BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 39, PP. 643-702, PLS. 19-24 SEPTEMBER 30, 1928

BARS OF CHANNELED SCABLAND[1]

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(Read before the Geological Society December 29, 1927)

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INTRODUCTION

Gravel deposits in which the combination of topography, composition, structure, and magnitude is unlike anything described in geologic litera-

[1] Manuscript received by the Secretary of the Society December 28, 1927.

ture are widely distributed over the channeled scablands of the Columbia Plateau in Washington and thence along the Snake and Columbia rivers as far down as Portland, Oregon. They record extraordinary conditions of origin. No hypothesis for channeled scabland which does not account for them can be worthy of consideration. The writer's interpretation of channeled scabland [2] is so great a departure from prevailing conceptions of rivers and river work that numerous suggestions have been made by other geologists looking toward more acceptable, more conventional explanations. In none of them, however, is there an adequate appreciation of the character of these gravel deposits, perhaps because no adequate descriptions have been made by the writer. The endeavor in this paper is to show clearly just what these deposits are and to show the limitations of various hypotheses for them.

The people of southern and central Washington use the term "scabland" to describe a type of land surface which has little or no soil above the basalt bedrock and therefore has little or no agricultural value. It is in most striking contrast with and is sharply delimited from contiguous areas of deep, fertile, loessial soil. That part of eastern Washington inclosed by the Spokane, Columbia, and Snake rivers and the Idaho-Washington boundary line, exceeding in area the State of Maryland, contains all of this scabland.[3]

When mapped, the scabland exhibits a remarkable braided pattern of elongate continuous tracts along drainage lines from the northeast toward the southwest as far as the bounding Snake or Columbia valleys. There is abundant evidence that this denuded country is the result of glacial drainage across the once completely loess-covered plateau. This is admitted by the most vigorous critics of the writer's work.[4] The term "channeled" is added to the local name of "scabland" to imply river-channel rather than river-valley origin, and to distinguish it from other areas of essentially soil-free rock, not of this character, though also termed "scabland." No detailed analysis of the channeled character will be presented here.[5] It will suffice to indicate the following features:

1. All the tracts of channeled scabland are lower than adjacent soil-covered tracts.

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[2] J H. Bretz: The channeled scablands of the Columbia Plateau. Jour Geol., vol. 31, 1923, pp. 617-649.

J H. Bretz: The Spokane flood beyond the channeled scablands. Jour. Geol., vol. 33, 1925, pp. 97-115 and 236-259.

[3] Except minor tracts closely bordering the Snake and Columbia for 50 and 75 miles respectively above their junction, and for the Columbia Valley itself between the junction and Portland.

[4] See discussion in "Channeled scabland and the Spokane flood," by J H. Bretz, Jour. Wash. Acad. Sci., vol. 17, 1927, pp. 200-211.

[5] It is analyzed in "The channeled scablands of the Columbia Plateau."

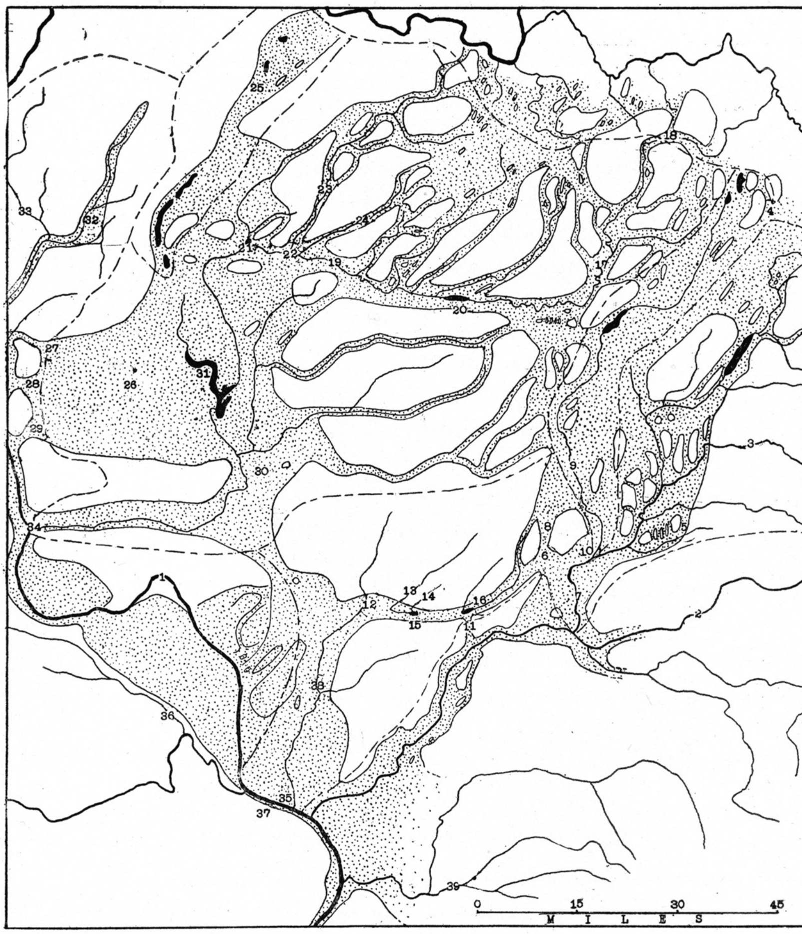

FIGURE 1.—*Sketch Map of the Scablands*

Only the channeled tracts and the gravel-covered areas are shown. Many minor channels and islands are omitted. Margins in the eastern and northern parts of the region are the upper limits of the glacial waters, marked by loessial scarps. In the southwestern part there was much semiponded water whose extent is not shown. Numbers refer to places, streams, lakes, et cetera, described in the text.

Beverly	34	Eltopia	38	Potholes Cataract	28
Brook Lake	21	Frenchman Springs	29	Quincy Basin	26
Cheney	4	Grand Coulee	25	Rattlesnake Coulee	13
Cold Creek	36	Hardesty Coulee	14	Reardan	18
Columbia River	1	Hooper	10	Snake River	2
Connawai Creek	24	Kennewick	37	Staircase Rapids	8
Connell	12	Krupp	19	Sulphur Lake	15
Cow Creek	9	La Crosse	5	Sylvan Lake	20
Crab Creek	17	Moses Coulee	32	Walla Walla River	39
Crater Falls	27	Moses Lake	31	Washtucna	6
Devils Canyon	11	Palouse River	3	Washtucna Lake	16
Douglas Coulee	33	Palouse Canyon	7	Wilson Creek	23
Drumheller Channels	30	Pasco	35	Wilson Creek Station	22

2. The boundaries between channeled scabland and the adjacent tracts are commonly marked by pronounced bluffs, or scarps, in the overlying weaker formation.

3. The elongation of the scabland tracts is almost everywhere down the dip slope of the plateau surface.

4. The channeled features of scabland itself, consisting of canyons and rock basins, are elongate with the outlines of the tract where they occur.

5. Two or more subparallel rock-bound channels in the same tract are common. The separating ridges and buttes thus formed are also elongate with the outlines of the scabland tract.

6. Gradients along the channeled scabland routes are high where the channels and basins are best developed. Where the gradients are low, the erosion in the basalt has been much less.

7. Channel floors are interrupted in many places by transverse ledges, which were cataracts in the glacial rivers.

The gravel deposits of channeled scabland occur in a variety of situations and their differences clearly are conditioned by the differences in the situations. More than 200 such individual deposits have been studied in this field. About a fifth of them will be described, to show the range in situation and character which they possess. The term "bar" will be used frequently in this paper, though the reader can be trusted not to accept its genetic implication unless the evidence presented is completely convincing.

Bars of Palouse River Drainage

THE PALOUSE RIVER SCABLAND AREA

The greatest scabland tract across the anastomosing pattern of the glacial rivers heads a few miles southwest of Spokane and extends for 75 miles southwest, to the canyon of Snake River at the junction of Palouse River. The head of this tract is essentially the preglacial divide of the plateau between the drainage of Snake River and Spokane River, the latter being nowhere more than 15 miles north of the divide. A cross-section through Cheney on the divide itself encounters several island areas that stood above the glacial river and there are very many islands all along the tract; but a straight line at right angles to its length and 21 miles long can be drawn across it a few miles from Cheney without encountering a single island. The surface of this great river descended from about 2,550 feet above tide at the head to 1,325 feet above tide at its entrance into Snake River Canyon.

The glacial river was not all contained within this tract from Cheney to the Snake. There were several definite spillways westward out of it, two of them of major importance. The northernmost of these major divergences is 20 miles below the head of the main tract (that is, more than 20 miles from the edge of the ice-sheet) and the surface of the glacial river at this divergence was 500 feet lower than at the head. One relatively small converging glacial river entered along the east side of the tract, but no other rivers entering here carried glacial water. Instead, their lower courses became ponded back for varying distances from the main discharge, ponded for the same reason that their divergences to the west originated, namely, the great volume of this discharge.

There are hundreds of individual gravel deposits scattered over this tract. The most significant for an understanding of the origin of channeled scabland are along the margins and at the debouchure of the glacial waters into Snake Canyon. It was in marginal situations that the preglacial topography was least modified and that deposition of glacial river gravel was especially favored. The vicinity of La Crosse, Whitman County, shows the combination very well.

VICINITY OF LA CROSSE

La Crosse stands between two valleys which drain westward from the maturely dissected, deeply loess-covered country to the channeled scabland; but it is built on a gravel flat, not on hill slopes, and immediately to the north are scarped relict hills separated by small scabland channels. The channels lead southward from a broad tract of scabland along lower Union Flat Creek. The sketch map (figure 2) shows that the preglacial divide between Union Flat Creek and Willow Creek was crossed by slender strands of the broader river at the north, and that the lower portion of Willow Creek Valley thus became involved in the marginal channeling of this great river. Most of these strands were short-lived and did not erode to bedrock, but the flat on which La Crosse is built is deeply covered with basalt gravel and the three channels a mile north have scabland floors.

The gravel deposit terminates abruptly about three miles southwest of La Crosse in a 50-foot scarp facing Willow Creek. For four miles down Willow Creek from this scarp the stream is trenching into a silt deposit (Pampa flat), which contains some sand strata and a little fine-textured basalt gravel. Its ravined course is 15 feet or more in depth. Except for the silt deposit, this broad flat bottom is the preglacial valley floor of Willow Creek. Glacial waters aggraded here, rather than eroded; and this preglacial floor has an accordant junction with the bottom of the Palouse River Valley just a few miles farther west. It does not hang above the Palouse River Valley bottom. Both have essentially the preglacial profile.

But between the silt flat and the scabland along Palouse River there is a great deposit of basalt gravel, at least 100 feet thick, completely *across* Willow Creek Valley. It is strictly limited, as shown in the sketch map, to the mouth of this tributary valley. The creek, of course, now has a trench through it, but originally it was a complete barrier.

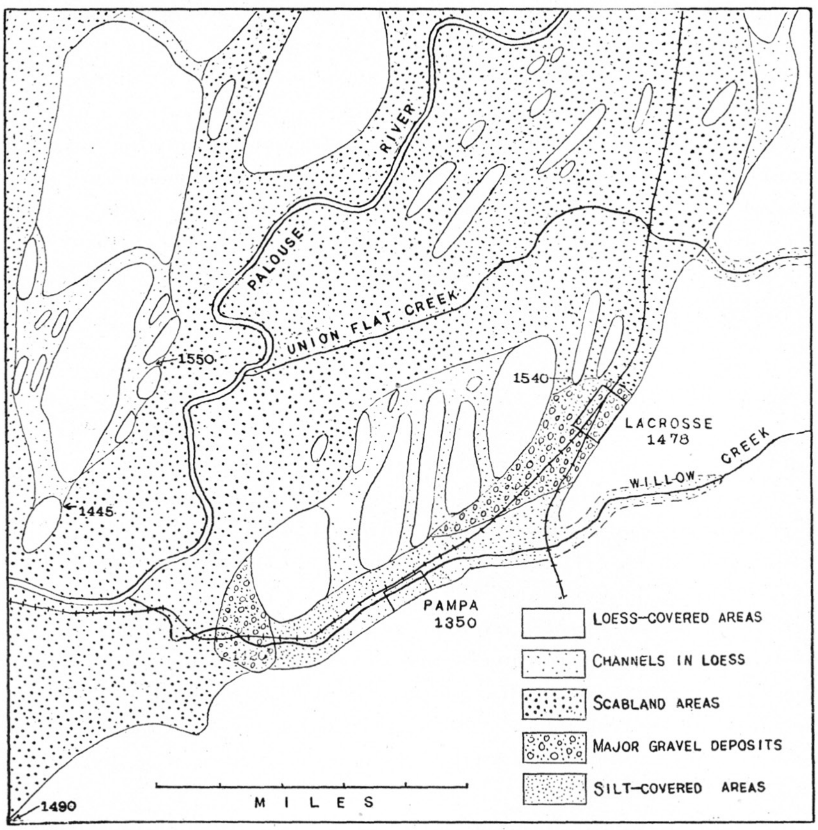

FIGURE 2.—*Sketch Map of the Vicinity of La Crosse, Washington*

Summarizing the evidence and drawing conclusions from the scabland features about La Crosse:

1. Willow Creek and Union Flat Creek east of the scabland are essentially as they were before the glacial waters entered from the north.

2. The preglacial divide between them extended westward from La Crosse to Palouse River.

3. There is no hanging condition of either tributary stream; therefore Palouse River Valley was essentially as deep before the episode of scabland-making as it now is.

4. Glacial waters flowing down Palouse River breached this divide between the two creeks, making at least seven channels across it. Three of them were eroded down to bedrock basalt.

5. Basaltic gravel came through these three channels into Willow Creek Valley, there building a flat whose southern steep margin is essentially a depositional slope.

6. Basaltic gravel was deposited as a great bar across the mouth of Willow Creek Valley by the main glacial stream that swung around the west end of the breached loessial divide.

7. The silt flat about Pampa was deposited in ponded water during and immediately after the glacial flooding.

This La Crosse region has a significant bearing on the hypothesis of the Spokane flood. If the field relations are as stated, the volume of that flood was great enough to spread out of the preglacial Palouse Valley, which here was 300 feet deep in basalt, to sweep off almost all the loessial hills in making the scabland along lower Union Flat Creek, to cross the divide south of this creek in seven places and enter lower Willow Creek, and to throw a bar across the mouth of Willow Creek 100 feet high and more than a mile long.

The top of this bar is 1,420 feet above tide. This is 70 feet lower than the upper limit of glacial waters four miles farther down the Palouse Valley. The upper limit there (1,490 above tide) is clearly marked by a steep scarp in the loess, at the foot of which are scabland surfaces of basalt and deposits of poorly worn, poorly sorted, 100 per cent basalt stream gravel.

VICINITY OF WASHTUCNA

Another marginal combination of scabland channels and gravel deposits among scarped loess hills lies north of the town of Washtucna, on the west edge of the great glacial river we are considering. The sketch map (figure 3) shows the significant relations. The preglacial valley system is as clearly identifiable here as about La Crosse. Palouse River received a major tributary, Cow Creek, from the north. The junction is just on the east edge of figure 3. This tributary valley was about 400 feet deep in basalt. The preglacial Palouse continued westward past Washtucna instead of making the present sharp turn southward. The old valley, also 400 feet into basalt, is subparallel with the Snake for 50 miles farther westward. It is nearly a mile wide at the top of its walls—as wide as the Snake Valley. Tributaries of the mature drainage system enter it with accordant grade. Its floor at Washtucna is approximately 500 feet higher than the bottom of Snake River Canyon directly south.

In most marked contrast is the present course of the Palouse south from the sharp bend. It reaches the Snake in about 9 miles by the new

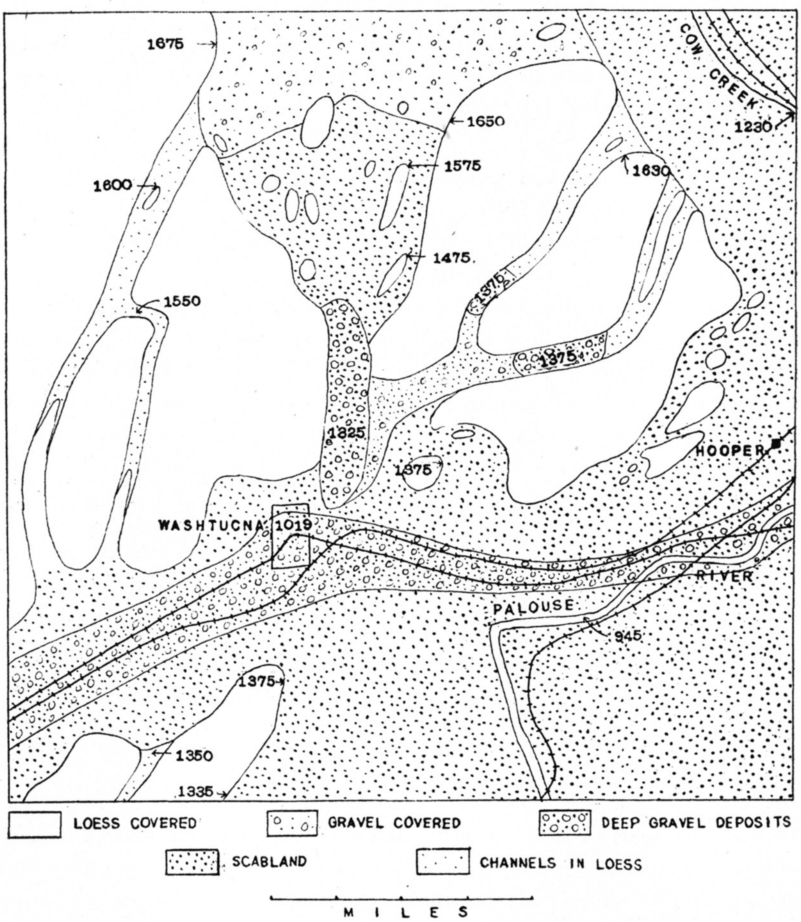

FIGURE 3.—*Sketch Map of the Vicinity of Washtucna, Washington*

route instead of 50 by the old route, flowing through a narrow canyon from 400 to 650 feet deep, with a waterfall 196 feet high in about mid-length. Indeed, at the sharp turn of the Palouse there are two canyons leading southward out of the old valley. The floor of the empty one is about 100 feet higher than that of the one carrying the river. They join less than a mile south of the old valley. Very rugged scabland

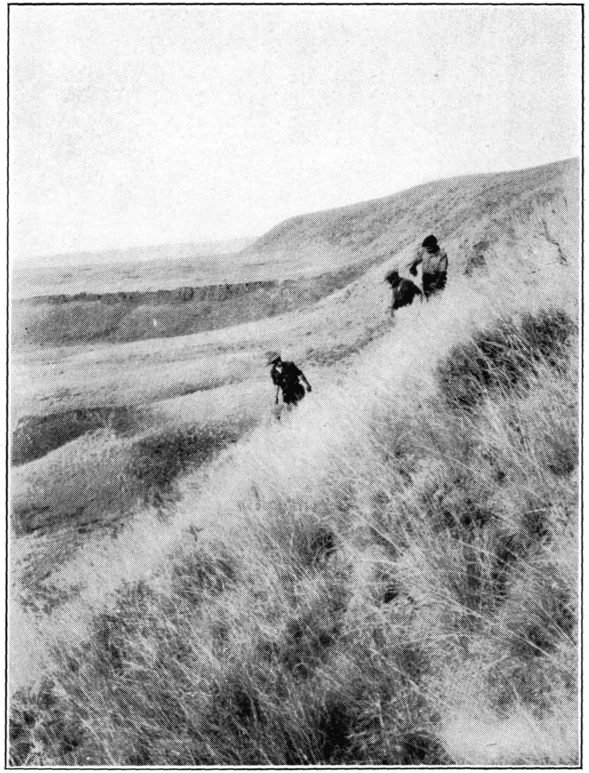

FIGURE 1.—MINOR CHANNEL IN LOESS EAST OF STAIRCASE RAPIDS

View is looking east. Loessial scarp on the right is nearly 100 feet high and has a slope of 35 degrees. Abandoned cataract 30 feet high, with plunge basin at the foot, crosses the channel. Rough surface of the basalt floor above the cataract shows faintly. Channel head is a mile distant and beyond it is a descent of 400 feet to the bottom of the preglacial Cow Creek Valley.

