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ALTERNATIVE HYPOTHESES FOR CHANNELED SCABLAND. I

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ABSTRACT

This paper begins with a summary statement of the features of scabland and of the writer's explanation of their origin. In the body of the paper, various criticisms and suggestions are considered in the light of significant field data. Revision of some of the writer's ideas is indicated. The second half of the paper deals with the question of simultaneous development of all channels of the scabland pattern and with proposed tests of the writer's hypothesis.

Since 1923 the writer has published several papers describing the assemblage of exceedingly peculiar erosional and depositional forms found only on the Columbia Plateau in Washington and farther downstream along the Columbia Valley. In every paper he has urged that the only adequate explanation for this assemblage is a very great but very short-lived discharge of glacial water from the Cordilleran ice sheet. Since this interpretation is wholly without precedent in geological literature it has been received by many with considerable reservation. Since there seemed to be no possibility of producing such a flood by any known causes of glacial ablation, definite skepticism has arisen in some quarters. Had the writer's insistence ceased here, the matter might have rested at this stage, but continued assertion has evoked suggestions in print looking toward other explanations for the phenomena. This paper attempts to show to what extent the alternative explanations can be used. It is based largely on new data and new kinds of data collected during a subsequent field season.

A brief statement of the flood hypothesis and the nature of the evidence for it, as presented for criticism early in 1927, is here reprinted.[1]

That part of the Columbia Plateau which lies north of Snake River in Washington bears a remarkable system of erosional and depositional land forms. They are extraordinary in their magnitude, in their extent and distribution, and unique in their relationships. Running water is generally conceded to have caused them, but the unparalleled results indicate unparalleled conditions under which it acted.

The channeled scablands constitute the erosional part of the record. They cover almost 2,000 square miles, about one-sixth of the area of this part of the plateau. They are elongate tracts, oriented with the gentle dip slope of the underlying basalt flows, mostly bare rock or with a thin cover of coarse basaltic rubble, commonly with canyons in them, and are bounded by steep slopes of the deep loessial soil of the plateau. They constitute a curious anastomosing pattern, the down-dip convergences inherited from an earlier normal drainage pattern and the divergences, equally numerous, produced by crossing of divides of this older pattern. There are hundreds of tracts of the higher loess-covered areas in the scablands, from a fraction of a square mile to many townships in area, all discontinuous and bounded by the scabland areas. The steep marginal slopes in loess are in striking contrast to the gentle slopes of the older drainage pattern surviving within each isolated loessial tract. Canyons in the scablands are multiple and anastomosing, amazingly so in some tracts; deep canyons and shallow ones uniting and dividing in a labyrinthine fashion about bare rock knobs and buttes unlike any other land surfaces on the earth. Certainly but few of these canyons are inherited from the older pattern.

The scabland drainage was discharged from the northern glaciated portion of the plateau through ten openings into the loess-covered area and led thence by nearly one hundred different routes of varying lengths to nine discharge ways into Snake and Columbia rivers on the south and west. The canyon plexus is the most striking feature of the scablands and probably is most significant of conditions of origin. These canyons are interpreted as channels, not valleys, hence the term "channeled scabland."

The depositional land forms associated with channeled scabland are chiefly great mounded masses of little-worn basaltic gravel. They occur on the down-gradient side of eminences and in other protected places in the scablands, and in the Snake and Columbia valleys below the entrance of the scabland drainage

[1] From *Journal of the Washington Academy of Sciences*, Vol. XVII, No. 8 (April 19, 1927), pp. 200–203.

routes. They are not eroded forms, they possess aggradational slopes, and they inclose depressions or by their position aid in inclosing depressions between themselves and adjacent rock walls. All attempts to interpret them as dissected remnants of terraces or originally continuous gravel deposits have failed. They are gravel bars of huge size.

A brief summary concerning the more significant features and relationships follows.

Canyons of the scablands.—Largely channels of huge rivers, eroded during the Spokane epoch.

A. *Rock basins in the canyons.*—Thousands of them. Commonly elongate with the canyons, generally constituting the canyon floor. Lengths as great as 8 miles, depths as great as 200 feet. Some canyon floors essentially a series of rock basins. Formed by large vigorous streams plucking the columnar basalt. In no other way can most of these basins be explained. Some are potholes at the foot of extinct waterfalls.

