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THE SPOKANE FLOOD BEYOND THE CHANNELED SCABLANDS

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ABSTRACT

The channeled scablands of the Columbia Plateau in Washington are extensive elongate denuded tracts of basalt, deeply scored by huge high-gradient glacier-born rivers. As physiographic features they are unique. All the rivers which produced them converged to Snake and Columbia valleys, and the record of the tremendous flood thus engendered has been found all the way from the plateau scablands to Portland. Columbia River Valley below the confluence of Snake River carried a flood which at Wallula Gateway was 2 miles wide and reached 750 feet above present river level, at Arlington was 7 miles wide and 450 feet above present river level, at Lyle was 3 miles wide and 430 feet above present river level, and at Portland was nearly 20 miles wide and 350 feet above present river level.

The field evidence for the flood consists of (1) noteworthy, even spectacular, denudation and erosion of slopes below the upper surface of the flood, (2) spreading of the river in favorable places back among preglacial hills, (3) deposition of great gravel bars, some of them nearly as thick as the flood was deep, (4) damming of Snake River above the entrance of the glacial rivers by a delta built upstream against the course of the Snake, and (5) deposition of the Portland Delta, 350 feet thick, 200 square miles in area, and with bars 100 feet high on its surface.

THE PHYSIOGRAPHIC SETTING FOR THE FLOOD

Channeled scabland is limited to that part of the Columbia Plateau which lies between, and above the confluence of, the Snake and Columbia River canyons (Fig. 1). The slope of the plateau in general is southwestward, away from Columbia River on the north and toward Snake River and the lower part of the bounding Columbia on the south and southwest. Almost all the drainage of the plateau is consequent on this slope.

The Spokane ice sheet crossed the Columbia Valley north of the plateau and advanced a few miles out on it along almost the entire northern margin. Water from the melting of this ice flowed in the preglacial consequent drainage system, entering at or near the heads of these valleys and traversing their entire lengths. The ablation of the Spokane ice sheet must have been extraordinarily rapid, for the volume of water was very great, almost incredibly great, and in spite of high gradients to draw it off, the pre-existing valleys first entered were inadequate to carry it all, and the flood spread widely in a complicated group of anastomosing routes. This pattern is unique in that all the routes were greatly eroded, many of them being developed into canyons of notable proportions by the glacial streams, and some of them crossing prominent preglacial divides on the plateau.[1]

The pre-Spokane drainage of the plateau which entered the Snake was conveyed to one main route, that of Esquatzel Coulee, near Pasco. During the Spokane epoch, two other discharge ways were formed, one through Devils Canyon, near Kahlotus, and one through Palouse Canyon, between Hooper and Perry. The Palouse Canyon route now carries most of Snake River's share of the plateau run-off, Devils Canyon carries none, and Esquatzel Coulee carries but a small portion. This change from preglacial conditions was due to the profound erosion by glacial waters in Palouse Canyon. Greater volume and higher gradient at this place determined the change.

Columbia River had two considerable pre-Spokane tributaries from the plateau, Moses Coulee and Crab Creek. These proved inadequate to carry the Spokane flood, and six others were opened: "The Potholes," Frenchman Springs, and the Koontz Coulee group of channels, the first two being simply cataracts over the cliffs of Columbia Valley. All of these discharge ways leave the west side of that part of the plateau concerned in this study. None of them now carry plateau drainage.

[1] Set forth in some detail in the writer's paper on "The Channeled Scablands of the Columbia Plateau," *Jour. Geol.*, Vol. XXXI (1923), pp. 617–49.

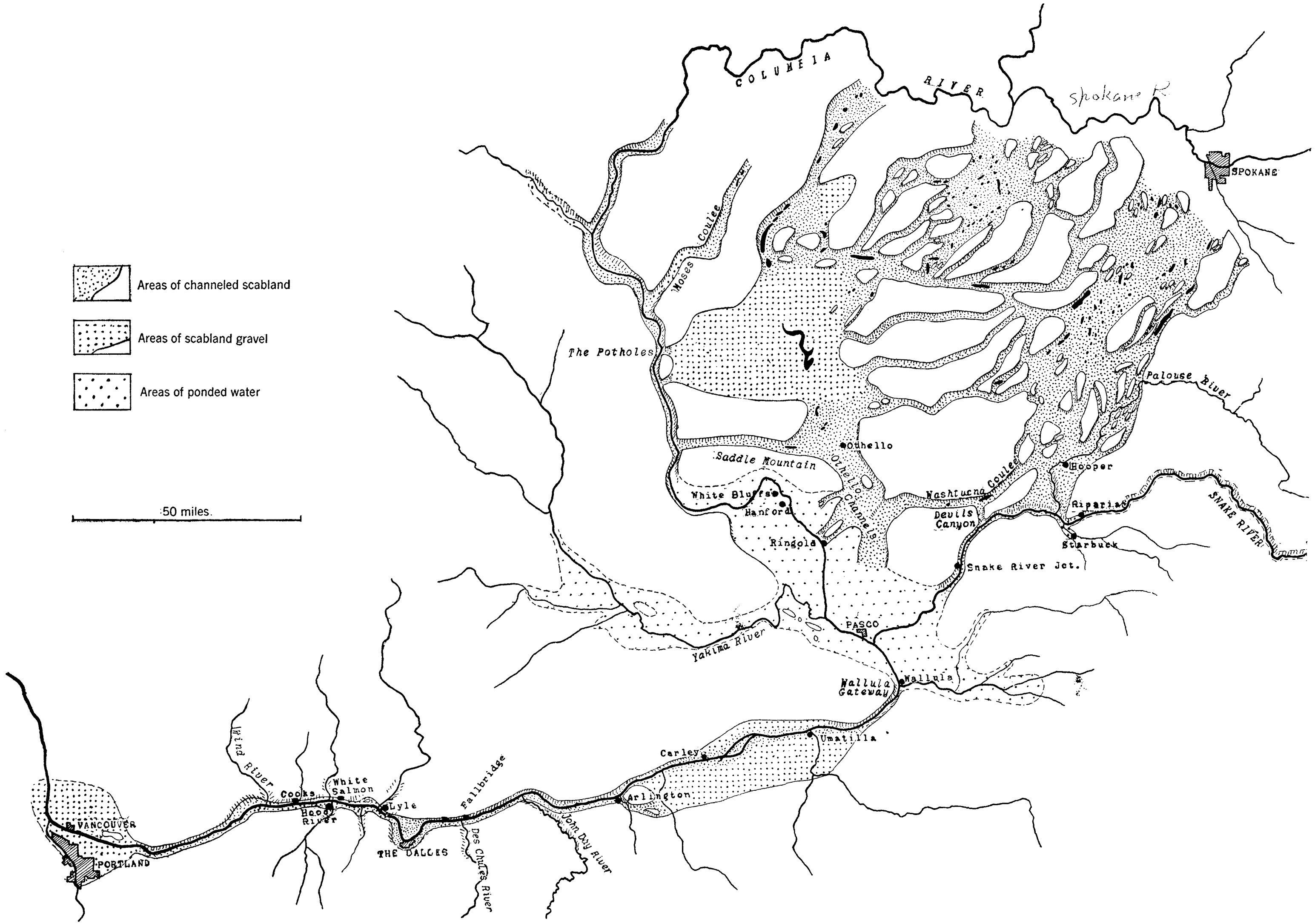

FIG. 1.—Sketch map of the region affected by the Spokane flood

The history of the channeled scablands, very briefly outlined above, has been accepted only with considerable reservation and qualification by many, for the volume of the flood described and the results it produced surpass anything previously known in river phenomena. That this huge volume was a verity, the character of Snake and Columbia valleys below the entrance of the Spokane rivers amply proves. This paper describes the remarkable features produced in these valleys by the concentration of discharge from the scabland rivers. Though details generally render a paper less readable, they are presented here to show more clearly the nature of the field evidence.

THE CHANNELED SCABLANDS

The phenomena which characterize the channeled scabland of the Columbia Plateau are briefly summarized here. The argument thus may be clear without a reading, or re-reading, of the writer's previous papers on the subject.[1]

1. Channeled scabland (Fig. 2) is the eroded surface of the Columbia basalt formation. It is bare rock or is but thinly covered with basaltic débris. It is distributed in an intricate interlacing pattern whose strands are traceable up-gradient to, but not across, the area glaciated by the Spokane ice sheet, and down-gradient to, but not across, the Snake and Columbia valleys. This bare, or nearly bare, rock has a total area of about 2,000 square miles, and its linear tracts are bounded by thousands of miles of cliffs. Basins excavated in the solid basalt are common, many of them at the foot of cliffs transverse to the linear tracts, the sites of former cataracts. Knobs of basalt standing on the floor of the channels are common also.

2. Stream gravel, 99 per cent basalt, occurs in all scabland tracts. Except rarely, it does not occur in terraces, nor does it cover the floors of the channels. It is deposited in great rounded mounds, commonly on the lee side of basalt knobs and elongated with the channels. Less commonly, it lies high up on the sides of the scabland

[1] "Glacial Drainage on the Columbia Plateau," *Bull. Geol. Soc. Am.*, Vol. XXXIV (1923), pp. 573–608; "The Channeled Scablands of the Columbia Plateau," *Jour. Geol.*, Vol. XXXI (1923), pp. 617–49; "The Dalles Type of River Channel," *Jour. Geol.*, Vol. XXXII (1924), pp. 139–49; "The Age of the Spokane Glaciation," *Amer. Jour. Sci.*, Vol. VIII (1924), pp. 336–42.

channels against the cliffs, though here it generally has the rounded, elongated forms. These gravel deposits are interpreted as bars made by the glacial rivers.

3. Above the level of the scablands and their associated gravel deposits is a deep mantle of loess on the plateau. This loess deposit has been dissected to maturity and almost everywhere is in gentle slopes. But along the linear scabland tracts, the loess is steeply scarped, the slopes averaging 30°, all facing and descending to the scabland. There are many isolated hills of loess entirely surrounded

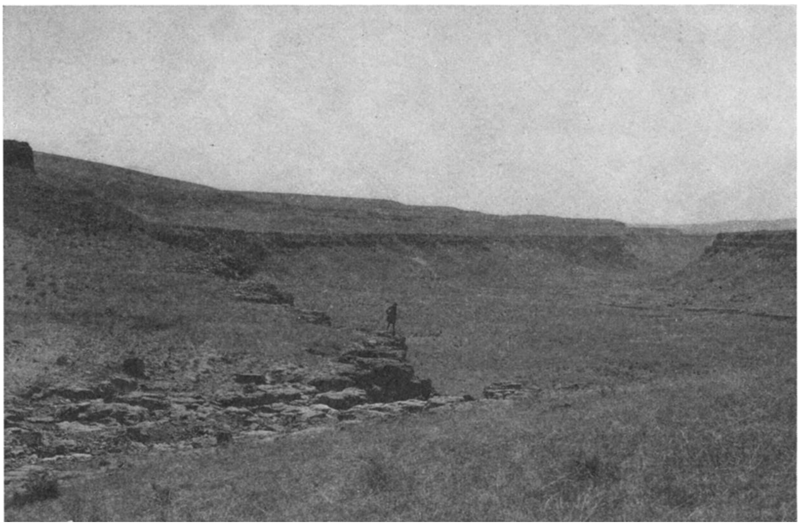

FIG. 2.—Channeled scabland on the Columbia Plateau. The figure in the picture stands on the brink of an abandoned cataract. Photo by F. L. Pickett.

by scabland (Fig. 3), and these commonly have striking prows which point up the scabland gradient. Some of these isolated loess hills, bounded by steep slopes, have the rounded, elongated deposits of gravel on the down-gradient end. The scarps are interpreted as river bluffs of the Spokane glacial streams, produced when the preglacial valleys were not sufficiently deep in basalt to contain the flood which was poured into them. The anastomosing pattern of the whole group of associated phenomena is likewise the consequence of a greater volume than some valleys could carry away, the waters flooding over many minor and some major divides of the plateau.

