoroughly stable foundation and right abutment, owing to fractures and to mineralogic changes that have taken place in the basalt along the principal fracture zone. Thus, the exposure described in the preceding paragraph is bisected by two fractures that dip about 70° N. 70° W. and that are about 35 feet apart. Between these two main fractures all the rock is cut by closely spaced cross-fractures in many directions; some of the rock is thoroughly crushed to "gouge". In this fracture zone many of the blocks are tilted rather steeply in several directions. Also their faces commonly are somewhat decomposed and at some places are silicified. All these features imply that the zone is a fault with appreciable displacement. Because its strike, N. 20° E., prolongs the course of the river farther upstream, the zone may be a line of serious weakness at the dam site. Other fracture zones are not unlikely ~~to exist~~ beneath the slope wash.

Coarse fragmental volcanic rock, which comprises a dense basaltic matrix and fragments as much as 2 feet through, crops out extensively on the left bank of the river downstream from the dam site. It is likely to occur at the site beneath the cover of slope wash. Rock of this sort is moderately weaker than the non-fragmental volcanics.

The sedimentary rocks in the vicinity of the dam site are largely shale but include some strata of earthy sandstone. These rocks are moderately low in bearing power and probably are in part plastic when wet. At the site these weak rocks are exposed on the right bank (1) at one spot along the road at the downstream edge of the basalt already described, where they dip 70°-85° N. 70° W., are deeply weathered, and are air-slaked; (2) along the 750-foot contour in prolongation of the thin spur that affords the abutment for the proposed dam; and (3) in shallow cuts along the road from 1,300 to 1,600 feet farther upstream, where they dip 20°-35° N. 20° W. They are inferred to form most of the right bank both upstream and downstream from the basaltic spur, for there the upper hillsides are scarred by several land slides - commonly shallow and only a few yards across - which indicate either unstable bedrock or weathering to a greater depth than is common for the volcanic rocks. Whether the sedimentary rocks exist on the opposite or left bank is not known.

On plate 1, the line marked "AB" indicates roughly the one feasible position for a dam with foundation and abutments largely or entirely on the volcanic rocks. At this position the permissible maximum height of a dam probably is limited by the bearing power and perviousness of the relatively narrow basaltic spur forming the right abutment; neither of these two factors can be evaluated closely from the data now available. However, owing to fractures that have been described and to the possibility that extensive sheets of weak fragmental material (tuff) may separate some of the layers of basalt, this position seems wholly unsuited for a high rigid dam with narrow base, though it might be suitable for a fill of earth or rock.

At the line marked "CD" a dam would be slightly shorter and both abutments would have considerable mass. There, all the right abutment is believed to be formed of the relatively weak shale and sandstone; also, the character of the bedrock in the left abutment is unknown. Only a flexible dam with comparatively broad base would be stable. Altogether, the Jewell dam site appears to be distinctly inferior in geologic features to the alternative site near Elsie.

Elsie dam site and spillway site

<u>Character and extent of the bedrock units</u>.- At the Elsie dam site (pl. 2), three distinct bedrock units may be discriminated, which

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Plate 2.- Geologic map of the Elsie dam site, Nehalem River.

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differ greatly in perviousness and bearing power. In order of increasing geologic age, these include shale, a non-fragmental volcanic rock (basalt), and fragmental volcanic rocks (basaltic).

The shale is thinly laminated, bluish gray in color when fresh, of extremely fine grain, and moderately indurated. Doubtless it is essentially impervious and relatively low in bearing power. In part it is somewhat clayey and probably is plastic if wet. Where exposed at the land surface it slakes and weathers deeply to a yellowish brown clayey soil. The shale is known to exist at four places along the left (east) bank of the stream, as follows: (1) in road cuts 20 to 30 feet above the river near the downstream edge of the mapped area, where it dips 20° N. 40° W.; (2) at the inner edge of the flood plain about 450 feet downstream from the line marked "AB" on plate 2, where it is nearly horizontal; (3) along the 440-foot contour 100 feet upstream from the line AB, in a test pit for a pier of a highway bridge that is to be constructed; and (4) at the inner edge of the flood plain about 200 feet farther upstream, where it dips 30°-90° E. and is not clearly in place. Except in the central part of the site, along the line AB, this shale is inferred to underlie the volcanic rocks beneath all the area that is shown on plate 2.

The non-fragmental basalt is non-cellular and sub-crystalline throughout; its crushing strength is high, probably not less than 40,000 pounds to the square inch. This rock is exposed only in the central part of the site, along the line AB, where the river pierces it in a narrow chute. The outcrop is from 200 to 400 feet wide along the river and rises to an altitude of about 480 feet in either bank - that is, to a height of about 90 feet above low river stage. In its lower part this non-fragmental basalt is parted into conspicuous radial columns that average about 3 feet across, in its upper part into concentric shells from 3 to 8 feet thick. (See pl. 3.) All these partings

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Plate 3.- Columnar basalt forming the lower 90 feet of the abutments at the Elsie dam site.

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are snug and free from "gouge"; except as they afford openings, the rock is wholly impermeable.

The mass of basalt just described is inferred to be the uppermost part of a dike which trends across the river and extends steeply to a great depth. Thus, it would form a rigid subvertical plate piercing the shale below river level.

The fragmental volcanic rocks, of which all are basaltic, overlie both the shale and the dike of non-fragmental basalt and are believed to form a sheet as much as 225 feet thick over most of the area shown on plate 2. They range widely in physical character. Thus, on the right (west) bank of the river they are massive and are composed of a relatively dense basaltic matrix in which are embedded fragments of basalt as much as 8 feet across. There, they form a sub-vertical bluff from 100 to 150 feet high and so are believed to be fairly rigid and to have moderate bearing power. Also, they probably are not highly pervious except for fractures. On the opposite or east side of the river, on the other hand, these rocks are decidedly inferior in bearing power and in part are unstable and probably pervious. There, they include: (1) coarse basaltic tuff and agglomerate with a weak fragmental matrix, all somewhat decomposed and cut by veinlets and scattered masses of silica; (2) discontinuous sheets of fine-grained basalt, most of which has been reduced to rubble by random fractures from 1 foot to 8 feet apart; and (3) a few thin ribs (dikes ?) of fine-grained or glassy basalt, ordinarily brecciated throughout and at some places silicified. In general, the fragmental rocks on the east bank are essentially incoherent; thus, along the Wolf Creek highway, which is now being built across the dam-site area, a cut 700 feet long and 53 feet deep was excavated without blasting. Fully 90 percent of the hillward face of the cut (pl. 4,A) exposes only a rubble of basalt blocks less than 1 foot across embedded

Plate 4.- A, Basalt rubble in highway cut along the flank of the left abutment at the Elsie dam site.

in an earthy matrix. Not even the base of the cut discloses massive unweathered rock. Further, these fragmental rocks on the east bank commonly are unstable, as is indicated by several landslides to be described.

<u>Character and extent of unconsolidated materials</u>.- In addition to the slope wash that covers most of the area, the unconsolidated materials at the Elsie dam site include landslide rubble as well as discontinuous deposits on the bed and banks of the stream and on a terrace about 20 feet above the stream. Obviously, all these are unsatisfactory foundation materials for a dam.

The stream deposits are composed of sand, pebbles, and cobbles with some boulders of local origin. In the central third of the mapped area they are not extensive and probably are thin, for commonly they rest on rock shelves a few feet above river level.

Landslide rubble forms two flats along the left bank of the river, one close upstream from the line AB and the other about 500 feet downstream. The one upstream lies at the foot of a landslide alcove which is 450 feet wide and which rises approximately 150 feet above the river in the fragmental volcanic rocks. Above stream level the landslide rubble is composed of clayey earth mingled with basaltic blocks as much as 20 feet long; on the two flats, the earth matrix has been washed away.

The weak shale that has been described crops out along the sole of each of these two slides; thus, the most likely cause of failure in the volcanic rocks appears to be plastic deformation in the shale. Another slide, clearly so caused, has occurred within a year in a highway cut 0.6 mile east of the dam site (pl. 4,B). There, the slide block is about

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Plate 4.- B, Slide in fragmental basalt and shale in highway cut 0.6 mile east of the Elsie dam site.

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700 feet long and 50 feet thick; its upper half is composed of the fragmental volcanics, the lower half of shale. All these features suggest that: (1) the excessive fragmentation of the basaltic rocks on the east bank is due in part to subsidence and (2) a considerable part of the area between the highway and the river on that bank is unstable. Indeed, all that area, which is characterized by large-scale hummocky topography, may be an old landslide whose form has been somewhat modified by erosion.

Summary of features pertinent to the design of a dam.- The lines that are marked "ABC" and "DE" on plate 8 indicate the two positions that appear to be most advantageous for a dam at the Elsie site. The downstream position crosses the mass of dense non-fragmental basalt that has been interpreted as a rigid subvertical plate extending to considerable depth through the shale. Accordingly, to a height of about 90 feet above the river, this position appears suitable for a thin rigid dam that is arched for stability. This conclusion should not be considered final until the vertical extent of the non-fragmental basalt has been determined by test drilling in the river bed and on either bank along the axis of the proposed dam. Neither this position nor any other within the area shown on plate 8 appears suitable for a thin rigid dam of greater height, because the upper part of either abutment would be formed of the fragmental volcanics.

To supersede the site upstream near Jewell, a dam at the Elsie site should afford a pond level at the 600-foot contour or higher - that is, at least 200 feet above the river. To be stable, a dam so high should be broad and flexible; a fill of earth or rock is suggested as most feasible. Even for a flexible dam the left or east abutment at the downstream position may not be sufficiently sound above the 480-foot contour. Also, (1) the potential leakage may be excessive all along that abutment for about 2,000 feet from the river, and (2) a considerable part of the abutment may prove unstable if saturated up to or above the 600-foot contour.

To avoid these deficiencies in the left abutment the upstream position, EF, is suggested as more advantageous for a flexible dam up to the 600-foot contour. The advantages of that position, which tend to compensate for a moderately greater length, are: (1) both abutments are broad, so that excessive leakage seems unlikely, and (2) the weak shale, which is a major cause of instability in the fragmental volcanics, is inferred to lie below stream level and so not to expose a sole for potential landslides.

For a rock-fill dam, the sound basalt near the site is suitable, although quarrying at any place above the 600-foot contour may require a moderately large proportion of the rock to be rejected. The most promising quarry site appears to be the flank of the ridge that overlooks the right abutment.

To restrain percolation under the low rigid dam should be easy, for such fractures as exist in the non-fragmental basalt are clean and can be effectively sealed by grouting. The high flexible dam would call for more extensive cut-off measures, how extensive can not be estimated without thorough test drilling. The most critical requirement appears to be an impervious connection from the dam well into the shale that underlies the volcanic rocks, unless the shale is proven to lie far beneath river level.

Spillway problems.- Except for the non-fragmental basalt and the more massive parts of the fragmental volcanics, all the materials that form the Elsie dam site would be eroded rapidly by swiftly flowing water of considerable depth. Thus, the design of an adequate spillway involves critical problems.

For the low rigid dam, an over-fall spillway appears feasible because firm rock is believed to underlie the stream bed at relatively shallow depth for at least 500 feet downstream from the line AB. Accordingly, an extensive downstream apron probably would not be necessary, although works to protect the left bank might be desirable. As an alternative, a spillway tunnel could be driven through the heavy-bedded rock in the right abutment without undue difficulty.

For the high dam, on the other hand, an over-fall spillway seems undesirable and a spillway at the side is topographically feasible only across the east abutment with the dam in the less advantageous or downstream position, ABC. For assured stability, a spillway structure there should embody a substantial and extensive cut-off and an extensive pavement downstream. The alternative spillway site that is afforded by a saddle about 1.2 miles northwest of the dam site (pl. 5) is equally

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Plate 5.- Geologic map of the spillway site in the
$S\frac{1}{2}$ sec. 32, T. 5 N., R. 5 W.

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advantageous for a dam at either of the two positions shown on plate 2. Within 1,000 feet of that saddle in every direction all the bedrock appears to be shale. Like the similar rock that crops out at the dam site, this shale is thoroughly decomposed to a moderate depth beneath the land surface and even if unweathered has low bearing power and would be abraded easily by swiftly flowing water. However, it is essentially impervious. Any spillway structure across the saddle should have an extensive pavement downstream. If it is contemplated that the main dam would rise above the 600-foot contour, the spillway structure must also serve as a dike to close the saddle. For this dual purpose, the structure should have a relatively wide base and should be seated on unweathered shale. Its maximum feasible height can not be estimated closely without loading tests and percolation tests on the foundation material.

Nehalem Falls dam site

The lowest dam site on the Nehalem River, at Nehalem Falls (pls. 6, 7),

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Plate 6.- Geologic map of the Nehalem Falls dam site, Nehalem River.