B. *Plexus grouping of canyons.*—Occur on crossings of divides of the older drainage pattern, the four largest groups ranging from 6 to 10 miles wide. Developed subfluvially like the high-water anastomosing channels of the present Columbia at the Dalles. Alternative explanation demands a remarkably braided pattern of an eroding stream, with narrower strands in many cases cutting deeper than broader ones.

C. *Cataracts.*—Hundreds of extinct waterfalls, many of which during recession became wider, several 2–3 miles wide. Unless the record of very large streams, they should show the "horseshoe" concentration from any initially great width.

Areas surrounded by the channeled scabland tracts.—Residuals of a once continuous loessial cover, with maturely eroded drainage ways. One hundred to 200 feet of loess removed over large areas.

A. *Aligned scarps of loess facing the scablands.*—Slopes 30°–35°. The bluffs left by undercutting of streams whose width was that of the adjacent scabland, from $\frac{1}{2}$ to 15 miles. They truncate minor valleys of the older drainage pattern.

B. *Small isolated loessial hills on the scabland.*—Slopes as above indicated, with "prows" pointing up the scabland gradient. Some are miles from any other loess. Others, in groups, record abrupt introduction of a large volume of water which simultaneously entered several of the pre-Spokane drainage ways and eroded them to bed rock, leaving these remnants of the former divides.

Trenched divides —Several remarkable cases where a canyon plexus has three or four closely spaced rock-basined gashes 200–400 feet deep across a divide, yet only one case where one of them cut deeply enough to divert subsequent drainage. Water must have been 100–300 feet deep above preglacial valley bottoms on the north to have crossed. No piracy nor headward erosion nor local drainage has been responsible. Good evidence that no post-Spokane uplift has occurred in these places.

Deposits on the scabland and in Snake and Columbia valleys.—Discontinuous originally. Their features clearly record actual building of each individual deposit. Any explanation must start with this.

A. *Gravel chiefly.*—Pebbles little worn, 90–99 per cent basalt, unweathered.

B. *High deposits,* above brink of canyons 400 feet deep and at foot of loessial scarps, yet identical with other deposits down in the canyons.

C. *Bar forms,* undissected, foreset bedding conforming to slopes where required by this hypothesis. Associated depressions as much as 50 feet deep where vigorous eddies existed. Some bars, 20–100 feet high, blocked subsequent drainage.

D. *Deltaic bar,* 5 miles long and 200 feet thick in Snake and Tucannon valleys, with foresets dipping up these valleys from point of entrance of scabland stream. In striking contrast with Snake River gravels immediately upstream, which are in 60-foot terraces, dissected and with large alluvial fans built out on them, and are composed of 90–95 per cent non-basalt, well-rounded gravel.

E. *Quincy structural basin.*—More than fifteen townships covered with basaltic gravel in terrace-like and mesa-like forms. Channeled canyons tributary to and distributary from this settling basin. The forms, however, are bars, as field study has amply demonstrated. No interpretation as terraces will account for many significant relationships.

Anastomosis of entire scabland tract on the plateau.—Contemporaneous occupation of all scabland routes seems indicated. No evidence on glaciated tract of marginal drainage to supply, in turn, any one or two of ten entrances to the scabland during any conceivable shifting of ice edge. All channels seem to have headed on margin of the glaciated tract. Anastomosis due to the huge volume of glacial water and the abrupt introduction, thus flooding a multitude of minor drainage ways of the plateau and crossing a multitude of minor divides. Insufficient time for erosion of a few adequately capacious spillways. Debouchure into Snake and Columbia valleys at very different levels, indicating varying depth of different channel ways and a lowering water-level in these valleys during the discharge.

Wallula Gateway high-level scabland.—A short, narrow canyon south of junction of Snake and Columbia rivers, 20 miles from nearest plateau scabland. Yet with same features of subparallel lateral canyons, rock basins, knobs, and buttes as high on canyon walls as in the Snake and Columbia upstream. All scabland drainage passed through this canyon, and the flood reached 900 feet above present river bottom, perhaps 650 feet above canyon bottom at beginning of Spokane episode. Constriction here caused the ponding recorded in lower scabland tracts on plateau and made possible the plexus crossings of divides. Erosion of Gateway Canyon was rapid enough to lower the ponded waters while the scabland rivers were still running. No other conceivable cause of ponding is indicated elsewhere in the Columbia Valley below the plateau.