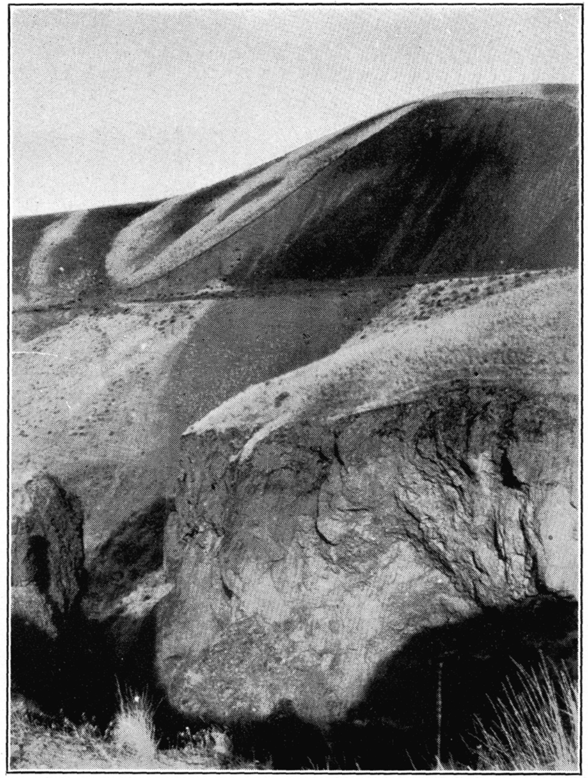

FIGURE 2.—SHOULDER BAR NEAR MOUTH OF PALOUSE RIVER

View is looking east. Snake River is one-fourth mile to the left and 250 feet lower; 325 feet of gravel exposed. Constructional slope, paralleling the foreset bedding, descends to the left. Youthful gorge in basalt in foreground is due to deflection of the tributary stream by the bar. Photograph by Robert Landon.

SCABLAND TRACT, PALOUSE VALLEY

covers the top of the former Palouse-Snake divide here for 10 miles along the south wall of the old valley.

The surviving loess-covered areas shown in figure 3 are sharply scarped along all margins. A glance will show the presence of several channels through these hills, leading as short cuts from the main scabland tract across the angle to the eastern end of the abandoned preglacial Palouse Valley (see figure 1, plate 19). Only one of these, the largest, has any notable amount of scabland floor, though all have ledges and knobs of scabland here and there. The spillway with the well-developed scabland carries scattered loessial islands that are remnants of minor divides between minor tributaries. There is a great extinct rapids extending over three prominent basalt ledges. The water of this cascade (the Staircase Rapids) fell 300 feet in three miles.

But the scabland is discontinued below about 1,350 feet above tide and the lower part of the preglacial tributary valley carries a flat-topped gravel deposit more than two miles long and 300 feet in maximum thickness, the surface of which is 300 feet above the floor of the abandoned Palouse Valley. A steep slope descends from this flat top to the town of Washtucna.

A portion of the Washtucna sheet of the United States Geological Survey, reproduced in figure 4, shows the forms of the scabland cataract ledges, the loessial islands, the gravel flat and its scarp, and the bounding higher loess hills. But perhaps the altitudes marked in figure 3 will show even more graphically the relations of this group of marginal channels. The glacial flood in Cow Creek Valley brimmed over its western wall and entered the loess hills at altitudes ranging from 1,630 to 1,675 feet above tide. This occurred despite the fact that the major part of the glacial flood went around this channeled salient and used two routes from Hooper to the Snake. The loess scarp at the down-stream angle between the old and new Palouse routes is 1,375 feet above tide at its base and has fine scabland surfaces with knobs, rock basins, and small bars of basalt gravel right up to the foot. The flat top of the big gravel deposit in lower Staircase Rapids is 1,325 feet above tide and its surface is fluted as though by great currents across it.

Staircase Rapids, therefore, is a spectacular abandoned glacial river cascade, a short cut from a main route of glacial waters to a major divergence, its head 400 feet above the preglacial floor of the main and its debouchure deposit 300 feet above the preglacial floor where it joins the divergence. Yet its descent was 300 feet for the rapids portion. At least that amount of fall must have existed in the surface of the main

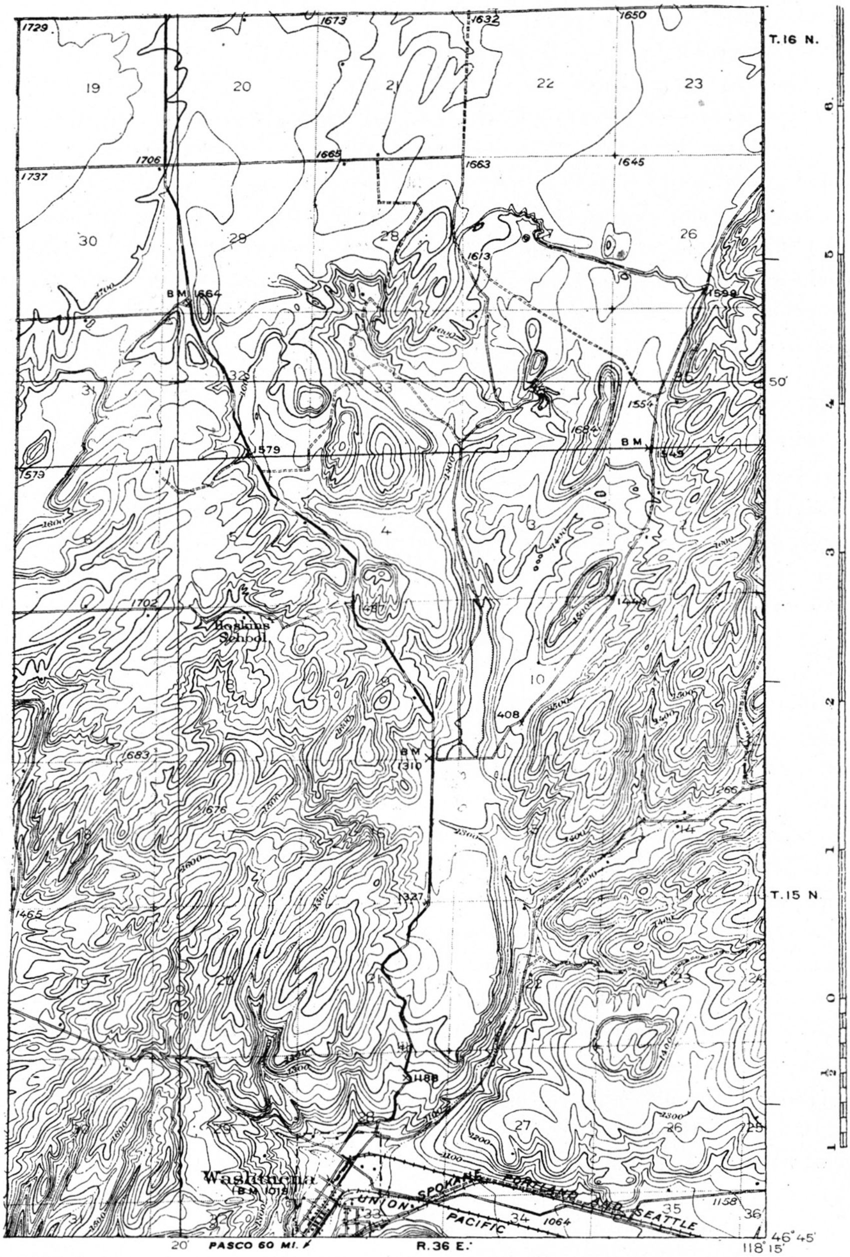

FIGURE 4.—*Part of Washtucna, Washington, Sheet, showing Staircase Rapids*

flood down Cow Creek and the old Palouse route. Staircase Rapids did not lead from one pond to another.

The conviction that gravel deposits of channeled scabland were originally as discontinuous as they are today, and that the glacial streams had the enormous depths that are here indicated, has continually led the investigator directly to previously undiscovered deposits simply because, if the hypothesis is correct, they should be there. The Washtucna region exhibits an example of this. The Staircase Rapids were already known. It was also known that three channel heads were notched in the loess scarps overlooking Cow Creek to the east, 300 feet above the Staircase bar, and that they mouthed as one on the east side of this bar, 300 feet lower than the bar top. The lower mouthing was because of the unfilled preglacial valley here. If the hypothesis were correct, these minor streams, if they carried gravel, should have deposits back up in their channels at altitudes somewhere between the top of the Staircase bar (1,325 feet above tide) and the foot of adjacent loess scarps (1,375 feet above tide). Directed by this idea, a traverse was made and two gravel deposits in the channels were discovered, both with flat tops at 1,375 feet above tide, with steep frontal slope 100 feet high facing down the channels and with foreset beds dipping down the channels. Each records the same ponding that produced the big bar in the lower Staircase Rapids. Their summit flats are about 50 feet higher than the Staircase bar, indicating 50 feet less depth to the glacial streams which built them. They are essentially intact, for the channels now carry no streams adequate to trench them. The channel floors to the east lead down to their flat tops, with here and there some scabland surfaces. But the flat tops and the steep frontal slopes are constructional.

Further evidence that these gravel deposits are not erosional remnants of an originally continuous fill is found at the east base of the Staircase Rapids bar. The contour map seems to show a ravine here heading back toward the Rapids, but field inspection shows that the steep east front of the bar is made up of definite minor lobings which project out into the pseudo-gulch. One of these was built completely across, constituting a low barrier, and thus made a closed basin about a half mile long in the bed of the apparent gulch. Sand, silt, and gravel have been washed into this basin in post-scabland times and it was nearly filled before trenching of the minor lobe was initiated. Eighteen feet of sediments are now exposed in the narrow ravine across the basin fill and its dam. This is the sum total of post-Spokane erosion in this pseudo-gulch. Though the sediments are derived from the flood débris, they are distinctly different. The stratification is horizontal, the bedding is thin, iron-stain-

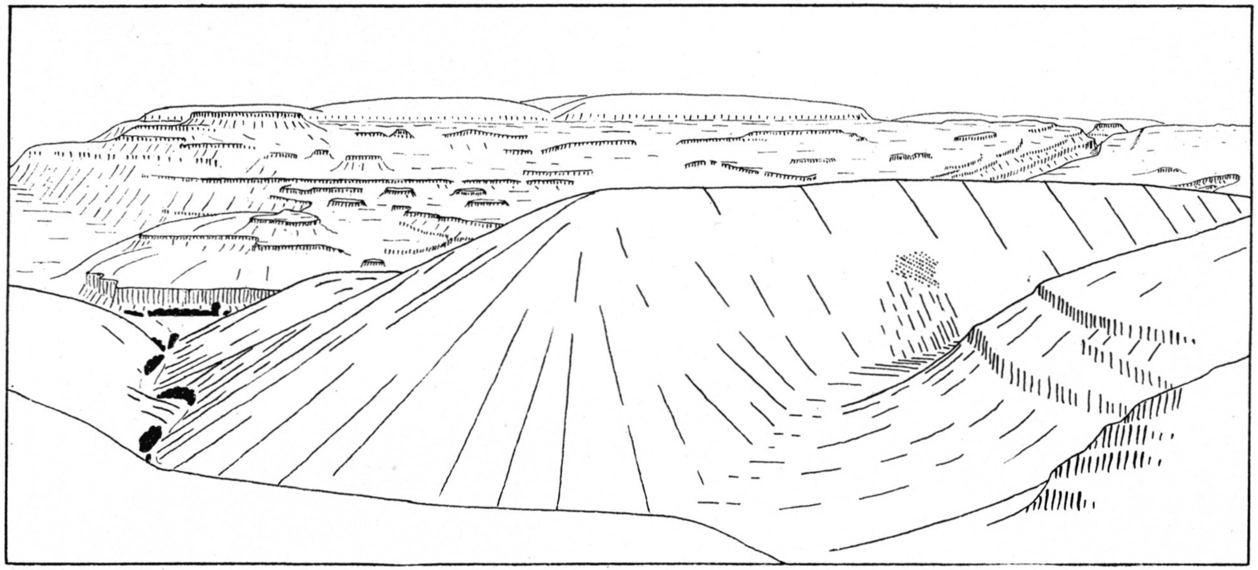

FIGURE 5.—*Spur Bar east of Palouse Canyon*

Looking west on left side and north on right side of view. The view shows loessial islands on skyline, scabland of the summit of the preglacial divide, part of Palouse Canyon, and the bar and partially blocked preglacial tributary valley in foreground. Gravel is 245 feet thick at terminus of the bar. Foreset bedding, which dips diagonally into and up the tributary, is shown. Farther east (to the right) the gravel is thinner and the preglacial spur of basalt is exposed in gullies. Drawn from photographs.

ing is prominent in certain layers, root casts are prominent in the finer material, and the vertebra of a large herbivore was found in one layer. There are curious limited depressions in the finer sediments in places that may possibly be a record of down-punching by the feet of herbivores that wandered across the basin flat while it was being filled. The 200-foot front of the great bar here has foreset bedding which dips southward, toward the old Palouse Valley.

Why did not this deltaic bar of Staircase Rapids grow across and obliterate the pseudo-gulch? Why is its top so nearly level for almost three miles, and why does the deposit terminate in a slope descending 300 feet in a mile at its entrance to the old Palouse Valley? Why are all three gravel deposits foreset-bedded? Why are their flat tops so nearly the same altitude? How did the glacial water come to spill through these channels? How was it possible for the divergent channel at the western margin of the head of Staircase Rapids (see figure 3) to function? What scarped the loessial hills so strikingly along such narrow valleys? Why are the scarp bases so high above the preglacial valley floors? What produced the remarkable shift in the course of the Palouse River? Similar questions may be asked for combinations of scabland features in hundreds of situations on the plateau. In but few of them can alternative explanations be successfully used for single features. In none of them can the *ensemble* be explained except by the hypothesis of enormous volume of discharging glacial water—the Spokane flood.

VICINITY OF THE MOUTH OF PALOUSE RIVER

One of the most remarkable tracts of channeled scablands is the preglacial Snake-Palouse divide, now trenched by Palouse Canyon. Before the inception of the glacial discharge four small tributary valleys, eroded into the basalt, drained southward into the Snake, but nothing worthy of the name of valley drained northward. The crest of the divide was much closer to the old Palouse Valley. Of the four Snake River tributaries on this 10-mile stretch, three are wholly included in the scabland, one of them having its head stoped back completely through the divide to constitute the present Palouse Canyon trench. The fourth headed east of the ravaged portion of the divide and only its lower two miles are involved in the scabland. Here conditions were especially favorable for deposition of flood gravel and here lies a deposit of singularly significant character.

The terminus of the minor divide north of this tributary, and nearly at right angles to the course of the flood, was overrun by the glacial waters and for nearly two miles the northern wall of the tributary valley is completely buried from top to bottom in basalt gravel (figure 5). The south wall is good rugged scabland with no gravel on it. Near the western end of this spur the gravel bar deposited on it is 245 feet thick. Its structure is foreset, the beds dipping 21 degrees down the north wall into the tributary. This gravel certainly came over the divide from the north. As shown by the foresets, it did not come from the tributary valley above the scabland portion and it was not eddied back from the

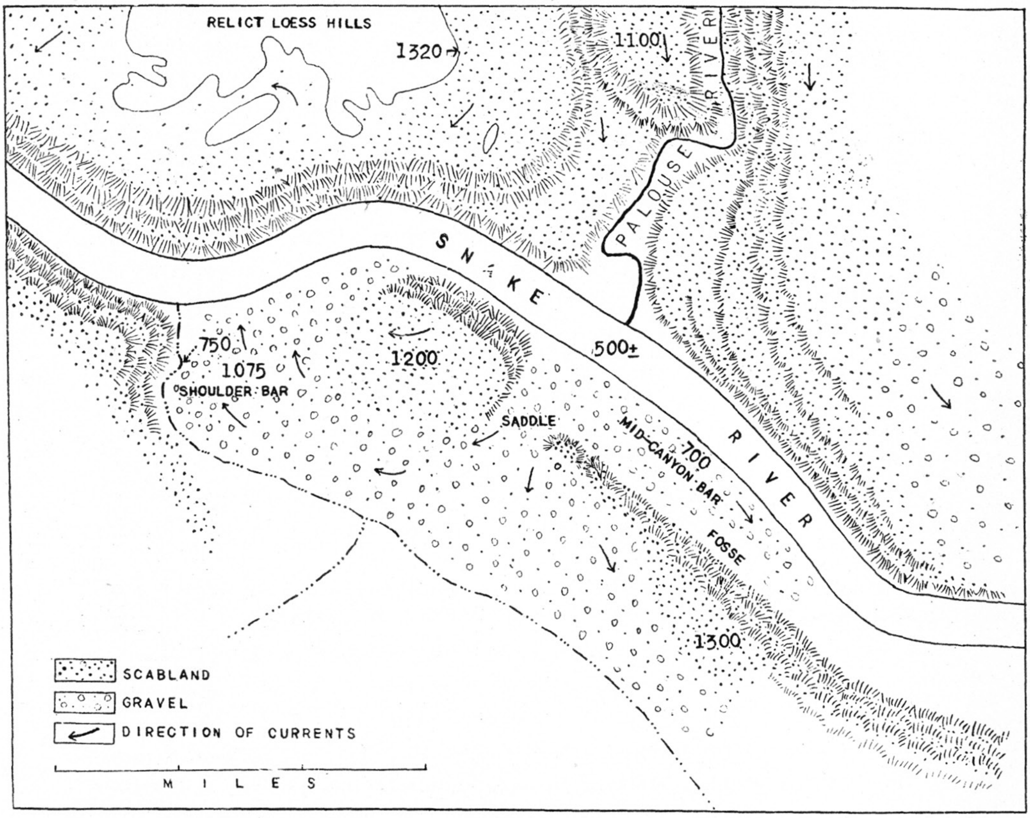

FIGURE 6.—*Sketch Map of Region at Mouth of Palouse River, Washington*

mouth. The valley contains the deposit and is therefore pre-scabland. The top of the bar is about 1,050 feet above tide and its base, at about 800, is 200 feet above Palouse River, half a mile away. Scabland surfaces, with rolled basalt cobbles and a few erratics, extend up to 1,325 feet above tide south of the east end of the bar.

If the combination of features shown by this deposit can be explained in conventional terms, the writer lacks the ingenuity required to do it.

An explanation logically should not be attempted without consideration of the more massive and more peculiarly placed gravel deposits in Snake River canyon at the mouthing of the great glacial stream.