Plate 7.- Nehalem Falls dam site viewed upstream from the road bridge.

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appears to involve only two extensive rock units, an incoherent terrace deposit and volcanic bedrock (basalt). The character of each of these units with respect to the construction of a dam is treated in following paragraphs.

The terrace deposit consists largely of poorly assorted sand grains, pebbles, and cobbles as much as 8 inches in diameter. These are derived from dense volcanic rocks, chiefly from basalt; all are slightly weathered so that their exteriors are bleached and iron-stained but even the finest sand commonly is not thoroughly disintegrated. These stream-borne materials are exposed along the streamward faces of two terrace remnants about 30 feet above the river: one on the left (east) bank at the upstream edge of the area shown on plate 6, the other on the right bank near the downstream edge of the area. Near the landward edges of the two remnants, the stream-borne materials are mingled with slightly assorted slope wash. The deposit as a whole rests on a rock shelf from 2 to 15 feet above river level; thus, its maximum thickness is estimated as about 30 feet. It is highly pervious and incompetent to sustain a rigid dam.

The greater part of the volcanic rock (basalt) is composed by several thick sheets which dip about 5°-10° N. 30° E. or diagonally upstream, and which are fine-grained, dense, and relatively fresh. Such rock has moderately high crushing strength, probably at least 20,000 pounds to the square inch. However, three features detract somewhat from its strength in mass, as follows:

1. Fractures, which in all parts of the mapped area are undulatory, discontinuous, and commonly 10 feet or more apart. The most persistent are subvertical and trend about NE. or NW. - that is, roughly parallel or transverse to the course of the river in the central third of the area. A few have crushed selvages as much as 4 inches thick. Cross fractures, random in strike and dip, are common. Together, these fractures probably weaken large masses of the basalt only slightly, for the plates and blocks that intervene between fractures are random in size and shape and are rather closely interlocked. However, this is not true of the thin spur that affords the east bridgehead near the downstream edge of the area: a considerable part of that spur is unstable and seems to be sliding toward the river. The stability of the thin spurs on either side of the valley in the central part of the area is likewise questionable.

2. Thin fragmental partings (basaltic scoria and flow-breccia) which separate the sheets of dense basalt at some places, as on the rock platform along the west bank of the river in the central part of the area. Such fragmental materials are relatively weak. However, fairly extensive outcrops suggest that such partings are neither thick nor extensive; also those which are exposed dip upstream and so would oppose the tendency of a dam to slide downstream.

3. Zones in which the basalt is slightly or moderately decomposed and is cut by veinlets of non-metallic minerals (drusy quartz and zeolites, in part cellular) as much as 2 inches thick. These zones undoubtedly are somewhat weak. Their number and extent are not fully disclosed by the outcrops, but they seem to be most extensive in the downstream half of the area.

Small portions of the volcanics that crop out are composed, respectively, of fine-grained dense basalt in thin dikes and of massive coarsely fragmental rock (basaltic agglomerate in large part) similar to that which occurs at the Elsie site upstream. Both upstream and downstream near Nehalem Falls massive fragmental rock is extensive and commonly is deeply weathered. Possibly it is also extensive in the parts of the site that are covered by slope wash. This possibility is a critical feature of the site with respect to the erection of a dam, for doubtless the fragmental rock is materially weaker than the non-fragmental basalt and probably would not sustain an extremely thin dam. However, because landslide forms are absent, it is believed that any fragmental rocks at the Nehalem Falls site are not nearly as weak as those on the east bank of the river at the Elsie site.

The most advantageous position for a dam at Nehalem Falls appears to be that indicated by the line marked "AB" on plate 6. At that position both abutments are broad, whence it is inferred that fractures do not make either unstable. Nearly continuous exposures show dense non-fragmental basalt of high bearing power all across the stream bed and the full height of the right abutment. The unconsolidated stream deposits are neither extensive nor very thick and so can be removed with little excavation. However, the nature of the bedrock below the stream bed and in the left abutment is not known and should be explored by core drilling. If all the bedrock is non-fragmental basalt such as forms the right abutment, the site probably is suitable for a rigid dam of gravity cross-section. If, however, the bedrock in the left abutment or beneath the river bed is largely fragmental the site may be suitable only for a flexible dam. A structure of this sort might well be a fill of rock quarried from the dense basalt high on the right bank.

To restrain leakage, the dam should embody an impervious membrane seated in sound bedrock and extending somewhat below the floor of the chute which forms the "falls" about 250 feet downstream. In addition a grouted curtain or other measures to seal fractures in the abutments will probably prove desirable; the extent of such a curtain can not be determined from data now available.

With respect to the design of a permanent spillway, the geologic features of the dam site at Nehalem Falls offer no critical problems, for the dense basalt that forms nearly all the bedrock along the stream would be abraded very slowly by water flowing swiftly and in considerable depth. Thus, an over-fall spillway appears feasible. Some paving may be necessary to prevent the plucking of small blocks from fracture zones but this need not be extensive.

Rogue River basin

Little Butte Creek

South Fork dam site

The dam site on the South Fork of Little Butte Creek (fig. 1) com-

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Figure 1.- South Fork dam site, Little Butte Creek.

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prises an alluvial plain from 250 to 600 feet wide, bluffs 70 to 80 feet high along either margin of that plain, and gently sloping terraces 750 to 1,000 feet wide rising to the proposed pond level at the 1,840-foot contour.

The alluvium is composed largely of unassorted gravel and cobbles. It is a tongue of the extensive fill in the Medford Valley to the west and has buried the floor of an older and somewhat deeper valley. Accordingly, where it is thickest, the alluvium at the South Fork site may extend several tens of feet below the stream bed.

From the alluvial plain up to and above the 1,840-foot contour, all the exposed rock in both abutments is volcanic (andesite or rhyolite) and appears to form a single thick sheet which dips gently northward or northeastward. This rock is dense, fine-grained, and brownish maroon in color. Locally it has a pronounced platy parting, as in the right (east) abutment near the point marked "b" on figure 1 where the plates average about an inch in thickness, are nearly horizontal below the 1,750-foot contour, but steepen gradually until they are nearly vertical at the 1,790-foot contour. Platy parting is not conspicuous in the left (west) abutment. Except for the platy parting and for joints that are described below, the andesite is not pervious and has moderately high bearing power although much of it is slightly decomposed and contains opaline silica in crevices.

Whether the dense andesite is underlain by weak or pervious rock at a depth so shallow as to influence the construction of a dam is not known. Obviously, that possibility should be tested by exploratory drilling.

Two sets of fractures cut the andesite; these dip 75°-90° N. 65°-80° W. and 65°-90° S. 20° W., respectively. Fractures of the first set, which strike sub-parallel to the river, are conspicuous in the left (west) bluff near the point marked "a" on figure 1. There, these fractures are from 2 to 10 feet apart, clean, undulating, and discontinuous; secondary fractures are few and random in direction. Also, the outermost fracture plates along the face of the bluff are sagging and have pulled apart as much as half a foot. In the right (east) bluff, a fracture in this direction passes through the small saddle just east of the point "b"; along it, the matrix of the andesite has been altered to an earthy white mass and silica has been deposited locally.

Fractures of the second set are prominent in the right bluff along the end of the spur ridge that is bisected by the line marked "BC". These strike across the river and are parallel to the north and south flanks of the spur, whence it is inferred that the two flanks are likely to follow zones of weakness caused by fractures. If these inferred zones of weakness are prolonged westward across the river, the one to the south passes through a notch in the left bluff; the one to the north passes across the north end of a cliff-forming ledge near the point "a".

Three alternative positions for a dam at the South Fork site are indicated on figure 1 by the lines marked "AB", "BC", and "CD". Position AB crosses the tongue of alluvial gravel where it is narrowest within the area represented by figure 1, but position CD appears to involve the dam of shortest crest and of least volume above the present land surface. However, either of these positions crosses one of the two inferred zones of weakness due to fractures. Position BC lies mid-way between the two zones but requires the longest dam of the three. Before a prudent choice can be made between these alternatives, exploratory excavations and borings should determine the thickness of the alluvium and the character of the andesite in the two inferred zones of weakness.

A rigid dam with a moderately wide base probably would be feasible if it were founded wholly on the sound andesite. Satisfactory aggregate for concrete probably could be screened from the alluvium close at hand although it might prove necessary to reject a considerable portion in order to obtain the proper assortment in sizes of particles. A rock-fill dam likewise seems feasible and advantageous quarry sites occur on the ridge above the right abutment. A structure of this sort would call for a substantial impervious membrane to connect the dam with the bedrock below the alluvium. Sufficient material for an earthen dam is not available near the site.

Neither abutment appears to call for elaborate measures to restrain percolation, for the visible fractures in the bedrock are clean and probably could be sealed effectively by grouting. Only exploratory drilling will show whether more elaborate measures would be necessary for the rocks below stream level.

Lakecreek dam site

At the Lakecreek dam site (fig. 8) successive sheets of non-fragmental

Figure 8.- Lakecreek dam site, Little Butte Creek.

and fragmental volcanic rock (basalt, basaltic agglomerate, and basaltic tuff) dip slightly downstream. The non-fragmental basalt is massive and fine-grained. At most places it is parted into rude columns about 5 feet across and at a few places is cut by subvertical shear zones an inch or so wide. This rock has fairly high bearing power and is impervious except for its fractures. The coarsest fragmental rock (agglomerate) comprises a moderately dense matrix and enclosed blocks of basalt, andesite, and rhyolite (?) as much as 8 inches through. In bearing power it is moderately inferior to the non-fragmental basalt. The fine-grained fragmental rock (tuff), which is very poorly exposed, appears to be massive and somewhat friable; doubtless it is rather low in bearing power and in part may be plastic if saturated with water.

A single sheet of the basalt about 75 feet thick forms the upper part of each abutment. Along the west bank of Lake Creek this basalt appears to grade downward into the agglomerate at an altitude of about 1700 feet and the agglomerate in turn into tuff. Along the road that ascends the right (northeast) abutment, however, the basalt rests directly on tuff at an altitude of about 1,674 feet. Still lower, basalt recurs along the edge of the alluvial plain for a distance of more than 500 feet on either side of the line that is marked "AB" on figure 8.

The alluvium along Little Butte Creek at this site consists of coarse gravel and cobbles as large as 8 inches in diameter. This material may extend several tens of feet below the stream bed.

Before a dam for the Lakecreek site is designed the extent and thickness of the relatively weak agglomerate and tuff in the abutments and beneath the foundation should be thoroughly explored. Only a flexible dam with a moderately wide base seems feasible. Rather extensive works to restrain seepage might be required.

Unnamed dam site near Butte Creek School

At the dam site about a quarter of a mile east of the Butte Creek School, fractured volcanic rock (andesite) is exposed in a road cut for about 250 feet along the base of the right (north) abutment. The exposure is bisected by the line marked "AB" on figure 3. The principal

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Figure 3.- Unnamed dam site near Butte Creek School.

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fractures are subvertical and strike about N. 50° E. - that is, nearly parallel to the line AB. Commonly they pass into shear zones as much as 18 inches wide and their wall rocks are decomposed and soft. Some of the secondary fractures are subvertical and strike about N. 80° E. or N. 65° W.; others strike about N. 30° W. (roughly parallel to the stream) and dip about 10° NE. Together, these fractures form a rubble of blocks 1 to 4 feet across. The upstream (eastern) end of the road cut exposes chalky-white "gouge" (fault breccia?) that strikes across the stream in prolongation of the upstream flank of the spur that forms the left abutment.

On the left (south) abutment a small mass of decomposed fractured andesite crops out at an altitude of about 1,610 feet. There also the principal fractures are parallel to the line AB. About 50 feet higher, deeply weathered andesite (?) is exposed in the banks of the canal that follows the 1,660-foot contour.

Altogether, this unnamed site appears to hold serious obstacles to the construction of a dam. Much of the volcanic bedrock is fractured and decomposed. The land forms close at hand imply shear zones or faults transverse to the stream. The alluvial tongue that forms the flood plain is relatively wide and may be thick. Probably, therefore, the foundation and abutments would not sustain a heavy load and would require elaborate works to control percolation through abutments and foundation.

Brownsboro dam site

The Brownsboro site involves two potential dams - one across Little Butte Creek in the position marked "AB" on figure 4, the other in the

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Figure 4.- Brownsboro dam site, Little Butte Creek.

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position marked "CD" to close a low saddle in the left (south) bank. (See also pl. 8,A.) The right (north) abutment for the main dam is

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Plate 8.- A, Brownsboro dam site: left abutment of main dam and site for saddle dam, viewed from right abutment.