Columbia Valley below Wallula Gateway.—For 150 miles a descending series of scabland tracts and gravel deposits in Columbia Valley.

A. *Bars in mouths of tributaries.*—Basalt gravel, ranging in height up to 600 feet above the Columbia. Delta foresets which prevailingly dip back into tributary mouths.

B. *Portland delta,* area 200 square miles, foreset bedded throughout, basalt gravel, channels, and great bars, remarkable eddy depression on upstream side of a rock island in the delta.

There are many apparently possible alternative explanations for the remarkable features of the preceding list. Virtually every one of these, when applied, involves exceptional combinations of factors, and no one of them will explain more than one or two of the fifteen listed phenomena. Most of them have been tested in the field and rejected. These extraordinary features must be treated as a *genetic system.* Their assemblage on, and limitation to, this little corner of the globe cannot be coincidence, as required by alternative hypotheses. The only genetic interpretation yet proposed which is inherently harmonious and which fits all known facts is that of a great flood of water abruptly issuing from the Spokane ice sheet. The unfilled rock basins with gravel bars perched on their walls indicate abrupt cessation of this flood.

The cause of this Spokane flood is unknown. It may have been a *Jökullaup* or glacier flood produced by subglacial vulcanism, but this hypothesis must stand or fall on field data not yet secured.

Virtually all of the alternatives proposed for the scabland phenomena spring from a belief that the flood hypothesis is essentially impossible, and a product of too hasty observation and immature reflection. Every alternative implies that field evidence and criteria exist which have not yet been found and which, if recognized, would notably alter the character of the writer's explanation, or would eliminate it altogether. Only three of the alternatives are based on personal study of any part of the scablands, only five on personal knowledge of the region in general. A belief that the flood hypothesis is an outrage obviously has been the stimulus for most of these alternatives. Yet the alternative hypotheses are valuable; indeed, necessary. No notable departure from proved types of interpretation should be accepted until it has passed the test of vigorous adverse criticism of others. No one observer can be trusted to apply the alternatives with sufficient rigor, especially so if he be the author of the "outrageous hypothesis." In the following pages suggested errors in observation are taken up first and a discussion of alternative generalizations follows.

MARGINAL SCARPS IN WEAK MATERIALS ABOVE THE BASALT

A persistent feature of the margins of scabland spillways is the 30°–35° slope in weaker material overlying the basalt. These are distinctly steeper and definitely younger than other slopes in the overlying sediments. If they are banks or bluffs of the glacial streams, as the writer's hypothesis holds, they record the following extraordinary conditions:

1. *Depth of the streams.*—The bases of some of the scarps stand 400 feet above the floor of closely adjacent preglacial valleys that carried glacial rivers.

2. *Width of the streams.*—There are fairly plane, fairly level scabland tracts as much as 20 miles wide between some of the scarps, yet their bases are essentially at the same altitude.

3. *Surface gradient of these streams.*—Altitude of bases descends 15 feet per mile for 75 miles along one wide route, 29 feet per mile along 33 miles of one narrow canyoned route, and there are comparable descents along most other routes.

4. *Contemporaneous occupation of the spillways.*—One large route has ten divergences from it, from 3 to 50 miles from the ice front, the bases of these scarps at each divergence being successively lower and comparable to the altitude of scarp bases margining the main spillway at the place of departure.[1]

Only one alternative hypothesis has yet been proposed to the writer for these scarps. Dr. G. O. Smith[2] reports similar features in Yakima Valley west of the scabland where the relatively weak Ellensburg formation above the Columbia basalt has been eroded back from the brink of basalt cliffs by wind and rain-wash, to produce a scarp overlooking bare rock above the cliff. This is the relation in many places in the scablands and gives plausibility to the suggestion.

[1] These conclusions may be denied by one unfamiliar with the field evidence and doubtful of the writer's ability to recognize the features he names. There is no remedy for such an attitude except a personal examination of the phenomena by the skeptic. This paper is written with the conviction that the items reported are facts. Details regarding altitudes of scarp bases and depths of preglacial valleys in basalt are shown on a map of the scabland to be published in the *Geographical Review* for July, 1928.

[2] Oral communication.

But there are many features of the scarps margining scabland that are not found in the Yakima Valley type of scarps.

1. Most of the scabland marginal scarps face flats which do not have cliffs descending to a canyon or deep valley a short distance in front of them. Yet they are of the same character and same degree of development as those with cliffs below them.