One of these deposits is an elongated mid-canyon hill 200 feet above the Snake. It extends up the canyon two miles above the mouth of Palouse River (see figure 6). Snake River flows north of this hill, with basalt cliffs on one side and a 200-foot scarp of gravel on the other (figure 7). Basalt cliffs constitute the southern wall of the canyon also, and between them and the mid-canyon hill there is a depression, a fosse, 160 feet below the hilltop. The deepest part of this was a closed basin originally, about 50 feet below the lowest place in its rim. The hill slope toward the south wall is relatively gentle. At the west end the hill is wider and is built up against the south wall, which is as typically scabland as anything on the plateau to the north.

The material of this gravel hill is more than 90 per cent basalt. The fragments are very little worn. In contrast, the pebbles of nonbasaltic rock are conspicuously round and are unlike foreign pebbles in the scabland gravels of the plateau. Comparison with Snake River gravel, in present bars and in older terraces for 100 miles farther up the river, makes it as clear that this 5 per cent nonbasaltic material came down the Snake as it is clear that the angular basaltic débris came from the Palouse drainage. The comparison also makes it clear that the mid-canyon hill, the 200-foot trench of the Snake on one side, the 160-foot empty fosse on the other, and the scabland basalt cliffs to the south are wholly unlike anything farther up the Snake. East of the entrance of the scabland glacial flood, gravel deposits in the Snake Canyon are terraces, not bars. They are 75 per cent or more of nonbasalt pebbles. Nowhere in the first 50 miles up the Snake from the Palouse River junction are these terraces known to be 75 feet above the river. They are topographically older than the bar deposits, for considerable alluvial fans have grown out on them, while the fosse depressions of the bars are still unfilled. The rock walls adjacent to the terraces are much less vigorously expressed with ledges and cliffs than are those facing the great deposits of basaltic gravel in the scablands and at the mouth of the Palouse River.

But this mid-channel hill of gravel is not alone, nor is it the largest of its kind in Snake River Canyon. The south side of the canyon, opposite the mouthing of the glacial river from the north, possesses features so extraordinary that the writer almost fears that his description will be doubted. Only a very sketchy map (figure 6) can be presented here, although it shows relations correctly. The sketch shows a short tributary

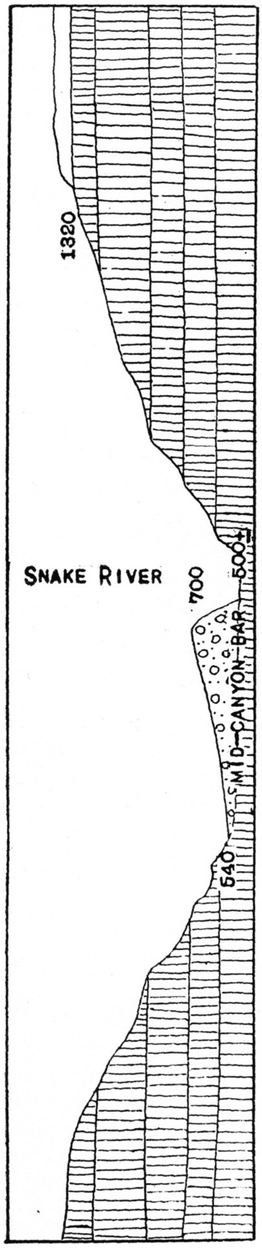

FIGURE 7.—*Cross-section of Snake River Canyon through the Mid-canyon Bar*

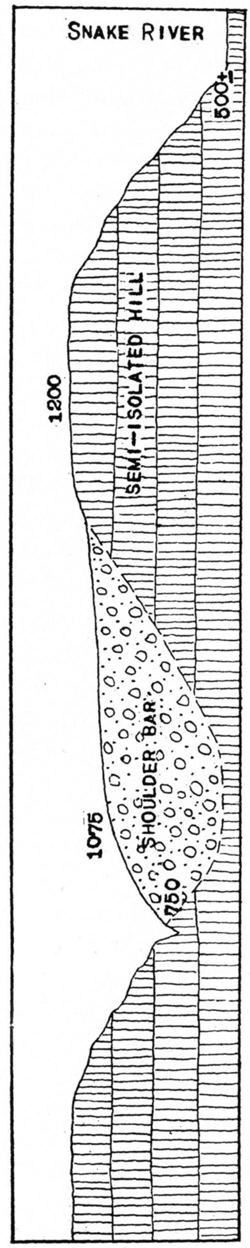

FIGURE 8.—*Cross-section Semi-parallel with Snake River Canyon through the Shoulder Bar*

View is near the mouth of Palouse River.

of the Snake flowing westward for a few miles parallel with it and entering it a little below the mouth of Palouse River. The divide between this tributary and the Snake has a saddle in it directly opposite the entrance of the Palouse, making a semi-isolated hill of the western terminus of the divide. The hill summit is about 1,200 feet above tide, 700 feet above Snake River. Both the saddle and the hill to the west are strikingly eroded into scabland forms, but on the south side, over into the tributary valley, there is an extensive gravel fill most of whose surface descends southward for half a mile with a 4-degree slope. Its placement is similar to that of the gravel in the minor tributary on the Snake-Palouse divide. There is no other gravel in the tributary valley. Another tributary draining northward and entering the one subparallel with the Snake is blocked by the extreme southern margin of this gravel deposit. The margin is a steep frontal slope descending 40 feet to the silt-covered flat which floors the valley immediately to the south.

The down-valley terminus of the divide is the most interesting place here on the south side of the Snake River. The semi-isolated hill, very greatly scoured and plucked on the north side and summit, is heavily mantled with gravel on the south side, almost from the summit down to the broad fill with the 4-degree slope. This heavy mantle is yet thicker on the southwest, and on the west side the gravel constitutes a great shoulder, projecting into and nearly closing the mouth of the tributary valley (figure 7). The top of this great shoulder is about 1,075 above tide, 550 feet above the Snake and hardly 100 feet below the rocky semi-isolated summit. The gravel in it is at least 325 feet deep. It is foreset-bedded, dipping 26 degrees northward *toward* the Snake, paralleling the 26-degree northward slope of the shoulder.

The gravel is 12 per cent nonbasalt. The nonbasaltic pebbles are all very well rolled and many are polished. Almost all are more than an inch in diameter. The basalt pebbles are subangular and for the most part small, so that much of the gravel is fine. In this sorted, fine gravel are no recognizable foreign pebbles.

The 325-foot shoulder of gravel extending westward from the semi-isolated scabland summit crosses the axial line of the preglacial tributary valley. The present discharge from this tributary swings around the tip of the shoulder and, after passing it, straightway returns to the axial line, thus in effect flowing eastward for a short distance *down* its own valley wall. In this short stretch it has cut a very narrow cleft in the basalt 100 feet in maximum depth—a canyon that is completely out of harmony with all other features of the tributary valley, and, let it be repeated, is essentially down the original slope of the valley wall (see figure 2, plate 19).

Though there are many other remarkable features of the district where the glacial flood entered Snake River Canyon, they will not be outlined here. Enough has been presented to show the nature of the problem. Conclusions that seem unavoidable are as follows:

1. The basaltic gravel south of Snake Canyon was derived from the scablands of Palouse River drainage, not from the walls of Snake River Canyon farther east, nor from the deeply soil-covered slopes of the tributary.

2. The scabland buttes and cliffs of the walls of Snake River Canyon are associated with, and only with, the deposits of basalt gravel in the canyon. This is a genetic association, not fortuitous.

3. The profiles of the hills, mounds, and mantles of this gravel are constructional, not erosional. Witness the fosse on the south side of the mid-canyon hill, the long foresets of the 325-foot shoulder which dip parallel with the surface, and the partial blocking of the tributary mouth.

4. If constructional, then these slopes are the original profiles of the deposits.

5. If original forms, they must be considered as gigantic bar deposits.

6 (*a*). If they are bars, then the mid-canyon bar, which is bulkiest at the west end and tails out up the Snake away from the mouth of the Palouse, was built by a great current setting up the Snake from the entrance of the huge scabland river.

(*b*). If they are bars, then the sheet of gravel extending south from the saddle was built by water flowing vigorously across that saddle southward out of the Snake and into the minor tributary valley.

(*c*). If they are bars, then the 325-foot shoulder of gravel which depends westward from the semi-isolated hill, which partially blocks the mouth of the tributary, and which has long foresets dipping into Snake Canyon, is a bar built largely by water returning to the Snake after crossing the saddle.

7. The base of the great shoulder bar is as high as the summit of the mid-canyon bar; yet, from all field evidence of degree of weathering and erosion and of continuous aggradational profiles across the saddle between the two bars, they are contemporaneous forms.

8. The easily identifiable pebbles of Snake River gravel in the great shoulder bar are more than 450 feet higher (above the Snake) than in any known terraces for 50 miles east of the entrance of the scabland flood.

9. The upper limit of the well-expressed scabland just west of the mouth of the Palouse is marked by a pronounced and ungullied scarp in loess whose base is 1,320 feet above tide, or 800 feet above Snake River. The summit of the rock hill, semi-isolated by the saddle through the divide, is about 1,200 and not three miles distant. The summit of the great shoulder bar, therefore, was under 150 to 250 feet of flowing water.

If the description alone was not sufficiently challenging to raise doubts as to the actual existence of these phenomena, the above almost unescapable conclusions may succeed. The writer's answer to such doubts can only be, "Come and see!" The physiographic features of channeled scabland are spectacular enough to repay the visitor. And they are unique. They can not be classified under textbook analyses of land forms.

According to the Spokane Flood hypothesis, the glacial water, which crossed the Palouse-Snake divide in a stream nearly 10 miles wide, here entered the Snake in such volume and with such current that much of the flood crossed the canyon,[6] poured through the saddle and returned in a broad curve down the lower two miles of the tributary to reenter the canyon from the *south* side and to build the great shoulder bar with foresets dipping northward. Pre-Spokane terrace deposits in the Snake (like those now existing above the junction of Palouse River) were destroyed by the entering flood, and their characteristic pebbles, in a trip not to exceed three miles, were dragged 450 feet higher up the subfluvial slope and were thoroughly intermingled with the angular basalt gravel in the shoulder bar. Another diverging current flowed up the Snake Canyon, though no *outlet* exists in that direction, and built a bar 200 feet thick beneath its surface. Data to be submitted in another paper indicate a vigorous current, full of floating ice, moving *up* the Snake at least 25 miles above the mouth of the Palouse and probably much farther. The preglacial depth of Snake River Canyon here was essentially its present depth. This is attested by the accordant junction of many unviolated tributaries of the preglacial drainage system. The minor valleys of this system in many places on the plateau and along the Snake contain heavy deposits of gravel, sand, and silt, thrown back into them by the flood water. There is no escape from these conclusions, therefore, by holding that Snake Canyon has been deepened here since glacial water first crossed the divide from the north.

[6] Some of the water took the normal course, directly down Snake Canyon from the mouth of the Palouse, but some flowed vigorously up Snake Canyon to make a great pond whose record will be described in another paper.

The mid-channel bar was built in a strong current more than 200 feet deep. The shoulder bar, if built during the same episode, attests a depth of 550 feet. The scabby summit of the semi-isolated hill indicates that the depth was at least 675 feet, and the loess scarp, with scabland basalt ledges and scabland gravel deposits at its base, 1,320 above tide, requires a total depth of 800 feet of flowing water at Snake Canyon at this place. These are shocking conclusions.[7] But this brief account of some bars of channeled scabland is only well started. For more data let us return to the plateau.

Bars of Washtucna Coulee

A very large divergent strand of the glacial torrent followed the old Palouse Valley west from Hooper and Washtucna to reenter the main flood at Pasco. This abandoned valley is Washtucna Coulee. The familiar loessial scarps, overlooking scarred basaltic surfaces and basaltic gravel deposits, stand well above the walls of this abandoned valley, generally a quarter of a mile to half a mile back from the brink. At Devils Canyon a part of the glacial flood spilled over to the Snake out of the old valley, just as it did at Palouse Canyon; but this was a very narrow spill, not to exceed a quarter of a mile wide, instead of 10 miles, as at Palouse Canyon. Nevertheless, the divide was trenched 450 to 500 feet deep, almost completely through, and a large deposit of poorly

[7] Their validity depends on (1) the pre-scabland existence of the Snake and Palouse valleys; (2) the actuality of the divide crossing by glacial waters, and (3) the bar genesis of the gravel deposits. Evidence is submitted in many places in this and other papers to establish the first point. There should be no need to repeat it and there is no possibility of challenging it except by denying the existence or the described character and setting of the features noted. A reader unconvinced will remain so until he sees the region himself or until some investigator he will trust has reported on it. The divide crossing (item 2) exists and its very youthful features postdate the divide and the valleys on either side. The gravel deposits (item 3) exist and if correctly described clearly must be bars. Since no one bar at the mouth of the Palouse extends from the bottom of the canyon up to the level of the loessial scarps, one may demur at the conclusion that they all postdate the canyon's present depth; but to call for two or more episodes of rivers great enough to build such bars (one or more to predate the present canyon depths) does violence to the older terrace gravels farther up the Snake, to the character of the episode (for such bar-building obviously was unique in Pleistocene history), and to the existence of other bars whose uneroded forms do extend almost all the way from valley bottom to the scarp-marked upper limit of glacial waters.

The writer appreciates that hesitancy to accept the flood hypothesis, even definite denial of his interpretations of the land forms themselves, will exist until other workers enter the region. He has come to realize that probably no amount of printed description will dispel a belief that selection of data has been made to support a favored hypothesis rather than to find the true explanation; but if the field evidence for the flood exists as described, it is obviously useless to attempt an explanation by the hypothesis of a long and complicated series of Pleistocene drainage changes. (See the writer's article, "Alternative hypothesis for channeled scabland," Journal of Geology, vol. 36, 1928, numbers 3 and 4.)

worn basaltic material was built a quarter of a mile out into Snake River Canyon from the mouth of this trench. The deposit has no really definitive shape and no significant altitude, but it constitutes (or did constitute) a complete barrier 50 feet high in the middle of Devils Canyon, and its form, position, and composition indicate its origin in a flooded Snake River Valley by a large and vigorous stream through Devils Canyon.

Washtucna Coulee carries a great deal of gravel veneered as thin, side-hill bars throughout most of its length, but gravel is most prominent in the vicinity of Connell and Sulphur Lake. Connell is built on a broad gravel flat on the coulee floor. The gravel deposit here blocks the old valley for 12 miles eastward.[8] If the region had sufficient rainfall, a lake of this length and more than 100 feet deep would exist here. Though the surface of the gravel fill is undulatory, its slopes are not erosional. Indeed, the hypothesis that seeks to explain these discontinuous gravel deposits of channeled scabland as erosional remnants fails utterly when applied here. No normal stream through Washtucna Coulee could erode a basin more than 12 miles long and 100 feet deep. Even the glacial stream, prodigious as it was, left the basin only as a consequence of bars built in the vicinity of Connell.

If the trenching into basalt by glacial water at the head of Palouse Canyon had been 100 feet less in depth, Palouse River in post-Spokane time would have resumed its preglacial course through Washtucna Coulee and this hypothetical lake would have existed until an outlet channel had been cut through the Connell gravel bar. Palouse Canyon thus would have been left a dry trench like Devils Canyon. If the Connell bar had been built up 50 feet higher in the coulee and Palouse Canyon had been 100 feet less in depth, Devils Canyon would have been the route of the post-Spokane Palouse. When the depths of erosion in basalt by the flood waters and the thicknesses of river bars they left are considered, it is obvious that relatively slight differences in such results have determined the present routing of the lower Palouse.

Two tributary valleys to the abandoned portion of the old Palouse, entering from the north between Devils Canyon and Connell, had their mouths completely closed by bars. In both cases the bars have been cut through subsequently. The great rounded bar at the mouth of Rattlesnake Coulee, three miles east of Connell, is composed of basaltic sand and fine gravel with foreset beds dipping back into the minor valley from the main. Basalt ledges show in the lower slopes, but the upper

[8] The United States Geological Survey's Connell sheet should have the 800 and 850 contours hachured. They are closed contours.

part, 170 feet above Washtucna Coulee floor, is built up on the walls in a true bar form, with a broad fosse from 10 to 30 feet deep between its crest and the adjacent basalt cliff.

Hardesty Coulee, the eastern of the two preglacial tributary valleys just noted, has a bar dam, now trenched, whose summit is about 300 feet above Sulphur Lake, the lowest place in Washtucna Coulee. The slopes of this bar come down almost to the lake surface. The writer knows of no place in the whole system of channeled scabland where more bars can be seen from one viewpoint and where their forms are more convincingly shown. The entire slope of the coulee south of the lake carries bars. They lie at various altitudes and are of different magnitudes, most of them side-hill bars, great heavy veneers of gravel extending through 100 to 200 feet of vertical range. There are also bars with good rounded summits standing out from the basalt wall above them and sloping back toward this wall, and there are bar forms on the floor of the coulee. Excellent exposures along a new road throughout the entire vertical range show that everywhere the dominantly basaltic gravel is bluish black and "bright" 18 inches or less beneath the surface. The higher gravel deposits are as fresh as those on the floor of the abandoned valley.

Scabland extends from the surface of Sulphur Lake, below 740 above tide, up to the foot of good loessial scarps, at 1,125 above tide, and these bars range through at least the lower three-fourths of this distance. The large glacial river strand down Washtucna Coulee was more than 375 feet deep here. Its surface was 250 feet lower than at Washtucna, 30 miles upstream. At Devils Canyon the water was up to 1,250, as shown by a minor spillway near the head of the canyon, a spillway that was early abandoned. This is nearly 375 feet above Washtucna Lake, on the coulee floor.

The very youthful Palouse Canyon and Devils Canyon divide transections are simply inexplicable without a Washtucna Coulee (pre-scabland Palouse Valley) flooded to the brim. Altitudes show this clearly. Yet, when they operated, a glacial river about a mile wide and 350 to 375 feet deep was also flowing westward. The river's own record is there, downstream from the divide crossings. It must not be ignored if we are definitely committed to the finding of the true explanation for scabland.

Bars of Crab Creek Drainage

PALOUSE RIVER DRAINAGE AREA

Palouse River is the largest stream flowing from the plateau in Washington. Its drainage area, however,[9] is less than half as large as that of Crab Creek. This creek, hardly more than an intermittent stream at its mouth, receives the run-off of one-third of the plateau as delimited by the Columbia, Snake, and Spokane rivers and the Washington-Idaho boundary line. Its divide is even closer to Spokane and Columbia canyons on the north than is that of the Palouse River system. The length of this divide is about 65 miles. One-third of it is channeled scabland. This scabland extends northward on to slopes descending to the Columbia, though it was made by glacial water flowing southward.[10] Crab Creek drainage also received several glacial rivers from the main discharge along the Palouse drainage.

Yet this system has no such broad river-swept tract completely along it as does the Palouse drainage. The anastomosis of the initial stage of the flood has largely survived. Favorable lodgment places for stream gravel are more numerous, in part because of the intricacy of this channel pattern, and bars, therefore, are more common than in the Palouse scabland. Only a few, however, can be described here. They are selected chiefly to show the principles controlling such deposits and to establish the verity of the glacial flood.[11]

REARDAN BAR

In the map published by the writer in 1923 [12] the easternmost channel of the Crab Creek system is shown leaving the margin of the ice-sheet about six miles north of the town of Reardan. It was known then that a prominent mounded gravel deposit largely blocked this channel about one mile north of Reardan, and that in part, at least, its structure was foreset northward. This seemed explicable as an eddy current structure, but later study has shown that there are two bars here, 20 and 30 feet high, respectively; that they completely block the channel from the north, and that each has a steep northward slope like a delta front. A small lake is inclosed between them, and the channel, after restudy, proves

[9] Including the portion in Idaho and not shown in figure 1.