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afforded by a single terrace-forming sheet of dense volcanic rock (andesite ?) which is exposed by road cuts for about 200 yards on either side on the line AB and in a small road-metal quarry about a quarter of a mile farther east. At the westernmost exposures the andesite is fresh, massive, and columnar. Its fractures are clean, discontinuous, undulatory, and on the average about 4 feet apart. Upward toward the terrace and eastward along the road the andesite becomes less crystalline and somewhat platy. At the quarry, both blocky and platy fractures are well disclosed for about half the height of the abutment. (See pl. 8, B.)

Plate 8.- B, Platy and blocky andesite (?) in quarry near the Brownsboro dam site.

The left (south) abutment for the main dam and the west abutment for the saddle dam are afforded by the flank of an outlying knob that appears to comprise several subvertical plates of massive medium-grained andesite (?). These plates strike diagonally across the stream (N. 10° W.), are from 2 to 30 feet thick, and are composed of subhorizontal columns from 1 to 3 feet across. All fractures are clean. An extension of this andesite mass forms the east abutment for the saddle dam but there the rock is less crystalline and the fractures are random in strike and dip.

The outlying knob just described probably is the eroded remnant of a lava dome and the terrace-forming extensions to the north and east probably are segments of its marginal lava field. A lava field of that sort may have buried tuff, agglomerate, or stream deposits that would now underlie the foundation or abutments of the dams.

The recent stream deposits probably are composed largely of poorly assorted gravel and cobbles and, where thickest, may extend several tens of feet below the stream bed.

With respect to the most advantageous type of dam the geologic features of the Brownsboro site are very much like those at the South Fork site (p. 32). Possibly the advantage rests with a rock fill for the main dam owing to convenient quarry sites in the knob that overlooks the left abutment. On the other hand the saddle dam probably could be founded wholly on the sound andesite without deep excavation, so that a rigid structure is probably feasible.

Evans Creek

Upper dam site

At the upper dam site on Evans Creek the bedrock in both abutments and beneath the flood plain is dense, highly silicified, and thoroughly recrystallized. Locally it is traversed by veinlets of coarse-grained granitoid rock (quartz-diorite ?). Diller 3/ has indicated that this rock was probably derived from a volcanic rock (rhyolite) and has termed it "metarhyolite". Commonly, this rock is distinctly laminated owing to partial segregation of its dark and light minerals into alternate bands a few millimeters thick. However, these laminations are not planes of weakness for they are inclined in all directions, are contorted at some places, and are commonly transected by joints. Except as it may be weakened by fractures, and possibly by faults, the sound metarhyolite is competent to sustain a concentrated load such as would be imposed by an inflexible narrow-base dam.

3/ Diller, J. S., U. S. Geol. Survey Geol. Atlas, Riddle folio (no. 218), p. 4, 1924.

Both subvertical and low-angle fractures are present. Except along the east edge of the area that is represented by figure 5 nearly all the

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Figure 5.- Upper dam site, Evans Creek.

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visible subvertical fractures are undulating, discontinuous, tight, and clean. The most extensive strike about N. 40° W. (across the stream) and are from 10 to 15 feet apart but intervening discontinuous fractures in the same direction may be as little as 6 inches apart. Other subvertical fractures trend about N. 65° W. or N. 85° E. The low-angle fractures are inconstant in direction but usually dip 15°-30° from S. 10° E. to S. 20° W.- that is, into the left or south abutment. Commonly they are from a few inches to a foot apart and produce coarse platy parting. All these fractures are especially well disclosed in the bed and left bank of the creek for about 400 feet upstream from the line that is marked "AB" on figure 5.

Near the southeast corner of the area that is represented by figure 5, along the east bank of Ramsey Creek, road cuts disclose a broad zone of subvertical shearing and crushing which appears to prolong the bold facet at the eastern end of the ridge across Evans Creek. Obviously this zone is a line of weakness; possibly it is a fault. Its strike is roughly parallel to the most extensive joints described in the preceding paragraph, also to two pairs of collinear ravines that descend either bank of Evans Creek within 400 feet downstream from the line AB. These features imply lines of weakness in the bedrock near the center of the area, a possibility that can be investigated by trenching through the slope wash.

The recent stream deposits at the upper dam site comprise sand, gravel, cobbles, and some boulders as much as 18 inches long; they are disposed in flood-plain bars and a low discontinuous terrace about 12 feet above the stream. It is inferred that within the dam-site area, these deposits are usually less than 15 feet thick because the underlying bedrock forms much of the creek bed and crops out here and there across the full width of the flood plain, also because the stream appears to have been degrading steadily.

A slope-wash fan extends along the base of the right (north) bank from about 600 feet upstream to 200 feet downstream from the line AB; its apex is at least 60 feet above the flood plain. This fan may very well have overridden tongues of stream gravel in former and somewhat higher channels of the creek. An analogous fan occurs along the opposite bank beginning about 100 feet downstream from the line AB and extending to and beyond the west boundary of the area shown on figure 5. Fans of this sort may well be formed of rehandled landslide rubble but recent landslide amphitheatres or scarps were not discriminated among the land forms of the site and its vicinity.

Lower dam site

At the lower dam site on Evans Creek (fig. 6), which is an alterna-

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Figure 6.- Lower dam site, Evans Creek.

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tive to the upper site just described, the bedrock is also fractured silicified "metarhyolite". At this lower site, however, the bedrock is less distinctly laminated, has coarser and less extensive low-angle parting, and contains more veinlets of quartz diorite. These features are disclosed by continuous outcrops across the stream bed along the line marked "AB" on figure 6 and on the left (south) abutment as high as the 1,440-foot contour, also by discontinuous outcrops equally high on the north slope of the valley. Within the area shown on figure 6 the higher part of either valley slope is mantled with stony soil and fragments of the bedrock. Nowhere do the land forms suggest that this slope wash is thick or that the bedrock is unstable.

The principal subvertical fractures are from 2 to 10 feet apart and dip (1) about 80° N. 70° E., (2) 75°-90° N. 30° E., or (3) 70° N. 25° W. Commonly these fractures are discontinuous and are arranged en echelon; those exposed at the land surface are undulating and are not accompanied by shear zones or partings of gouge. Each of the three fracture sets just described strikes roughly parallel to certain segments of Evans Creek at and near the dam site; two strike parallel to ravines in the right (north) wall of the valley. Possibly, therefore, concealed joints or shear zones determine the course of the stream locally and might afford zones of material weakness in the foundation or abutments of a dam. This possibility is believed to be remote; nevertheless, if a narrow-base dam is contemplated the possibility should be explored thoroughly, particularly along the northwest and east flanks of the spur that forms the left abutment and along their prolongations to the collinear ravines across the valley. (However, see p. 43 .)

The low-angle fractures are undulating and discontinuous. Where they are disclosed along the stream for more than 200 feet in either direction from the line AB they dip 5°-20° upstream.

The stringers or dikes of quartz diorite are coarse-grained, range from half an inch to 5 feet in width, are subvertical, and generally trend across the stream. They appear not to create zones of weakness for commonly they are transected by the fractures. Outcrops and slope wash suggest that these dikes are uncommonly numerous in the spur that forms the left abutment below an altitude of 1,490 feet, whence it is inferred that the spur may exist only because the dikes and accompanying silicified zones are unusually resistant to erosion.

Both upstream and downstream from the line marked "AB" on figure 6, the floor of the Evans Creek Valley widens moderately and is veneered with poorly assorted gravel and cobbles as large as 12 inches in diameter. These unconsolidated deposits are inferred to be thin as at the upper site.

Both sites along Evans Creek appear suitable for a rigid narrow-base dam as much as 125 feet high if that dam is founded wholly on the metarhyolite. The lower site probably would involve less excavation and scaling to prepare a satisfactory foundation and perhaps could be more effectively grouted to restrain percolation through the abutments.

As the steep north slope of the valley affords a quarry site close above each of the dam sites, a rock fill might be advantageous. The impervious membrane of a rock-fill dam at either site should be extended through slope wash and stream gravel into sound rock beneath.

Either dam site appears to favor a simple over-fall spillway without an extensive downstream apron, for sound metarhyolite would be particularly resistant to scour except where closely fractured. Works to prevent undercutting the concave bank of the creek just below either site would probably be needed.

Willamette River basin

South and Middle Santiam Rivers

Cascadia (Upper Cascadia) dam site

Character and extent of the rocks.- At the Cascadia dam site, which is known also as the Upper Cascadia site (pl. 9), all the bedrock is

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Plate 9.- Geologic map of the Cascadia (Upper Cascadia) dam site, South Santiam River.

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basalt (a lava rock). Two distinct sheets of this rock are exposed: an upper sheet which is columnar and a lower sheet which is non-columnar and in part fragmental. The two are thought to be nearly parallel and to dip about 10° SE. (upstream), but to be separated by an unconformity of slight relief.

The upper sheet of basalt appears to be about 200 feet thick and, along the line marked "AC" on plate 9, to form both walls of the valley from about the 975-foot contour down to the 760-foot contour, which is about 15 feet above ordinary river stage. This upper basalt is fine-grained, non-cellular, and doubtless of high compressive strength. Throughout it is parted into columns which are rudely hexagonal in cross-section, on the average are about 2 feet through, and are inclined 60°-75° N. 10° W. (downstream). Their inclination is least at the base of the sheet. At the land surface, the columnar partings commonly are crevices as much as an inch wide; below the zone of frost, however, they are probably tight so that the columns are interlocked rather securely.

The uppermost part of the lower basalt, in a zone which is fairly continuous but commonly not more than 5 feet thick, is fragmental (a flow-breccia). It comprises a dense fine-grained matrix and angular inclusions which are also dense and which ordinarily are not more than 4 inches long. Only here and there is the matrix cellular (vesicular or scoriaceous). This fragmental zone undoubtedly extends into either bank of the stream but, because it probably has only slightly less crushing strength than the non-fragmental rock and is no more pervious, does not cause serious weakness.

The remainder of the lower basalt, in which the United States Army Engineers have sunk one diamond-drill hole to a depth of 105 feet (see p. 51), is dense and strong. Two specimens of its core failed under compressive loads of 19,500 and 30,900 pounds to the square inch, respectively. Throughout, it is parted by fractures that provide openings for seepage but probably do not materially diminish the bearing power. So far as is indicated by outcrops, all the fractures are discontinuous, snug, and lack crushed selvages that would act as lubricants increasing the tendency for sliding. The principal sets of fractures are as follows:

(1) dip 70°-90° N. 30°-40° W., commonly from 2 to 6 inches apart in platy or crushed zones that are fairly well healed by veinlets of non-metallic minerals (zeolites and quartz); (2) dip subvertical, strike N. 55°-70° W. or N. 25°-40° W., commonly en echelon and 0.7 foot to 8 feet apart; (3) dip about 10° S. 50° E., or upstream and roughly parallel to the top of the non-columnar basalt; and (4) dip 15°-25° from N. 55° W. to S. 75° W., or diagonally downstream. Even so fractured, the non-columnar basalt is believed to be essentially rigid.

There are at least two unconsolidated stream deposits at the site: one which forms bars in the stream bed and a discontinuous veneer on the flood plain, and another which veneers remnants of a terrace about 40 feet above the stream or 760 to 780 feet above sea level. A third stream deposit is suggested by a terrace remnant, 830 feet in altitude, on the right bank upstream from the line AC (see pl. 9). The deposits of the stream bed and of the 780-foot terrace are composed of sand, pebbles, cobbles, and a few boulders. Both doubtless are highly pervious and lack stability to support a masonry dam.

Summary of features pertinent to the construction of a dam.- The area that is represented by plate 9 affords only one position for a high dam of economic volume, about along the line AC. The most critical feature of this position is the thinness of the two abutments, which are composed of columnar basalt throughout - at least below the 910-foot contour on the left (west) bank and below the 970-foot contour on the right bank. Because they are columnar it is doubtful whether they can withstand horizontal stresses exceeding their weight. Thus, the site probably is not suitable for a thin rigid dam that is arched for stability. However, it is believed that the site is suitable for a rigid dam of gravity cross-section, provided all loose columns are scaled from either abutment.

The depth of excavation and sealing necessary to uncover sound bedrock is imperfectly known. Judging from the record of the single diamond-drill hole and from the height of the stream-bed bars, the thickness of the lower unconsolidated deposit does not average more than 15 feet. However, the maximum thickness may be greater if, as seems likely, the rock floor of the stream bed is fluted as at the cascade 750 feet downstream from the drill hole. On the right or east abutment, it is estimated that the average depth of sealing may be at least 25 feet. On the left abutment, the zone of slope wash and insecure rock is probably somewhat thinner.

Openings for leakage in serious volume are afforded by the columnar partings in the upper sheet of basalt and by the less numerous but more extensive fractures in the lower sheet. In this respect, the whole right or east abutment is critical for it is so thin that the proposed 260-foot dam would impose a hydraulic gradient ranging from about 50 to fully 200 percent. Obviously, thorough measures to seal the openings will be necessary in this abutment. Somewhat less extensive sealing would be required in the left abutment.