2. The exposure to wind and rain of the weaker overlying material, chiefly loess, is no greater in general along scabland margins than in the wide tracts completely covered with loess, yet such scarps are not found back in these tracts.

3. Basalt at the base of the scabland marginal scarps is channeled parallel to them and contains rock basins. The Yakima Valley scarps do not have these features.

4. Deposits of stream gravel lie on this channeled basalt close to the scarp bases. The gravel is clearly of the same date as the channeling and scarping; it was not uncovered by removal of loess. The Yakima Valley scarps do not have this.

5. The basalt of the channels and the basin walls, and constituting the stream gravel, is but little altered. The basalt exposed in front of the Yakima Valley scarps is mantled with fine residual waste except on the very brink of the cliff and in gullies that notch the edge of the cliff.

6. The scarps in Yakima Valley are almost everywhere furrowed by rain-wash. The scabland scarps have almost no furrows.

7. The slopes of the Yakima Valley scarps are gently concave. Those of the scabland are plane except at the very base.

8. The maximum width of the exposed basalt in front of the valley scarps is but a few hundred feet. In front of the scabland scarps it may be miles to the first descending cliff in basalt.

9. There are many minor spillways across loess-covered tracts, half a mile or less in width, yet bounded by scarps as steep and as high as those facing wide, flat scabland or overlooking deep scabland canyons. Parallel and immediately adjacent are valleys in the loess without scarps, without basalt ledges on the floor, without stream gravel; clearly unentered by glacial water.

10. Marginal scarps in weaker material above basalt, identical

in every respect with those in loess, exist in gravel and in piedmont cobbly waste. No wind or rain-wash could have made them.

11. Where the scabland and associated gravel deposits do not reach to the upper limit of basalt in preglacial valleys, there are no scarps or only weakly developed scarps of the Yakima Valley type.

12. Some minor spillways lead *out* of major scabland tracts through notches in the loessial scarps. The floors of these notches, bounded by their own scarps, may be 40 feet above the base of the scarps facing the larger tract.

It follows, therefore, that the alternative proposed cannot explain the marginal scarps in scabland. The features are similar only in a very general way, and in their origins are quite dissimilar.

HANGING VALLEYS IN WEAK MATERIALS ABOVE THE BASALT

In one place in the scablands there are several channels cut by glacial waters in a silt deposit (the Ringold formation). These channels mouth in the wall of Columbia Valley from 150 to 400 feet above the river. The entire wall is of the weak Ringold sediment. Basalt here is below river-level. The Ringold never could have maintained the lip of a cataract at the mouths of the valleys. The writer's interpretation has been that the surface of the glacial Columbia was as high along this wall as these channels now hang. Little or no deepening of Columbia Valley in post-glacial time and little retreat of the wall by undercutting have been allowed for in this explanation. A river at least 400 feet deep is therefore demanded for the highest channel mouth.

Mr. E. T. McKnight has offered an alternative explanation[1] to the effect that these channels have been left hanging by undercutting of the bluffs of Ringold silt, the Columbia Valley being deepened and the mouths of the channels becoming higher because shifted farther up their gradient. By this conception there was no hanging condition when the channels functioned.

In reply to this paper[2] the writer cited several features of the region which cannot be harmonized with McKnight's conception. A new item that has an important bearing on the alternative has

[1] "The Spokane Flood: A Discussion," *Jour. Geol.*, Vol. XXXV (1927), pp. 453–60.

[2] "The Spokane Flood: A Reply," *ibid.*, pp. 461–68.

come to light subsequently. It lies at the mouth of one of the hanging channels. By McKnight's conception, the original mouthing was at least 2 or 3 miles farther west, and lateral planation and deepening by the Columbia have destroyed this junction and removed all trace of deposits which the channel stream might have made at that place. Yet a newly graded roadway down from the hanging mouth of this channel to the Columbia has exposed 115 feet of sand and gravel, the top of which is the channel floor and the bottom of which is 125 feet above present high water in the Columbia. The material is composed of Columbia basalt and Ringold silt. The silt, as well as the basalt, occurs in pebbles, cobbles, and boulders. Some parts of the deposit are 50–90 per cent Ringold fragments. In other parts the weak Ringold fragments occur only as lenses in dominantly basalt débris. Foreset beds are common throughout, dipping out of the channel toward the Columbia. No long delta foresets were seen however. The current of the swollen Columbia into which this was deposited appears to have prevented their formation. There is no possibility of considering this material a part of the Ringold formation. If it is not a deltaic deposit lying on the slope of the preglacial Columbia Valley (perhaps in part filling a minor preglacial gully at this place), it must record 115 feet of filling in the channel 2 or 3 miles back from the mouth. This is obviously impossible, for the bottom of the deposit is as low as the junction of the channel and Columbia by McKnight's interpretation. His scheme cannot provide conditions for such aggradation. Indeed, he showed that channel deepening did not reach an equilibrium profile before the episode was closed. The deposit was made when the highest scabland channels were functioning, for its basalt was swept down from one of the remarkable divide crossings of the system. It constitutes a complete denial of the alternative offered by Mr. McKnight.