THE SPOKANE FLOOD IN SNAKE RIVER VALLEY

Between Lewiston and Riparia.—At Lewiston, Idaho, Snake River occupies a structural valley in whose northern wall the Columbia basalt flows are tilted 60° from horizontal. It leaves this open valley a few miles below the Idaho-Washington boundary line and traverses a narrow, winding canyon, cut in nearly horizontal flows of basalt, thence nearly to its junction with Columbia River.

The distance from Lewiston to Riparia is about 100 miles, and the descent is 200 feet. Terraces of river gravel occur on the inside of almost every curve in the course. None of these are more than

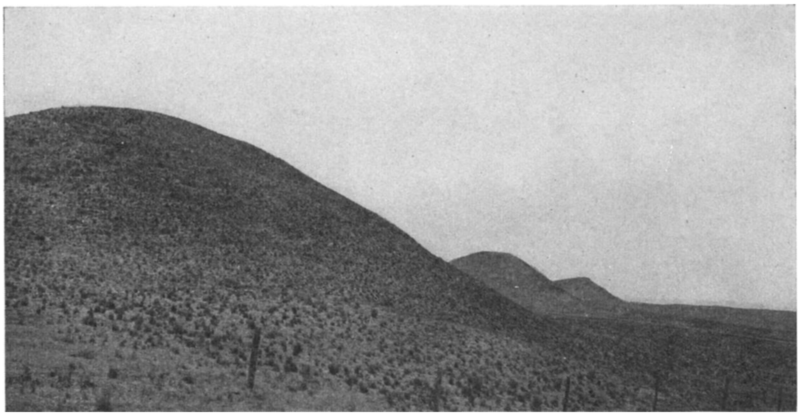

FIG. 3.—Isolated loessial hills on the scabland of the plateau. Photo by F. L. Pickett.

50 feet above the river, if talus and alluvial fan deposits on top of them are not reckoned. Less than 50 per cent of the gravel of which they are composed has been derived from the Columbia basalt. Though the canyon walls are steep, there are no great cliffs, and a mantle of débris and vegetation occurs on most of the slopes. All of these are normal features, and none suggests the occurrence of the Spokane flood in this part of Snake River Valley.

Between Riparia and the mouth of Palouse River.—A great terrace of gravel, 150 to 260 feet above low-water level, lies on the north side of Snake River Canyon in this stretch. Much of it is flat-topped. Exposures are numerous along its steep scarp. Almost without exception the gravel is foreset-bedded, and almost without exception this foreset bedding dips *up* the Snake River Valley. The amount of gravel not derived from the Columbia basalt in most sections does not exceed 1 per cent. The pebbles are worn, well sorted, and progressively smaller with increasing distance *up* the Snake. At the upstream terminus of the great terrace, a mile west of Riparia (Fig. 4), all the material is fine enough for highway gravel. The summit here is about 150 feet above the Snake. Though the Snake descends westward, the terrace top descends eastward.

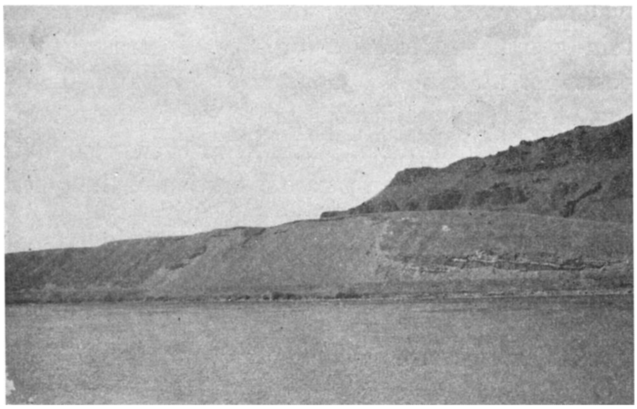

FIG. 4.—Upstream terminus of the Riparia terrace. Foreset beds dip to the right, or up the Snake, parallel with the terminal slope.

There is a terrace on the south side of the Snake comparable to the one described except that its extent along the canyon is much less. Another gravel deposit on the south side, also opposite the great terrace, lies in the mouth of the tributary valley of Tucannon River. Its surface is lower than that of the great terrace and descends southward *up* the Tucannon Valley to Starbuck, a distance of 4 miles. Here it meets the bottom of the pre-Spokane Tucannon Valley, descending toward the Snake. The stratification of the basaltic gravel of this deposit is inclined, and the dip is *up* the tributary. The material is progressively finer, also, as the distance from the Snake is greater. Some of the gravel apparently was carried into the lower part of Tucannon Valley from the east, across the angle between the Tucannon and the Snake, but most of it came up the Tucannon.[1]

These three remnants of a great gravel deposit in Snake River Valley indicate

1) a supply of river gravel introduced some miles below Riparia and Starbuck, and carried eastward up the Snake and Tucannon valleys,

2) a depth of ponded water at Riparia of about 250 feet, and

3) the basalt plateau as the source of the gravel.

This deposit was made rapidly, else Snake River would have filled its valley above Riparia with the coarse débris of its hundreds of mountain-born, high-gradient tributaries. There is no evidence of such deposits for at least 100 miles above Riparia. The ponded Snake, if 250 feet deep at Riparia, was 50 feet deep at Lewiston.

Nothing on the south side of Snake River even suggests that the gravel of these terraces came from that portion of the plateau. On the contrary, the features of Tucannon Valley below Starbuck indicate that the débris came from the northern side, which bears the scablands.

Between Palouse River and Devils Canyon.—There are many large gravel deposits in this stretch, all falling into two groups: great rounded mounds, and flat-topped terraces. The great mounds are strictly only half-mounds, for they rest against the canyon walls somewhat like alluvial fans. Almost all of them occur on the inside of the broad curves of the canyon's course. Almost all of them slope from their summit contact, at the base of a basalt cliff, down toward the middle of the valley. These slopes are all convex. Where there is no notable cliff back of the mound, the gravel deposit has a convex top and is highest a little out in the valley. One such deposit lies like a great dam across the mouth of a tributary valley, and a narrow gash has been cut by that tributary subsequently. These half-mounds stand 150 to 200 feet above the river-level, and in the scarps cut by the Snake the gravel descends to river-level. In com-

[1] I. C. Russell (U.S. Geol. Survey, *Water Supply Paper* No. 4. p. 21) noted this gravel deposit in the Tucannon valley below Starbuck and interpreted it as Snake River gravel carried back up the tributary valley. He noted also great gravel deposits in the Snake Canyon. His interpretation is couched in the conventional terms of overloading of the main stream by excess supply from the headwaters.

position, they are 99 per cent Columbia basalt. Their structure is largely foreset, with the dip consistently *down* the canyon. They bear almost no gullies, ravines, or other erosional slopes except the steep riverward faces. Some of the mounds show a horizontal fluting and a minor mounding on their slopes which can only be original, depositional outlines, as, indeed, the convex slopes are original slopes.

The deposits of this group are bars. They were deposited during one short episode when the stream was deeper than they are high, yet had a mid-current velocity sufficient to keep most of the channel open from side to side and from top to bottom. The flood in which they were built came from the surface of the plateau, carried almost nothing but basaltic débris, and entered the Snake Canyon somewhere above the stretch in which they occur. This flood subsided so quickly that there was almost no modification of their outlines by either erosion or deposition from the lowering stream. Hillside and roadside gullies often show similar phenomena in miniature after torrential rains.

Only two flat-topped terraces were seen in this part of Snake Canyon. One is on the south side, opposite the mouth of Devils Canyon, the other is at Davin Station, on the north side, a few miles below the mouth of Palouse River. The summits of both are well above the tops of the mounded bars, the one on the south side 350 feet above the Snake, the one at Davin 200 to 250 feet above. Both are composed of basaltic gravel from top to bottom and scarcely touched by gullies.

In brief, then, the features of Snake River Valley for a few miles both up and down stream from the mouth of Palouse River indicate the entrance at that place of a great river from the north, far surpassing the proportions of either the Palouse or the Snake of today. The volume of this river actually ponded the Snake for 100 miles or so upstream, and into this pond was built a deltaic gravel deposit, reaching to Starbuck in the tributary Tucannon and nearly to Riparia in the main valley. And it is here, at the mouth of Palouse River, that the greatest contribution from the Spokane flood across the plateau scabland entered Snake River. The evidence for this has been presented in a previous paper and will not be reviewed here. The glacial river at its inception was 10 or 15 miles wide, and in its central portion it eroded at least 500 feet deep just above its junction with the Snake. The Davin terrace lies at the debouchure of a distributary course of this river, and the plateau scabland extends almost to the brink of the Snake Canyon here. In a similar fashion the great terrace below Riparia can be traced northward to the scabland along the eastern margin of the wide glacial river.

Mouth of Devils Canyon.—Devils Canyon was eroded by overflow from Washtucna Coulee across a preglacial divide to Snake River Canyon during the Spokane epoch. As shown by the scarped loessial hills margining this glacial river course, the flood rose to 1,300 feet A.T. in Washtucna Coulee, at which altitude part of it spilled over to the deeper valley, and the large torrential stream thus formed rapidly eroded Devils Canyon. Before the close of the episode, the canyon was gashed 500 feet deep in basalt, all but cutting the divide down to the floor of Washtucna Coulee. The spill-over apparently entered a short preglacial tributary of Snake River, for the mouth of Devils Canyon is flaring, unlike the extreme narrowness of the rest of it. In the middle of this flaring mouth is a basalt knob, of no remarkable proportions, but characteristically a scabland knob, and flanked by post-Spokane talus. It is clearly an erosional remnant of the pre-Spokane floor of the tributary. Below this knob, and projecting in part out into the Snake Valley beyond the line of the canyon walls, is a gravel deposit about 160 feet above the level of Snake River. The surface of this deposit bears an exceptional ridge, shaped in ground plan like a horseshoe, with the concavity facing up Devils Canyon and the two ends abutting against the walls of the flaring mouth. The middle of this semicircular ridge is about 60 feet above the rest of the gravel deposit. It is symmetrically lower on both limbs, the lowest places being next to the rock walls. The slopes of the ridge are gentler toward the concavity, i.e., upstream, than they are toward Snake River. Post-Spokane run-off has cut a narrow ravine through the ridge at its contact with the eastern rock wall,[1] but when the glacial river ceased to flow,

[1] The topographer who sketched this ridge was quite at sea as to its origin. The Connell sheet shows it as a minor ridge projecting from the west wall of Devils Canyon and due to stream erosion.

this semicircular ridge was complete and inclosed a basin in the mouth of Devils Canyon. In this basin stood the eroded basalt knob above noted.

Closer scrutiny of the ridge shows that it is fluted radially, or composed of low radially elongated mounds, largely coalesced, and that on its downstream face, out in Snake River Valley, are traces of larger, older flutings on which the semicircular ridge has been built.

This curious gravel ridge is a bar. It is identical with the bars formed across torrential streams where there is a slackening of velocity because of increased width of channel and decreased gradient. It is duplicated in roadside gutters after heavy rains. It is evidence conclusive that a great torrent made Devils Canyon, that that torrent abruptly ceased to flow, and that the surface of Snake River at that time was more than 220 feet above its present summer level. The fact that the gravel deposit extends down almost to the river-level shows that Snake Canyon was then eroded approximately to present depth and the stream at that time was more than 220 feet deep.