[10] See second part of the writer's paper "Alternative hypotheses for channeled scabland."

[11] It is understood, of course, that the flood hypothesis is to be tested, also, by other criteria than bar deposits.

[12] The channeled scabland of the Columbia Plateau. Journal of Geology, vol. 31, 1923, opposite p. 618.

to be an insignificant thing, though it is truly open through from the north. There is almost no scabland in this channel and only faint loessial scarps high up on the sides. The scabland and its bounding bluffs in loess, which are prominent from Reardan southwestward, actually begin at that town. A situation such as this challenges the whole hypothesis; for scabland, if formed by glacial streams, should be traceable continuously to the glacial margin. Were glacial waters required to make scabland? Might not the prevalent bare rock in bottoms of the plateau valleys be the result of local stream-work aided, possibly, by wind scour? A few paragraphs will be devoted to this local problem because of its bearing on larger interpretations.

Reardan stands almost on a three-way divide. Drainage goes northward directly to Spokane River, southeastward to Deep Creek and thence to the Spokane, and southwestward to the head of Crab Creek. The north-draining valley is the most marked, it is the narrowest, and it has the steepest gradient of the three. It clearly is a preglacial drainage route. The valley leading southwestward has a low gradient and its rugose rocky floor is more than a mile wide, in striking contrast with the north-draining valley; and the valley leading southeastward is likewise broad and has a low gradient, but has no loessial scarps and, except for the first two miles east, has no scabland on its floor. It descends about 10 feet to the mile.

The two mounded gravel deposits, here called bars, require by the flood hypothesis a large glacial stream flowing either east or west across the site of Reardan, across the preglacial divide *on* which they are built. That river never flowed up Crab Creek and down to Deep Creek. Could it have flowed up from Deep Creek, up a gradient of 10 feet to the mile, and across to Crab Creek?

The answer was found in the wide distribution of fresh erratic boulders among the loessial hills northeast of Reardan. They occur at upper altitudes, ranging from 2,500 to 2,525,[13] in all the valleys of this group of hills. They came from the near-by ice-sheet and were berg-rafted in standing water between the ice on the north and the plateau divide on the south. The uncanyoned head of the great Palouse scabland tract, 21 miles wide, is only a few miles distant and its floor is from 2,450 to 2,490 above tide. No glacial ice or preglacial hills stood between it and Reardan; yet the depth of water was so pronounced at the head of this broad spillway that the wide, unscarred valley southeast of Reardan became a divergent route and shared in it, carrying a broad, deep, gentle

[13] One is recorded at 2,560, but this reading was not checked.

current westward, *up* its bottom gradient, to cross the divide at Reardan and thence to flow turbulently enough to make the scabland channel to Crab Creek. No gravel came out of this semiponded area; the bars are built of basaltic débris picked up in the two miles between them and the head of scabland. The angular character of the gravel suggests the same thing. Ponding among the loessial hills resulted also, and thus the erratic boulders were scattered among them.

The channel floor at Reardan is 2,440 feet above tide and the upper limit of the glacial water here was 2,500. How deep was the river at its initiation? How much was the original divide lowered by its corrasion? The sum is 60 feet. The bars indicate a depth of more than 30 feet when they were built. And certainly the Reardan channel was only a minor western divergence contemporaneous with the rest of the great Palouse spill.

KRUPP (MARLIN) BAR

This deposit is 70 miles farther down Crab Creek, though less than 50 miles by another route of the plexus from the ice-sheet. For a mile or more at this town the northern wall of Crab Creek Valley is completely buried in gravel. The crest of the deposit here is level and it looks from the south like the frontal slope of a great delta or terrace. The total height is 260 feet. Rugged basalt cliffs constitute the northern wall of the valley both upstream and downstream from the steep gravel-covered portion. The frontal slope is unfurrowed by gullies, but is fluted with small, mounded forms, among which are a few undrained depressions. There is no definite angle between the steeper frontal slope and the top. For nearly a mile north of the brink the deposit constitutes a gravel plain, *descending* 40 to 50 feet in that distance away from Crab Creek Valley to meet the maturely dissected, loess-covered basalt hills which rise 100 feet in another mile north. The highest part of the deposit is on the brink overlooking Crab Creek Valley.

The material at the north limit is well-sorted basaltic sand with a few cobbles of basalt and of dense, white, calcareous material, such as is common in seams in the loess and in pockets between loess and basalt. Angular basalt fragments are imbedded in some of the limestone—a relationship which clearly was produced before the cobble-making. Only one foreign pebble was found—a quartzite.

Nearer the crest the material is dominantly gravel and limestone pebbles are relatively rare. In both places there are 18 to 30 inches of dust above the deposit and a discolored zone of the upper 6 inches of the gravel and sand. Below that the material is blue black in color for the full depth of exposure, 15 feet. Near the base of the frontal

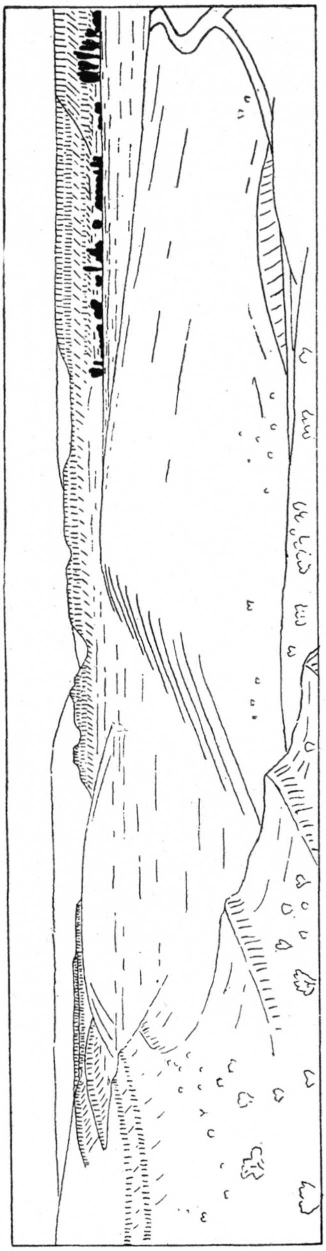

FIGURE 9.—*Bars and Fosse in Crab Creek Valley, Washington, near Wilson Creek Station*

View taken looking west. Main current of the glacial river swung to the right of these bars. Drawn from photographs.

slope the material has abundant subangular basalt cobbles. There is no scabland back of (north of) this deposit, and no loessial scarp. The waters which put the material here were not vigorous enough, as witness the dominant sand. It was a protected place at the downstream terminus of a large loessial island; but the deposit is a unit from bottom to top—a unit in form, in composition, in degree of freshness. Here at Krupp, apparently, is a stream deposit of the Spokane flood which extends through the entire vertical range of the great glacial Crab River. It is not a remnant of a former fill. Such a fill would have completely obliterated Crab Creek Valley. Since made of débris taken from the valley walls, the idea of such a fill is an absurdity. Such a fill, dissected to a depth of 260 feet, would have exceedingly conspicuous remnants for a hundred miles along Crab Creek, and there is nothing remotely approaching such features. Instead, the buttes, cliffs, and basins in basalt on all slopes from bottom to top are river-channel features, simply impossible by the erosion of Crab Creek in post-Spokane time. Furthermore, there are large bars at lower levels, some of which block the drainage of the creek itself.[14]

BARS NEAR WILSON CREEK STATION

The floor of Crab Creek Valley west of this town carries several very

[14] Sylvan Lake, four miles long; Crab Lake (now drained), six miles long, and Brook (Stratford) Lake are examples.

well-expressed bar deposits. They lie in protected situations provided by the original irregularities of the pre-Spokane valley. One which is crossed by the North Central Highway (figure 9) lies in the lee of a rocky shoulder on the south side of the valley and has a long, gentle slope toward the main part of the valley, on which slope are the characteristic flutings and moundings. Its south slope toward scabland walls is considerably steeper; but it does not reach these walls, and there is a broad unfilled tract between bar and wall—a tract that no one can explain as erosional in origin. Another bar, farther west, assists in inclosing the unfilled tract.

East of Wilson Creek Station and on the north side of Crab Creek a bar almost completely blocks the mouth of Connawai Creek, a minor glacial river strand from the north. The bar is much like that at Krupp, though smaller. It rises 180 feet above Crab Creek, toward which it has a slope of 20 degrees. Its back slope descends approximately 5 degrees toward the minor valley and is about 50 feet high. The bar constitutes the north wall of Crab Creek Valley for a thousand feet or so. Connawai Creek in post-Spokane time has cut a gulch along the west edge of the bar and encountered the basalt shoulder buried beneath the gravel. The bar is highest in the middle of the mouth of the tributary. The material of the bar is 95 per cent basalt, and all constituents, including the foreign pebbles and cobbles, appear almost perfectly fresh in the slope wash. Scabland in this vicinity extends about 100 feet higher. The bases of loessial scarps margining Crab Creek Valley near this place are 200 feet above the bar top.

Nine miles by road up Wilson Creek, which is another ravaged preglacial tributary of Crab Creek, is an interesting bar deposit. It lies in the mouth of a minor and unviolated tributary of Wilson Creek. In form it is a terrace about 60 feet above the floor of Wilson Creek Valley, but its surface slopes about 3 degrees back into the mouth of the tributary valley for half a mile and there descends in slopes of 12 to 25 degrees to the broad floor of the tributary. This margin is distinctly convex in profile. It is not an erosional scarp. In ground plan it is crenulate and the whole deposit constricts the tributary valley floor to about one-tenth of the width it has immediately upstream. Looking down the tributary valley from a point about a mile above this deposit, it appears like a complete dam. There is no gravel farther up the minor valley. The gently sloping surface of the bar top is littered with cobbles and rolled boulders, some of them two feet in maximum diameter. The steeper slope of this terracelike deposit, facing Wilson Creek Valley, looks like an erosional scarp.

Wilson Creek carried a glacial stream; the tributary did not. That glacial stream was deep enough and vigorous enough to build this local deposit back for half a mile into the tributary, and to roll boulders back into ponded water in the tributary valley along the 3-degree slope. But the main valley was not filled. The deposit, therefore, is a bar.

BAR NEAR THE HEAD OF GRAND COULEE

This feature is described here as a part of the record of the Spokane flood. It may, however, be younger in age, for Grand Coulee carried a great river during the later Wisconsin glaciation, but it shows well the characteristics of bars all over the scabland, and its age, for this purpose, is immaterial.

The bar lies in an alcove in the upper wall of the coulee, just south of the fairly continuous granite ridge that crosses the coulee near the head. Its summit is about 150 feet above the coulee floor and about 50 feet above the alcove floor between it and the coulee wall. A narrow gulch out of the alcove pocket has cut away one end somewhat, but otherwise its bar form is very good. The essential characteristics are the elongate crest (which is foreshortened in figure 3, plate 20) parallel to the coulee wall, but standing out from it, the back slope toward the wall, the fosse thus formed, and the general roundness and convexity of all profiles, gullying being almost wholly absent. Features of this class are individual deposits made in vigorous streams at least as deep as their crests are high above the valley floor. With but one exception, no terraces eroded in gravel are known in channeled scabland. Virtually all gravel deposits have the characteristics of bars.

BARS OF QUINCY BASIN

The entire plexus of Crab Creek glacial drainage, that from the edge of the ice directly and that from the west side of the Palouse spillway, converges to a shallow structural basin in the western part of the plateau. The basin had no outlet adequate for the great volume and more than twenty townships were covered completely with basalt sand and gravel; but, since the basin is a likely place for sand and gravel to come to rest, since this basin was here before and has been here ever since the Spokane episode, and since the local rock is all basalt, why should the deposits in it be called Spokane?

The answer is that they are not all Spokane in age, but that the dominant upper sand and gravel deposits, here called Spokane, are distinctly different in composition, in degree of weathering, in structure and texture, in topographic expression, and in relation to dischargeways, from other deposits known in the basin.

A study of the dischargeways of Quincy Basin shows most clearly what the conditions in the basin must have been when they functioned. There are four—a fact challenging enough in itself. These four operated simultaneously. The upper limit of scabland and its gravel, or the base of loessial scarps, or both, are essentially the same at each outlet, ranging between 1,275 and 1,325 feet above tide. Since the range in latitude among these outlets is 18 miles and that in longitude is 35 miles, it is unlikely that any warping in the structure that makes the basin has occurred subsequent to operation of these spillways. If they were closer together, the unavoidable error in determining the upper surface of water from these physiographic features might be held to include some movement without revealing the fact, though the objection would be a weak one even then.

No sequence in operation being admissible, at least at the inception of the discharge, the size of the dischargeways becomes especially significant. Three of the outlets appear to have been great cataracts into Columbia Valley to the west. Scabland channels from half a mile to two miles wide lead across the western rim to the brink of cliffs 200 to 400 feet high at the head of deeply recessed rock-walled alcoves in the walls of the Columbia. Rock basins with a maximum depth of 200 feet lie in the alcoves at the foot of these cliffs. The total range from floor to upper limit of water in two of the channels above these cataracts is 100 feet.

The fourth spillway out of Quincy Basin was a great cascade over the southern rim. It is a marvelous region of scabland buttes and knobs, canyoned channels, rock basins interrelated in a complex unparalleled elsewhere, even in the scablands. At the head its width is 9 miles and the vertical range of scabland is nearly 375 feet. It seems clear that this was the site of preglacial discharge out of Quincy Basin and that part of this erosion across the southern rim was pre-Spokane. But 375 feet at this great spillway is the sum of original glacial stream depth and total glacial stream erosion, and the 100-foot depth at the head of the two larger cataracts is similarly the sum of these two quantities. If one seeks to minimize the volume of escaping glacial water, he may estimate a larger fraction of this vertical range as erosion in the basalt-floored channels. This requires very much more time. During this time he must keep the two great cataracts and the great cascade *contemporaneously* operating while nearly 100 feet of basalt is eroded, this in spite of the strong probability that the southern and deepest dischargeway was already a complete notch in the basin rim; and, furthermore, he must keep these small streams from two to nine miles wide. The factor of deepening in basalt by local run-off can not be introduced into the problem. There has been none at the cataract heads and very little, if any, in the great cascade spillway. To use the hypothesis of two or more episodes of glacial discharge for the production of these great spillways, Quincy Basin must be supplied each time with a volume

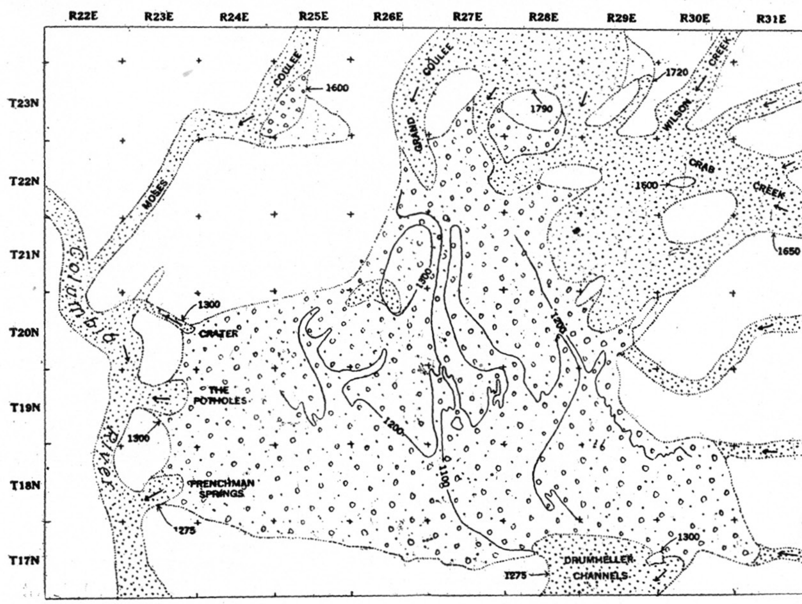

FIGURE 10.—*Scabland and gravel Deposits of Quincy Basin and Vicinity*

Contours on the gravel deposits generalized from Quincy, Winchester, Moses Lake, and Wheeler sheets of the United States Geological Survey. Township corners indicate scale and can be used to locate cultural features.

adequate to maintain all four spillways, or a complicated warping must be postulated, the present net result of which has been to put upper limits at dischargeways all in the same horizontal plane, and thus to destroy evidence of the warping. Terracing across the gravel fill then should exist to show the sequence of operation; but there is none (except the Moses Lake channel), and to this it should be added that, though there must be evidence of greater age of the earlier dischargeways, the writer has failed to find it or has neglected to report it. The writer again confesses his inability to interpret scabland phenomena—the Quincy

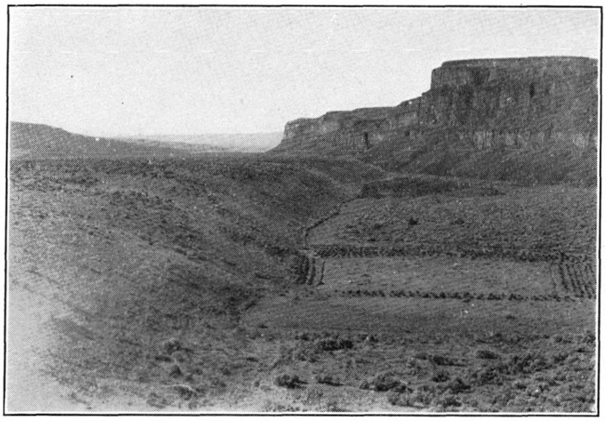

FIGURE 1.—BAR IN MOSES COULEE

View taken looking south. Fosse, which is the mouth of a preglacial tributary, is 50 feet below the crest of the bar.

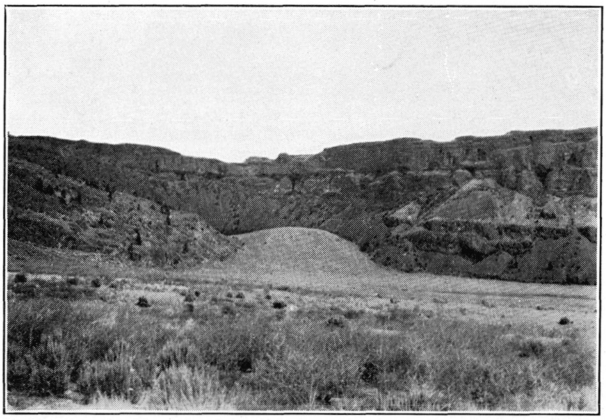

FIGURE 2.—BAR IN GRAND COULEE

Looking east. Crest of bar is 150 feet above coulee floor.