EROSION IN BASALT

The amount of erosion performed by glacial rivers across the plateau has been spectacularly great. No critic denies this. But the erosion of several canyons 300–900 feet deep across preglacial divides appears to demand a long time for each, and some sequence in development. Thus G. R. Mansfield says, "I am not convinced that so much work could be done on basalt (by undermining and plucking) in so short a time, even by such a flood as is postulated."[1] Did plucking occur? Did it require a large volume? If these two points can be established, and if simultaneous occupation can be shown from other evidence, we perforce find ourselves staring catastrophism in the face.

The discontinuous deposits of coarse débris in the scabland have been called "gravel bars" by the writer, but some of these débris accumulations are so bouldery and so little assorted that J. T. Pardee[2] has called them "till" and "glacial drift." Their restriction to narrow linear scabland tracts, the multitudes of loessial islands all over the scabland with no trace of glacial overriding, and the large bordering loess-covered tracts, also "drift" free, indicate error in this interpretation. Glacial ice was involved, for there are a few granite boulders in these accumulations, but it was berg-ice floating in the scabland rivers. Mr. Pardee has never reiterated this interpretation during the development, or the criticism, of the flood hypothesis, and among his group, the men of the United States Geological Survey, no voice is raised against the conception of stream origin for channeled scabland. The bouldery accumulations may, therefore, be considered as bars. Indeed, all gradations exist between these boulder bars and the gravel bars.

The boulder bars lie in the lee of prominent ledges of large-columned basalt. No canyon walls are necessary; the ledges may be at the level of the deposit and in some places are actually lower. Some of the boulders are more than 6 feet in length, some still preserve traces of columnar outline, some lie on remnants of the sedimentary cover of the basalt, in one place[3] 100 feet above scabland ledges in the same slope and 2 miles from any ledges at their level. Here the preglacial valley floor was 250 feet below the lodging place of the boulders. These boulders were not carried by berg-ice. The associated gravelly débris on the sedimentary deposit indicates running water as the transporting agent. Plucking did occur. It was done in a stream at least 250 feet deep, a stream vigorous enough

[1] *Journal of the Washington Academy of Science*, Vol. XVII, No. 8, p. 206.

[2] "Glaciation in the Cordilleran Region," *Science* (Dec. 15, 1922).

[3] West-central part of sec. 4, T. 16 N., R. 28 E., a part of Drumheller Channels.

to roll huge boulders, where local conditions favored, up its channel sides or to keep them from rolling down as they traveled along its channel slope.

If the basalt floors left by the scabland rivers are preserved intact anywhere, it will be underneath the gravel bars. Evidence as to the character of the erosion of basalt might be expected in such contacts. One of them will be examined. It is shown in a gravel pit[1] 70 feet up on the slopes of a preglacial valley that carried a scabland river. Though not more than 15 miles from the edge of the ice, the gravel is 99 per cent basalt. Most of the fragments are very little worn, many of them with prominent re-entrant angles adding rude pyramidal points and thin sharp ribs to the outline. Similarity with fragments picked out of weather-fractured ledges of dense basalt is very striking. It strongly suggests that much of this angular gravel has been plucked out of ledges on the preglacial valley slopes, surely not worn off and probably not battered off. The angular fragments are largely of hard, nearly fresh material.