The materials of the gravel deposit are not well shown. In the exposures available, the gravel is poorly sorted and little worn. It is practically all basalt. The large amount of interstitial silt in the gravel suggests its derivation from the destruction of loessial hills on the scablands farther north.

Snake River Junction.—In many ways the vicinity of Snake River Junction[1] exhibits the remarkable changes caused by the Spokane flood better than any other place in the canyon. An observer standing on the hilltop centrally located in Section 11, T. 10 N., R. 33 E. (Fig. 5), $2\frac{1}{2}$ miles southeast of the junction, can see for miles both up and down the valley. The canyon proper, with very steep, rugged, bare cliffs and ledges, lies below a broad higher valley floor that is several times as wide as the top of the canyon. Above this broad floor rise the gently rolling loessial hills of the plateau, but almost without exception their slopes toward the broad floor are about 30.°

[1] Junction of Spokane, Portland and Seattle Railroad and Lewiston branch of Northern Pacific Railroad.

The severely eroded bare basalt below the higher broad floor, typical scabland in its character, carries great isolated gravel deposits with rounded summits and convex slopes. The higher floor is 1,000 feet A.T. in maximum elevation at Snake River Junction, where it is determined by the upper surface of the Columbia basalt formation, from which the loess has been removed by the wide

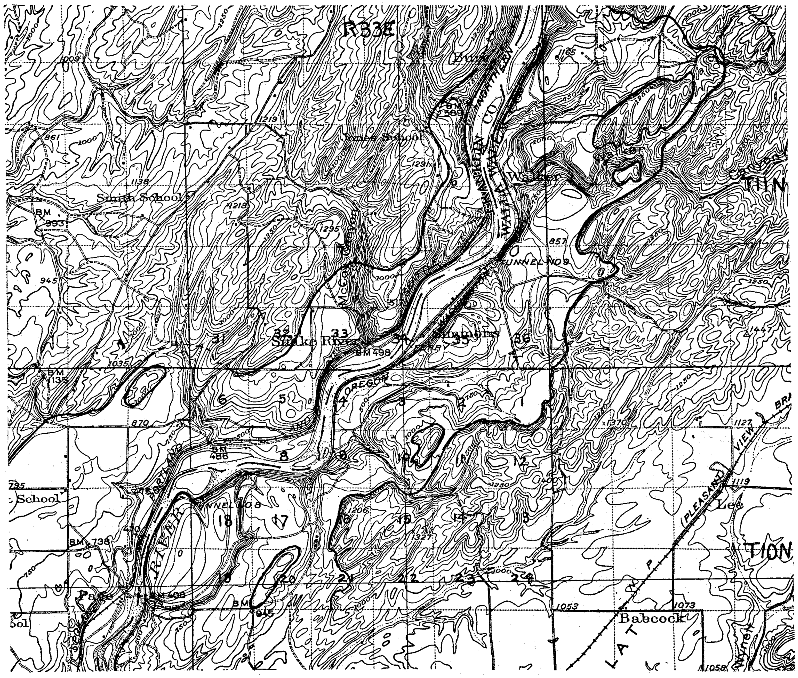

FIG. 5.—Vicinity of Snake River Junction, showing the loess-covered plateau, the extent of the upper floor of scabland basalt from which the loess has been removed, its steep margining slopes of loess, isolated hills of loess, and the abandoned portions of Snake River Canyon. From the Wallula, Washington, topographic map, U.S. Geological Survey.

glacial river, and on which gravel has been spread. The absence of such a floor from Riparia down to the vicinity of Snake River Junction is due to the failure of the flood to reach the upper limit of the basalt cliffs.

In the extreme northwest corner of Section 11, above noted, is an isolated loess hill, with slopes of 30°, with elongation parallel to the Snake Canyon and with a prow pointing up the canyon (Fig. 6). Between it and the hill, centrally located in this section, is a flat-bottomed valley, walled by loess bluffs and floored by Columbia basalt at about 1,025 feet A.T. Here a small part of the glacial flood spread across a minor divide of the invaded loessial drainage system, to re-enter the main flood about a mile farther down. This isolated hill is typical of hundreds in the plateau scabland.

But at the cornering of sections 1, 2, 11, and 12 is another small preglacial valley in loess, similarly oriented and proportioned and with similar altitude of floor, but with the divide at the head intact. The divide is composed of loess and lies a little above 1,100. We

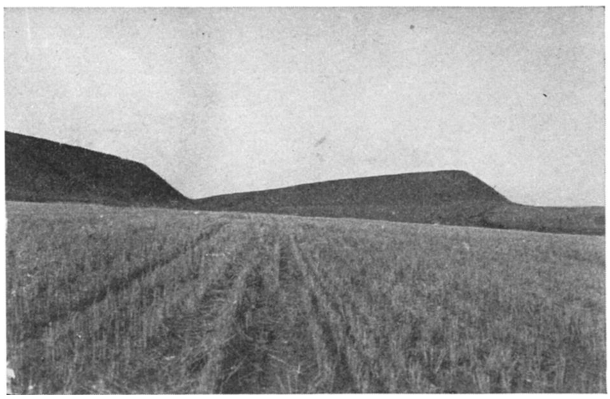

FIG. 6.—Isolated hill of loess, $2\frac{1}{2}$ miles southeast of Snake River Junction

conclude, therefore, that the glacial flood which swept the loess from Section 1 and made the steep cliff in loess along its southern margin failed to rise to 1,100 feet A.T.

East of Simmons Station is a greatly eroded hill of nearly bare basalt (Sec. 35, T. 11 N., R. 33 E.), its summit a little below 1,100, with Snake River on the northwest side and a valley in basalt on the east fully as broad as the Snake Canyon but 250 feet less in depth. On the downstream end of the hill is a bar of basaltic gravel 250 feet thick. The broad streamless valley east of the hill is a part of the pre-Spokane course of Snake River, the stream having located and eroded a more direct route during the flood which so greatly denuded the basalt hill. This abandoned portion contains remnants of a stained and indurated river gravel, of which not more than 25 per cent was derived from the underlying formation.

A great bar along the Spokane, Portland and Seattle Railroad, 2½ miles northeast of Snake River Junction, is 400 feet thick. The gravel pit excavated by the railroad here has a scarp 200 feet high. The gravel is unindurated and slides easily, so that the structure is difficult to decipher. But it is 99 per cent basalt.

One more feature in the vicinity of Snake River Junction may be described and the list then closed, though every mile of the canyon here contributes to the history of the Spokane flood. The locality is between Page Station of the Spokane, Portland and Seattle Railroad and Tunnel No. 8 on the Oregon-Washington Railroad, and involves 4 square miles, most of it east of the river. The canyon here is narrower than at any other place in the plateau. East of the narrow place is a basalt hill 400 feet above river-level, possessing the typical severely scrubbed scabland aspect. The hill is separated from the rest of the higher land to the east by an abandoned valley which is open to the Snake at Tunnel No. 8 and opposite Page. Its floor is nearly 150 feet above the present river. Depending from the downstream end of the bare rock hill and overlying it in part is a gravel bar about 200 feet thick, whose convex outlines are unmistakable. The growth of the bar has constricted the southern part of the abandoned valley. The present course of the Snake through the exceptionally narrow canyon west of the hill departs from the fairly symmetrical meandering pattern it elsewhere possesses in the vicinity of Snake River Junction. Were the narrow canyon filled, the bar removed, and the Snake replaced in the old course east of the scabland hill, the symmetry would be restored, all steeper bluffs would stand on the outside of curves with the river undercutting them. and a uniform width of valley would exist throughout. It seems probable that the Spokane flood, which at its inception was at least 250 feet deep over the top of this hill, cut across a pre-Spokane spur in the valley's course and eroded the narrow canyon west of the hill. If this be correct, then Snake River Canyon was deepened here about 150 feet by the glacial stream.

In summary, the vicinity of Snake River Junction records a river of dimensions so great that the pre-Spokane valley was but a channel for it. The glacial waters, in prodigious volume, reached at least 1,000 feet A.T., though the surface of the river today is but 400 feet A.T. here. About 150 feet of deepening in basalt occurred, all exposed rock slopes were greatly eroded to typical scabland forms, two new routes were cut across the pre-existing curves, huge amounts of basaltic gravel were eroded and transported. All the features of the plateau scabland are here. Bluffs of loess 250 feet high and with 30° slopes face the broad scabland floor, isolated prow-pointed hills of loess stand on the margins of the broad floor, bars of basaltic gravel with the typical convex slopes so often seen in the plateau scablands lie in protected places below the level of the broad floor, and cliffs without streams at their bases have talus standing three-fourths of the height of the original cliffs. The glacial river was at least 400 feet deep and 3 miles wide here at its inception.

THE SPOKANE FLOOD IN COLUMBIA VALLEY ABOVE THE MOUTH OF SNAKE RIVER

Columbia Valley between the limits reached by the Spokane ice sheet and the mouth of Snake River has not been studied as carefully as it deserves. But enough is known to warrant the statement that nothing comparable to the Spokane features of Snake River Canyon is found in it. No great bars are known, no bluffs of loess, no relocations of the stream course, almost no scablands. Yet the flood was there and left its record.

Columbia Valley is deeper and considerably wider than Snake Canyon, and carried its share of the Spokane flood without rising to the summit of the basalt cliffs. Hence the absence of the steepened slopes in loess and of scabland above and margining the river valley. Much of the water entering it passed through settling-basins which trapped the waste of the scablands. Much came directly from the margin of the ice sheet. The basaltic gravel which did enter appears to have been mingled with older gravel, and the striking dominance of basalt, seen in Snake River bars, is absent here. Evidence of the height reached by the flood has been found largely in the features of the scabland spillways from the plateau.

Moses Coulee.—The largest single spillway was Moses Coulee, a pre-Spokane drainage way which was greatly modified during the

Spokane epoch. In Columbia Valley at its mouth, and extending back up the coulee, is a gravel deposit more than 300 feet thick, the highest part of which is 925 feet A.T. and the lowest surface about 800. Since the coulee carried some discharge from the Wisconsin ice sheet, subsequent to the Spokane glaciation, this lower surface, which floors most of the mouth of the coulee, may not date from the earlier epoch. But the higher part certainly does. And below the mouth of Moses Coulee the high gravel terrace lies against the foot of an exceptionally high steep cliff of basalt. The cliff strikingly truncates a number of short tributaries to the Columbia and their separating spurs. It constitutes the east side of Columbia Valley and of Moses Coulee, and thus is traceable into the scablands. Only a great stream undercutting at about 1,000 feet A.T. could make this cliff, and the character of its talus dates it as Spokane in age.

"*The Potholes*."—Ten miles south of the mouth of Moses Coulee is "The Potholes," a huge alcove caused by retreat of a scabland cataract. Not considering the remarkable holes, which are more than 125 feet deep in bedrock, the cataract made a sheer leap of 200 feet from the brink of the Columbia cliffs to the surface of a prominent rock terrace of the Columbia Valley, itself about 400 feet above the river. Over the edge of this terrace the stream spread in several channels and leaped again, this time about 125 feet. Much less work was done by the cataract on the edge of the terrace than on the summit of the cliffs, and for this notable difference a reason must be found. The terrace extends northward from "The Potholes" along Columbia Valley for several miles, rising upstream about 80 feet to the mile with the gentle tilt of the basalt flow which holds it up. For 2 miles north of the ancient cataract, the surface of the terrace is greatly channeled in typical scabland fashion, with "holes" and rock islands in complex profusion.[1] East of this scabland on the terrace top is the upper cliff with three-fourths talus.