Spillway.- It is proposed to spill excess water across the north abutment into Shotpouch Creek by means of a cut about 50 feet deep across the narrow saddle at the point marked "D" on plate 9. Any spillway structure at that place would have a firm foundation on basalt. The wasteway is underlain throughout by basalt, which probably would erode so slowly that an extensive pavement would not be required to assure the stability of the structure. However, the wasteway is steep and is mantled almost continuously with loose slope wash whose volume probably is so great in proportion to the small creek valley below that the wasteway should be stripped to fairly sound rock before any large quantity of water is passed over it.

Record of diamond-drill hole.- One vertical diamond-drill hole has been sunk at the Cascadia dam site by the United States Engineer Department. The following record of this hole is based on an examination of the core by the writer and on supplemental data from McKitrick. 4/

4/ McKitrick, W. E., op. cit., p. 17 and table following, graphic record of drill hole.

Hole no. 1

[In center of river bed 80 feet upstream from line marked "AB" on plate 9; altitude of river bed, 740.4 feet above sea level. Core recovery 91 percent of the bedrock.]

	Thickness (feet)	Depth (feet)
Stream gravel	5.7	5.7
Basaltic flow-breccia: fragments of basalt as much as 8 inches through embedded in dense fine-grained basalt. Oxidized and leached	1.9	7.6
Basalt, dense, porphyritic (contains scattered crystals large enough to be seen without magnification). Lower part brecciated and healed with veinlets of non-metallic minerals; decomposed slightly throughout and thoroughly at bottom	13.4	21
Basalt, dense, fine-grained; contains a few veinlets; contact with underlying rock well defined and snug. Ultimate crushing strength of one specimen 19,500 pounds to the square inch	11.6	32.6
Basalt, dense, sub-crystalline and brittle (core partly in small chips); contains a few flecks and veinlets of secondary minerals; Central part closely fractured	14.9	47.5
Basalt, dense, fine-grained; many veinlets of secondary minerals	6.3	53.8
Basalt, dense, sub-crystalline, and brittle; flecks and veinlets of non-metallic minerals, also scattered crystals of pyrite (iron sulphide). Several zones of close fractures. Ultimate crushing strength of one specimen 30,900 pounds to the square inch.	51.2	105.0

Lower Cascadia (Horseshoe) dam site

<u>Character and extent of unconsolidated materials</u>.- The Lower Cascadia or Horseshoe dam site (pl. 10) exposes at least two unconsolidated

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Plate 10.- Geologic map of the Lower Cascadia (Horseshoe) dam site, South Santiam River.

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stream deposits, a young deposit in the stream bed and on the narrow discontinuous flood plain and materials that form remnants of a terrace from 40 to 60 feet above the river. The young stream deposit is composed largely of unassorted cobbles and boulders which are as much as 18 inches in diameter and which are derived from dense volcanic rocks. It is not extensive and probably is not thick at most places. Being pervious and incoherent, it is not a desirable material to remain beneath a dam; however, little of it is present where a dam would be feasible, in the vicinity of the lines marked "AB" and "CD" on plate 10. The terrace deposit is similar in character except that it contains more fine particles and is somewhat weathered. It does not occur within several hundred feet of the feasible position for a dam.

Incoherent slope wash and loose rock cover nearly all the area except the bluffs, from 30 to 100 feet high, along either bank of the river. This material consists of rock fragments mingled with residual earth; it is in part clayey and undoubtedly would be quite unstable if saturated with water. Its thickness has not been determined by test pits or drilled holes but undoubtedly is several tens of feet at many places, especially on the left (south) bank above an altitude of 700 to 775 feet.

<u>Character of the bedrock</u>.- Three distinct bedrock units are discriminated tentatively, as follows: (1) an upper unit, very poorly exposed, which seems to be composed largely of fragmental volcanics (tuff) with some sheets of lava rock (basalt); (2) a middle unit of thick-bedded basalt, which forms the stream bed and the lower part of either valley wall at the site; and (3) a lower unit, of unknown thickness, which consists of stratified fragmental volcanics (tuff and agglomerate). These three units appear to be parallel to one another and to dip about 2°-6° S. 40° E. (diagonally upstream), but exposures are not adequate to establish this relation with certainty. The character and extent of each unit are described in following paragraphs.

The upper unit, of fragmental volcanics and basalt, is inferred to form a large part of the left (south) bank above an altitude of 720 to 800 feet. Possibly it occurs also on the right bank between the 740-foot and 800-foot contours in the upstream third of the area shown on plate 10. To judge from a few exposures in road cuts on the left bank and from the residual soil, the fragmental volcanics range from laminated fine-grained tuff to unstratified agglomerate that comprises fragments of dense volcanic rock with a fragmental matrix of fairly fine grain. The finest material probably is plastic when wet and is self-slaking in the air. A small portion of the material may be somewhat pervious. Crushing tests on 15 specimens of diamond-drill core from similar fragmental rocks at other dam sites in the region indicate ultimate strengths ranging from 760 to 8,940 pounds to the square inch 5/ and averaging 2,860 pounds.

5/ McKitrick, W. E., op. cit. (North, Middle, and South Santiam Rivers; Calapooya River).

Even this average, which is moderate, may not be reliable, for some of the material - presumably the finer-grained and weaker part - did not yield a core and so was not represented in the crushing tests. Obviously, the similar fragmental rocks at the Lower Cascadia site can not sustain a heavy load or give adequate support for a rigid dam. If their extent has been correctly inferred, they may limit the height of dam for which the site is adapted. (See p. 59.)

The middle unit, of basalt, is an extensive sheet or series of sheets with an aggregate thickness of about 200 feet. Throughout, it contains no extensive cellular or fragmental (tuffaceous or scoriaceous) zones. Most of it is fine-grained to sub-crystalline and fairly fresh; thus, its crushing strength may be inferred to be at least 20,000 pounds to the square inch and possibly as much as 50,000 pounds. In a few zones, the basalt is somewhat decomposed, is cut by many thin veinlets of non-metallic minerals; and so is weakened moderately. However, such zones appear to be neither numerous nor extensive and so probably are not a serious deficiency in the site. This basalt forms the stream bed and either wall of the valley to a height of at least 120 feet; also, it passes beneath the upper unit of fragmental rocks on either bank. It is essentially rigid and a superior foundation material.

All the basalt is parted by fractures, which afford openings for seepage under high head and loosen some plates and blocks. Characteristically, these fractures are wavy, discontinuous, and lack extensive selvages of crushed rock such as might facilitate the sliding of one rock plate upon another. Many are open crevices at the land surface, owing to frost action and in part to local sliding; probably these are snug below the zone of weathering. The principal directions and types of fractures appear to be as follows: (1) Strike N. 5°-20° W., dip 85°-90° E., relatively extensive all along the river, ordinarily from 10 to 30 feet apart but form some platy zones as much as 5 feet wide. In the upstream third of the mapped area, some plates formed by these fractures are sagging toward the stream. (2) Strike about N. 75° W., dip subvertical. (3) Dip less than 8° in various directions, wavy; common in the lower 50 feet of the bluffs along the river, particularly a few hundred feet downstream from the line AB where they are from 2 to 10 feet apart. These partings may follow flowage planes in the basalt or contacts between successive flows of the basaltic lava. (4) Discontinuous fractures, random in strike and dip, from 1½ to 10 feet apart in all parts of the area. (5) At a few places in the downstream part of the area, a parting into hexagonal columns such as are typical of some basalt.

Together, the fractures just described part all the basalt into blocks and plates of random form and size. Below the zone of weathering, these probably are rather tightly interlocked so that large masses of the rock would be stable under a stress equal to a large part of the crushing strength. However, small crags and spurs are not so secure and may be unstable under their own weight. Thus, to a moderate depth below the land surface at some places, doubtless there are many loose plates and blocks. The average thickness of this insecure zone is not known and can not be estimated in advance of intensive exploration by pits and drilled holes.

The lower of the three bedrock units, which is composed of stratified fragmental volcanics, crops out along the right bank of the river near the downstream edge of the area shown on plate 10. There, its beds range from compact gritty tuff to agglomerate that is composed of basaltic fragments as large as 2 inches across embedded in a compact fragmental matrix. These beds appear to be non-plastic and to have moderate bearing power; probably they are slightly pervious. It is not known whether any weak or plastic beds underlie those which are exposed. These fragmental rocks of the lower unit dip about 2° S. 50° E. (diagonally upstream) and pass beneath the thick-bedded basalt. Thus, their top is roughly estimated to be from 50 to 75 feet below the stream bed at the line AB and at progressively greater depth farther upstream.

Summary of critical features.- The three bedrock units that have been described - the upper fragmental rocks, the thick-bedded basalt, and the lower fragmental rocks - afford, respectively, (1) non-rigid materials of slight bearing power over the upper part of the left bank, perhaps also on the right bank in the upstream part of the area; (2) an underlying rigid material of uniform and high bearing power which forms the lower slopes and the floor of the valley; and (3) materials of medium or slight bearing power which underlie all the site at a moderate depth below the river bed. Thus, with respect to the type and height of a feasible dam, the most critical features of the site are: first, the thickness and extent of the weak fragmental rocks on the upper part of either abutment and, second, the thickness of the rigid basalt below the river bed. The foregoing descriptions of the rocks have presented tentative interpretations of these two critical features, based on the scant data that are afforded by the exposures. To verify these interpretations, test holes should be drilled (1) to a depth of about 100 feet from points on the 800-foot contour on either slope of the valley and (2) in the river bed.

General limits may be placed on the position, type, and height of dam for which the site is adapted. Thus, on plate 10 the line marked "AB" indicates the most economical position for a dam of the full height contemplated - that is, about 190 feet above the river or up to the 800-foot contour. The reach of the river from about 600 feet upstream to 300 feet downstream from that line includes all the desirable positions for a dam between 100 and 200 feet in height. Along the line AB, the rigid basalt forms all the right abutment, underlies the river bed to an estimated depth of about 50 feet, and forms the left abutment for about 110 feet above the river or up to about the 725-foot contour. Thus, to that height the site appears suitable for a rigid dam, of gravity cross-section if the basalt is only moderately thick beneath the stream bed but possibly thin and arched for stability if the basalt is so thick as to distribute the load adequately onto the weaker fragmental rocks beneath. A higher dam would extend onto the weak fragmental rocks in the left abutment and so should be broad and probably flexible. A rock fill is suggested, for which basalt could be quarried high on the right bank.

If a dam only 110 feet high is adequate for utilization of the stream, the most advantageous position is probably along the line marked "CD" on plate 10. That position would require a shorter dam. Also it may afford a greater thickness of the rigid basalt beneath the stream and so permit a thinner dam.

Under heads between 100 and 200 feet the fractured basalt doubtless would leak moderately, especially in the left or thinner abutment. Grouting or other measures to control this potential leakage seem essential; the extent to which the rock should be sealed can not be estimated from data now available. If the high dam should be erected, special care will be essential in providing an adequate cut-off in the weak fragmental rocks on the upper part of the left abutment.

Spillway problems.- It is proposed to spill excess water across the low saddle on the left bank, which has an altitude of 818 feet above sea level. That saddle and the slope below are deeply mantled with fine residual soil and are underlain, to an inferred maximum depth of 60 feet, by the weak fragmental rocks. Both these materials would scour easily. Accordingly, the spillway structure should embody a substantial cut-off and a relatively extensive pavement on the downstream slope.

Greenpeter dam site

Character, thickness, and extent of unconsolidated deposits.- The 1-mile reach of the Middle Santiam River that constitutes the Greenpeter dam site (pl. 11) contains at least four unconsolidated deposits whose

Plate 11.- Geologic map of the Greenpeter dam site, Middle Santiam River.

character and extent are relevant to the placing and construction of a dam. These are: a young stream deposit in the river bed and on the flood plain, an older stream deposit on a terrace about 75 feet above the river, coarse debris from rock slides, and materials of diverse origin that mantle the greater part of either valley wall. Succeeding paragraphs describe each in turn.

The young stream deposit comprises water-worn particles in all sizes from coarse sand to boulders 30 inches long; all these are derived from dense volcanic rocks and are quite fresh. The deposit is discontinuous, both in the stream bed and on the flood plain; commonly it rests on a rock-cut shelf a few feet above river level. Its thickness probably is not more than 10 feet except where it may fill flutes in the bedrock. Because it is unstable and highly pervious, the deposit should be removed completely from beneath a dam; because it is so thin and is not extensive, the volume of this excavation would be slight at any place along the 1-mile reach of river.

To judge from a very few small exposures, the older stream deposit is similar to the young deposit in range of grain sizes and in the types of rock from which it was derived. It is dissimilar in that it is rather thoroughly weathered, so that its smaller particles have disintegrated to gritty clay. The deposit is extensive only in the upstream half of the area covered by the geologic map where it forms two remnants, one on either bank, of a terrace about 800 feet above sea level. Its maximum thickness may well exceed 50 feet. This older stream deposit is likewise unsuitable to remain beneath a dam; its removal would entail considerable excavation at any place in the upstream part of the area.