Below 10 feet of this gravel a wall of basalt has been uncovered. It has almost as hackly a surface as that of ledges never covered by gravel and crumbling ever since the episode closed. It has numerous re-entrant niches and pockets, some walls of which make an acute angle with the exposed face. Many are still filled with stratified fine gravel, as all were when the pit was first opened. The angularity of this exhumed channel wall is slightly smoothed; the sharp points and angles are gone. Perhaps a quarter of an inch of rock added to the angles would restore the original sharpness. This is all of the abrasion that is recorded. The wall wasted away far more rapidly by plucking than by abrasion. It can now be plucked by hand or by a little work with the geological pick. The ledge was not more than 30 feet below the upper surface of the glacial stream and had been fractured and loosened by centuries of pre-Spokane weathering. The glacial waters did their work here easily and rapidly though the depth was slight.

The fracturing involved is more intimate than the joints bounding and transecting columns. Weather-shattering begins along such joints but in many cases extends into the interior of the columns.

[1] In the northern part of the town of Wilbur.

Such rock along the Columbia, apparently unweathered, is described by army engineers as "hard to drill, but easy to blast." The sharp edges of the fragments indicate the notable lag of chemical decomposition behind physical disintegration. Indeed, in many road cuts and quarries on the plateau, the physical integrity of ledges appears to lie in the interlocking of already separated fragments. A little work with a pick, the removal of a key fragment, and a surprising amount of rock becomes loose and removable by hand.

The minimum depth for plucking must have varied with condition of the basalt and velocity of the water. Several places have been observed where a gradient of about 50 feet per mile and a depth of 30–50 feet was adequate to make rock basins and buttes with a relief of 15–20 feet.

A revision of the writer's idea of erosion in basalt by the glacial rivers has come from a recognition of the large preglacial capacity of most of the scabland coulees. The evidence for this appears elsewhere in this paper. The revised idea holds that erosion of basalt to make the scabland extended in most places but a few tens of feet below the rock surface which the rivers found when the loess had been swept away. The preglacial fracturing had made it ready for rapid removal. Broad scabland tracts and many scabland valley slopes, therefore, were simply vigorously scoured.

This conception, however, cannot be applied to canyons across preglacial divides or slip-off spurs, or to the higher cataracts. Here erosion in basalt occurred hundreds of feet below the original surface, but here again a factor not amplified in earlier discussion must be considered. It is difficult to present it convincingly as a general idea. The special conditions must be clearly visualized in order to understand the basis for the writer's argument. Only a brief statement will be presented.

Two crossings of one preglacial divide (between Palouse River and Snake River) occurred in the extreme southern portion of the scabland 65 and 80 miles by direct scabland routes from the southern limit of the ice sheet. Two canyons were thus produced; Palouse Canyon and Devils Canyon, each about 500 feet deep and each trenching the divide essentially to its base (Fig. 1). Palouse Canyon now carries Palouse River by a short-cut to the Snake. The abandoned portion of the preglacial Palouse (Washtucna-Esquatzel Coulee) is about 40 miles long, a mile wide, and much of it is 350 feet or so deep in basalt.

The evidence for this interpretation is as follows:

1. Tributary valleys of the preglacial mature drainage pattern, flowing from loess-covered tracts, enter Palouse Valley above the canyon, Washtucna-Esquatzel Coulee below the canyon, and Snake River Valley essentially with accordant grades.

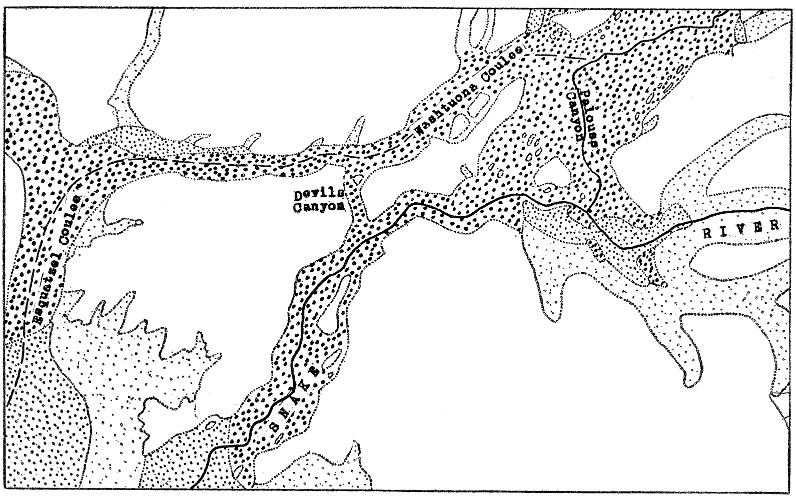

FIG. 1.—Sketch map showing old and new courses of Palouse River and associated features. Heaviest stippling indicates scabland; intermediate represents gravel deposits; and lightest shows areas with silt and sand. Blank areas are loess covered. Preglacial course of Palouse River shown by dashed line.