Farther north, however, the terrace surface bears no scabland, and the cliff has soil-covered talus to the very summit. The Spokane flood, therefore, entered on this southward-sloping rock terrace at an

[1] Some of these are shown on the Quincy sheet, but most of them are too small to be caught by any contour.

altitude of about 1,200 feet A.T., scored its surface, and undercut the cliff above it. The three-fourths talus of this cliff indicates that all the wastage has accumulated since the scablands were formed. But 1,200 is the altitude of the brink of the upper Potholes cataract. No cataract existed, then, at the beginning of the spill-over. Its development waited until the main Columbia Valley flood subsided, though the scabland flood was still running at full volume. The explanation for this seems to be that some constriction farther down the Columbia Valley held up the great flood at first, but was rapidly eroded during the episode. The surface of the stream therefore fell until, late in the cataract's history, the rock terrace was exposed and the lower falls took origin. Such a constriction exists, and is described in this paper.

Gable Butte and Gable Mountain.—Near the towns of Hanford and White Bluffs, 35 miles above the junction of Snake and Columbia rivers, the Columbia Valley is 15 miles wide. Most of the valley floor here lies about 500 feet A.T., though the river surface is below 375. This 500-foot floor consists of a great gravel deposit which extends southward to and beyond the mouth of Snake River. This broad part of the Columbia Valley is largely structural, the basalt dipping below the bottom of the river channel. But near Hanford two large hills of basalt stand in the gravel plain (Fig. 7). They are parts of the north limb of an anticline which pitches eastward beneath the valley from the high basalt hills to the west. Gable Butte rises 763 feet A.T., or about 250 feet above the plain. Gable Mountain has two summits, one of them 1,075 feet A.T., the other 1,116, and the plain surrounding the mountain is as low as 425 feet A.T. Both hills have been greatly scoured and carry the scabland type of knobs and channels. The channels cut across the summits and vary in depth from 50 feet to 150 feet. Trenching the surface of the gravel plain about the base of the hills are much larger channels. They flank the hills in such a fashion that it is clear that the waters which scoured the hills developed the margining channels. The surface of the Spokane flood, therefore, rose above 1,100 feet in this wide valley.[1]

[1] Olaf Jenkins, in *Bull. 26, Div. Geology, Dept. Conservation and Development, State of Washington,* notes that the channels in the plain record a great glacial stream in the valley.

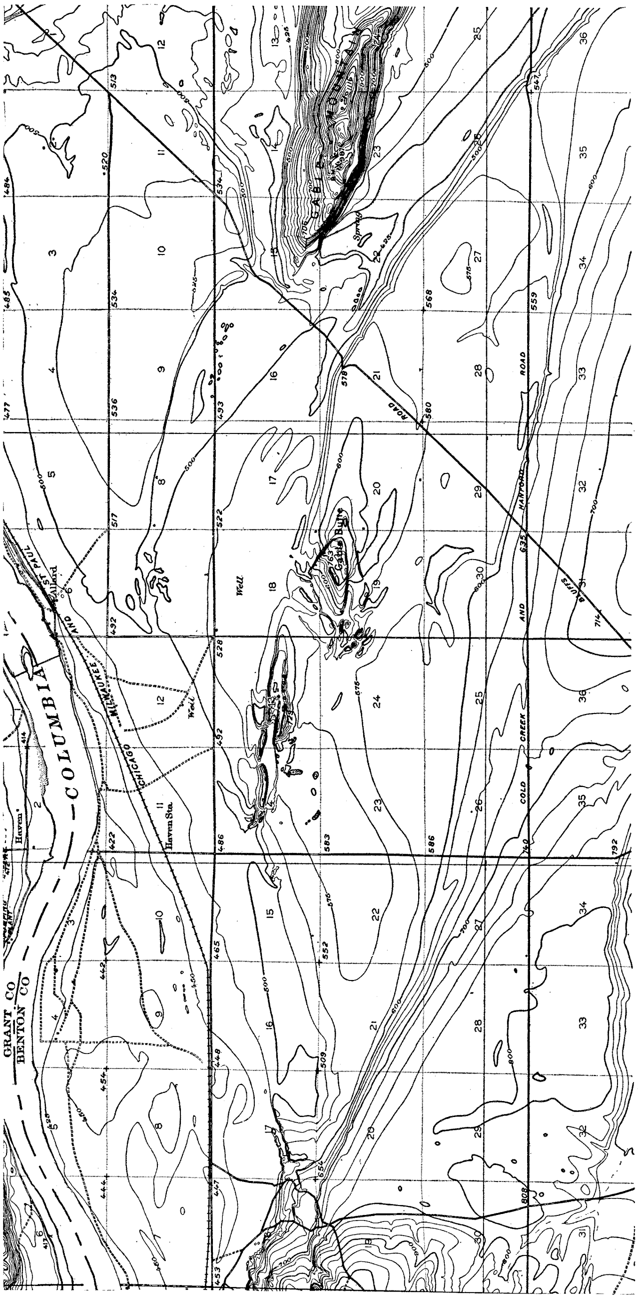

FIG. 7.—Gable Butte, Gable Mountain, and associated channels in the flanking gravel deposits. From the Coyote Rapids, Washington, topographic map, U.S. Geological Survey.

That the gravel plain flooring the wide valley is a deposit of this stream is not clear. Its surface is greatly obscured by sand dunes, and of its expression before they grew, only the large channels remain. Its materials include a large percentage of non-basaltic material. Its altitude is far below the surface of the flood. Yet it may be a gravel floor built where the wide valley invited deposition at the bottom of the great stream. If not, it is older than Spokane, rather than younger, as its trenching shows.

Othello Channels distributaries.—At the east end of Saddle Mountain, near Othello, part of the scabland flood on the plateau spilled southward over a pre-Spokane divide and took several distributary courses thence to both Snake Valley and Columbia Valley. At least four channels seem to have carried glacial water to the Columbia,[1] the northernmost entering in the latitude of White Bluffs and the southernmost mouthing at Ringold. Two of these open on the brink of the Columbia bluffs at 200 and 300 feet above the river, and two open back from the brink at altitudes of about 400 feet above the river, or 750 feet A.T. All of these altitudes are much below the upper limit of the flood as indicated by the rock terrace just north of "The Potholes" (1,200 ft. A.T.) and the summit of Gable Mountain (1,116 ft. A.T.). All are eroded in the weak Ringold silt and clay, which here constitutes the east bluff of the Columbia.

The relations of these channels and Gable Mountain seem to indicate the same situation as at "The Potholes": an initial great depth of water in Columbia Valley, and the lowering of that water-level while the scablands were being eroded. The differences in altitude of the channel mouths seem to indicate abandonment of some during the lowering of the Columbia and continued deepening of the remaining ones until the close of the episode. The gravel deposit at the mouth of Moses Coulee likewise records a late stage in the episode.

It is now in order to seek for the cause of the rapid lowering of the flooded Columbia during the Spokane epoch.

[1] Only the southern two were mapped in "The Channeled Scablands of the Columbia Plateau."

[*To be continued*]

THE SPOKANE FLOOD BEYOND THE CHANNELED SCABLANDS. II

J HARLEN BRETZ
The University of Chicago

THE SPOKANE FLOOD IN COLUMBIA VALLEY BELOW THE MOUTH OF SNAKE RIVER

Wallula Gateway.—Concentration of all the Spokane discharge into one valley occurred at Wallula, where Columbia River in an antecedent course crosses a prominent upwarp of the basalt plateau, a few miles below the mouth of Snake River (Figs. 8 and 9). The canyon here has very steep walls for 750 feet above the river, and its minimum width at the top of these cliffs is a mile. This is Wallula Gateway, probably the narrowest place in Columbia Valley south of the Canadian line. Whatever its depth at the inception of the Spokane flood, the canyon was inadequate to contain the great stream. The glacial Columbia rose above the summit of the cliffs and spread westward a mile and eastward an average of more than half a mile.

The top of the western wall, for a mile back from the brink of the Gateway cliffs, is scored and channeled by a plexus of anastomosing ravines and gulches in basalt, which trend with the river course. Their gradients descend southward. At their heads they open toward the broad, low structural valley north of the uplifted tract. Southward, they lead to the brink of the broader part of the canyon below the Gateway. Erosive action has been great, for the basalt is bitten 100 to 150 feet deep in these channels. Rock basins excavated in their bottoms record great volume of water moving with considerable velocity.

And the water which traversed them did not come from higher land to the west; it came from the broad, low structural valley to the north. It entered at an altitude of 1,050 feet A.T., hundreds of feet above the bottom of that valley. The streams left the south-

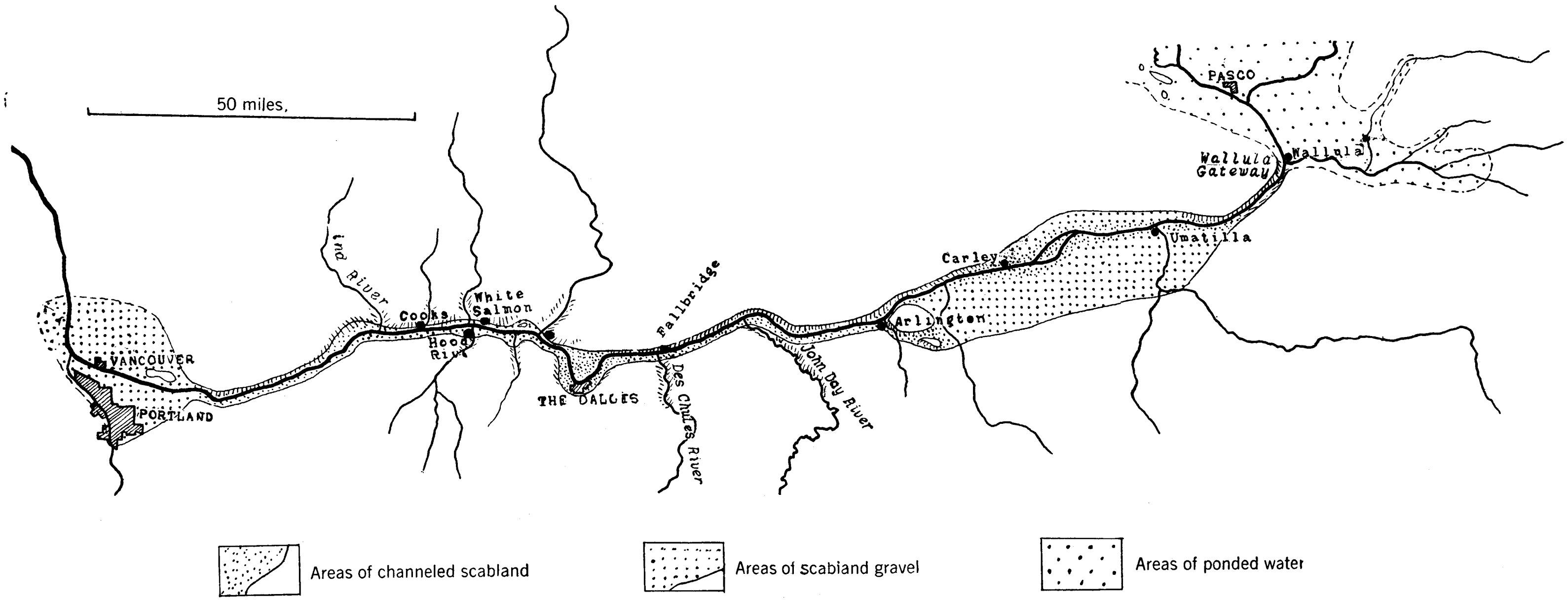

FIG. 8.—Sketch map of Columbia Valley between Wallula and Portland, showing area affected by the Spokane Flood

ern ends of these channels at altitudes of about 950 feet A.T. They did not flow down the slope to any lower level. Since they ceased to erode below an altitude of about 900, they must have entered a body of water in the broader canyon below the Gateway whose surface was not much above 950.