Within the area shown on the geologic map, rock-slide debris is most extensive just below the mouth of Greenpeter Creek, where it spans the flood plain and river bed for a distance of 600 feet. There, it comprises angular blocks of the local bedrock, basalt, from about 2 feet to 20 feet long. Other large blocks are scattered along the banks and in the bed of the river for a distance of 0.6 mile downstream.

The slide just described is one of several along the north bank of the river in the 5-mile reach downstream from Greenpeter Creek. The largest slide, which is 2.7 miles downstream from Greenpeter Creek, extends from river level to a height of about 150 feet and terminates in a cone that is separated from the main wall of the valley - which is a slope and not a cliff - by an arcuate depression. This slide is a rubble of angular blocks of which the smallest is about 2 feet long and the largest about 55 by 18 by 12 feet. (See pl. 12.)

Plate 12.- A, Rock-slide rubble on right bank of the Middle Santiam River 2.7 miles downstream from Greenpeter Creek; B, Blocks in the river at the toe of the slide.

These slides are young in the geologic time scale, for their toes have over-ridden the present stream channel. On the other hand, they are moderately old historically, for blocks in the river channel are scarred by potholes. They are uncommon in the coarseness of the material that forms them. Together, they suggest that the bedrock is unstable to an uncommon depth all along the 5-mile reach of the river. (See p. 64.)

The incoherent materials that mantle either wall of the valley comprise slope wash, debris from small slides, and rock glaciers. Possibly the rock glaciers are the most extensive; their character is best shown in the clearing and by the records of diamond-drill holes (p. 70) at site no. 2 of the United States Engineer Department, which is 1,550 feet downstream from the line marked "AB" on plate 11. There, all the right bank from the 825-foot contour up to and above the 1,100-foot contour is oddly hummocky, somewhat like glacial moraine although the form of the valley as a whole seems not to indicate glaciation. Exposures, test pits, and drill holes show that the area of hummocky topography is underlain everywhere by incoherent material to a depth of 50 to 80 feet. This material is quite heterogeneous and comprises a matrix of gritty clay and many subangular to ill-rounded blocks of basalt as large as 6 feet long. It lacks other types of rock that occur in the surrounding region and that would be expected if the material had been transported from a distance. To an unknown depth beneath the land surface, the material is thoroughly weathered. That this material forms a rock glacier is inferred tentatively. It is also inferred that the blocks which compose it have slid out of place along low-angle fractures - which are numerous and which dip toward the opposite bank (see p. 67) - and possibly along partings of tuff that separate the basalt layers (see p. 66). Movement of the incoherent mass is now facilitated by the abundant clayey matrix. This interpretation also implies that the bedrock may be unstable to a considerable depth. Analogous conditions probably are common all along the reach that is shown on the geologic map; obviously they imply a considerable depth of excavation to reach sound bedrock.

Small landslide amphitheatres are common on both slopes of the valley, especially above the mapped area. Doubtless these are sources for a part of the material in the rock glaciers just described.

Character of the bedrock.- All the bedrock at the Greenpeter dam site is volcanic (basalt and basaltic tuff), but this rock is of two generations that differ greatly in strength. The earlier basalt, which is by far the more extensive, is dense and is spotted with crystals a few millimeters long (porphyritic texture). If sound, its strength in compression appears to be moderately high, for five specimens of un-oxidized core failed between 10,070 and 26,450 pounds to the square inch, on the average at 17,400 pounds. (See p. 72.) Among three specimens of oxidized core, failure occurred as low as 6,920 pounds. The strength indicated by these crushing tests is surprisingly high in view of rather thorough mineralogic changes in the older basalt, to be described. Also they are believed to be misleading, owing to the features suggesting that a thick zone of insecure rock exists on the right abutment if not on both abutments.

The mineralogic changes, which have affected all the early basalt, range widely in intensity. The rock least modified is somewhat earthy in luster but otherwise appears sound. On the other hand, the rock most thoroughly modified is partly decomposed throughout and contains secondary non-metallic minerals (silica and fibrous zeolites) in a network of veinlets or in scattered globular masses (amygdule fillings). The veinlets are as much as half an inch thick and at some places are somewhat cellular. The amygdule fillings are as much as an inch in diameter and where they are most abundant compose fully a third of the rock. In the absence of a crushing test, the most thoroughly modified basalt is believed to be quite weak for its diamond-drill cores can be broken easily with the fingers - like much of the core from the single hole that was drilled at site no. 1 (along the line marked "CD" on pl. 11 ; see p. 71). Basalt so modified is fairly extensive in the outcrops all along the river and so may form zones of serious weakness in foundation or abutments.

This early basalt consists of successive thick sheets that are separated locally by tuff, such as was penetrated at site no. 2 in drill holes nos. 1 and 3. (See pp. 72, 74 .) This tuff is largely fine-grained and earthy but in a small part contains fragments of basalt as much as 3/4 inch through. It probably is essentially impervious except for fractures, and perhaps somewhat plastic when saturated with water. Two specimens of its core had ultimate compressive strengths of 2,440 and 3,870 pounds to the square inch. It seems likely that some sheets of this material are so extensive as seriously to lessen the stability of large masses of the basalt. (See p. 64 .)

The younger basalt, which is not extensive in the outcrops, is fine-grained, dense, and fresh; it forms a few discontinuous dikes that intrude the older basalt. These dikes are from 50 to 600 feet apart; ordinarily they are subvertical, though a few are nearly horizontal (sills). This young basalt is doubtless superior in crushing strength but it forms so little of the mapped area that nowhere does it appear to afford two sound abutments for a dam.

Fractures, which are fairly close throughout the basalt provide openings for percolation to considerable depth and loosen a large volume of the bedrock. The most extensive sets of fractures are as follows: (1) Dip subvertical, strike N. 15°-40° E. or subparallel to the river, and N. 45°-60° W. or transverse to the river. The fractures in these two directions are commonly from 2 to 10 feet apart; a few are platy shear zones. Together they part the basalt into subvertical prisms that are rhomboidal in cross section and that extend the full height of the outcrops on either bank. (2) Strike N. 40° E., dip 60°-65° NW. or toward the right bank. (3) Strike N. 30°-35° W., dip 15°-25° NE. or upstream. (4) Strike N. 60°-70° E., dip 5°-10° SE. or toward the left bank. Fractures in this direction are numerous in outcrops all along the right bank; these are the fractures that are thought to favor development of the rock glaciers.

Because the individual fractures appear to be moderately extensive and nearly plane, the intervening prisms and blocks probably are not securely interlocked. Many of the subvertical fractures are open several inches at the land surface, doubtless owing to slippage along the low-angle partings.

<u>Summary of features pertinent to the erection of a dam.</u>- Owing to the relative weakness of the older basalt that forms most of the bedrock, (p. 65), to the intervening sheets of tuff which doubtless tend to be plastic and of which some probably are extensive (p. 66), also to the close fractures all through the basalt, it is believed that the Greenpeter site is wholly unsuitable for a thin rigid dam that is arched for stability. For the height proposed - about 200 feet above the river or up to the 900-foot contour - the site probably is suitable for a rigid dam of gravity cross-section if all unsound and insecure rock is stripped from the two abutments. To satisfy this requirement may entail scaling the bedrock well below the mantle of incoherent materials; thus, the average depth of excavation may well be as much as 75 feet, especially on the right bank. Obviously, excavation so voluminous would add greatly to the cost of the structure. For a minimum of excavation, the position indicated by the line marked "AB" on plate 11 is perhaps most advantageous. Also, that position appears to offer bedrock as sound as at any place along the river; that the rock may be sounder is suggested by several dikes of the younger basalt which crop out in the left or south bank and trend diagonally upstream.

Thorough exploration may show that the site is best adapted to a rock-fill or some other type of non-rigid dam which would require less excavation to prepare a satisfactory foundation. The relative advantage of such a dam can not be evaluated from the data now available.

With a proposed dam 200 feet high there is potential leakage through the bedrock along the many fractures and possibly along the contacts between the older basalt and the sheets of tuff. However, because neither abutment is thin, this leakage probably would be moderate. Some cut-off structure seems advisable. Its extent would depend on the type of dam; its kind would depend on the depth and extent of pervious zones, which have not been explored by drilling.

Spillway problems.- The permanence of a spillway at the Greenpeter site depends both on the capacity of the rocks to resist erosion and on the stability of the rocks that might become saturated. Deep swiftly flowing water would not abrade either the older or the younger basalt rapidly but it might pluck either of these rocks where they are most closely fractured. The tuff that is interspersed in the older basalt doubtless would be abraded moderately; in part it would probably become plastic if saturated and so might not give adequate support to overlying basalt. Whether this material lies at shallow depth in the vicinity of the line AB is not known. All the unconsolidated materials would be eroded rapidly. If saturated, those which overlie the basalt on either slope of the valley would be plastic and unstable. Owing to these properties of the rocks, special care in designing an adequate permanent spillway seems advisable.

Records of diamond drilling.- The United States Engineer Department has put down one vertical diamond-drill hole at its site no. 1 and four holes at its site no. 2; these two sites are, respectively, about 3,850 feet upstream and 1,330 feet downstream from the line AB. Records for these five holes, based in part on data by McKitrick, 6/ follow:

6/ McKitrick, W. E., op. cit., pp. 5-8 and tables following graphic record of drill holes

Site no. 1, hole no. 1

[Near north bank of river, land-surface altitude about 695 feet. High percentage recovery of core throughout]

	Thickness (feet)	Depth (feet)
Stream deposit	7.0	7.0
Basalt, fine-grained, slightly decomposed throughout; cut by network of fine non-metallic veins (zeolites)	1.0	8.0
Basalt, fine-grained at top but sub-crystalline toward bottom, fairly fresh; a few flecks and thin seams of non-metallic minerals	14.4	22.4
Basalt, medium-grained (porphyritic), slightly decomposed throughout and not thoroughly sound	19.6	42
Basalt, fine-grained, fairly fresh; a few non-metallic veinlets, in part cellular	41	83
Basalt, medium-grained, slightly decomposed	4.2	87.2
Basalt, fine-grained, fairly fresh	3.8	91
Basalt, medium-grained; so decomposed that core can be broken with the fingers	8.9	99.9

Site no. 2, hole no. 1

[On north bank about 275 feet from the river, land-surface altitude 641.5 feet above sea level. Core recovery 78 percent of the bedrock.]

	Thickness (feet)	Depth (feet)
Slope wash (rock glacier ?): boulders in residual clay soil	49.6	49.6
Basalt, medium-grained (porphyritic); about a third replaced by small globular masses of non-metallic minerals (amygdule fillings of zeolites) and the remainder partly decomposed. Ultimate compressive strength on one specimen 18,200 pounds to the square inch.	22.2	71.8
Tuff, red, very fine ("clay")	2.5	74.3
Basalt, medium-grained, partly decomposed and flecked with secondary non-metallic minerals. Ultimate strength, one specimen, 8,400 pounds to the square inch	21.6	95.9

Site no. 2, hole no. 2

[On north bank about 600 feet from the river. Land-surface altitude 894.4 feet above sea level. Core recovery 78 percent in the bedrock.]

	Thickness (feet)	Depth (feet)
Slope wash: boulders in residual clay soil	53.4	53.4
Basalt, medium-grained (porphyritic), partly decomposed throughout, spotted with small globular masses of non-metallic minerals (amygdaloidal), also a few small cavities. Ultimate compressive strength of two specimens 8,680 and 16,660 pounds to the square inch, respectively	52.6	106.0

Site no. 2, hole no. 5

[On north bank about 15 feet from the river. Land-surface altitude 694.9 feet. Core recovery 96 percent of the bedrock.]

	Thickness (feet)	Depth (feet)
Basalt, medium-grained (porphyritic), dense and fairly fresh. A few seams of secondary non-metallic minerals. One specimen had a crushing strength of 15,450 pounds to the square inch	49.3	49.3
Tuff, red; fine-grained and textureless at the top; becomes coarser grained toward the bottom, where its fragments are 3/4 inch through. Some recovered as sludge. Crushing strength of one medium-grained specimen 5,870 pounds to the square inch	13.2	62.5
Tuff and fine agglomerate, black, earthy at top, dense at bottom. Yielded some sludge. Crushing strength, one specimen, 2,440 pounds to the square inch	8.5	71.0
Basalt, medium-grained, somewhat decomposed throughout; a few cavities (amygdules), in part filled with non-metallic minerals; a few crushed zones healed by non-metallic veinlets	4.5	75.5
Basalt, medium-grained, fairly fresh, brittle. Numerous non-metallic veinlets	15.6	91.1

Site no. 2, hole no. 4

[On north bank about 920 feet from the river, land-surface altitude 964.2 feet. Core recovery 58 percent of the bedrock.]