2. Palouse Canyon and Devils Canyon are exceedingly youthful features, very narrow, and bounded by cliffs that cannot be climbed in most places. Neither has tributary canyons. The length of both is limited to the width of the divide.

3. The descending surface gradient of glacial waters from the ice, recorded by loess scarp bases for 65 miles northward, crosses the old Palouse Valley 400 feet above its floor and continues without change as the base of loessial scarps bounding both canyoned spillways across the divide.

4. The great spread of channeled scabland on the divide along Palouse Canyon, high above all valley and canyon floors, with scarped loessial islands and gravel deposits, is identical with such features farther north. This denuded divide top with its deep transecting trench ties the divide crossing into the glacial-flood episode. So does the immense amount of scabland gravel in Snake Valley south of the crossing. Individual bar deposits here are 200–325 feet thick, and bar summits on the walls of the canyon are 500 feet higher above the river than any gravel in Snake Valley for at least 50 miles upstream. Glacial water did cross the divide, and Palouse and Snake valleys were as deep then as now.

When Washtucna-Esquatzel Valley and Snake River Valley are examined downstream from the divide crossings, the associated features of scabland basalt, of gravel deposits in separate great moundings, and of loessial scarps and even islands are found, identical with those north of the divide transections. The same descending gradients in the same profile are recorded. Only where contact of loess and basalt was higher than the surface of the great streams are the scarps absent. Furthermore, there is ample record of extensive ponds below the profile of the scarp bases in non-scabland valleys which enter the Snake and old Palouse. The upper limits of the silt, sand, and ice-rafted erratics deposited in these ponds are essentially the same as the profiles of the scarp bases across the mouths of the ponded valleys. That is, they vary from pond to pond, becoming lower with increasing distance down the Snake and old Palouse. The volume of glacial river waters in these two main valleys caused this ponding as it caused the overflow from the old Palouse.

With the special conditions of this district in mind, we may turn to the problem of erosion in basalt. How were the two canyons across the divide eroded? Earlier interpretations by the writer considered both the Palouse Canyon and Devils Canyon spillways to have cascaded notably in reaching the Snake. But profiles of scarp bases down both major preglacial valleys below these transections, and indeed down the Columbia for many miles beyond the plateau scabland, record the valleys as brimful and running over with the same flood. The scabland and great gravel deposits on the south side of the Snake at the Palouse Canyon spillway shows the same thing. So does the ponding back up the Snake. There was no notable cascading down the south slope of this divide.

Yet the canyons are there, indubitably a part of the scabland system, a part of the record all over the face of the plateau that preglacial valleys were not adequate to the task imposed on them and that they became channels for the glacial rivers. Where the subfluvial slopes descended steeply in the direction of the current, plucking in the basalt reached much below the zone of preglacial weather fracturing. Such slopes, doubtless in part as short, high-gradient, preglacial tributaries, were available on the south side of the Snake-Palouse divide. Indeed, the lower part of both Palouse and Devils canyons indicates modification of such tributaries. The mechanics of subfluvial cascades must differ from those in which the stream surface descends notably over the ledges. The deep rock basins of scabland indicate the same mechanism. Few of them were eroded at the foot of cascades or cataracts. Most of them are products of current flow across, not current plunge into, them.[1]

It is difficult to conceive of the conditions which made glacial river bottom of such tracts as long continued. It is impossible by any suggested hypothesis that the Snake-Palouse divide crossings were long continued. If one insists that the conception of rapid plucking is impossible, the field facts and relations here presented must be dismissed, and refuge can be taken only in the assertion that "not enough is known in detail of the glacial geology and physiography of the region to furnish an adequate basis for any connected story of events here."

BARS

The writer's descriptions of the great glacial river canyons of the plateau have conveyed the impression that they are "very striking," "astounding," "bizarre," etc. But they are canyons nevertheless. A small stream may make a large canyon. No large canyon was ever known to be filled to the brim with its own stream. That they could be canyons developed below river-level was very difficult to

[1] Such must have been the origin of the Rock Lake Basin (more than 7 miles long and reported to be 250 feet deep), of the large basins in Othello Channels, one of them $2\frac{1}{4}$ miles long and more than 100 feet deep, and of the 182 rock basins in Drumheller Channels, one of them a mile long and more than 100 feet deep.

believe. Failure to appreciate such features as preglacial depths, height of present scarp bases above the preglacial floors, the great rock basins in them, the great improbability of divergences far from the edge of the ice without great volume, nullifies such critic's judgment of the argument for river-channel origin.