This is scabland on top of the western cliff of the Gateway. It is wholly unlike the topography of the higher slopes. To be typical, it needs only the bounding bluffs of loess, bar and terrace gravel, and three-fourths talus on its basalt cliffs. The steep bluffs of loess are absent, because the higher land here is all basalt. The gravel deposits are not shown, but may be present in certain rounded hillocks and shoulders. Most of the talus is higher than three-quarters, though some is typical. The basalt at this horizon breaks readily into small pieces and perhaps may have disintegrated more rapidly than the average rate.

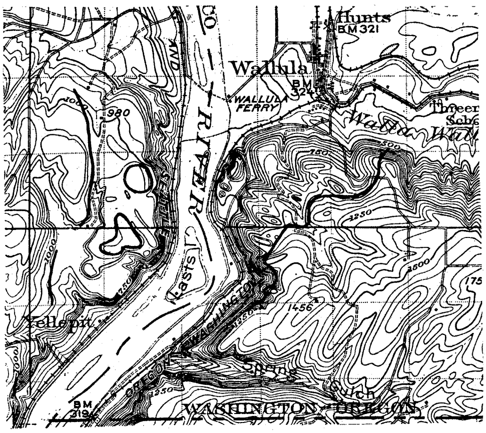

FIG. 9.—Wallula Gateway, showing the scabland type of topography within and above the canyon walls. From the Wallula, Washington, topographic map, U.S. Geological Survey.

The east side of the Gateway has scabland up to the same level, and gentle, soil-covered slopes above. "The Sentinels" (Figs. 10 and 11) and their associated bare rock hills and channels are clearly scabland forms. And all the divides between the pre-Spokane tributary ravines which drain the higher land to the east are severely scored and notched below 1,050, so that they are separate hills instead of ridges.

Here, then, the entire Spokane flood was finally converged to make the prodigious river which filled and overflowed WallulaGateway. Here, also, was the constriction which first held up the surface of Snake and Columbia rivers, and whose enlargement allowed the fall in their levels while the scabland rivers were running at full volume. How much widening was accomplished is not clear, but the deepening probably extended from the base of the Sentinel group of scabland buttes, 500 feet A.T., to the rock ledges in the river today at about 300 feet A.T. The increase in capacity was very rapidly produced and the backwater above the Gateway lowered early in the Spokane epoch.

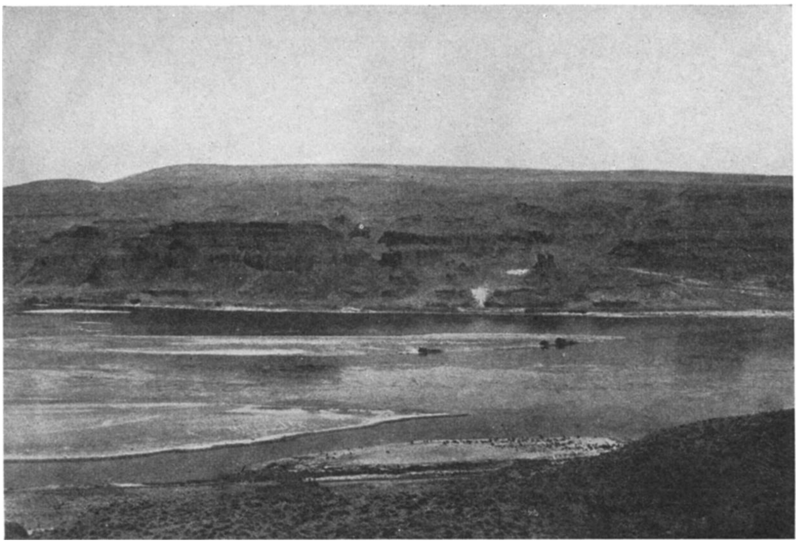

FIG. 10.—The east wall of Wallula Gateway. Scabland cliffs extend about 700 feet above the Columbia. Above them, the basalt is covered with loess, and all slopes are gentle. A prominent scabland channel, shown in Figure 7, lies back among the cliffs and is not shown in this view. "The Sentinels" stand a little to the right of the center of the picture.

Estimating from the scabland above the cliffs west of the Gateway, the glacial river surface descended 50 feet or more in 3 miles. But near Snake River Junction, 25 miles upstream, the highest river-level was no greater than at the entrance to the Gateway. The cause of this is the broad structural depression in the basalt. The flood waters spread over several townships immediately north of the narrow Gateway. And in this region was deposited all gravel which had traveled with the flood through Snake River Canyon and

Columbia Valley.[1] Therefore, gravel left by the Spokane flood in Columbia Valley below Wallula Gateway must have been derived from erosion of rock ledges and cliffs also below the Gateway. In distribution and topographic expression, these deposits are unlike those in Snake River Canyon, as will appear in the following descriptions.[2]

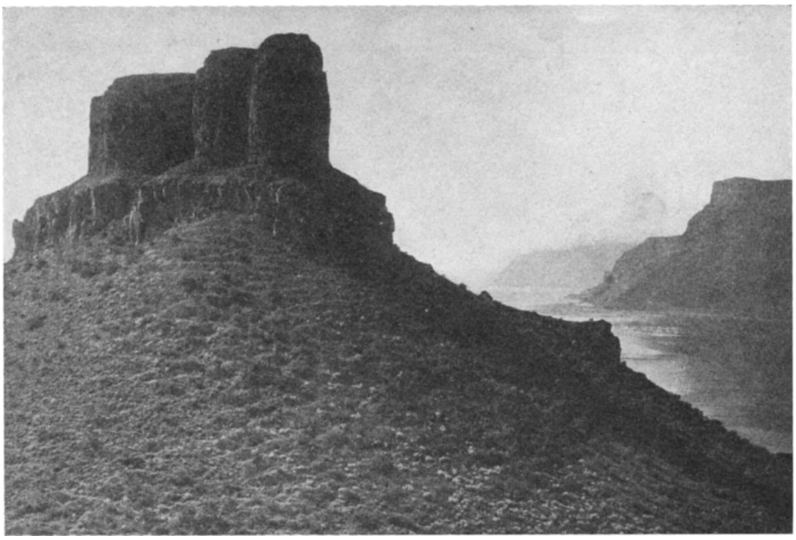

FIG. 11.—"The Sentinels," scabland buttes in the Wallula Gateway. Talus and cliffs together are 100 feet high. Copyright G. M. Weister.

Vicinity of Umatilla.—Columbia Valley has much lower walls about 10 miles below Wallula Gateway. At Cold Springs Station, on the south side, the bluffs are not 250 feet above the river, and for 10 miles south of the Columbia here (vicinity of Stanfield [Foster] and Hermiston), the country does not rise 500 feet above the river.

[1] These deposits are now masked by eolian sand and not easily identified.

[2] The significance of the Wallula Gateway constriction was not realized when the plateau scablands were studied. The early ponding of the flood north of the Gateway must have affected the lower part of the plateau as well as the Snake and Columbia valleys. Examination of altitudes shows that lower Crab Creek Valley and Washtucna Coulee must have contained backwater from the Gateway, and that this was very probably responsible for the high water-levels which initiated Othello Channels and Devils Canyon divide crossings, and probably was a factor favoring the Drumheller Channels and Palouse Canyon crossings.

This region south of the river is largely covered with basaltic gravel deposits, disposed in broad, low hills and separated by equally broad ramifying channels which lead out of the Columbia and back again a few miles farther downstream (Fig. 12). Basalt buttes appear here and there in this area of gentle slopes. Umatilla Butte and

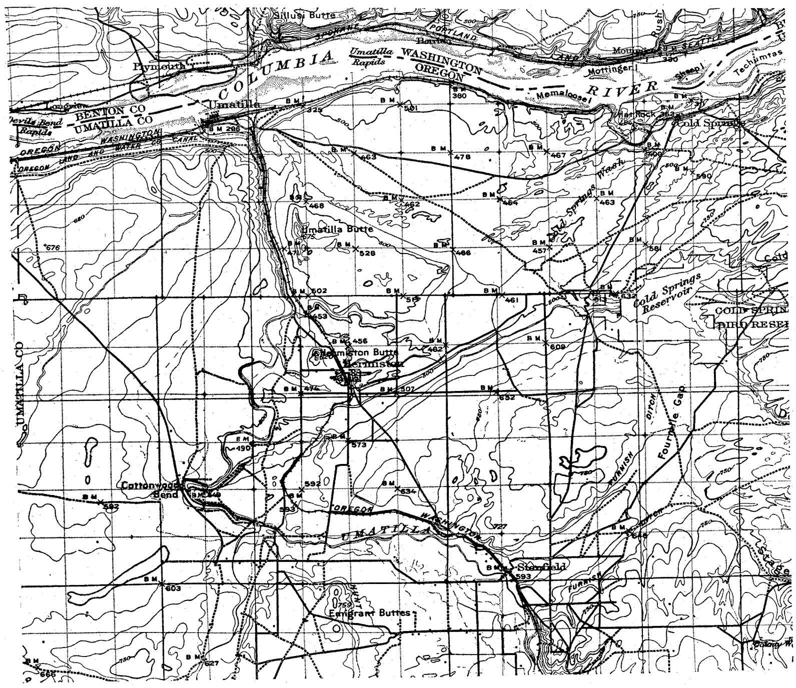

FIG. 12.—Umatilla lowland, showing braided course of the Spokane Columbia across the gravel-covered flat, and the situation of Emigrant, Hermiston, Umatilla, and Sillusi buttes. From the Umatilla, Oregon-Washington topographic map, U.S. Geological Survey.

Hermiston Butte are the most prominent ones. They, as well as the basalt bluffs of the river, are severely eroded bare rock scabland forms, and their association with the channels and gravel deposits indicates a common origin.

Both of the buttes named are due primarily to sharp local upwarp of the basalt along a north-south line. Sillusi Butte, just north of the Columbia and also on this line of deformation, is similarly eroded on its riverward face, though wind-driven sand masks its character in part. Emigrant Buttes, 10 miles south of the Columbia, is another sharp pucker on this line, but possesses gentle slopes and a complete cover of soil. The contrast between the uneroded Emigrant Buttes and the craggy Hermiston and Umatilla buttes is very instructive. The only explanation applicable is that Hermiston and Umatilla buttes, respectively 620 and 675 feet A.T., were overrun by the Spokane flood, while Emigrant Buttes, 759 feet A.T., stood beyond and above the limits of the flood and were spared. It therefore appears that in the Umatilla lowland this flood rose nearly but not quite to 750 feet A.T. Elsewhere in the region the 700-foot contour approximately marks the upper limit of scabland and basaltic gravel.[1] A descent of about 250 feet in the surface of the Spokane Columbia therefore occurred at the beginning of the episode in about 15 miles of distance. Most of this probably occurred in the Gateway and the gorge immediately below. Certainly the walls of the canyon here bear witness to very vigorous scour for several hundred feet above the river-level. The talus on the great cliffs southeast of the river below the Gateway stands two-thirds to three-fourths the height of these cliffs. This is a good Spokane ratio; considering that post-Spokane river work probably has carried away some of the talus. The Sentinels and associated scabland knobs in the Gateway bear three-fourths talus, and therefore have not been touched by waters of the Columbia since the flood subsided. Their bases are about 200 feet above the river.