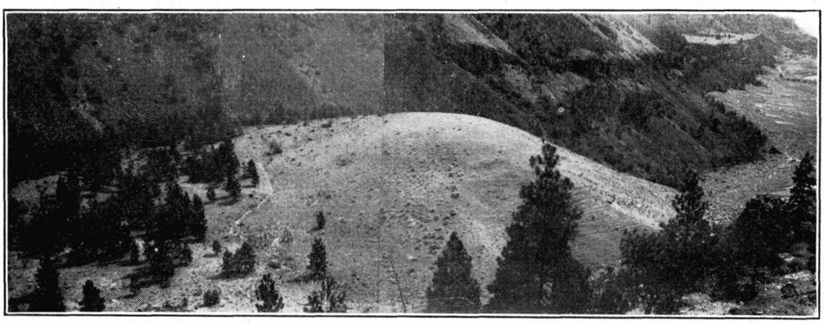

FIGURE 3.—BAR IN GRAND COULEE

Looking south. Crest of bar is 50 feet above the fosse between it and the cliffs.

BARS IN MOSES AND GRAND COULEES

Basin spillways in this case—in the conventional concepts for melting ice and the escape of its waters.

With the case for great volume of discharge set forth above, the deposits of the basin may be examined. They are shown in figure 10. If they were not made by the great streams the writer conceives of, a fairly uniform aggradational plain would have been built, its surface marked, perhaps, by abandoned channels of distributary type and perhaps by terraces, if the dominant outlet was deepened later in the period of aggradation. Such a plane would be highest at the entrance of the glacial rivers and would slope southward and westward across the basin.

Though there are flat tracts on the gravel fill, it is impossible to interpret the topography of the basin floor in these terms. Except along Moses Lake trench, which was eroded in gravel during the later Wisconsin epoch, there are no terrace flats or terrace scarps. The gravel is piled in great mounds with broad lateral flutings. The depressions which occur among them do not have the characteristics of eroded channelways, their floors do not have continuously descending gradients, their sides vary greatly in slope and in distance apart, and they generally flare out and lose their identity by a decrease in the height of the margining mounds. Others begin out in the plain and their heads are closed in by the moundings in a way that no true channel could possibly be. Some are closed basins among the mounds, which everywhere are characterized by convex profiles. Many mounds extend 50 feet above their surroundings. They show almost no trace of work done by local run-off. Though broader and flatter, they are as definitely constructional forms as the channel bars already described in this paper.

Scabland basalt knobs outcrop in the northern part of the deposit near the entrance of the glacial streams into the basin. From data not presented here, 30 feet seems to have been the minimum depth of current necessary to pluck the rock basins and the irregular knobs which characterize basalt scabland. This scabland is 50 feet above the upper limits of dischargeways and the adjacent gravel deposits.

Bars in Moses Coulee

Of the scabland channels only Grand Coulee and Moses Coulee were open to Wisconsin waters. Moses Coulee carried but a small stream and there is little question that features well above the floor are pre-Wisconsin in age. A remarkably well-shown bar on the walls of Moses Coulee is crossed by the Sunset Highway. It is on the west side and 200 feet above the floor (see figure 1, plate 20). The depression back of it is completely inclosed, is 50 feet deep, and covers 5 to 10 acres. The depression is the blocked mouth of a minor gulch cut on the coulee slopes. The bar deposit is very bulky. It extends all the way down to the coulee floor and its length is two miles. Farther south it abuts directly against the basalt cliffs and is only 100 feet high. Its cross-section profile is convex throughout.

One of the most strikingly placed gravel deposits of the scabland system is on the upper brink of Moses Coulee and on the outside of the sharp-angled westward turn in the course of the coulee. This east-west part of the coulee, about eight miles in length, is inclosed between two nearly east-west anticlinal upwarps of the basalt plateau. It is essentially a syncline and the structural-topographic depression extends five miles or so farther east than the entrance of Moses Coulee from the north. In pre-Spokane time Douglas Coulee (which has no channeled scabland) probably was the main drainage line of this part of the plateau and certainly had a canyon across the southern anticline south of Palisades. Minor drainage from the syncline was tributary to it. Much of the synclinal floor was undissected. The Spokane glacial waters tremendously eroded this syncline and the lower course of Douglas Coulee, now considered a part of Moses Coulee. This erosion left upper Douglas Coulee as a hanging tributary, its lip 350 feet above the gravel fill in the scabland canyon. A cataract or cascade originating in the glacial river close to the junction with Douglas Coulee retreated eastward along the synclinal floor almost to the sharp angle where the coulee enters the syncline. Here it is today, a mile wide, 400 feet high—a series of great steplike cataracts and cascade-chutes, of recession alcoves and buttress-like remnants between them, mute evidence of the size and vigor of the glacial stream which made it. This, however, is not all of the evidence. Just east of the sharp turn in the course of the coulee, above all the amazing display of wildly rugged scabland, 500 feet higher than the foot of the great cataract-cascade and back on the undissected floor of the syncline, is a deep, widespread deposit of stream gravel. It is a broad mound whose surface undulates through 50 feet of vertical range in unmistakable bar forms. The deposit ends abruptly toward the southeast in a slope of 25 degrees. The flat floor of the syncline immediately in front of it carries three to four feet of silt and dust directly on basalt. The gravel is 99 per cent basalt. The total height of the deposit is 80 feet.

The topography and distribution of this gravel permits of but one logical interpretation. It was built southeastward into the undissected part of the syncline, which then contained ponded or semiponded water, surely 100 feet deep. Its débris came from the glacial river down Moses Coulee. There is no retaining wall to the west and there never was any. The ponding was due to the great volume of the Moses Coulee stream immediately to the west. It is true that the great series of cataracts and cascades probably had not receded far at this time, and that perhaps the synclinal floor above Palisades then had only a canyon in it like Douglas Coulee today; but the Douglas Creek notch across Badger Hills anticline was open then, and only large volume and vigorous current can explain the transportation of the débris and the building of this form on the margin of a glacial river more than a mile wide.

Bars in Columbia Valley

BARS WEST OF QUINCY BASIN

A prominent rock terrace lies along the east side of Columbia Valley where the three cataracts discharged out of Quincy Basin. It is not horizontal. Its surface rises northward from 975 at the middle cataract (The Potholes) to 1,375 feet above tide in about five miles. It has a maximum width of a mile. The southern part of this terrace, where it is below 1,300 feet above tide, is truly scabland in character. This is particularly marked at and below 1,200 feet above tide, where on the riverward edge of the terrace there is a wilderness of low buttes and rock basins with a local relief of 30 to 40 feet. Connected channel forms are not conspicuous. Between this scabland and the foot of the 200- to 300-foot basalt cliff east of it are broad gentle swells or mounds of gravel higher than the scabland by 50 feet or so. Nearer the base of the cliff the material in these mounds is mostly sand instead of gravel. Ninety per cent of the pebbles are basalt, about twice the content of basalt in present Columbia River gravel here.

A fosse 20 to 30 feet deep separates these mounds from the base of the cliff. Toward it the bar forms are crenulate, as though built out irregularly, but never reaching the cliff. The fosse is not due to subsequent erosion. The talus of the cliff partially fills it and wash is accumulating in small basins on its floor. The bar forms have hardly been scarred by erosion. The relation is what should be found if a great flood swept this basalt bench.

Farther north the aspect of the surface of this rock terrace, where its altitude is above 1,300 feet, is wholly different. It has no gravel bars, no scabland, no rock ledges of any sort. Its edge is trenched by ravines; the cliff above it is without ledges or talus and is much less steep than that back of the scabland part of the terrace. The scabland-making condi-

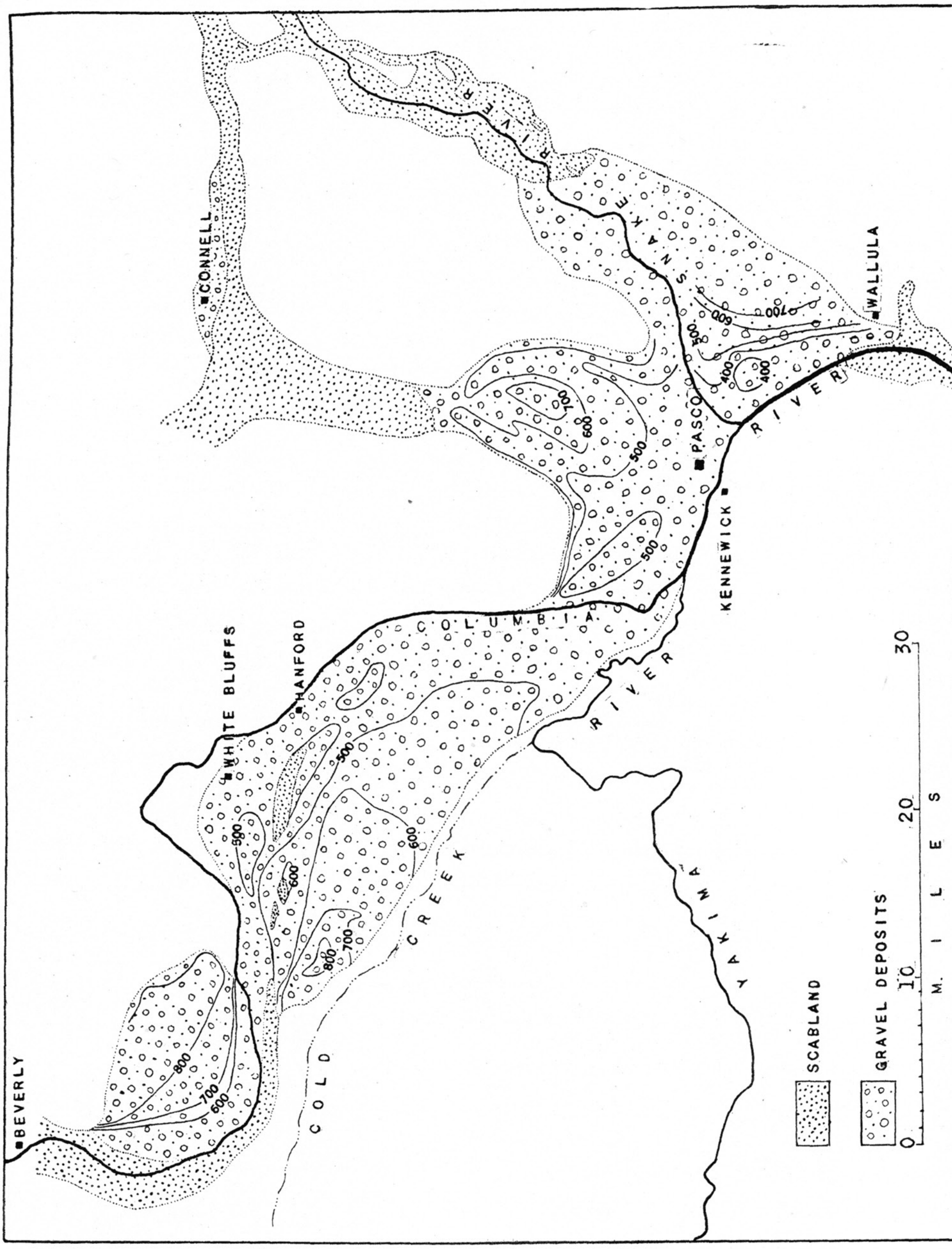

FIGURE 11.—*Sketch Map near Junction of Snake and Columbia Rivers*

Showing scabland and gravel deposits. Contours on the gravel deposits are generalized from the Beverly, Priest Rapids, Coyote Rapids, Hanford, Pasco, and Wallula sheets of the United States Geological Survey. Slack-water deposits and channels in weaker formations above the basalt not shown.

tions never obtained here. Yet two miles farther north, at the northern cataract (Crater Falls), this terrace is trenched completely across and in the reentrant alcove the cliffs are 300 feet high and nearly vertical. The Crater cataract is all of 200 feet high.

There are huge gravel bars in the Potholes alcoves, noted in an earlier paper.[15] The northern alcove has a bar along its north side for a mile. The bar crest is distinct; it is elongate like a great beach ridge and throughout it is separated from the basalt wall by a fosse whose depth is 50 feet maximum. Talus in one place has nearly filled the fosse. Boulders of basalt 2 to 3 feet in diameter lie on the bar, clearly not débris from the crumbling wall adjacent. The channel in the middle of the alcove floor is at least 125 feet lower than the bar top. The water at the time the bar was built was at least that deep, for the lower 75 feet of this channel depth is a rock basin. The channel is more than half a mile wide. The size and vigor of the stream here is thus indicated. There was, moreover, another stream of equal size in the southern alcove of the double fall. Potholes Cataract was only one, and not the largest one, of four different spillways out of Quincy Basin, and Quincy Basin probably did not receive more than half of all the glacial water discharging across the Columbia Plateau during the Spokane epoch.

BARS BETWEEN BEVERLY AND PASCO

For 60 miles above the junction of Snake River the valley of the Columbia, which here is largely structural, carries great gravel deposits in huge mounds separated by river channels. The course of the Columbia is largely lateral to the elongate group, but it crosses in two places. Elsewhere the channels are abandoned. Not all the mounds are composed of gravel to the base, but there are no indications otherwise in most of them. These accumulations stand as much as 400 feet above adjacent empty channels. Their forms are very striking indeed, and there is no escape from the conclusion that they are river bars of great magnitude. This interpretation has been admitted in the only detailed challenge of the Spokane Flood hypothesis yet in print—a challenge that deals with this particular area.[16] In the writer's reply[17] it was stated that the Spokane age of these bars was not yet established. More data are now at hand.

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[15] J H. Bretz: Glacial drainage on the Columbia Plateau. Bull. Geol. Soc. Am., vol. 34, 1923, pp. 573-608.

[16] E. T. Knight: The Spokane flood: a discussion. Jour. of Geology, vol. 35, 1927, pp. 453-460.

[17] J H. Bretz: The Spokane flood; A reply. Jour. of Geology, vol. 35, 1927, pp. 461-468.

Listing only the major features, such as 50-foot contours would show, there are eight definite bars in this group. They range from 4 to 25 miles in length. They may be considered in three sections, determined by the crossings of the group by the Columbia (see figure 11). The bar farthest upstream may be in a large part a veneer bar. It lies east of the Columbia, is about 12 miles long, 850 feet above tide, and nearly 400 feet above the Columbia at its head. It lies on the inside of a broad curve in the valley, its base close to the river. The outside of this curve is a dissected basalt valley wall which rises well above the upper limits ascribed to the flood. The bar profile and the location of the river with reference to the basaltic wall on the outside of the curve makes the *ensemble* look like the result of lateral planation, the side of the bar thus being a slip-off slope. It may be that in part, but the character of the deep gap five miles north, where Columbia River crosses Saddle Mountain anticline, debars the Columbia from ever having had its main course over the higher part of this slope. Furthermore, there is lower land back of (east of) the bar.

The entire riverward slope from 850 down is covered with rolled basaltic gravel. This is coarser on the lower slopes, and with increasing distance from the Columbia, especially across the summit, and toward the back slope it grades into a coarse basaltic sand. The gravel is as fresh on the summit, 400 feet above the Columbia, as it is on the lower slopes. It is difficult to explain these features in terms of normal valley deepening. They conform to the requirements of the flood hypothesis, but they should not be interpreted by themselves. A regional study alone will afford a safe basis. The evidence already presented has shown the need for a greater volume of water in the plateau drainage lines. Even more exceptional features farther down the Columbia await our study.

The second section of the group begins across the river three miles directly south of the downstream terminus of this bar. Here is a terrace-like spur, 800 feet above tide, projecting southeastward from the higher basalt hills and traceable in this direction to the junction of the Yakima River with the Columbia, 25 miles distant. Its surface descends gradually a total of 400 feet in this distance. The spur separates an intermittent stream, Cold Creek, from the Columbia for this entire distance. At the head (the 800-foot portion) the slopes of the spur are equally steep toward the Columbia to the north and Cold Creek to the south. The southern slope is 100 feet high and is quite surely constructional. Cold Creek Valley is two to three miles wide and the stream is now filling it and disappears in it south of this slope because of evaporation and seepage. The terrace spur either is wholly of gravel or is so completely mantled with gravel that nothing else shows. The gravel ranges from 60 to 87 per cent basalt and is well rolled. There is no greater degree of weathering of the upper gravel than anywhere else in the bars described thus far.

Traced southeast, the form of this gravel bar between Cold Creek Valley and the Columbia becomes broader, flatter, and lower. Much wind-drifted sand overlies it in its southern portion, but the very broad creek valley clearly has been determined for 21 miles by the building of the gravel deposit, not by erosion of that stream.

The more limited, more accentuated, bars of the group and their separating abandoned channels have already been described sufficiently to make their origin clear.[16] Their locations out in the central part of the structural valley, where the greater current of the glacial Columbia flowed, are due to basalt hills that project above the level at which the gravel was carried. These hills (Gable Butte and Gable Mountain) were overrun and sculptured into striking scabland forms. Part of their débris is recognizable as angular boulders abundantly strewn over the bars in the immediate lee. A marked scabland ledge outcrops also in the lower north slope of the 800-foot terrace spur. Many pebble counts show that basalt in the gravel of these bars ranges between 60 and 80 per cent. The present Columbia gravel adjacent to them has not been found to exceed 50 per cent basalt. No difference in weathering in the upper and lower bars has been found. The thickness of dust cover varies from 4 to 14 inches. It is not regarded, however, as a trustworthy criterion of age, for dust on gravel only 25 feet above the Columbia is as thick as on the highest bars.

Southeast of this middle section of the group the Columbia crosses to the western side. The bars in this southern section are related to the glacial rivers in Columbia Valley, in Washtucna Coulee and in Snake Valley, all of which coalesced at one place. The field relations here indicate that the bars are all members of one genetic group. Neither Washtucna Coulee nor Snake River received drainage from the Cordilleran ice-sheet during the Wisconsin glaciation—another indication that the group as a whole is a part of the Spokane record.

The gravel in this district is disposed in large, low, rounded mounds from one to five miles across and as much as 100 feet high. These mounds are separated by wide swales which are not post-gravel erosional features. One of these broad, low gravel piles, lying northwest of Pasco, is 6 miles wide and more than 100 feet high at its southeast end. It is

[16] J H. Bretz: The Spokane Flood: A reply. Jour. of Geology, vol. 35, 1927, pp. 461-468.

separated from higher land on the east by a swale two miles wide. This swale becomes narrower and shallower toward the north until it nearly disappears; but it is recognizable on the north side of the mound, with two closed depressions in it. Its gradient almost from the brink of the Columbia bluffs at the north end of the mound descends southeastward away from the river. This bar clearly is of the glacial Columbia.

Another mound lies between Eltopia and Pasco. It is about eight miles long and 100 feet above the valleys on the east and west and the broad lowland on the south. This bar lies just south of the lowest scabland of Esquatzel Coulee.[19] Indeed, it overlaps scabland, for buttes and knobs of basalt project through the gravel in the northern part of this bar. It may be conceived of as lying in the mouth of the Washtucna-Esquatzel glacial stream. The basal portion of that stream certainly divided at Eltopia, and the valleys on either side are the courses of the deeper channels. The main channel was on the west side. Gravel directly from the scabland, with only 1 per cent foreign material, is at least 30 feet deep at the head of the eastern channel. It is foreset-bedded in several different horizons, with eastward dip into the smaller channel. The floor of the western channel at the head of this bar is 25 feet lower than that of the eastern channel, yet this gravel was carried out of the main and lower route up into the smaller, shallower channel. Only ephemeral streams flow in either channel today. Erosion has hardly touched these topographic forms since they were made.

Another broad, low gravel pile lies in the downstream angle between the Snake and the Columbia. It is more than 50 feet high on its eastern side, next to the abandoned channel which separates it from the higher land farther east. It is 70 per cent basalt.