	Thickness (feet)	Depth (feet)
Slope wash (rock glacier): boulders in residual clay soil. Lower part may be pebbly tuff	50.3	50.3
Basalt, fine-grained, slightly decomposed; a few cavities, in part filled by non-metallic minerals. Ultimate strength in compression, one specimen, 26,450 pounds to the square inch	8.0	58.3
Basalt, medium-grained (porphyritic), partly decomposed throughout; three conspicuous zones are spotted with globular masses of secondary non-metallic minerals (amygdule fillings). For two specimens in compression the ultimate strengths were 6,920 and 10,070 pounds to the square inch, respectively	32.8	91.1

Sweet Home dam site

The dam site on the South Santiam River at Sweet Home (pl. 13, fig. 7)

Plate 13.- Geologic map of the Sweet Home dam site, South Santiam River.

Figure 7.- Tentative geologic section of the Sweet Home dam site along the line EF.

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involves rocks that differ greatly in load-bearing power, in water-tightness, and in resistance to abrasion and plucking. In downward succession these are: unconsolidated stream-bed and flood-plain deposits, unconsolidated deposits on remnants of two terraces, lava rock (basalt), and stratified fragmental rocks largely of volcanic origin (tuffaceous rocks). Following paragraphs describe the physical character of each and then summarize with respect to the construction of a dam.

Character and extent of the rocks.- The stream-bed and flood-plain deposits consist of unassorted pebbles, cobbles, and boulders as large as 18 inches long. Nearly all the particles are from dense volcanic rocks, all are quite fresh and sound, and except in their range of sizes would be suitable aggregate for concrete. As a whole, the deposit is highly pervious. Its greatest thickness, to judge from the records of diamond-drill holes nos. 1 and 3 (see p. 83), is about 75 feet - that is, from about 10 feet above to about 65 feet below the ordinary low-water stage of the river.

The terrace deposits are likewise stream-laid and comprise particles that were derived from volcanic rocks and that range from sand to boulders about a foot through. The terrace remnants which they form are from 30 to 40 feet and from 60 to 80 feet above the river, respectively. Both deposits are oxidized, especially that of the high terrace in which the finer particles are decomposed to gritty clay. Accordingly, neither is suitable for making concrete and the high-terrace deposit probably is only moderately pervious. The greatest thickness of the high-terrace deposit is about 25 feet.

The basalt is fine-grained, dense, and for the most part quite fresh at the very land surface. If unfractured, its compressive strength is high: three specimens of sound core had ultimate strengths between 45,900 and 50,000 pounds to the square inch. (See pp. 86, 87.) A fourth specimen that was partly decomposed by weathering, failed at 7,150 pounds. All the basalt is parted into vertical hexagonal columns, which ordinarily are about a foot through. Also, it is parted by moderately extensive fractures that are subvertical, transverse to the river, and from 20 to 50 feet apart. These partings are probably snug below the zone of frost. Neither the columnar partings nor the more extensive fractures have crushed walls or fillings of "gouge" that might serve as a lubricant to facilitate slippage of one rock plate on another. Thus, even so fractured, the basalt is inferred to be essentially rigid except where it is thin. However, the partings are so numerous that all the basalt is slightly or moderately pervious.

The stratified rocks crop out at only one spot in the area that is represented by plate 13, but their character is shown rather well by the records of diamond-drill holes nos. 2 and 4 (pp. 85, 87), also by outcrops downstream. All are moderately consolidated and are composed largely of fragments formed by explosive volcanism. The several strata are each fairly uniform in range of grain sizes. The finest are waxy and textureless to the unaided eye; the coarsest are agglomerates which are composed of angular particles as much as 3/4 inch through and a scant fine-grained matrix. Commonly these rocks weather to gritty clay. Even when fresh they are far weaker than the basalt: among nine specimens representing several kinds of the fragmental rocks, the ultimate strength ranged from 720 to 6,400 pounds to the square inch (excluding one specimen too short to give a reliable determination); the average for the nine specimens was 3,600 pounds. These specimens probably are fairly representative, for the recovery of core was moderately high. Further, the cores commonly disintegrated if immersed in water at once or dried and then immersed. The beds of finest grain doubtless are plastic if saturated with water and loaded. As a whole, therefore, the fragmental rocks are non-rigid; probably they are only slightly pervious.

The thickness and extent of the rigid basalt and of the non-rigid fragmental rocks are probably the most critical features of the site with respect to the construction of a stable dam. Information as to these features is drawn from the records of diamond drilling and from outcrops beyond the area that is represented on plate 13 . Apparently the basalt forms a single plate which rests on and is very nearly parallel to the strata of fragmental rocks. However, the surface of contact between the two kinds of rock probably is an erosional unconformity of moderate relief, of the order of 50 feet. At the dam site, the basalt plate was found to be 32.7 feet thick in diamond-drill hole no. 1 and 13.3 feet thick in hole no. 3; both these holes were drilled in the river bed. On the right or north bank of the river the plate thins, so that it is 12.8 feet thick at hole no. 4 and feathers out between holes nos. 4 and 2; these two holes are on the high (550-foot) terrace. Still farther north, the basalt recurs on the hillslope above the terrace.

For several miles upstream and downstream from the site, tuff and intercalated sheets of basalt commonly dip 5°-15° SE. (diagonally upstream) though they are flexed locally in small gentle folds. If the average dip prevails at the site, four critical conclusions may be drawn tentatively, as follows: (1) The inclined basalt plate is beveled by the present stream bed so that it has a feather edge a short distance downstream from drill hole no. 1; accordingly, beneath the river bed the plate is too thin to be rigid anywhere downstream from hole no. 3. (2) The basalt plate tends to thicken steadily upstream so that between 200 and 300 feet upstream from the wagon bridge it may have sufficient thickness to be rigid. (3) Beneath all the left abutment the basalt is at least 100 feet thick, amply thick to be rigid. (4) On the right abutment above the 550-foot terrace, the basalt plate is quite thin along the line CD (pl. 13) and ends in a feather edge a short distance downstream; there, accordingly, the plate probably is non-rigid.

The non-rigid fragmental rocks that underlie the basalt are estimated to be at least 100 feet thick and to extend beneath all parts of the area that is represented on plate 13.

<u>Summary of features pertinent to the construction of a dam</u>.- On plate 13, the line marked "AD" indicates the position for a dam containing a minimum of material and rising to the 660-foot contour - that is, 180 feet above the river. That position appears to be suitable only for a flexible dam, because the foundation and abutments are far from uniform in load-bearing power. Thus, the lower 60 feet of each bank is formed of the dense basalt, which assures two rigid abutments from the stream up to the 540-foot contour. Between these abutments, however, a dam would rest on basalt too thin to distribute the load adequately onto the non-rigid fragmental rocks beneath. Above the 540-foot contour, the left or south wing of a dam would rest on basalt, presumably so thick as to support a rigid structure of gravity cross-section. On the other hand, the right wing would rest in part on the fragmental rocks and probably in part on a feather edge of basalt, much too thin to be effective in distributing the load. Accordingly, that wing would of necessity be flexible and broad.

There is a possibility that a rigid foundation beneath the center of a dam may exist upstream from the wagon bridge, for it has been inferred that the basalt tends to thicken in that direction. The possibility should be explored by further drilling in the bed of the stream. However, a dam upstream would be longer: a material increase in length might offset any saving that would be afforded by an inflexible dam.

The amount of stripping to prepare a satisfactory foundation and the measures necessary to prevent leakage seem to be about the same wherever the central part of the dam might be. Because slope wash and terrace deposits are unsuitable for the foundation of any type of dam, both should be completely removed. As test pits and drill holes by the United States Army Engineers indicate, the depth of stripping in these materials probably would not exceed 25 feet at most places. The stream-bed deposit is of course too unstable to support a masonry structure. The thickness of this deposit was found to be 34 and 38 feet in drill holes nos. 1 and 3, respectively. The maximum thickness may be even more, for it is not unlikely that the rock floor of the stream bed is deeply fluted in the narrows at the wagon bridge.

In the bedrock, there is likely to be material leakage through the columnar partings and the more extensive fractures of the basalt and along the contact between the basalt and the underlying fragmental rocks, especially beneath the river bed and through the tip of the narrow spur that affords the lower part of the right abutment. Measures to seal these zones seem essential to assure the stability of a high dam. Whatever the type of dam, an impervious connection with sound bedrock should of course be made the full length of the structure.

Spillway.- About a mile north of the dam site, in the NW¼NW¼ sec. 30, T. 13 S., R. 1 E., there is a natural spillway through a saddle whose altitude is about 685 feet. Bedrock does not crop out in that vicinity, but is inferred to be largely or wholly bedded tuff and other fragmental rocks. Since these rocks would be abraded with moderate ease by rapidly flowing water of considerable depth, a spillway structure at that place should embody a substantial cut-off to restrain percolation and an extensive pavement, possibly the full height of the wasteway.

Records of diamond drilling.- Four vertical diamond-drill holes have been sunk at the Sweet Home site by the United States Engineer Department. The records, including data by McKitrick 7/, follow.

7/ McKitrick, W. E., op. cit., pp. 11-14 and tables following. graphic record of drill holes.

Hole no. 1

[In center of river about 400 feet downstream from road bridge; altitude of river bed 473.4 feet above sea level. Core recovery 77 percent of the bedrock.]

	Ultimate compressive strength (pounds to the square inch)	Thickness (feet)	Depth (feet)
Stream gravel		34.3	34.3
Basalt, dense fine-grained, fresh; brittle (core partly in small chips)	50,000	32.7	67.0
Tuff, maroon to dark purplish red, fine-grained and waxy at top, gritty at bottom	5,170	22	89
Tuff, light greenish gray, glassy, compact		4.0	93.0
Tuff or tuffaceous sandstone, dark maroon, grit and chips in somewhat waxy matrix	720	13.1	106.1
Agglomerate, greenish and purplish gray; grit and fragments of andesite as much as 3/4 inch through make up three fourths of the rock; matrix somewhat decomposed	3,600	3.4	109.5
Tuff, light greenish to reddish gray, largely fine-grained, lower 2 feet gritty	6,400	9.2	118.7

Hole no. 2

[On terrace, about 630 feet north and 170 feet east of north bridge head; altitude of land surface 561.4 feet above sea level. Core recovery 84 percent of bedrock.]

	Thickness (feet)	Depth (feet)
Terrace deposit, clayey	24.9	24.9
Tuff, greenish gray, earthy and gritty	9.6	34.5
Tuff, or tuffaceous clay, light gray, upper third textureless, lower part sandy and pebbly; contains a few flecks and plates of carbonaceous matter	15.0	49.5
Tuff, greenish grey, fine-grained. Ultimate compressive strength of one specimen, 8,940 pounds to the square inch	10.0	59.5
Tuffaceous shale, black, laminated	5.7	65.2
Tuffaceous siltstone and sandstone, olive-green to dark greenish gray, earthy to waxy, non-laminated. Two specimens, one of fine grain and the other coarse, had ultimate strengths of 2,140 and 3,360 pounds to the square inch	24.3	89.5
Tuff, dark lead grey to black, non-laminated	4.2	93.7

Hole no. 5

/In center of river about 140 feet downstream from road bridge; altitude of river bed 450.4 feet above sea level. Core recovery 93 percent of the bedrock./

	Thickness (feet)	Depth (feet)
Stream gravel, coarse	37.9	37.9
Basalt, fine-grained, dense, fresh. Ultimate crushing strength of one specimen 49,800 pounds to the square inch	13.3	51.2
Tuff, dark maroon, fine-grained, earthy to sub-waxy; grades into underlying bed. One specimen in compression failed at 5,260 pounds to the square inch	8.8	60
Tuff, dark maroon; grit and small chips make as much as two thirds of the rock, matrix fine-grained and in part waxy. Ultimate strength of one specimen 2,140 pounds to the square inch	15.9	75.9

Hole no. 4

[On terrace, about 350 feet north of bridge head; altitude of land surface, 354.5 feet above sea level. Core recovery 66 percent of bedrock.]