Vicinity of Carley.—There are two anticlinal folds in the basalt on the north side of Columbia River near Carley Station, both parallel to the river and both clearly expressed in the topography. Tributary streams, antecedent to the folding, have cut them into several short ridges or buttes, and, subsequent to this, the Columbia has risen high enough to flow around them all. Artesian Coulee is the most prominent erosional feature here, due largely to the flood. Its floor is so low, however, that it cannot be cited as a channel abandoned ever since the Spokane epoch. Crow Butte, anticlinal in

[1] Not all of the gravel in this lowland is of Spokane age. At Echo, Stanfield (Foster), and elsewhere are outcrops of a stained, indurated gravel with a considerable proportion of non-basaltic material. It is much older than the scabland gravel.

structure, has the scabland erosional features, though much obscured by wind-blown sand. Golgotha Butte is an isolated part of the other fold and was also surrounded. On its north side, away from the river and about 3 miles distant, is a large gravel deposit, 650 feet A.T. and 400 feet above the river. The material is unweathered and largely basaltic, but from the presence of quartzite pebbles there seems to have been incorporation of older gravel in it during the Spokane flood.

When the river was high enough to deposit this gravel, it must have spread over miles of the low country south of the river here and west of the Umatilla region. Much basaltic gravel is exposed along the railroad south of the river, but its altitude is not more than 150 feet above the river and its significance therefore slight. The low country is heavily mantled with wind-blown sand, and little is known about the material beneath. The most prominent feature is a broad flat which rises gradually westward from Umatilla River to an altitude of 650 feet and descends abruptly from this summit flat toward the west. See Fig. 12. It probably is a Spokane bar, but if so it contains a large amount of reworked material derived from the older gravel deposit below the scabland waste. There are no elevations of basalt in this low country.

Vicinity of Arlington.—The surface of the basalt rises west of Carley, and the Columbia is encanyoned thence to The Dalles, where another structural depression is entered. At Arlington, on the south side of the river and about 50 miles below Umatilla, the wall of the canyon is 850 feet above the river. On the north side here it is 1,200 feet above. The Spokane flood was confined within these walls. But there was a lower surface of the basalt, southeast of Arlington and about 6 miles south of the Columbia, constituting the broad divide between Willow Creek and Alkali Canyon, both northward-flowing tributaries to the Columbia. Overflow from the Columbia Valley backed up Willow Creek Canyon and crossed this low place to Alkali Canyon. The divide here is about 5 miles wide and nearly flat-topped (Fig. 13). On it are two distinct channels, the floors of which are about 700 feet A.T. They have much bare rock in irregular low buttes and crags, exactly like those in the scablands and along the Columbia in many places at low water. There are numerous gravel deposits of no great magnitude on these channel floors, and a well-formed delta front with 30° slope and fine foreset bedding at the same angle extends out into Alkali Canyon at their mouths. The delta front is about $2\frac{1}{2}$ miles wide, and the brink varies from 650 to 700 feet A.T.

Between Arlington and The Dalles.—Evidence for the presence of the Spokane flood is well distributed along the Columbia Valley in

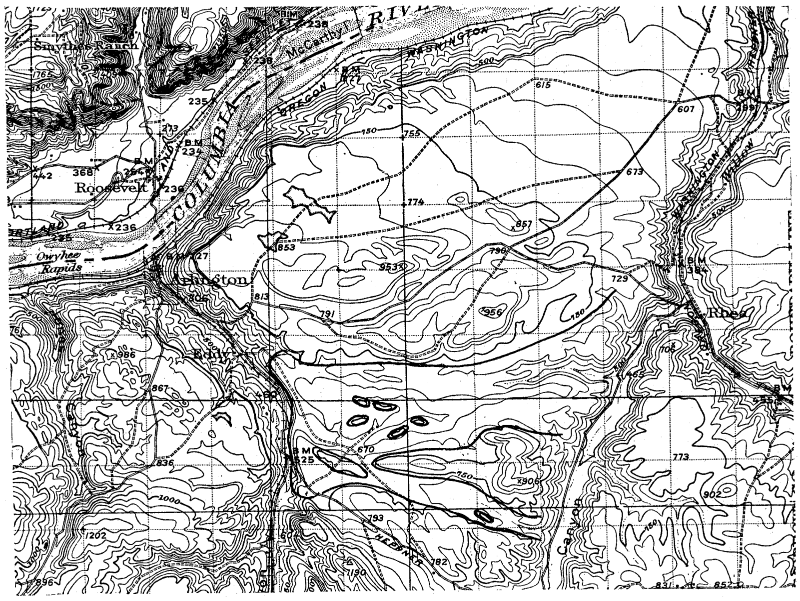

FIG. 13.—Vicinity of Arlington, showing the scabland channels between Willow Creek and Alkali Canyon and the delta front in Alkali Canyon. From the Arlington, Oregon-Washington topographic map, U.S. Geological Survey.

the 50 miles between these two towns, though there are no lowlands for records such as those at Umatilla, Carley, and Arlington. Large gravel deposits are commonly present in the mouths of tributaries whose walls at junction with the Columbia were lower than the upper surface of the flood. Salients in the Columbia's walls are strikingly cliffed, and many have secondary channels in basalt back of them where the flooded main spread. Since the character of such features is already familiar to the reader, only a list is given here, as the simplest method of indicating the weight of the evidence.

Jones Canyon, south side of Columbia, 1 mile west of Arlington. Large gravel bar with beautiful aggradational slopes descends into canyon mouth from rock shoulder on the east. Rim rock of the cliffs both east and west of the canyon mouth is scrubbed.

Lang Canyon, south side of Columbia, 4 miles west of Arlington. Large gravel bar in mouth, depending from the eastern or up-Columbia shoulder. Scabland topography on summit of rock terrace just east of bar. Upper limit of scabland 650 feet A.T.

Chapman Creek, north side of Columbia, 5 miles west of Roosevelt. Gravel terrace of basaltic débris in mouth. Summit about 600.

Blalock Canyon, south side of Columbia, 8 miles west of Arlington. No gravel deposit in mouth. Eastern wall at mouth is 950 A.T., too high for the flood to cross.

Rock Creek Valley, north side of Columbia, 13 miles west of Roosevelt. Gravel terrace on west side of mouth. Altitude about 650. Basaltic material.

Unnamed canyon, south side of Columbia, ½ mile below Rock Creek Rapids. Pronounced gravel bar in mouth.

Goodnoe Station, north side of Columbia. A well-formed gravel bar lying against the Columbia bluffs a little west of station. Not a dependent bar. Has aggradational slopes on both upstream and downstream ends.

Columbia Mountain, north side of Columbia, about 10 miles east of Maryhill Station. Lower ledges of basalt are much scrubbed and carry the "dalles," or flat-topped, steep-sided knobs and low buttes. Except along face of Columbia Mountain, the talus here is three-fourths. Eroded face of the mountain is composed of nearly vertical basalt flows, much brecciated, which crumble much more rapidly than the average. Talus covers the whole face of the great cliff.

Rufus Station, south side of Columbia. Good gravel bars depend down the Columbia Valley from salients here. Two tributary gulches, each with bars or remnants of a complete blocking in their mouths.

John Day Canyon, south side of Columbia. No gravel bar in mouth. East wall at junction with Columbia was too high.

Maryhill Station, north side of Columbia. A side-hill bar, not dependent from a salient, extends from 500 to 600 feet A.T. on the slope above the station. Face of basalt cliff between Maryhill and Fallbridge is rugose like scabland. Buttes of same character on south side of river near summit of bluffs. Also a sidehill gravel bar whose bedding dips parallel to the down-valley surface slope of the bar.

Biggs Station, south side of Columbia. Large gravel bar, like a great shoulder, partially fills mouth of canyon here. It depends from the west, or downstream, spur and points up the Columbia. An unusual but not unknown type of bar, due to an eddy in the great stream in a re-entrant of the valley walls to the lee of a prominent salient.

Des Chutes Canyon, south side of Columbia. No bar here. East wall of tributary canyon too high for flood to cross. Scabland forms along much of the south wall of Columbia Valley between mouths of John Day and Des Chutes rivers.

Fallbridge Station, north side of Columbia. In vicinity of this station are striking basalt knobs, high, narrow, and steepsided, above the railroad level but at foot of the high bluffs. A great, butte-like island, castellated and channeled, stands here in mid-river. It is genuine scabland, identical with hundreds of such features on the plateau, except that a river still swirls past its base and its talus ratio is therefore low. Prominent rock terrace 100 feet or so above railroad bears scabland for some distance from Fallbridge downstream.

The Dalles.—This city is built in the middle of a structurally determined broad valley in the basalt. Two sedimentary formations here overlie the basalt, one older than the deformation and one younger. The lower one is a river deposit commonly known as "The Dalles Beds," and in all probability is a phase of the Satsop formation. The upper deposit, largely of volcanic débris, has never been described.

Into this structural depression the Columbia enters from the east through a series of cascades and races known as "The Dalles of the Columbia." There is no place in the Pacific Northwest today which more closely reproduces the Pleistocene scabland rivers of the plateau than do these "dalles."[1] The river races almost all the way across the depression and, on leaving it, enters the famous Gorge of the Columbia across the Cascade Range.

A large part of the low area on the north side of the river is swept clean of the sedimentary formations above the basalt and is a barren waste of black rock knobs and buttes, rock basins, gravel bars, and active dunes. So far as its character is concerned, it might have been transposed bodily from the plateau scablands. Its altitude above the Columbia is not great, however, and it has been easy to assume that the obviously stream-eroded rock flat, 10 square miles or more in area, was an abandoned portion of the valley floor, left in the ordinary course of valley-deepening by the present stream. However, the Columbia of the present is a puny stream with which to sweep this flat. Almost all of it must be covered by a stream at one time, for the tract has but little relief. Furthermore, the breaking down of the knobs and basin walls during normal valley-deepening would

[1] "The Dalles Type of River Channel," J Harlen Bretz, *Jour. Geol.*, Vol. XXXII (1924), pp. 139–49.

have obliterated the higher of these features, while those nearer present river-level would be relatively fresh, and this contrast does not exist. The open channels and holes in basalt, associated with gravel bars in the lee of knobs, indicate a volume adequate to cover the flat when they were formed.

It is significant that the weakly consolidated sedimentary deposits above the basalt have steep slopes facing this scabland at The Dalles. Though they are not as distinctive as the same features in the plateau loess, the occurrence of two or three circumdenuded hills of sediment on the upper margin of the scrubbed basalt strongly suggests the same origin. There seems to be no definite marker in the topography here for the upper limit of the flood.

Lyle.—There is probably no better-displayed bar of the Spokane flood below Wallula Gateway than the one which lies just north of the town of Lyle, Washington. Its outlines are clearly expressed, its location and relations to the shape of the valley are ideal, its structure is unequivocal, its composition is exactly what is demanded, and its altitude above the present river is adequate.

Lyle is in the Columbia Gorge, ten miles below The Dalles. Columbia River crosses an upwarp of 3,000 feet in the basalt[1] between these towns and enters at Lyle a synclinal area[2] in which its gorge has much lower walls. The Spokane flood rose above these walls and overflowed a part of the structural valley's floor. Slackened current resulted in places along the margins of the broadened river, and deposition was the consequence. The Lyle bar was one product (Fig. 14). Its summit is about 200 feet above the Columbia (precise altitude not known), its materials descend on the slope to about 50 feet above the river, its slopes are convex, it has no river cliff and almost no gullies, its structure in excavations is foreset with the dip *up* the Columbia, and its situation is in the lee of a prominent cliff of basalt. It rests against the hillside back of it, but its eastern and upstream end is a rounded ridge not in contact with the hill. Probably its débris has come in large part from the face of the cliff immediately upstream.