Throughout this entire group of bars all features are in harmony with the conception of three contemporaneous glacial streams of great depth, with large traction load of gravel, and with sufficient vigor to pluck protruding basaltic surfaces and to maintain channels among the bars. There is no evidence that the gravel is of different age in different parts. There is little possibility of explaining any of the mounds as due to dissection by the Columbia or Snake of a valley-train type of gravel fill. In this wide tract there are no good upper limits, but the waters were certainly well above 800 feet above tide. Though much of the tract carries a mantle of wind-blown sand and dunes are common, there are enough exposures to show that the larger relief is due to the mounding of stream gravel. The highest per cent of basalt

[19] The abandoned preglacial valley of Palouse River is locally known as Washtucna Coulee east of Connell and as Esquatzel Coulee south of that town.

is found at the mouth of Esquatzel, whose drainage was essentially all on basalt. Both the Snake and the Columbia had plenty of earlier terrace gravel to be torn up by the glacial flood and mixed with the local débris.[20] The rounding of basalt pebbles, which is greater than in the channel bars on the plateau, is to be expected. They have traveled farther.

Scabland and their gravel deposits extend down the Columbia below the junction of the Snake, as far as Willamette Valley, west of the Cascade Range. This 200-mile stretch has not been studied in as much detail as has the plateau in eastern Washington. It possesses, however, more remarkable associations of scabland basalt and gravel bars than anything on the plateau. The writer realizes that the descriptions presented thus far in this paper may have passed the reader's limit of credulity. Nevertheless, these features do exist and the descriptions will some day be verified. That other students of land forms critically examine the field is earnestly to be desired.

BARS NEAR THE MOUTH OF UMATILLA RIVER

The Snake and Yakima valleys converge to the Columbia, from the east and west respectively, because of a pronounced structural-topographic ridge, the Horse Heaven Hills. The Columbia crosses this where the river and the Washington-Oregon boundary become one. About 20 miles farther down the stream, at the junction of Umatilla River from the Oregon side, the Columbia is in a large structural basin whose floor carries a heavy deposit of gravel (see figure 12). Like the structural basin north of the junction of the Snake River, it also has basaltic eminences projecting above this gravel, all of them with scabland. Emigrant Buttes, 10 miles up the Umatilla and 759 feet above tide, earlier reported as without scabland, have low scabby ledges on the west edge of the highest summit, and a rubble of large angular basalt fragments lies on the west slope immediately below. Among these fragments on the relatively gentle slope are several angular pieces of a porphyritic diorite which has been found in almost every scabland channel on the plateau, which occurs among the ice-rafted erratics northeast of Reardan, and which is present in Spokane

[20] Indeed, large remnants of old terrace gravels are known south and west of Kennewick, 12 per cent basalt in their composition. The upper part is distinctly altered by weathering. Older gravel is also exposed in a pit four miles northeast of Pasco, 60 per cent basalt, all pebbles well rounded, overlain by Spokane gravel, 90 per cent basalt, with subangularity very prominent in its pebbles. Foreign pebbles, however, are well worn. The absence of a weathered zone in the older gravel at this place is due to stripping of the upper part by the glacial stream.

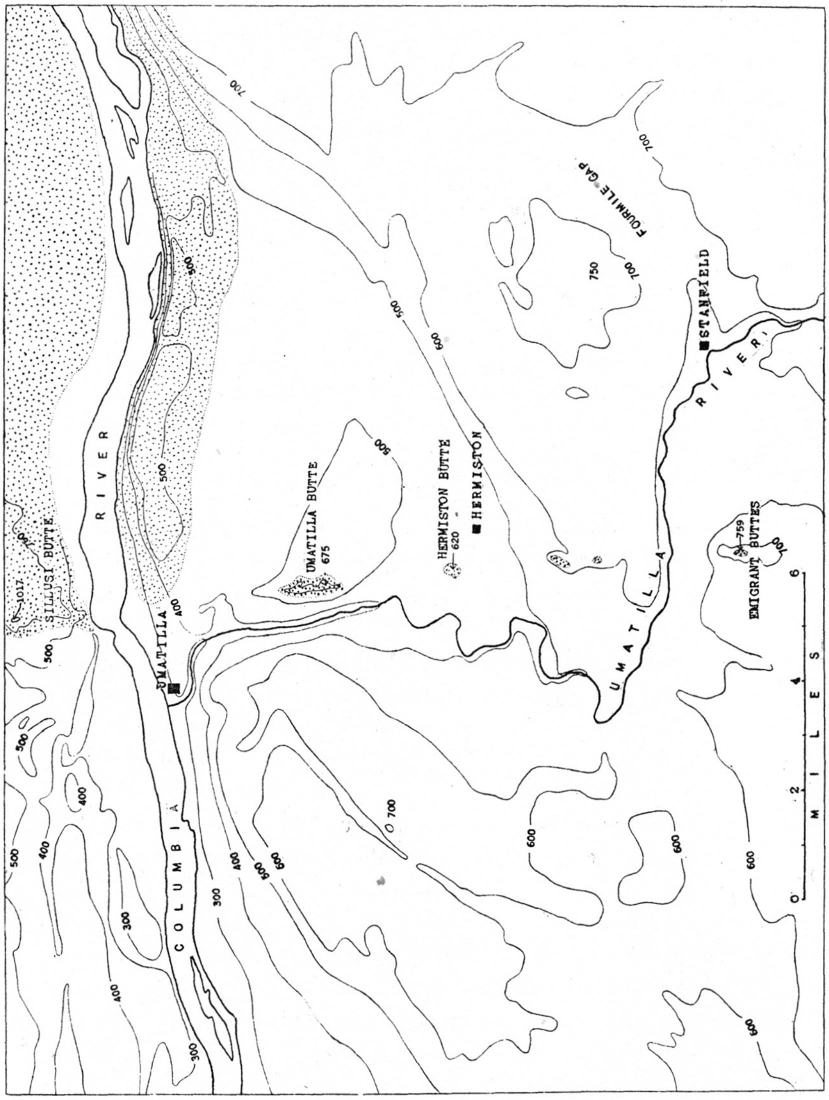

FIGURE 12.—*Part of Arlington, Oregon-Washington, Sheet, showing Vicinity of*

Entire area below 700 feet, except the stippled scabland tracts, is covered with gravel.

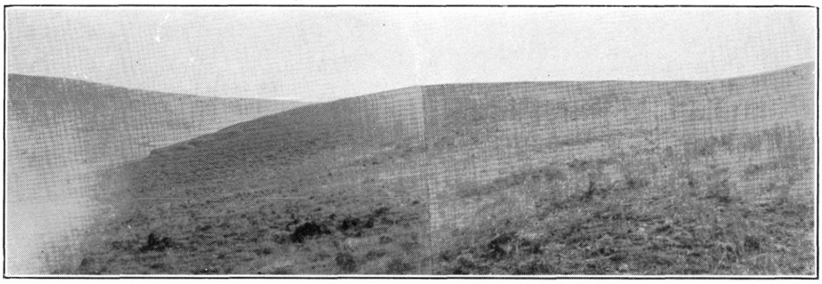

FIGURE 1.—PROFILE VIEW OF THE ARLINGTON BAR

Looking east. Columbia River to the left. Foreground shows the Columbia Valley slope on which the bar is built. Top of bar is 270 feet higher than the base and 400 feet above the river.

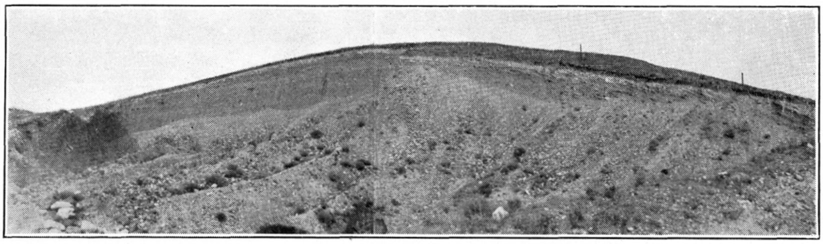

FIGURE 2.—SECTION IN THE ARLINGTON BAR

Looking south. Stratification is parallel with the curvature of the surface of the bar, except on west side, where foresets are steeper than the slope.

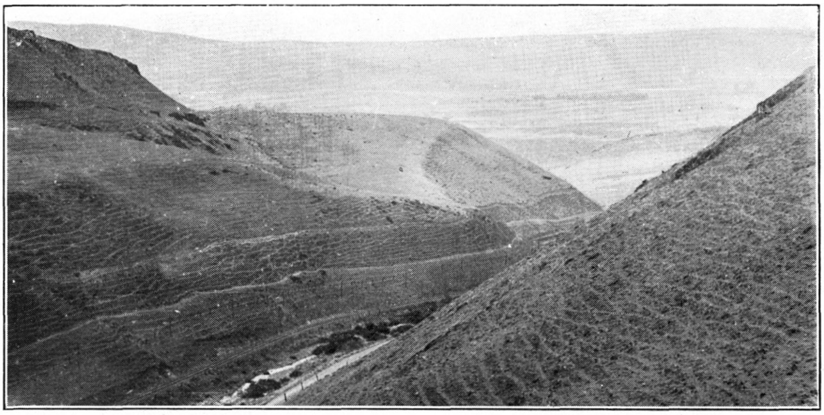

FIGURE 3.—TRENCHED BAR AT BIGGS STATION, OREGON

Looking north into Columbia Valley. Crest line of bar, transverse to the tributary valley, is shown; also the back slope into that valley and the steeper slope of the trench.

ARLINGTON AND BIGGS STATION BARS

gravel deposits 25 miles *up* the Snake from the mouth of Palouse River.

Between Emigrant Buttes and Columbia River are four different areas of scabland, so definitely marked by knobs, basins, and rugged bare rock and so clearly associated with the gravel deposits of this tract that origin is a glacially swollen Columbia can hardly be gainsaid. The gravel just north of Emigrant Buttes constitutes a broad hill elongated toward the southwest, 750 feet above tide (the Columbia surface is a little above 250 feet above tide) and 100 feet above Fourmile Gap, the empty channel to the east. A section on the western slope shows 18 inches of dust over a bluish gray "bright" gravel that is 86 per cent basalt. Columbia River gravel at the mouth of Umatilla River is 23 per cent basalt. The structure in the broad, low hill is foreset in many layers with the dip southwest away from the Columbia and toward Emigrant Buttes. The broad summit surface of this hill is diversified with elongate smaller hills of gravel. They rise gently from the northeast along their axes and descend more steeply southwestward at their termini. Their profiles suggest drumlins, which, of course, they are not. They surely are aggradational piles of gravel. There is no possibility of interpreting them as erosional remnants. They are simply bar flutings on the larger accumulation. This thick gravel mantle is wholly unterraced; it is traceable continuously from the belt of scabland south of the Columbia bluffs, at about 500 feet above tide, to its maximum altitude of 750. Two small areas of well-marked scabland project slightly above its western slopes.

Another and smaller bar of this character lies near the Columbia and a little west of the main mass of this bar. Umatilla Butte, which is well-marked, rises through the smaller bar. Still another bar, larger than either of these, lies west of Umatilla River, elongated northeast-southwest, and with a steep lee slope on the northwest side. Indeed, from Umatilla westward along the Columbia for seven miles the gravel of this lowland constitutes a conspicuous bluff, utterly without ravines or gullies, but marked by a succession of parallel longitudinal flutings, a series of ridges along the face of the bluff, each higher than the one to the north. Even larger and more striking longitudinal flutings in heavy gravel deposits are shown by the contours on the north side of the Columbia here. They lie to the lee of Sillusi Butte, a marked scabland form. Can these flutings be explained by any conception other than that of bars?

A few pits show fresh loose gravel beneath the wind-blown sand, 88 to 96 per cent basalt and local limestone.[21] The limestone pebbles and cobbles fall apart soon after excavation. A significant feature in one of these exposures is that about half of the basalt content consists of firm, unweathered, well-rolled pebbles and half of angular decayed fragments. This feature is duplicated in many other exposures throughout the plateau.

THE ARLINGTON BAR

Columbia River leaves the structural, bar-covered valley about 40 miles west of Umatilla and flows through a canyoned course for another 40 to 50 miles. In this part of its valley are numerous deeply trenched tributary canyons, two of them of major rank. Deposits of fresh, dominantly little worn basalt gravel occur at various altitudes in this canyoned portion. If they are remnants left by dissection of a once complete fill, they should be most extensive between the tributary mouths, not *in* them. If they are original deposits left by a very great flood and individually determined by local conditions, tributary mouths would be logical places for them.

A mile and a half east of Arlington, along the Columbia River Highway, is a large gravel mound lying on the valley wall. The mound is essentially an ellipsoidal segment of one base, the base being the 10 degree slope of the valley wall (see figure 1, plate 21). The slopes of the mound start at the upper edge at almost zero and, traced downhill through diverging directions, steepen consistently to a maximum of 27 degrees at the lowest edge. The height from the lowest edge to the highest is 270 feet. The river is 130 feet below the lowest edge.

A large pit in the lower part, just above the Columbia River Highway, shows the structure excellently (see figure 2, plate 21). The bedding conforms to the curved surface. There is no perspective error involved; the profile is curved and the stratification is curved. On the west (downstream) side the bedding contains short foresets which are steeper than the profile. The gravel is 99 per cent basalt and soft limestone, perhaps 20 per cent limestone. A large percentage of the basalt is subangular to nearly completely angular. Columbia River gravel directly below this bar is only 20 per cent basalt and has no limestone pebbles.

The large content of the basalt fragments, its unworn character, and the presence of much soft limestone, all indicate local derivation

[21] One pit, at Messner, has only 20 per cent basalt in a clean, somewhat indurated gravel with well-rolled pebbles. This is so similar to the older gravels near Kennewick and Pasco and in the Snake above the entrance of the flood that the explanation is apparent.

and very little travel. The form, structure, and location of the deposit are inexplicable by any other interpretation than the one used here. It is a very large side-channel river bar. Allowing 30 feet of water over the top of the bar, Columbia River was at least 300 feet deep when this bar was built. Assuming, also, that the valley had its present depth, the river was more than 400 feet deep, and it had a vigorous current.

BAR IN JONES CANYON

A shoulder bar, like a great embankment, projects westward from the upstream angle between Columbia Valley and Jones Canyon, a mile and a half west of Arlington. It originally completely blocked the mouth of this tributary. The deposit extends from 250 above tide (about 50 feet above the Columbia) to 670 feet above tide, a total height of 420 feet. The convex profiles are unlike anything in land forms sculptured from the Columbia basalt or the overlying gravel formation (commonly known as the "Dalles" formation), which is prominent from Arlington to The Dalles. The bar is compound, the larger, higher part not reaching out notably into Jones Canyon, but overlying a basalt ledge at this altitude. The lower part is twofold, the wider lobe being farther up Jones Canyon than the narrower, but both lobes originally completely filling the lower half mile of the canyon up to 400 feet above tide. This means a dam half a mile wide and nearly 150 feet deep.

The great embankment has been trenched through, the stream hugging the western wall of the preglacial tributary valley, but nevertheless leaving large portions of the fill on the west side. In trenching, the stream has been superimposed in one place on a basalt ledge and has cut a small gulch in it about 18 feet deep. The constructional slopes of the bar are strikingly different from the slopes made by the trenching. The steepest bar slope, 23 degrees, is on the back side, facing Jones Canyon. The trench slopes are between 30 and 37 degrees. Upstream from the trench the floor of Jones Canyon is wide and flat and has terraces 30 to 50 feet high.

The material of the bar is not well displayed. A few gullies in the lower part show that it is mostly basaltic rubble of cobble and boulder dimensions. More than 99 per cent by volume is basalt and at least 80 per cent by number of fragments is basalt. Dense green siliceous pebbles, so characteristic of "The Dalles" gravel, and pebbles of holocrystallines, abundant in Columbia River gravel, but not found in the overlying gravel formation, are both present. There are very few limestone fragments.

The Jones Canyon bar is the greatest feature of its class yet described. Its form is splendidly preserved. Its relations to older and younger topographic slopes are very clear. Its composition is typical. A visitor should go up the secondary road just west of the mouth of the canyon. From this road the full height, the dependence from basalt ledges, the blocking of Jones Canyon, and the postglacial trenching are diagrammatically clear.

"THE NARROWS"

Probably the most remarkable unit record of the Spokane Flood yet known lies one to two miles south of Columbia River, on the west edge

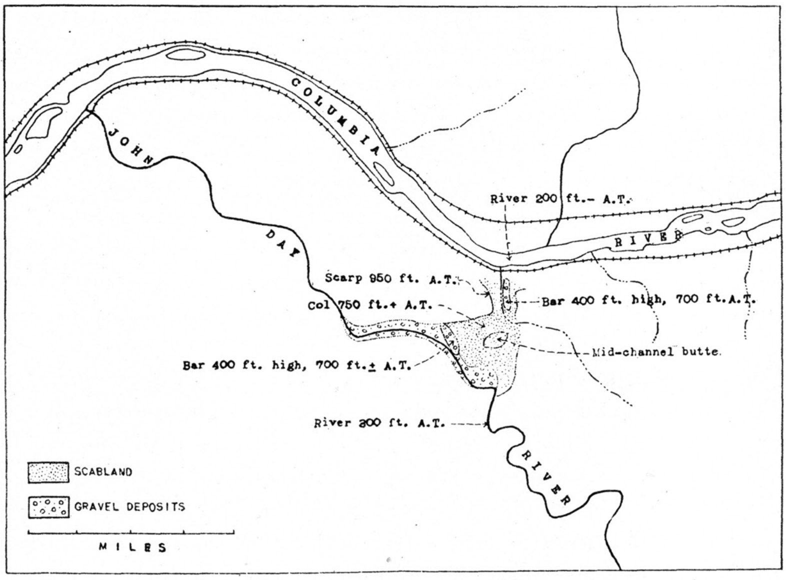

FIGURE 13.—*Sketch Map of "The Narrows" and Vicinity*

of the Arlington sheet. Unfortunately, an important part of it lies just off the map and the scale and contour interval are inadequate to show the mapped portion well.