	Thickness (feet)	Depth (feet)
Terrace deposit		
Clayey soil	5.0	5.0
Sand, gravel, and boulders	7.2	12.2
Basalt, fine-grained and dense. Ultimate compressive strengths of two specimens, one fresh and the other oxidized, were 45,900 and 7,150 pounds to the square inch, respectively	17.8	30
Tuff or tuffaceous shale, greenish gray to black, fine-grained and gritty, laminated in part	9.4	39.4

Luckiamute River

Seekay (Upper Hoskins) dam site

At the Seekay dam site (fig. 8) the Luckiamute River cuts squarely

Figure 8.- Seekay (Upper Hoskins) dam site, Luckiamute River.

across an elongate intrusive mass of dense crystalline rock (diabase) that is about 1,200 feet wide and is enclosed by thin-bedded shale and earthy sandstone. As is disclosed in a railroad cut along the left (east) bank, the fresh diabase is massive, fine-grained, and black. This rock forms the bed of the stream at the Spaulding log dam and by inference all along the gorge that extends 800 feet downstream. Outcrops and slope wash indicate that in the left bank the diabase rises to a height of about 170 feet above the river - that is, to an altitude of about 650 feet - and is overlain by fine-grained earthy sandstone and laminated shale. Along their surface of contact the diabase is glassy in part and the sedimentary rocks are somewhat metamorphosed. On the right (west) bank the diabase is exposed for about 75 feet above the river; at greater heights the bedrock is concealed.

Most of the diabase is parted by subvertical fractures that are from 3 to 10 feet apart and that strike about N. 10° W., N. 40° W., or N. 65° W. All these fractures are slightly undulating and discontinuous; those that strike N. 10° W., roughly parallel to the river, seem to be the most extensive. Most of the fractures are free from gouge, have sound fresh walls, and are tight. At a few places clean joints grade into shear zones as much as a foot wide; at other places, particularly along cross-fractures, the joints are sealed by veinlets of non-metallic minerals (zeolites) and the wall rocks are decomposed to a depth of an inch or less.

A section through the zone of weathering in the diabase is afforded by the railroad cut that crosses the left abutment. There, the upper few feet of the zone is composed of spheroidal residual boulders dispersed through a granular and somewhat nodular iron-red matrix. As the depth below the natural land surface increases the residual boulders are progressively larger and occupy a greater percentage of the space until the granular matrix becomes a network of partings only a few inches thick. Weathering of this sort is general to a depth of 15 to 20 feet below the land surface but some thin zones of weathering penetrate even deeper along fractures.

At the Seekay site both abutments are broad and are composed of the dense diabase, except perhaps high above the river where the character of the bedrock is only suggested by the slope wash. Neither abutment is believed to be weakened materially nor made excessively pervious by the joints that have been described. If the diabase has been interpreted correctly as intrusive into the shale, presumably it extends to considerable depth below the stream. Accordingly, the site appears suited to a rigid narrow-base dam as high as the diabase, also to an over-fall spillway without an extensive apron. On the other hand, the shale and earthy sandstone that overlie the diabase have only moderate or low bearing power and would sustain with safety only a flexible dam.

Sufficient earth for a fill possibly could be obtained in the broad parts of the valley either upstream or downstream from the site where the bedrock appears to be mantled with sandy loam to a depth of 10 to 15 feet. Rock suitable for a fill doubtless could be quarried from the diabase intrusion that affords the dam site.

Hoskins dam site

Like the Seekay site upstream, the Hoskins dam site (fig. 9) involves

Figure 9.- Hoskins dam site, Luckiamute River.

diabase and sedimentary rock. In a road cut along the base of the left (east) slope of the valley these rocks are exposed for a distance of about 1,000 feet and to a maximum depth of about 20 feet below the natural land surface, scarcely to the bottom of the zone of weathering. Elsewhere in the area that is represented by figure 9 the bedrock is covered almost continuously with timber, brush, and forest litter. Accordingly only a few facts and suggestions as to geologic features can be presented at this time.

The sedimentary rocks include laminated and thin-bedded shale or siltstone and at least one bed of massive earthy tuffaceous (?) sandstone from 3 to 5 feet thick. These rocks are bluish gray where they are not weathered but in small outcrops are olive drab. They appear to underlie both slopes of the valley in the upstream (north) half of the area that is represented by figure 9 - in the left slope downstream to and somewhat beyond the line AB and in the right slope somewhat beyond the line CD. These sedimentary rocks dip about 5° upstream at the road cut along the left slope; whether they are folded or faulted elsewhere in the dam-site area is not known.

The diabase is fractured and is thoroughly weathered down to and below the bottom of its artificial exposure along the road but it is inferred to be sound at slightly greater depth. As is indicated by the line of contact marked on figure 9, this rock abuts against the shale and sandstone about midway between lines AB and CD along the road and, by inference from sparse debris in the slope wash, about midway between lines CD and EF across the upper part of the left slope of the valley. From this contact it appears to extend downstream to and at least 200 feet beyond line EF. Along the latter line, diabase also crops out in both banks of the river and is inferred to rise at least 50 feet above the river in the right slope of the valley.

In the area that is represented by figure 9, the Luckiamute River has cut a channel about 15 feet deep into the alluvial flood plain, which is as much as 600 feet wide. The alluvium is largely sandy loam but contains some thin beds of gravel. Presumably the alluvium is not much more than 20 feet thick for the river flows over bedrock at many places farther upstream.

The sound diabase at the Hoskins dam site doubtless has high bearing power and, except for fractures, is not pervious. On the other hand, the shale and earthy sandstone probably will sustain only a moderate load and are not highly pervious; they are likely to contain minerals such as compose bentonite and so to afford "swelling ground" or to yield plastically under heavy load. The alluvium is doubtless somewhat pervious and of low bearing power.

Prudent design of a dam for the Hoskins site depends upon the extent of the several types of rock just described. Thus, extensive exploration of the site by pits and drill holes is essential. Three alternative locations are suggested by the lines marked "AB", "CD", and "EF" on figure 9. At the first or upstream position the crest of the dam would be shortest but the alluvial plain is relatively wide and both abutments probably are wholly of the sedimentary rocks. Doubtless a wide-base flexible dam would be necessary. At the intermediate position a dam would have the least volume above the natural land surface but the upper half of its left abutment and perhaps the whole right abutment probably would be formed by the sedimentary rocks. There, a flexible dam seems essential. The downstream position, EF, seems most likely to afford a foundation wholly on the diabase without excessive excavation. Accordingly, this position alone seems in any way suited to a rigid narrow-base dam.

If a fill of earth or rock is contemplated, its impervious membrane should be extended down into sound diabase if that is feasible, otherwise so far into the sedimentary rocks that the percolation factor would be moderately large. Suitable earth probably could be obtained from the alluvial plain between 1 and 2 miles upstream from the dam site but suitable rock could be quarried only from the diabase, possibly not far from the downstream position, EF.

About 2 miles upstream from the site, in secs. 12 and 13, T. 10 S., R. 7 W., the bed of the river is covered by unweathered coarse gravel derived from basalt, diabase, and related dense igneous rocks. Most of the component pebbles and cobbles are between 1 inch and 6 inches in diameter. This material is younger than the fine alluvium that forms the adjacent flood plain. Doubtless it would yield aggregate for concrete, though possibly not in sufficient volume for a concrete dam.

South Yamhill River basin

Cedar Creek dam site

At the Cedar Creek dam site on the South Yamhill River the bedrock comprises diabase or basalt, laminated shale, and possibly thin-bedded earthy (tuffaceous ?) sandstone. These rock types are not equally extensive in the two abutments.

Within the area that is represented by figure 10 the sedimentary

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Figure 10.- Cedar Creek dam site, South Yamhill River.

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rocks are very poorly exposed but are inferred to form the whole right (south) slope of the valley above the 475-foot contour, also between the river bank and the road except for a distance of about 250 feet upstream and 500 feet downstream from the line marked "BD". Shale is exposed discontinuously in cuts along the road, where it usually is air-slaked and leached. In the few small exposures where the bedding is preserved the shale dips about 20°-50° S. but dips so steep may have been caused by local slump.

The character of the sedimentary rocks below the zone of weathering at the Cedar Creek site is suggested by an exposure about 2½ miles farther east in the SE¼NW¼ sec. 2, T. 6 S., R. 8 E. There a road cut pierces interbedded shale and sandstone for a length of 600 feet and a depth of 35 feet below the natural land surface. (See pl. 14, A.) In large

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Plate 14.— A, Shale and thin-bedded sandstone exposed by road cut 2½ miles east of the Cedar Creek dam site.

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measure the shale is only moderately indurated and thinly laminated but some of it forms textureless beds as much as 12 inches thick. At intervals of 1 to 8 feet, the shale encloses beds of sandstone from 1 to 18 inches thick, of which the thickest are massive and uniformly medium in grain whereas the thinner beds are earthy, laminated, and locally somewhat micaceous or variegated in color. Both shale and sandstone appear to be composed largely of grains from volcanic rocks, possibly in part from tuff. To a depth of at least 5 feet below the land surface both are commonly disintegrated to thin flakes or chips less than an inch long. This composition and mode of weathering imply that both contain minerals such as compose bentonite. If so they might well afford swelling ground in excavations and yield plastically under moderate load, especially if saturated with water.

At all other exposures in the vicinity of the Cedar Creek site the sedimentary rocks are similar in physical character to those just described. At a few exposures they are cut by basalt dikes. It is inferred, therefore, that the same features are likely to recur at the site.

The diabase at the Cedar Creek site appears to form the whole left (north) slope of the valley from the river up to and above the 600-foot contour for at least 500 feet upstream and a like distance downstream from the line that is marked "AB" on figure 10. On the opposite (south) slope, however, it appears to crop out only below the shale and not to rise much more than 60 feet above the river, as is indicated by the line of contact marked on figure 10. No outcrops or slope wash of diabase were found above the 475-foot contour on that slope nor more than 150 feet upstream from the line marked "BC".

Where fresh, the diabase is compact, crystalline, and black. In an excavation low on the south slope of the valley, just above the road and along the line marked "BC", it is parted into rude subvertical columns from 3 to 8 feet across. The columnar partings are clean and snug; they do not seriously impair the high bearing power of the rock. At the same excavation a zone of pronounced weathering and exfoliation in the diabase extends to a depth of about 15 feet below the natural land surface.

The evidence now available does not indicate whether the diabase is a vertical intrusive into the shale or is a thick intercalated sheet that dips 15°-25° S. or SE. parallel to the bedding planes of the shale. In the first case, the diabase may extend to considerable depth beneath the river, but neither its lateral extent nor the form of its upper surface beneath the south slope of the valley can be inferred. In the second case, the diabase probably underlies the whole slope but the overlying sedimentary rocks are at least 200 feet thick along the south edge of the area that is represented by figure 10. To verify one or the other of these alternative interpretations will require exploratory drill holes.

One minor feature of the geologic structure is disclosed at the Cedar Creek site. Thus, along the road and about 40 feet downstream from the line marked "BD" a block of the laminated shale appears to be downfaulted against the diabase but the stratigraphic displacement is relatively small - a few tens of feet at the most. (See fig. 10.) The fault surface is subvertical. The fracture could not be traced far along its strike either southward into the valley slope or northward to the far bank of the river. Other possible elements of the structure at the Cedar Creek site are suggested by exposures in the vicinity. For example, at the road cut 2½ miles to the east, the sedimentary rocks are deformed into an open anticline whose limbs dip less than 10°; also they are cut by several subvertical normal faults whose displacements are not more than 5 feet. (See pl. 14, A.) These minor faults are distinct from landslide cracks (of which there are several) and commonly are filled with clay. Other exposures near the site likewise disclose segments of open folds and minor normal faults in the sedimentary rocks. However, no faults of large displacement were recognized at or near the site.

Both upstream and downstream from the constriction that affords the Cedar Creek site, a tongue of recent alluvium floors the valley of the South Yamhill River. However, this tongue lapses for about 350 feet at the line ABD where the valley is narrowest, so that the river occupies a rock chute.

Two alternative positions for a dam at the Cedar Creek site are suggested by the lines marked "ABC" and "ABD" on figure 10. These positions have a common left (north) abutment of diabase which doubtless would sustain a concentrated load and probably could be grouted effectively to restrain percolation. Of the two positions suggested for the right (south) abutment, BD requires the dam of less volume above the land surface but BC may afford a foundation on diabase to a somewhat greater height above the river. Whether it is feasible at either position to construct a dam so high as to pass from diabase onto shale can not be determined without extensive exploration. As minimum requirements, a high dam should be flexible owing to the great difference in bearing power between diabase and shale, should impose only a light load on the shale, and should provide for a relatively large percolation factor.

Wallace Bridge dam site

At the dam site near Wallace Bridge (fig. 11) a succession of

Figure 11.- Wallace Bridge dam site, South Yamhill River.

conformable rocks dips about 20°-30° N. to N. 70° W. - that is, into the north slope of the valley. This succession is imperfectly exposed but in ascending order appears to include basalt, thick-bedded tuff, and alternate thin beds of tuff, tuffaceous sandstone, and sandy shale.