It cannot be interpreted as a terrace remnant of a once continuous valley fill. The case is so clear that the writer, years before he

[1] The Ortley anticline. [2] The Mosier syncline.

knew of the existence and significance of plateau scabland, was convinced from the character and setting of this deposit that it was a shore bar built in an eddy in an immensely swollen river whose bottom then was not much higher than that at present.

Another deposit of the Spokane Columbia is well shown a mile west of Lyle on the Evergreen Highway. Pits along the highway show a gravel deposit whose bedding dips *away* from the Columbia and up a small tributary valley. The upper limit of the exposures is 390 feet above Lyle, 490 feet A.T., and it extends down the slope for 200 feet. Not one pebble in a thousand is of non-basaltic material. In the gravel are large angular fragments of basalt that have

FIG. 14.—Lyle bar in lee (to the left) of cliffed salient. Foreset bedding dips toward the cliff, or up the Columbia. Photo by C. S. Reeves.

been riven off near-by cliffs, up over which the fine gravel was carried from the open Columbia. The summit of the deposit constitutes a dissected terrace 530 feet A.T., and is traceable back into a channel which re-entered the Columbia about a mile farther downstream at an altitude not much less than 530. The channel is cut in the Satsop formation, itself a gravel deposit, but there is no possibility of confusing the two gravels, for the Satsop is much dissected, is tilted with the basalt, is somewhat indurated, has no foreset bedding, is capped by a lava flow, contains a lava flow, and also contains strata of volcanic ash and pebbles of quartzite and granite.

Scrubbed basalt slopes and cliffs are prominent features on both sides of the river about Lyle. On the Washington side above Lyle the slope of the valley is soil-covered from the summit (about 2,000

A.T.) down to an altitude of about 600 feet, but below this, though the slope is about the same, are exceedingly rough, bare rock surfaces.

Water from the Spokane Columbia crossed a low place in the spur between the main gorge and the canyon of Mosier Creek on the Oregon side, west of Lyle, and carried basaltic gravel over into the tributary canyon. The deposit lies on the east side of the canyon. Its material is fine subangular gravel, like that at and near Lyle, and it has foreset bedding which dips away from the Columbia and this notch and into Mosier Creek Valley. Its altitude is about 450 feet A.T., more than 350 feet above the surface of the Columbia.

Vicinity of Hood River, Oregon.—The Columbia crosses another anticline west of Mosier[1] and enters another synclinal valley at Hood River and White Salmon. On the south side of the deep gorge in this upfold are castellated crags and ridges paralleling the river, with linear channels in basalt separating them from the main hillside. The Columbia River Highway traverses some of these channels whose floors are at least 400 feet above tide. The crags are as severely eroded on the side toward the hill as they are on the river side, and talus about three-fourths the height of the cliffs flanks them in the abandoned high channels. They are as clear a record of erosion by the Spokane Columbia as anything in the Gorge.

Grading in the serpentine curves of Columbia River Highway on the east side of Hood River Valley has exposed a great deal of fresh subangular basaltic gravel up to 300 feet A.T. It lies just where a deposit should lie if the crags and channels were eroded by a greatly swollen stream.

In the southwest part of the city of Hood River is a gravel terrace 500 feet A.T. In it is a large pit at about 450. The deposit is like that elsewhere associated with the scabland flood in the Columbia Valley, except that it has a flat top and its structure consists of the ordinary current type of foreset laminae in horizontal strata. No long delta foreset structure was seen. Up to the same altitude for 3 miles or so west of Hood River are many large rolled bowlders of the underlying Herman Creek lava. Above this level, the orchard land is soil-covered, unterraced and unbroken by outcrops of rock,

[1] The Bingen anticline.

and without any bowlders. If it were not for features at White Salmon, shortly to be described, this would be taken for the upper limit of the flood.

At Columbia Gorge Hotel, west of Hood River a few miles and on the brink of the 200-foot cliffs of the Columbia, is a typical scabland expression of knobs and channels in the Herman Creek lava, and, in addition, a feature nowhere found in the Columbia basalt scabland—potholes! The worn surfaces are undeniably of this genesis, though their outlines record the onward sweep of river-borne débris, rather than the drilling in minor eddies or in cascades.

White Salmon, Washington.—The highest and largest deposit made in the Columbia Gorge during the Spokane flood underlies this town, directly across from Hood River. It is a great eddy bar, situated almost exactly as is the Lyle bar. Its material contains 90 to 95 per cent of Columbia basalt débris. The texture is fine enough for highway surfacing, though here and there are angular fragments of basalt a foot or so in diameter. Foreset delta bedding or foreset laminae in horizontal or gently inclined strata show in every cut. And, without exception, all of the many exposures show a dip up the Columbia or back into the tributary valley here or some component of the two. The summit altitude is the astonishing figure of 670 feet A.T.

The great bar depends up the Columbia Valley from White Salmon Butte. Its summit is highest at the base of the butte and is progressively lower, and its width progressively less, toward the east. It is 330 feet A.T. at the eastern terminus. It lies on a rock surface which slopes in the same direction, so that its thickness is nowhere the difference between the upper and lower limits.

The bar seems to be compound, a lower and longer bar lying on the riverward face of an older, higher bar. The summit of the lower is 600 feet A.T. Its eastern terminus originally blocked the tributary valley here. In the ravine subsequently cut through this tip, the foreset bedding is very well shown (Fig. 15). It is of the delta type and dips toward the back side of the bar, not along its length. The back slope (the slope away from the Columbia) parallels this bedding. The top and the front slope truncate it. Depth of the exposure is about 40 feet.

Cooks, Washington.—A gravel deposit along the Evergreen Highway east of this town has a terrace-like top 310 feet A.T. It lies on the west side of the mouth of the tributary Little White Salmon Valley. The north wall of the Columbia Valley here for 6 miles upstream is composed almost entirely of the Underwood lava, much younger than the Columbia basalt. 80 to 90 per cent of the material in the gravel deposit is of Columbia basalt, with Underwood lava ranking next in abundance.

FIG. 15.—White Salmon bar. Section in back slope near lower terminus, showing the foreset bedding, which dips away from the Columbia.

Foreset beds dip toward, and downstream along, the Columbia cliffs here. Large irregular blocks of Columbia basalt and large rolled pebbles of Underwood lava occur in the gravel, which otherwise is fine enough to put directly on the automobile highway. The riverward slope truncates the foreset bedding and carries the large pebbles of Underwood lava. Unless the deposit originally extended completely across the mouth of the Little White Salmon from the cliffs of Underwood lava, these pebbles must have been rolled up the slope something like 200 feet to come to their present position. The whole deposit lies on, and to the downstream side of, scabland knobs of Columbia basalt.

Mouth of Wind River, Washington.—Along the Evergreen Highway west of the bridge across this river is an excellent exposure of coarse sand and very fine gravel, 150 feet thick, which belongs to this category of deposits of the Spokane flood. It is much cross-bedded and has considerable long foreset bedding which dips away from the Columbia and up Wind River Canyon. The upper limit is 400 feet or more A.T. East of the mouth of Wind River perhaps a mile is another exposure of this material at 350 feet A.T. The upper limit here is 440 feet above the sea.

THE PORTLAND DELTA

Though the foregoing description of the effects of the Spokane flood in Columbia Valley below Wallula is not complete, it includes the more significant features now known. If it be granted that the observer has had an adequate training and that his field study has been sufficiently extensive and discriminating, it must be admitted that the existence of a great flood in the Columbia, transcending any known similar phenomenon, has been established. But the story is not complete until this vast river has been traced to its debouchure. To a consideration of this we now turn.

The debouchure of the Spokane Columbia was in the Williamette structural valley, between the Cascade and Coast ranges. Here it entered an estuary of the Pacific whose surface stood more than 350 feet above present sea-level. Here it built the Portland Delta, of which 150 square miles still remain. More than 50 square miles have been removed by the Columbia and Willamette rivers since it was deposited. The delta apparently never grew more than 8 or 10 miles beyond Vancouver.

The Portland Delta is a subaqueous deposit, an affair of river-bottom deposition, and was not a delta plain when constructed. The river was 100 feet deep over much of the surface when it was built. The evidence for this conclusion is developed in the following description.

The gravel of the delta is predominantly of basalt. It is unweathered except at the very surface, where there is some discoloration, and is easily distinguishable from the Satsop gravel, also widely exposed in this valley. Its structure is shown in hundreds of exposures throughout a vertical range of 350 feet. In almost every one, the gravel is delta foreset. The dip is dominantly southwestward in the southwestern part of the area covered, westward in the central part, and northwestward in the northwestern part.

The surface of the delta lies largely in two levels, about 200 and about 300 feet A.T. In some places the slope between the two levels is gentle, but in most places it is steep. The 300-foot level occurs in isolated portions. Some of these lie against higher land along the northern and southern sides of the delta, some occur in the lee of eminences of older rock which rose above the surface of the flood, and some constitute narrow ridges on the 200-foot level elongated with the direction of stream flow when the delta was made. Excepting only in the immediate vicinity of Columbia and Williamette rivers, the original surface of the great gravel deposit has been altered by erosion only to an insignificant degree. The land forms on it are constructional.

An earlier interpretation of the Portland Delta[1] considered the 200-foot level as the result of dissection of an originally continuous 300-foot plain. This view becomes untenable when the ridges on the 200-foot level are carefully studied. Most of these ridges are grouped in the vicinity of Hidden Station, 4 miles northeast of Vancouver. They are long, narrow, and straight. The most striking one is $1\frac{1}{2}$ miles in length and about 300 feet wide on top. They stand from 50 to 100 feet above the swales which separate them. Those which appear wide on the map (Fig. 16) are closely placed parallel groups, partially coalesced. They are composed of foreset-bedded sand and very fine gravel, 95 per cent basalt. The foreset bedding, so far as shown, dips down the northern slopes in parallelism with those slopes, and is truncated by the tops and the southern slopes. The swales among these ridges contain lakelets and swamps elongated with the ridges. There are no streams in them, and no ravines lead from them to the nearby Columbia. The ridges have an orientation approximately radial to the curved edge of the delta. This

[1] "The Late Pleistocene Submergence in the Columbia Valley of Oregon and Washington," J H. Bretz, *Jour. Geol.*, Vol. XXVII (1919), pp. 502–3. In this paper the age of the delta was considered as Wisconsin. Since the paper was written, the scabland history has been deciphered, and the delta is seen to be a product of the Spokane flood, not the Wisconsin submergence.

gives them a northwestward divergence. The northernmost are composed only of sand. In form they closely resemble eskers, but they lie 75 miles south of the limit reached by the continental ice, and their field relations clearly prove them to be parts of the delta.

These ridges are held to be river bars, standing about 100 feet above the main channel floors. A stream of at least that depth thus must have spread over the 200-foot level of the delta while it was

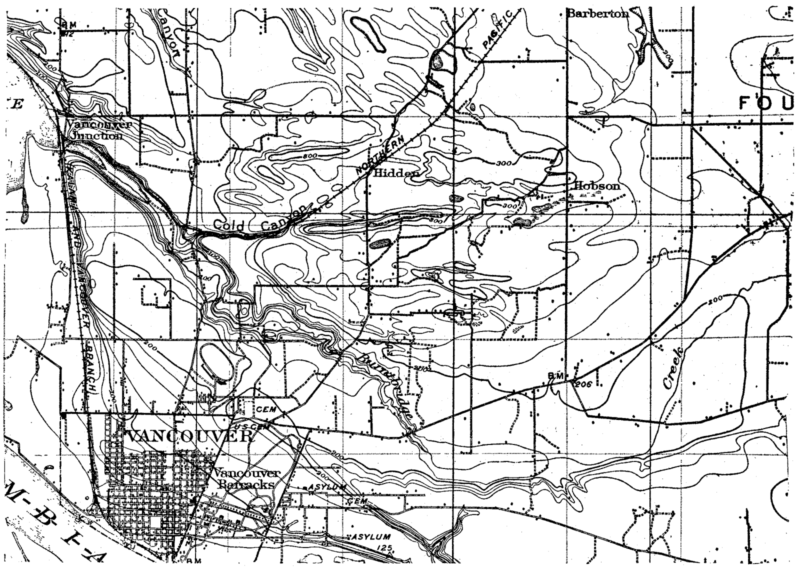

FIG. 16.—Part of the Portland Delta, showing portions of the 200-foot and 300-foot levels and the group of narrow linear bars about Hidden Station. From the Portland, Oregon-Washington topographic map, U.S. Geological Survey.

being built. Admittedly, this interpretation would be difficult to establish without other evidence for the depth of the river. Another feature of the delta, however, throws light on the question. It is Rocky Butte and the delta surface in its proximity.