John Day River, in a canyon 700 to 800 feet deep, approaches Columbia River from the south at an angle of 70 degrees until less than two miles distant. At this point the course of the Columbia's canyon swings essentially parallel to that of the John Day and the two canyons continue side by side separated by a narrow divide 900 to 1,000 feet above the Columbia, for nine miles farther down the stream (see figure 13). The upland back from the precipitous basalt walls of both canyons is deeply covered with "The Dalles" formation. Its surface is entirely in the smooth-flowing slopes of maturity, the appearance being very similar to the mature topography of the plateau in Washington. This mature topography ranges from about 1,000 feet above tide to the summit, 1,200

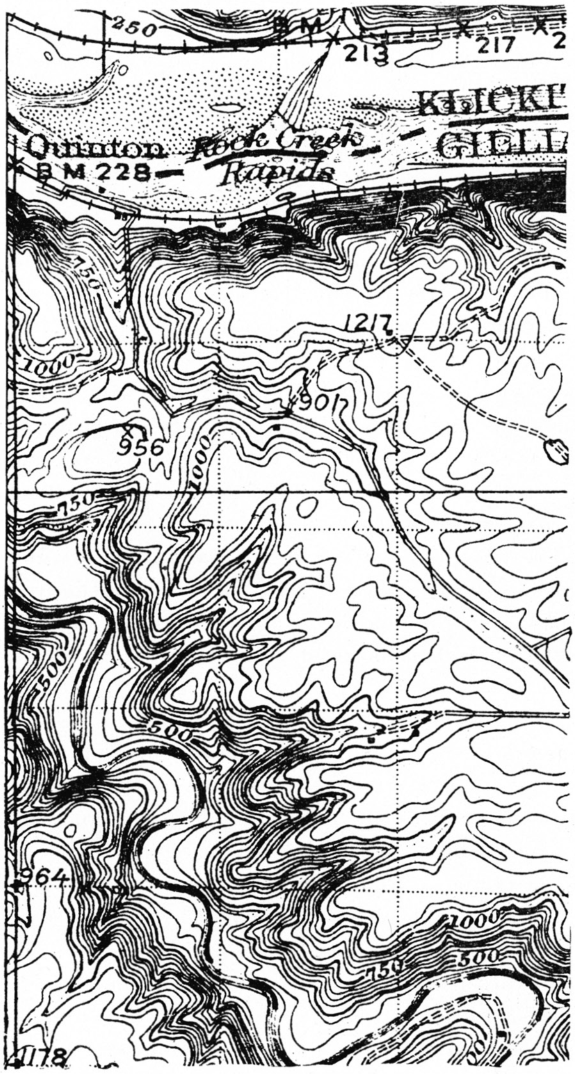

FIGURE 14.—*Part of Arlington, Oregon-Washington, Sheet, showing Vicinity of "The Narrows"*

feet, in this district. Below it are the steeper slopes and the cliffs of the two canyons and their tributaries. The narrow divide between the canyons carries this rolling topography on its summit also.

Almost bisecting the 70-degree angle between John Day River and Columbia River is a small tributary, only six miles long. It turns northward and enters the Columbia at the eastern base of the narrow divide, descending 950 feet in its total length, 550 of this in the last mile (see figure 14). There is an equally short distance and almost equally steep grade to the John Day at this northward turn in the tributary.

In the mouth of the canyoned lower mile of this tributary and on the east side is a bar whose symmetry is almost ideal and whose magnitude equals that of the Jones Canyon bar (see figures 1 and 2, plate 22). The base of this bar is 300 feet above tide, a little more than 100 feet above the Columbia. The summit is 700 feet above tide, 400 feet higher. It is all one simple constructional form. The elongate summit stands out from the east side of the canyon, parallel with it, and separated from it by a fosse about 30 feet deep. The total length of the bar is about half a mile.

Above and back of the bar the tributary valley floor is largely on rock, although there has been some filling here. The tributary now spills to the Columbia over a rock lip on the west side of its canyon. It has been forced over here by the presence of the bar. The tributary valley floor back of the bar, however, has some other features that are utterly astounding. The low place, or col, in the base of the divide spur, shown on the Arlington sheet, is amazingly wild scabland (figure 2, plate 23). The basalt has been channeled over a vertical range of 200 feet. There are cliffs 100 feet high, a maze of rock basins, vertically walled castellated buttes, a great cascade chute descending to the John Day Canyon, and a huge mid-channel butte whose summit flat is half a mile long, a quarter of a mile wide, 950 feet above tide, 100 feet above the eastern part of the channel and 200 feet above the northern part (figure 14). Its summit is swept clean of "The Dalles" gravel and roughened with bare basalt knobs 5 to 20 feet high.

The cascade chute in the northern channel descends from 750 to about 500 feet above tide down the wall of John Day Canyon. At its terminus is an enormous bar, *in John Day Canyon,* nearly a mile long, approximately half as high as the canyon is deep, approximately as high as the *head* of the cascade chute. On the side toward John Day River this bar presents an unbroken, unfurrowed front so steep that "trickles" of loose gravel are visible from a distance of a mile. This slope reaches essentially to river level, about 400 feet below the crest. The elongate crest of the bar is at right angles to the course of the cascade chute. It is not level; it is highest near the middle and descends in beautiful

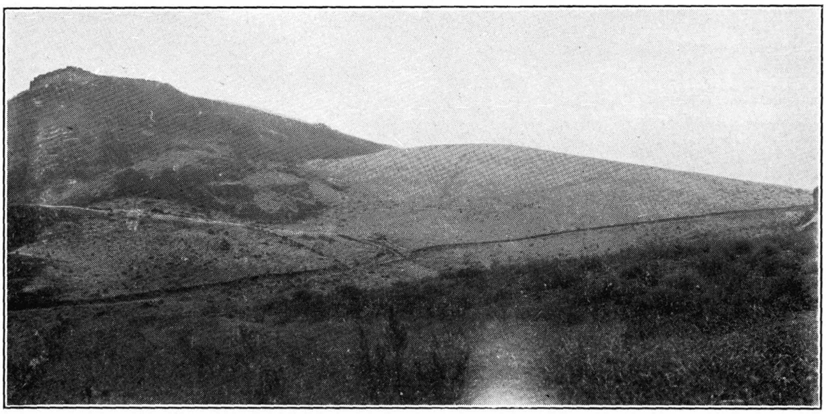

FIGURE 1.—BAR ON THE COLUMBIA END OF "THE NARROWS"

Looking southeast. View from near bottom of valley and camera tilted considerably. Crest of bar is 400 feet above its base. Photograph by L. C. Robinson.

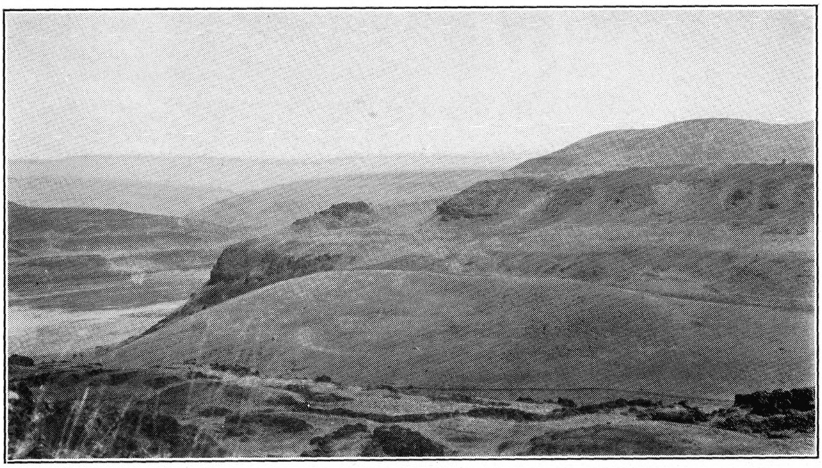

FIGURE 2.—BAR ON THE COLUMBIA END OF "THE NARROWS"

Looking northeast. Isolated crag above highest point of bar is the one on the skyline in figure 1. Note fosse east of the bar and scarp in Dalles formation above highest scabland in the background. Full length of valleyward slope of bar not shown. Summit of bar is 250 feet below the observer. Photograph by L. C. Robinson.

COLUMBIA BAR AT THE NARROWS

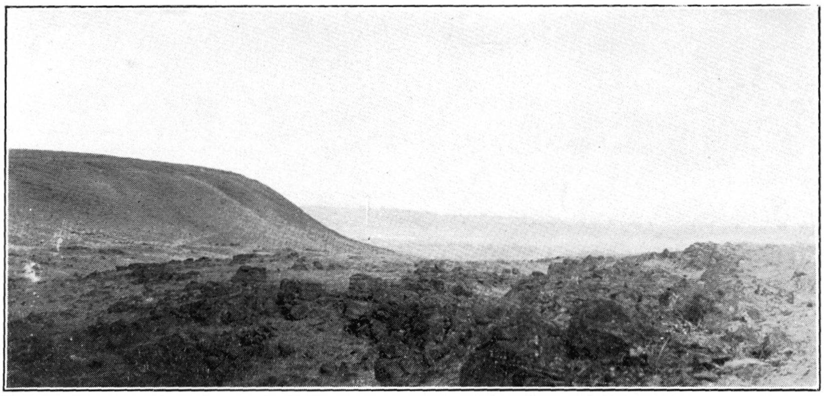

FIGURE 1.—UPPER LIMIT OF "THE NARROWS" DIVERGENCE

West side of the notch, looking north into Columbia Valley. Scabland about 750 feet above the river. Scarp in Dalles gravel 150 feet high and with 35-degree slope. Photograph by L. C. Robinson.

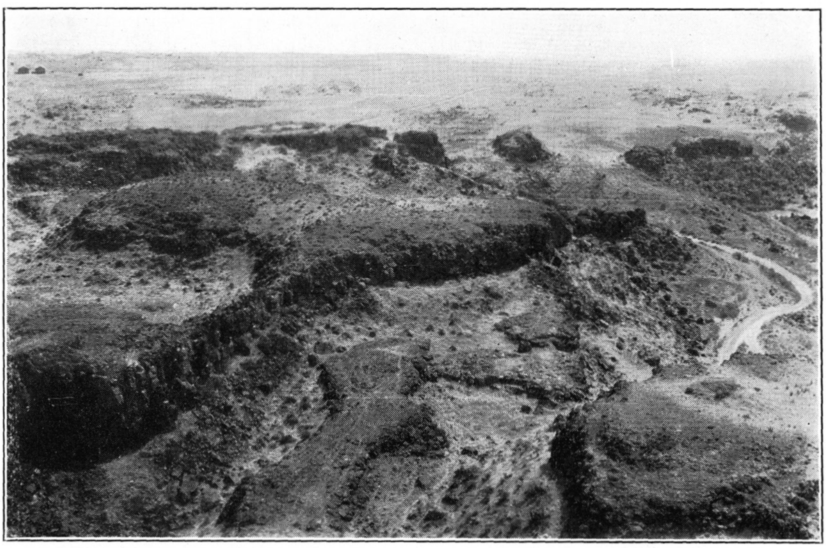

FIGURE 2.—SCABLAND OF "THE NARROWS"

About 100 feet below the scabland shown in figure 1. Irregularity of the small buttes and basins well shown. Photograph by L. C. Robinson.

SCABLAND OF THE NARROWS

curves toward both termini. In transverse profile the central higher part has the steep lee slope toward the John Day, descending from the very summit, but near both termini the summit slope descends gently for some distance past the crest before breaking off in the steep lee face.

This bar is limited to the mouth of the north channel canyon. The south channel, without a cascade chute, has a bar at its mouth, but it lies at the bottom of the 450-foot cliff, spread out on the floor of John Day Canyon, not built up in a great heap. The John Day has been

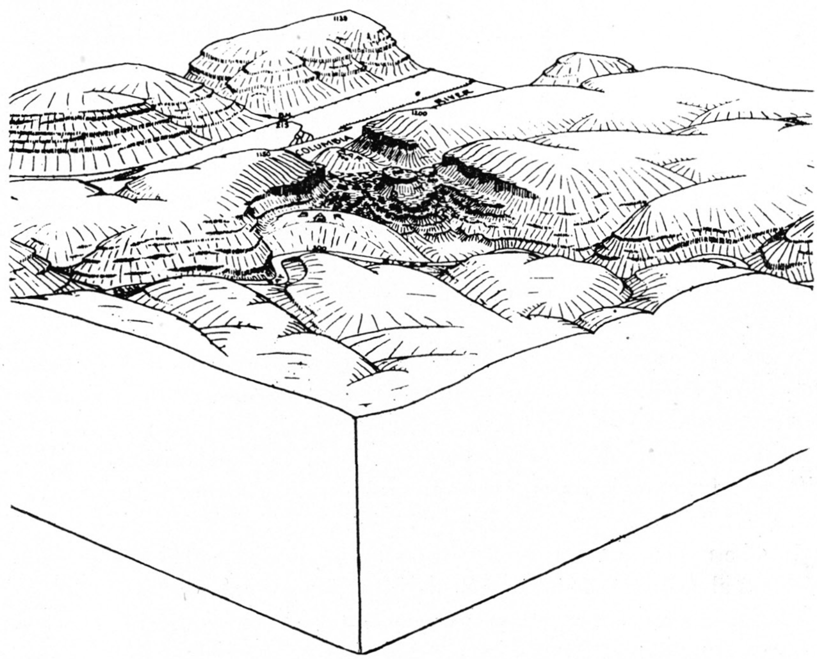

FIGURE 15.—*Block Diagram of "The Narrows" and Vicinity*
Drawn by J. R. Van Pelt, Jr.

pushed out of its normal looping course and back on to an abandoned slip-off slope by this bar. For a mile and a half down the John Day Valley below these bars there are fragmentary terraces of fresh basaltic gravel 40 feet and more above the stream.

The flowing contours of maturity developed in "The Dalles" gravel mark the entire region here above 950 feet, except where facing this wonderfully displayed scabland spillway. Here the old gravel stands in 25 to 30-degree scarps 100 to 150 feet high. In relation to older topography and to scabland at their base, they are identical with those on the plateau in Washington.

This truly remarkable group of features is known locally as "The Narrows." Seen from a viewpoint five miles to the west, on the plateau, "The Narrows" appear as a very definite black, jagged notch, subtending about 10 degrees of a horizon which elsewhere shows only the smooth flowing slopes of the mature upland topography.

Summarizing, "The Narrows" presents the features and demands the direct conclusions listed below:

1. A channeled scabland canyon, two miles long and less than a mile wide, cut as a notch across the summit of the divide between the Columbia and John Day rivers, nine miles above the junction of the two streams.

2. Gravel scarps, aligned along this scabland and 150 feet high, wholly unlike any other topographic slopes in the formation.

3. The eroding stream which crossed the divide, leaving Columbia Canyon and entering John Day Canyon.

4. A deposit by Columbia River waters just before entering the channeled scabland, lying inside the curve of the diverging current from the Columbia, 400 feet thick, but its summit 50 feet *below* the floor of the col.

5. Deposits made at the debouchure of the two channels from the floor of the notch over into John Day Canyon, one of them a nearly perfect bar form 400 feet thick.

6. The topographic forms, both erosional and depositional, wholly different from other land forms in John Day Canyon, both upstream and downstream as far as the eye can see.

7. The upper limit of the eroding stream at least 950 feet above tide, 750 feet above the Columbia and 650 feet above the John Day.

8. The floor of this channel canyon 550 feet above the present level of the Columbia.

9. The erosion performed by plucking, leaving vertical cliffs and rock basins.

10. *Surface* of the stream certainly not descending with the slope of the cascade chute; water surely over the top of the great bar in John Day Canyon, 400 feet above the present level.

11. John Day Canyon above the entrance of this divergence without any suggestion of such conditions farther upstream, yet its bottom now partially clogged with the bar débris; hence as deep then as now; hence the Columbia Canyon as deep then as now.

12. Water in Columbia Canyon, then 750 feet deep when the upper limit was reached.

FIGURE 1.—BAR AT FAIRBANKS STATION, OREGON

Looking west, down Fifteen-mile Valley. Slopes on left and extreme right (skyline) and flat in foreground constitute the profile of the preglacial valley. Into this the bar projects from the north, nearly closing the valley. Bar top is 200 feet above the valley floor.

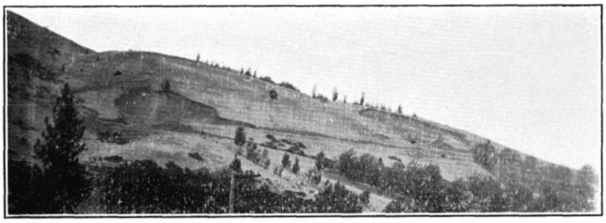

FIGURE 2.—BAR NEAR MOSIER, OREGON

Looking eastward. The bar is a side-hill mound built on the older slope. Only the frontal slopes of the bar are shown. Viewpoint is too low to show the top and the channel back of it.

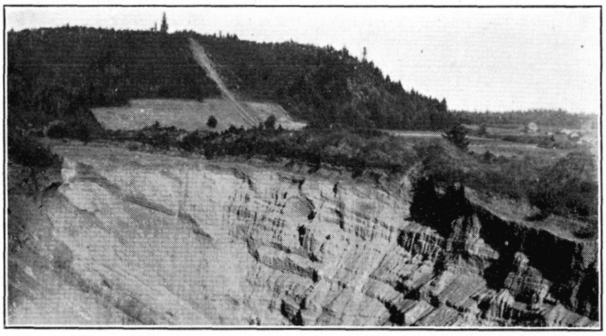

FIGURE 3.—SECTION IN BAR WEST OF ROCKY BUTTE, PORTLAND, OREGON

The pit is 60 feet deep. Forest bedding dips southward and southeastward. Channel around south end of Rocky Butte on the right in the background.

BARS AT FAIRBANKS STATION, MOSIER, AND ROCKY BUTTE

13. Yet the *surface* of this enormously deep river descending sufficiently in nine miles to allow "The Narrows" divergence enough gradient to erode the striking forms now exhibited.

The explanation of this extraordinary group of scabland features—scarps, channel canyons, bars—so utterly unlike anything about them, will never be found in the events which produced John Day Canyon, Columbia Canyon, or any of the smaller valleys of the region. The group is aberrant, abnormal, almost impossible. The writer anticipates that some readers have by now decided that the observation must be in error.[22] If correctly observed and reported, the group records aberrant, abnormal, almost impossible conditions. And there is only one combination of such almost impossibly abnormal conditions which, the writer believes, will explain it. There was a Spokane flood.

BARS AT BIGGS AND RUFUS STATIONS

Deposits of basaltic gravel and rubble in mouths of tributary gulches and on the irregular canyon walls are abundant in the vicinity of these stations. At Biggs Station (altitude 169 feet above tide) two bars are in view from the highway. The west one is not conspicuous when seen from below. It extends up to 550 feet above tide. Associated scabland knobs are identifiable up to 680 feet above tide. The water probably was higher, but the topographic evidence is not very definite here. The bar has 92 per cent basalt; most of the pebbles angular or subangular, though the foreign pebbles are well rolled. Columbia River gravel at Biggs has 50 per cent basalt. Foreset bedding in the bar is prominent and the dip is toward the wall, away from the open Columbia Valley.

The larger bar at Biggs lies in the mouth of a deep tributary valley, the one followed by the branch railroad to Shaniko. It is a fine embankment thrown eastward into the creek valley, thus pointing *up* the Columbia. Its summit is 520 feet above tide. The creek has cut away its terminus and if it ever completely crossed the valley the evidence has been destroyed. Figure 3, plate 21, shows the back slope toward the creek and a portion of a heavy veneer bar still farther up the valley.

At Rufus (altitude, 179 feet above tide) there are also two bars. One lies back in the mouth of the eastern of two gulches which enter here, on the west wall of this gulch and 560 feet above tide. The other is plainly seen from the station and is a very good example of a bar em-

[22] This can be checked easily. There is a good road up from Quinton, on the Columbia River Highway. An hour will be adequate to see the entire group and to make most of the measurements.