Basalt appears to compose the greater part of the right (south) slope of valley at and near the site but the only clear exposures are beyond the area that is represented by figure 11. A third of a mile to the west, in the NW$\frac{1}{4}$SW$\frac{1}{4}$ sec. 14, T. 6 S., R. 7 W., an abandoned road-metal quarry discloses a sheet of massive basalt at least 40 feet thick overlain by another sheet of fractured amygdaloidal basalt about 15 feet thick. All this rock is appreciably decomposed so that its fracture is somewhat earthy and its luster is waxy or dull. Of the waste rubble on the floor of the quarry, which is about 25 feet below the zone of pronounced weathering, a considerable part is disintegrating or exfoliating after having been exposed only a few years. In the bluff that forms the right bank of the river just east of the dam site, at and near the point marked "a" on figure 11, a sheet of amygdaloidal basalt about 40 feet thick is intercalated in decomposed basaltic tuff. The tuff which underlies the basalt is massive; a considerable part of that which overlies the basalt is thinly laminated. At that place also the basalt and associated tuff are somewhat decomposed, probably to considerable depth below the land surface. Thus, it is unlikely that the basalt will afford a foundation with more than moderate bearing power.

On the opposite (north) slope of the valley, fractured thick-bedded basaltic tuff forms the outlying knob that overlooks the river at the line marked "AB", as is disclosed by a cut for the railroad and highway. (See pl. 14, B.) This tuff is composed of fragments less than 0.3 inch

Plate 14.- B. Jointed thick-bedded basaltic tuff exposed at the base of the north abutment, Wallace Bridge dam site.

long in a textureless black matrix. Commonly the fragments are alined with their longest dimensions parallel, and so produce a crude lamination which dips about 20° N. Even at the base of the cut, 30 feet below the natural land surface, the tuff is thoroughly devitrified, slakes in the air, has an earthy fracture, and is somewhat friable. At some spots it is rather thoroughly decomposed and is cut by many veinlets of secondary minerals. To a depth of about 10 feet beneath the land surface, the tuff has disintegrated into granular material that encloses scattered residual boulders; spheroidal weathering and exfoliation are pronounced to a depth of 15 to 18 feet.

Above this heavy-bedded tuff, bedrock does not crop out along the line AB. From 1,500 to 1,800 feet west of the angle point in that line, however, interbedded tuff, tuffaceous sandstone, and sandy shale crop out at several places low on the valley slope. At these outcrops the dip is 25°-30° N. 60°-75° W. (upstream); also, the rocks are somewhat silicified and slightly decomposed.

Fractures and minor faults are common at the Wallace Bridge site. In the bluff that forms the right bank of the river, about 100 feet north of the point that is marked "a" on figure 11, a subvertical fault strikes about N. 85° E. and places laminated tuff against basalt. Along the fault the tuff has been sheared for a width of a foot or two. About 150 feet to the south another narrow shear zone dips about 55° S. 20° E. in the basalt. At each of these two faults the southern block is thrown down and the displacement is a few tens of feet. In the face of the railroad cut at the base of the north bank, the thick-bedded tuff is parted by undulating shear zones from 2 to 12 inches wide and from 5 to 15 feet apart; these dip (1) 70°-80° N. 85° E., (2) 20° N., or (3) 55°-70° S. 25° E. Of these three sets, the first is parallel to certain prominent fractures at the road-metal quarry west of the site, the second is parallel to the lamination in the tuff, and the third is parallel to one of the minor faults in the right bank of the river near the point "a". Each set may be a common element in the geologic structure about the dam site.

Stream deposits of three ages occur at the Wallace Bridge site. The oldest veneers the bench at an altitude of 340 feet on the north slope of the valley and contains cobbles and boulders as much as 10 inches in diameter. Its thickness is not disclosed at the site but from exposures on correlative terrace remnants downstream is inferred to be less than 10 feet. The deposit of intermediate age forms the main valley plain, which at the site is about 250 feet above sea level and from 900 to 2,000 feet wide and which is inferred to have been aggraded to that height in response to regional aggradation in the Willamette Valley to the east. Poor exposures along the banks of the river suggest that the deposit is composed largely of sand and silt. Where thickest it may extend to considerable depth below the present channel of the river, which is only beginning to degrade after having been superposed on the plain. This interpretation is not voided by the fact that for several miles downstream from the site the river flows over bedrock repeatedly wherever it swings against the foot of one or the other of the valley slopes. For example, it flows over bedrock for fully 1,000 feet along the eastern edge of the area shown on figure 11. The youngest stream deposit at the Wallace Bridge site is a veneer of cobble-bearing gravel on the floor of the river channel.

Only a flexible dam with moderately broad base seems suited to the Wallace Bridge site, for the bearing power of the volcanic rocks and tuffaceous sedimentary rocks is not large and ranges widely. An earthen dam may be the most practicable, for the moderately extensive valley plain just upstream from the site promises suitable material. To restrain leakage effectively, the impervious membrane of such a dam should pass through all stream deposits into sound volcanic or sedimentary rock beneath.

Willamina Creek dam site

At the dam site on Willamina Creek, massive fragmental volcanics (basaltic tuff and agglomerate) and thick-bedded tuffaceous sandstone dip about 15° N. 45° E., diagonally upstream, and pass beneath non-fragmental volcanic rock (basalt). (See fig. 12.) All these rocks

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Figure 12.- Willamina Creek dam site.

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are very imperfectly exposed at the site but the surrounding district shows them to be interbedded with one another and with thin-bedded bluish grey concretionary shale and thick-bedded black shale.

The massive tuff is black, was initially vitreous, but has been so decomposed that it has waxy or earthy luster and probably has only moderate bearing power. It slakes somewhat where it is exposed to the air. The agglomerate has a compact matrix; its inclusions are of dense basalt, unoriented, angular, and as much as 6 inches long. The basalt that overlies these rocks is largely dense and fine-grained but its lowest part is amygdaloidal and somewhat decomposed. Because none of its slope wash is cellular (vesicular) or distinctly tuffaceous, it probably does not contain extensive weak or pervious zones, except for fractures. Along and near the line marked "AB" on figure 12 this basalt probably underlies both slopes of the valley for at least 250 feet above the flood plain.

Both the basalt and the underlying fragmental volcanics are parted by subvertical fractures that strike N. 65°-80° W. or about N. 45° E. and that, so far as they are disclosed, appear to be discontinuous, undulating, and snug. Such fractures probably impair the load-sustaining capacity of the rock only slightly. Deep-seated faults have not been discriminated at the site but certain minor land forms suggest that shallow landslide faults exist. Thus, three collinear land-form elements trend across the northern part of the area that is represented by figure 12; these include (1) the small valley that drains from the northeast corner of the area, (2) the north face of the opposite spur which is distinctly sharp-pointed between altitudes of 500 and 600 feet, and (3) a north-facing scarp that is nearly 100 feet high, lies just beyond the west margin of the area, and rises to an altitude of about 750 feet. North of these collinear features the land surface is relatively low. Just south of the site, several spur ridges end in conspicuous facets that are alined northwestward and face southwestward. About 4½ miles south of the site the pit of the Willamina Clay Co. discloses that analogous land forms have been produced by landslide faulting in basalt, one displacement of about 50 feet in that rock having been largely dissipated by plastic deformation in underlying clay shale.

The unconsolidated rocks at the site include recent stream deposits, slope wash, talus, landslide rubble, and high-terrace deposits. The stream deposits that underlie the flood plain may be thick for Willamina Creek has aggraded its bed materially to conform with regional aggradation in the Willamette Valley. Talus occurs commonly along the base of the left (east) slope of the valley except where the creek skirts that slope. Its thickness is inferred not to be excessive. The landslide rubble lies in an alcove on the right slope of the valley near the northwest corner of the area, where it forms a fan that is about 800 feet wide along the road and that rises about to the 450-foot contour. This fan is immediately north of the inferred landslide fault that has been described. The high-terrace gravel, which is rather thoroughly decomposed, veneers flat ridge crests and benches at an altitude of about 650 feet on either side of the valley. None is known to occur as low as the 600-foot contour, to which the proposed dam would rise.

The line marked "AB" on figure 12 indicates the most advantageous position for a dam at the Willamina Creek site. A flexible wide-base dam probably would be quite practicable, and possibly even a rigid dam with moderately narrow base. Judgment as to the suitability of the site for a narrow-base dam is not possible without extensive exploration by pits, trenches, or drilled holes. Essentials to be proven by exploration would include: (1) sound basalt of sufficient thickness beneath the dam to distribute the load onto the weaker agglomerate and tuff beneath; (2) absence of weak shale or tuff in either abutment beneath the mantle of slope wash and talus; (3) absence of fractures of consequence, especially in the thin right (west) abutment. Rather extensive grouting might be necessary to restrain seepage through the abutments.

The spillway for a dam at the Willamina Creek site may require paving, for the dense basalt is not known to extend sufficiently far downstream to obviate excessive scour or undercutting.

Tualatin River basin

Gales Creek (Glenwood) dam site

At the Gales Creek (Glenwood) site dense crystalline diabase forms the bed of the stream almost continuously from a point about 250 feet upstream from the line that is marked "AB" on figure 13 to and beyond a

Figure 13.- Gales Creek dam site.

point about 600 feet downstream from the line marked "CD". For about 200 feet downstream from the line AB the diabase forms a bluff about 25 feet high along the right (west) bank but elsewhere it does not rise more than 5 feet above stream level in either bank. In these outcrops the diabase is relatively fresh. Further, it is parted by rude subvertical columnar fractures but usually these are undulating, discontinuous horizontally, and snug.

On the right slope of the valley diabase is also exposed between 85 and 125 feet above the stream in three cuts along the railroad. Even at the bottom of the deepest cut, which is marked "a" on figure 13 and which reaches about 25 feet below the natural land surface, exfoliation and disintegration have reduced the fractured diabase to a rubble of spheroidal boulders embedded in granular material. In that vicinity the highest known exposure of diabase is about 570 feet above sea level.

Still higher on the right slope of the valley no bedrock was found cropping out. However, the slope wash appears to be somewhat lighter in color and decidedly more clayey than the ordinary red granular residuum from diabase; also, it contains small chips of leached shale along the small creek and the wagon trail that are just north of the line AB. These features suggest that shale may be the common bedrock beneath the upper half of the valley slope. This suggestion is supported by the fact that laminated shale crops out in the bank of the stream about three quarters of a mile north of the site; also, that a mile south of the site a large road-metal quarry discloses a block of laminated shale about 30 feet long enclosed by crystalline diabase.

On the left (east) slope of the valley no bedrock whatever was found in place but the few recognizable fragments in the slope wash were largely of diabase. That some weak rock like shale forms the upper part of the slope is suggested by several small landslide alcoves above an altitude of 600 feet in the east-central part of the area that is shown on figure 13.

It is inferred that the diabase at the Gales Creek site is intrusive, perhaps as a sill. If that inference is correct the diabase may or may not be extensive horizontally and it may well be underlain by shale or other weak rock at slight depth below the stream bed.

Between the 550-foot contour and the road, the foot slope on the right (west) side of the valley is rather deeply mantled with slope wash. Still lower, about 25 feet above the stream and at an altitude of about 475 feet, recent stream deposits form a plain as much as 400 feet wide. These deposits are largely coarse gravel and cobbles. They are inferred to be not more than 25 feet thick, for the diabase that underlies them is exposed in the river bed across the full width of the plain.

At the Gales Creek site a rigid narrow-base dam can be built no higher than an abutment on sound diabase is afforded by either slope of the valley; this limiting height is not shown by the few outcrops. If a high dam should be founded partly on shale, it should be flexible, should have a broad base, and should include cut-off works of sufficient extent to restrain seepage.

Two alternative positions for a dam are suggested by the lines marked "AB" and "CD" on figure 13. The upstream position, AB, affords the broadest and highest spur of known diabase for the right abutment but it crosses the widest section of slope wash and recent stream deposits. Further, for a high dam, the left (east) abutment would be somewhat deficient in mass. The downstream position, CD, affords a thinner and possibly a lower spur of diabase for the right abutment but ample mass in the left abutment, a materially shorter dam, and probably less slope wash and recent stream gravel.

An over-fall spillway at the Gales Creek site would discharge onto diabase about at stream level. Accordingly special works to prevent scour do not appear to be necessary.

Portland, Oregon.
July 10, 1937.

691

Columnar basalt forming the lower
90 feet of the abutments at the Elsie
dam site (viewed from the left bank)

693

A, Basalt rubble in highway cut along the flank of the left abutment at the Elsie dam site.

713

B, Slide in fragmental basalt and shale in
highway cut 0.6 mile east of the
Elsie dam site

Plate 9

710 , 711, 712

Nehalem Falls dam site viewed upstream from the road bridge

705

A, Rock-slide rubble on the right bank of the Middle Santiam River 2.7 miles downstream from Greenpeter Creek (the scale is indicated by the packsack in the right foreground)

706

B. Blocks in the river at the toe of the slide

A. Shale and thin-bedded sandstone exposed by road cut $2\frac{1}{2}$ miles east of the Cedar Creek dam site

690

B, Jointed thick-bedded basaltic tuff exposed at the base of the north abutment, Wallace Bridge dam site