Rocky Butte.—Rocky Butte (Fig. 17), in the northeast part of Portland, is a hill of basalt nearly surrounded by the Portland Delta. Its lower slopes are cliffed on the east and north, and from its northern base the land descends to the flood plain of the Columbia. The delta surface east of the butte is 300 feet A.T., but between it and the cliffed face of the butte is a fosse whose floor is not far from 125 feet A.T. At the bottom is a closed depression more than 1 mile long, less than ½ mile wide, and averaging 20 to 25 feet deep. At the north the fosse opens toward the Columbia. At the south it widens and divides into two long arms, one extending west and one southwest.

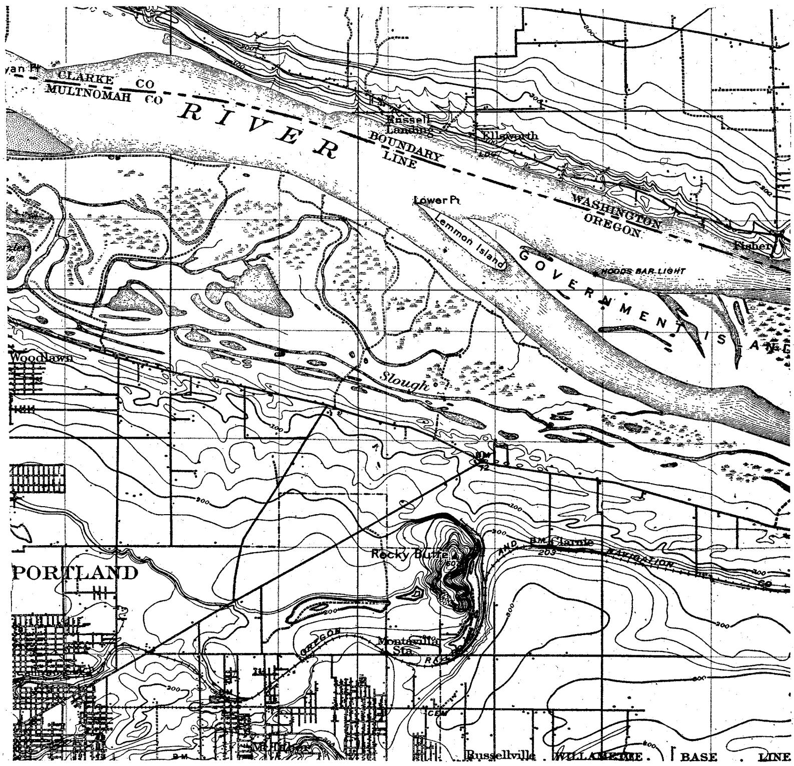

FIG. 17.—Part of the Portland Delta, showing Rocky Butte and environs. From the Portland, Oregon-Washington topographic map, U.S. Geological Survey.

Its floor gradually rises also, the trench-like character disappears, and it blends into the delta surface at about 225 feet A.T.

Abutting against the rock hill on the west is a terrace exceeding 250 feet in altitude. This terrace is much elongated and extends westward for about 9 miles, its summit descending below 150 feet in this distance. On the south, the terrace is bounded by a steep slope which, for $1\frac{1}{2}$ miles west of the butte, has an elongated depression at the base.

What is the explanation of these features at Rocky Butte? It is easy to say that Columbia River produced them, and probably no one would object to this assignment of responsibility. But the situation demands something more than the river at a higher level. The water that flowed southward through the fosse at the east foot of Rocky Butte had to rise from below 125 feet to above 225 feet. It therefore was more than 100 feet deep in the fosse. Even then, it is difficult to conceive of the narrow fosse as erosional in origin.

But if we postulate a flood of proportions sufficient to cover the entire surface of the delta, the whole situation becomes clear. The fosse is but the unfilled locus of an eddy caused by downward deflection where the current impinged on the east face of the butte. The lower cliffed portion of the butte is the product of the same eddy. The 300-foot terrace east of the fosse never was, never could have been, extended to reach Rocky Butte. The dependent terrace to the west was deposited in the slack water below the obstruction. All parts and all levels of the delta here were formed at the same time. The velocity of the water alone determined the height to which the subaqueous parts of the deposit grew. Exactly similar situations are seen in all streams with traction loads and mid-current obstructions of sufficient magnitude.

The highest known portion of the delta is a broad eddy bar in the lee of the southern shoulder at the mouth of the Gorge. It lies between Troutdale and Gresham, and its highest part reaches 363 feet A.T. All of it is above 325. Exposed in its eastern part is the familiar dark basalt gravel, foreset-bedded with dip up the Columbia, as all lateral eddy bars should have. Some of the foreset beds at the east end of the bar dip northward, recording the return current of the eddy, moving back into the main flood. West of this bar is a broad channel floor about 100 feet lower, and still farther west is the 300-foot portion which lies east of Rocky Butte. The butte stands 8 miles out on the delta from the mouth of the Gorge.

The eddy bar south of Troutdale is 50 miles down the Columbia from White Salmon. The difference in altitude between the Spokane gravel deposits at these two places is 300 feet. The valley in this distance has no noteworthy constrictions to which this difference in altitude could be ascribed, as in the case of Wallula Gateway. The river never had any such surface gradient as 60 feet to the mile in a broad, open valley. Further, the White Salmon bar is higher than any known deposits of the flood for 100 miles upstream. If these bars and the delta are contemporaneous, the superior altitude of the White Salmon deposit apparently must be attributed to post-Spokane differential uplift in the vicinity of that town. But bars and subaqueous delta forms do not record the surface of the water in which they were deposited. It is difficult, if not impossible, to ascertain definitely the upper limit of the flood below the loess-covered plateau. Because of this difficulty and because of the absence of direct field evidence for differential movement, the writer hesitates to build such items into his explanation of the Spokane flood.

THE VOLUME OF THE FLOOD

If the volume of the Spokane flood can be measured anywhere, it can be measured at Wallula Gateway. Certain assumptions must be made, however, as to the capacity of that notch at the inception of the flood. The platform on which "The Sentinels" stand appears to be a remnant of the pre-Spokane floor at about 500 feet A.T. Spring Gulch is a hanging tributary valley which enters the Columbia just below the Gateway. The abrupt steepening of gradient in it occurs at close to the same altitude. The position of "The Sentinels" indicates that the pre-Spokane width of the notch did not exceed $\frac{3}{4}$ mile.

The waters rose to about 1,025 feet A.T. in mid-length of the Gateway, and had a surface gradient through the Gateway of about 15 feet to the mile. A cross-sectional area of the flood at its inception, to include that which spread back on the summits of the cliffs, amounts to approximately 3,485,000 square feet. The surface of the flood descended to 775 feet A.T. at the mouth of Juniper Canyon, about $8\frac{1}{2}$ miles below mid-length of the Gateway, and its cross-sectional area there appears to have been about 2,006,000 square feet.

These figures have been used by Mr. D. F. Higgins, of the University of Chicago, as a basis for computing the volume of the initial flood before any noteworthy deepening or widening had lowered its surface. Mr. Higgins used Chezy's formula $v = c\sqrt{rs}$, in which v is velocity, r the hydraulic radius (area of section divided by wetted perimeter of same), s the slope of the surface (expressed as tangent of angle of slope), and c is a constant. The value of c depends on the character of the channel, and was chosen to indicate a maximum of impedance from irregularities of sides and from eddies and cross-currents generated by turns in the course of the valley. This formula was devised for and is applied to small-capacity drainage lines, such as sewers, ditches, etc., and its use here involves the assumption, which cannot be true, that conditions in this enormous river were similar. However, it is the nearest approach to any formula which can be used. The actual volume probably was greater than the computed one secured by its use.

On the basis of surface slopes, the velocities indicated are 20.6 feet per second for the current in the Gateway itself and 30.4 feet per second for the current just below Juniper Canyon. On the basis of cross-sectional areas, the velocities appear as 17.5 feet per second in the Gateway and 35.7 feet per second at Juniper Canyon. Using mean velocities and computing for discharge (area $\times$ velocity), the enormous quantity of 66,132,000 second-feet, or 38.9 cubic miles per day, is secured. As above noted, this figure is probably below the actual amount. As it stands, it represents the melting of about 42 cubic miles of ice daily. The maximum measured flood of the Columbia at The Dalles, 100 miles downstream, is 1,170,000 second-feet. The Spokane flood thus was much more than 50 times the volume of present-day floods in the Columbia.

Another quantity of importance in interpreting the Spokane flood is the area of ice which, by surface ablation, could yield this prodigious quantity of water. Using the average maximum summer solar radiation of Lincoln, Nebraska, and Madison, Wisconsin (about 500 calories per square centimeter), Mr. Higgins finds that a maximum depth of summer melting by direct insolation today would be 2.66 inches. At this rate of melting, approximately 1,000,000 square miles of ice would be required to yield the water for the Spokane flood. But if the drainage of the Cordilleran ice sheet was controlled by the existing major divides and river valleys, not

100,000 square miles could have contributed to the discharge which crossed the Columbia Plateau. Obviously, the rate of melting must have been far greater than any direct insolation could have produced.

Computations such as these strongly incline one to doubt the actual occurrence of the flood. The writer has repeatedly been driven to this position of doubt, only to be forced by reconsideration of the field evidence to use again the conception of enormous volume. It is the only adequate explanation of the phenomena. These remarkable records of running water on the Columbia Plateau and in the valleys of Snake and Columbia rivers cannot be interpreted in terms of ordinary river action and ordinary valley development. The factors of declivity, of valley shapes, of rock, and of time cannot be adjusted to explain them. Enormous volume, existing for a very short time, alone will account for their existence. The field evidence all the way from Spokane to Portland, a distance of 300 miles, knits together in a consistent whole to support this explanation. Though there are a few features of the record whose origin is not yet understood, none are known which weaken the hypothesis.

FINAL STATEMENT

That the Spokane flood occurred is clear. That it was short-lived and waned very promptly after diversion around the northern margin of the plateau seems probable. The exceptional conditions which caused it are still obscure. All phases of glacial behavior considered, the writer at present can conceive of only two possible explanations for this flood. One is a very rapid and short-lived climatic amelioration in which warm winds and warm rains produced great surface ablation of a much-fissured ice sheet before the front of the ice retreated from the northern margin of the plateau. Apparently no such climatic change is recorded elsewhere, and the rapidity demanded seems impossible of realization.

The other possible explanation is that the Spokane flood was a gigantic "jökulloup," such as have occurred in Iceland repeatedly when volcanic activity has broken out beneath the cover of an ice cap. But nothing has been found in the literature to suggest Pleistocene vulcanism in the area which was drained across the Columbia Plateau during this episode.