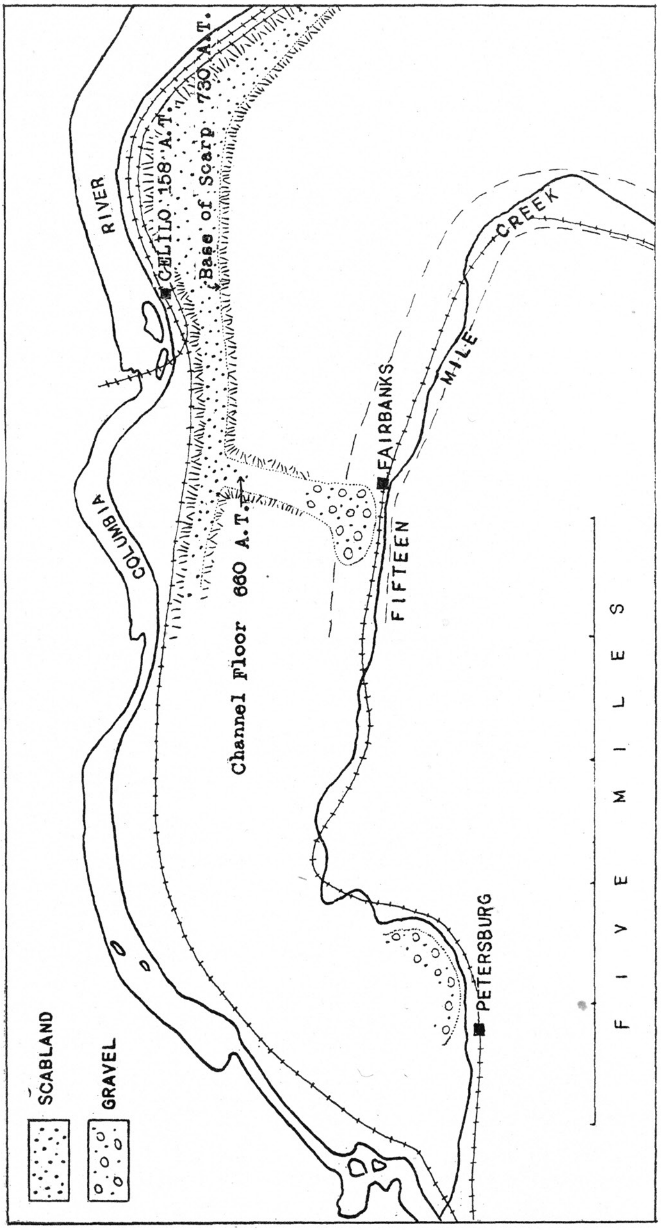

FIGURE 16.—*Sketch Map of Vicinity of Fairbanks Station, Oregon*

bankment built completely across the canyon mouth. It has been trenched near mid-length, but both termini are well preserved. The trench through it is 300 feet deep, all in the typical basalt waste of these features. The summit altitude is 665 feet above tide. The former existence of a complete barrier across a tributary mouth is more plainly seen here than at any other place known in the region.

BAR IN THE MOUTH OF DES CHUTES CANYON

A large bar lies in the mouth of this valley, against the west wall. Its base is 165 feet above tide, essentially at river level, and its rather flat summit is 455 feet above tide—a total thickness of 290 feet. There are several good exposures in recent gullies. They tell the familiar story of dominantly little-worn basalt material torn off the scabland walls. The bar is not conspicuous, for its slopes are not characteristic and it has several rocky knobs protruding through it. It probably is a shallow affair deposited on a rugged slope and not completely burying that slope.

BARS IN THE VALLEY OF FIFTEEN-MILE CREEK

This creek enters the Columbia about 5 miles east of The Dalles. Its course for 8 to 10 miles above its entrance is similar to that of John Day River—closely paralleling the Columbia, only a mile or two distant and with a high ridge between the two. In similar fashion, also, the flooded Columbia broke across the narrow divide, in this case in two places, and poured the débris eroded from the notches back into the tributary valley. The two bars thus built are at Petersburg and at Fairbanks (see figure 16). The Fairbanks bar and notch will be described.

Fifteen-mile Creek is one of the larger creeks of the extreme western part of the plateau, having a drainage area of about 240 square miles. It has a valley flat for much of its lower length, that flat being a quarter of a mile wide just east of Fairbanks. Immediately west of this station, however, the valley flat disappears and the creek enters a short, narrow valley close to the southern slopes, walled with a gravel cliff 150 feet high on the north and with lower basalt cliffs on the south. There are no basalt cliffs elsewhere in the vicinity.

This gravel cliff is stream-cut in the southern terminus of a great dam, or almost a dam, that projects out from the northern wall of the valley. Its total height is 200 feet above the valley flat. Its structure, exposed in a railroad cut, consists of long foresets, like those of a delta. They dip southeastward *up* Fifteen-mile Creek, parallel with the slope of the deposit. The surface of the gravel deposit has broad flutings and moundings on it. It is not a delta top, though in form the entire deposit looks like a delta.

The material of the deposit is 84 per cent basalt, the cobbles and boulders all of basalt. The nonbasalt pebbles are the typical materials of "The Dalles" gravel formation; not a true granular quartzite, not a granite, hardly a holocrystalline found. Columbia River gravel has plenty of granite and granular quartzite.

At the north end of this huge pile in Fifteen-mile Valley is a splendid clean-cut notch through the divide, leading south from the uppermost scabland ledges which overlook the Columbia. Its scarps in "The Dalles" gravel are 200 feet high. There is a closed basin in the bottom of the notch 40 feet lower than the channel head and 20 feet lower than the gravel deposit at the mouth. Scabland of the Columbia ledges extends a little way into the notch.

A road from Fairbanks Station traverses the notch and extends along the uppermost ledge of basalt eastward to the mouth of the Des Chutes. The ledge is 500 to 1,000 feet wide and most of it is very good scabland, with buttes, rock basins, gravel mounds, and mound-inclosed basins, all ranging through an immediate relief of 30 to 40 feet. The south edge of this rock terrace is margined by cliffs of "The Dalles" gravel, which stand 75 to 100 feet high, with 30 to 35-degree slopes, as good an old river bank as anything in the loess scarps of the plateau. The base of these scarps two miles east of the notch is approximately 730 feet above tide, nearly 600 feet above the Columbia. The channel floor leading to the Fairbanks bar is 660 feet above tide and the top of the bar is but little lower.

Only about half of the 200-foot depth of the notch was cut by the glacial stream. A preglacial saddle existed here, deep enough to contain the glacial spill southward and to prevent it from entering the head of a small south-flowing tributary of Fifteen-mile Creek just west of the bar. Had the surface of the glacial flood been up to 760 here, this tributary head would have been entered.

Not much of the débris of the Fairbanks bar could have come from the erosion of this channel notch. The volume of the deposit much exceeds the prism removed in making the notch. Most of the bar material must have been swept into the divergence from the basalt ledge and its gravel scarps.

There is no need to organize the argument from the Fairbanks notch and bar. Except for numerical values, it is essentially the same as that for "The Narrows." For water to pour through this notch from the

Columbia, as it assuredly did, the level in the Columbia must have been up to 700 feet above tide at least. For this deltaic bar to have been built on the flood plain of Fifteen-mile Creek, the tributary must have been essentially as deep as now. The main valley, therefore, was equally deep and the flood in Columbia Valley north of Fairbanks was at least 600 feet deep.

Another bar in the valley of Fifteen-mile Creek lies a little east of Petersburg, or about five miles farther down the valley. Its frontal slope has an inclination of 34 degrees and extends about a mile along the valley. Three pits in it all show south-dipping deltaic foresets. Its material is 86 per cent basalt. Cobbles and boulders are far more abundant here than in the Fairbanks bar and are all of basalt. The height of the frontal slope probably does not exceed 100 feet. The Petersburg bar was examined only along the road and can not yet supply information on the upper limits of the Spokane flood. It may be the result of a complete oversweeping of the western terminus of the divide.

THE MOSIER BAR

The last bar to be described in this paper, except the Portland Delta and its barlike features, lies on the east side of Mosier Creek Valley, near the mouth. The town of Mosier, at the mouth, is about 15 miles west of The Dalles and in the folded Cascade Range. The creek valley is incised approximately in the floor of a syncline, which, like those farther east on the plateau, is a topographic as well as a structural feature. The lower height of cliffs margining the Columbia near Mosier is due to the syncline. They were low enough to allow flood water to spill back across the upstream angle between the river and the creek, and to build a bar on the creek valley wall.

The mounded form of the deposit is definite (see figure 2, plate 24). The frontal slope is 28 degrees and in the exposures is paralleled by long foresets. The bar is lobed and some foresets, therefore, dip up Mosier Creek Valley and some down. Ninety per cent of the débris is basalt. A feature not found in any bars thus far described is the notable amount of decay in the worn cobbles and pebbles. The alteration clearly occurred after the pebbles were formed, and hence is not the same thing as that noted near the mouth of Umatilla River; yet the alteration clearly preceded the building of the bar, for the finer material is composed largely of angular chips of weathered rock broken from the decayed cobbles in transit, and pebbles of fresh basalt are scattered here and there through the deposit. This feature becomes explicable when the summit of the basalt shoulder between the Columbia and Mosier

Creek is examined. It carries the old gravel, called "Satsop" by Williams [23] and by the writer,[24] but recently rechristened the Hood River formation by J. P. Buwalda.[25] Most of the constituents of this deposit are considerably decayed and in this condition were torn out and thrown over the brink of Mosier Creek Valley in the building of this bar. The

FIGURE 17.—*Sketch Map of the Portland Delta, Oregon-Washington*

Contours generalized from the Portland, Oregon City, Boring, and Troutdale sheets of the United States Geological Survey. For the sake of graphic portrayal, culture and drainage are omitted. Scale is indicated and cultural features may be located by the township corners.

[23] Ira A. Williams: The Columbia River gorge. Mineral Resources of Oregon, vol. 2, no. 3, 1916.

[24] J. H. Bretz: The Satsop formation of Oregon and Washington. Journal of Geology, vol. 35, 1917, p. 446.

[25] J. P. Buwalda: Age of the "Satsop" and The Dalles formations of Oregon and Washington. Science, vol. 66, 1927, p. 236.

bar is 250 feet high. Its summit is 470 feet above tide, about 375 feet above the Columbia.

The Portland Delta

This feature has already been briefly described by the writer in two previous papers.[26] Revised interpretations contained in the later paper considered the delta to be wholly a subfluvial deposit. This conclusion seems amply sustained by more recent study.

The delta (figure 17) consists really of two groups of large bars separated by Columbia River. The highest bars stand 350 feet above the Columbia. The broad channel of the river between the two parts of the delta is here interpreted as essentially the Spokane Flood channel, not as a product of later dissection. Two prominent abandoned channels, each about 100 feet deep, lie on the delta top, their floors about 200 feet above the present river surface. Several rock islands stand in the deposit and their presence greatly influenced the growth of the bars.

There are four prominent bars on the Oregon part of the Portland Delta. One is in the lee of a high rock shoulder (Chamberlain Hill) at the head of the delta, one lies in the extreme southern lobe of the delta, in the mouth of Willamette River Valley, one is upstream from a group of three rock hills standing well out in the delta, and one extends nine miles westward, in the lee of the northernmost of these three hills. A study of figure 17 and the four topographic maps which portray the Oregon portion of the delta will promptly show how hopeless is any attempt to explain the surface contours of this deposit by the hypothesis of post-depositional stream erosion. The gravel is so porous that only a very few streamways have developed. All streams from higher land to the south avoid the delta, the most conspicuous case being the one which skirts the southern edge (Johnson Creek). The only prominent marks of running water on the deposit are those left by the great glacial river, and their pattern is largely controlled by the rock islands.

Hundreds of exposures of the delta material have been examined, not one of which fails to show foreset bedding. In most of them the only structures present are foreset. No topsets have been found. The direction of foreset plunge varies exactly as it should by the favored hypothesis. The easternmost bar is an eddy deposit, the southernmost bar was built southward into open standing water, and the fourth bar

[26] J. H. Bretz: The Late Pleistocene Submergence in the Columbia Valley of Oregon and Washington. Journal of Geology, vol. 27, 1918, p. 489.

J. H. Bretz: The Spokane Flood beyond the channeled scablands. Journal of Geology, vol. 33, 1925, pp. 97-115 and 236-259.

enumerated has a remarkable structure that admits of but one interpretation. It has a gentle northward slope toward the Columbia and a steep southern slope away from this deep main channel. The steep slope is better shown by the 25-foot contour interval of the Portland sheet. Everywhere in this slope the foresets dip directly transverse to the length of the bar and directly away from the Columbia in the main channel. Indeed, close to the southern end of the rocky hill which determined the location of this bar (Rocky Butte) the foresets dip southeast as well as south, toward a closed depression at the foot of the lee slope (see figure 3, plate 24). A pit here, 60 feet deep, shows this very well. The gentle northward slope of this bar was the subfluvial upgrade of this part of the glacial river bed and its steep southward slope was the lee face, the growing face.

Fully as remarkable a feature is the relation to this rock hill of the broad bar which lies upstream. A deep fosse separates them. The hill was more exposed than any other to the glacial river current and a huge upstream eddy maintained the fosse. Water deflected southward was divided into two strands around another rock hill (Mount Tabor). The summit of the bar nearest the hill was shaped by the deflected current and directed southward, transverse to the general downstream direction. Foreset beds support this topographic interpretation of the course of bottom currents. The elongated depression between the lee bar of Rocky Butte and the deflected current around the south end of the butte is not a true channel. It has resulted from southward growth of the bar over onto earlier slopes of the delta.

The riverward slope of the Oregon portions of the delta carries almost no gullies or ravines. Instead, it is diversified almost exactly as is the similar riverward face of the great gravel deposit west of Umatilla. There are linear ridges and troughs transverse to the direction of the slope and successively higher southward. They are minor bar flutings.

The composition of the delta in Oregon varies with location. A large part of the underlying material is the Satsop gravel formation, and the higher land south of the eddy bar in the eastern part of the delta is on Satsop. Much débris in this part of the delta came from the underlying older gravel. Such pebbles and cobbles are decayed throughout and crack spheroidally with ease. Many are already checked on the outside, ready to fall apart at a blow. They have not decayed in place, as shown by the freshness of much associated basaltic débris and the slight staining of the deposit as a whole. This condition of the deposit is identical with that in the Mosier bar. In most places in the Portland Delta in both Oregon and Washington there is an upper zone of iron-stained material about four feet thick. Basalt pebbles with thin grayish decayed rinds, but with glistening black cores, are found as deep as six feet. At greater depths the non-Satsop material is apparently as fresh as when deposited. The material at all altitudes in the gentle northward slope of the lee bar of Rocky Butte shows the typical alteration of Portland Delta gravel.[27] There is perhaps a greater depth of iron oxide staining in the lower slopes, but the gravel certainly is not Satsop in age and it surely is not postdelta. This slope is original with the deposit.

The Washington portion of the delta has a slightly larger area. On it occur one great bar about 12 miles long, numerous prominent bars a quarter of a mile to a mile and a half long, and hundreds of minor ridges. The great bar lies in the lee of the large rock hill (Prune Hill) near the head of the delta and extends northwestward between the main channel and the large abandoned channel which bisects this portion of the delta. It descends throughout its length from more than 300 feet to 200 feet above tide. The smaller bars that show on the map lie in the angle between two distributary courses of the abandoned channel in the northwest part of the delta. Some of them are as high as the great bar. As pointed out in a previous paper,[28] these bars are very curious features that look more like prominent eskers than anything else. The foreset bedding in the only bar adequately sectioned is essentially transverse to the length of the bar and dips northward. The sags among the bars contain swamps and lakelets. These bars were built up where they stand. If erosional in any part, that erosion was not by post-Spokane run-off.

The minor bars, too small and far too numerous to show on the map, literally cover the flattish surfaces of the delta between the two distributary courses noted. With only very minor exceptions, there is not a slope on this part of the delta that is not bar-determined. The prevailing orientation of these is northwest-southeast. Many of the associated minor sags are closed depressions.

There is a gentle eastward descent of the surface of the delta close to the higher land on the east. Streams entering from this higher land avoid the delta as they do in Oregon. There are only three stream-eroded valleys more than a mile long in the Washington part of the delta. Salmon Creek, north of the delta as mapped, apparently

[27] Because of greater rainfall west of the Cascade Range than east of it, the Portland Delta gravel is more decayed than the bar deposits on the plateau.

[28] J H. Bretz: The Spokane flood beyond the channeled scablands. Journal of Geology, vol 33, 1925, pp. 97-115, 236-259.

has no recognizable portions of this deposit north of it. The plain lying farther north (not shown in figure 17) is underlain by the Satsop formation, whose gravel is decayed to depths as great as 50 feet. It carries a silt cover with a known maximum of 20 feet which may be contemporaneous with the delta building. As in the Willamette Valley south of the Oregon part of the delta, the characteristic topography, structure, and composition ends with the limits shown. There is a gradation northward from gravel to sand in the Washington portions of the delta.

The Satsop formation underlies most of the delta north of the river and outcrops extensively at the mouth of the gorge, just above the delta. Similar to the situation on the Oregon side, the bars nearest the head of the delta have the mingling of old weathered pebbles and fresh bright pebbles of the same kind of rocks. This is true through a vertical range of 100 feet in these bars. In one exposure a boulder of the partially indurated Satsop two feet long is inclosed in the foreset delta gravel. The boulder has an abundance of quartzite pebbles characteristic of the Satsop and far more than in the delta material, and its matrix and basaltic pebbles are much more decayed. It could not have traveled far.

The upper limit of water over the Portland Delta is not definitely known. The highest bars in both Washington and Oregon reach a little above 350 feet above tide. The water was over them. But a saddle between Little Washougal River and a tributary of Lacamas Creek, 450 feet above tide, was not crossed. This, if used, would have been a direct route toward the northern edge of the delta. No lower saddles are known by which water could have escaped northward. No notches like those leading out of the Columbia to John Day River and to Fifteen-mile Creek have been found. The upper limit was somewhat above the highest bars, but not 100 feet above.

Conclusion

As stated in the introduction, the purpose of this paper is to show that the gravel deposits of channeled scabland are not interpretable as ordinary valley fill; and that, if they be interpreted as bars, very great streams must be dealt with and only one episode can be granted. The local origin of the débris has been pointed out repeatedly. The incorporation of decayed material into otherwise fresh material has been indicated. The presence of soft, almost incoherent, rock fragments in the deposits has been mentioned. The existence of clearly defined spillways out of preglacial valleys has been described. The meaning of these facts, when considered with the unique topographic forms, is obvious.

This paper covers only the more significant bar deposits of the region. There are slack-water deposits yet to be described; there are inter-relations among the channels to be set forth. There is an extraordinary relation between loessial scarps and the preglacial valley depths, only touched upon here, and an extraordinary limitation of these scarps to a definite *niveau*. There are new data concerning the glaciated plain north of the plateau scablands. There are significant items concerning the mechanics of erosion of basalt, and an adequate interpretation of the *ensemble* is still to be drawn up. The writer has not yet adjusted all items to a sequential series of events and has no satisfactory explanation for the cause of the hypothecated flood, but the argument for the hypothesis is not yet closed.

Ideas without precedent are generally looked on with disfavor and men are shocked if their conceptions of an orderly world are challenged. A hypothesis earnestly defended begets emotional reaction which may cloud the protagonist's view, but if such hypotheses outrage prevailing modes of thought the view of antagonists may also become fogged.

On the other hand, geology is plagued with extravagant ideas which spring from faulty observation and misinterpretation. They are worse than "outrageous hypotheses," for they lead nowhere. The writer's Spokane Flood hypothesis may belong to the latter class, but it can not be placed there unless errors of observation and direct inference are demonstrated. The writer insists that until then it should not be judged by the principles applicable to valley formation, for the scabland phenomena are the product of river channel mechanics. If this is in error, inherent disharmonies should establish the fact, and without adequate acquaintance with the region, this is the logical field for critics.