It is significant, however, that in the chorus of disapproval[1] no one attacked the interpretation of the mounded gravel deposits as bars. Though small streams may erode large canyons, obviously they cannot build bars any thicker than they are deep. Dr. Mansfield comments on high-level and low-level gravel bars, but fails to remark on bars one-half to three-fourths as thick as the canyons are deep, though these had been described. When the writer subsequently[2] took special care to emphasize the magnitude of the bars and in unescapable consequence the enormity of the rivers which built them a simple disposition was at hand. Such deposits cannot be bars! So one critic suggests that they are deltas or remnants of deltas, the foresets of the growing faces of the bars only delta foresets. Gravel deltas are conventional affairs; thick deltas are common enough. The whole difficulty vanishes at the magic of a word—except the difficulty of explaining their situations, their distribution their parallelism of structure with form, their lack of erosional shapes, and their composition. Detailed explanations of each of these "bars" with foreset bedding as deltas may give geology a wilder hypothesis than the "Spokane flood."

Mr. McKnight accepts the writer's published interpretation of the 200-foot relief features in river gravel near Hanford, Washington, as bars and channels, though he says, "I still believe that they are no larger than can be ascribed to the glacial Columbia as it has ordinarily been conceived heretofore."[3] Later examination of the Hanford region has shown that stream gravel, indistinguishable from that in the 200-foot bars, extends westward up on a definite terrace 200 feet still higher. This terrace may be underlaid largely by Ringold silt, but it is almost completely mantled with the gravel.

[1] Discussion in the *Journal of the Washington Academy of Science*, Vol. XVII, No. 8 (1927), pp. 203–8.

[2] At the Cleveland meeting of the Geological Society of America (1927).

[3] Personal communication.

These deposits with 400-feet vertical range lie on the west side of the Columbia in the concavity of a great eastward curve of the river.

Another gravel deposit in the district has also been studied. It lies on the east side of the river inside the first large reverse curve upstream. It is a huge rounded mound of basaltic débris, grading from cobbles and pebbles at the base (about 550 feet A.T., 75 feet above the river which is 2 miles away) into coarse basaltic sand at 825 to 850 about 5 miles farther back from the river. Still farther eastward its surface descends to lower land. There is no terracing on the broad convex slopes. The material everywhere appears fresh at a depth of about 2 feet. It belongs to the same class of mounded gravel deposits as those west of the river near Hanford. If it is not a glacial river bar, then the other features are not bars. When the gravelly débris was swept back and sorted out in this great pile, the river was as deep as the pile is high, 300 feet.[1] If the present Columbia course among these bars was inherited from the glacial stream[2] and has not been deepened subsequently, that river at the south end of the bar was 450 feet deep. These features record a river assuredly greater than the glacial Columbia has ordinarily been conceived heretofore.

DIVIDE CROSSINGS

Hundreds of minor divides of the preglacial dendritic drainage pattern in loess were crossed by the glacial waters. In most of these the erosion exposed basalt continuously through the notched divide and down the entered valley. Also, by widening the valley, it produced marginal scarps in the loess. In some places where two parallel adjacent valleys were entered, the divide was reduced to a row of relict hills surrounded by scabland and gravel deposits. These features are characteristic of the upper limit records of the flood. In most places they constitute the whole record.

But there are at least eight other places on the plateau where the basalt also was deeply eroded. Two of these, Palouse Canyon and Devils Canyon, have been noted. Four others will be briefly

[1] Though there may be Ringold underneath in part.

[2] Evidence for this presented in "The Spokane Flood; A Reply," *Jour. Geol.*, Vol. XXXV (1927), pp. 461–68.

described and alternatives to the flood hypothesis tried on them. These four are all associated with discharge from Quincy Basin.

Quincy Basin (Fig. 2) is a broad, shallow, downwarped tract in the western part of the scabland, containing about twenty-five townships of land. A pronounced monocline, Badger Hills, rises northward from it, and a definite anticline, Frenchman Hills, bounds

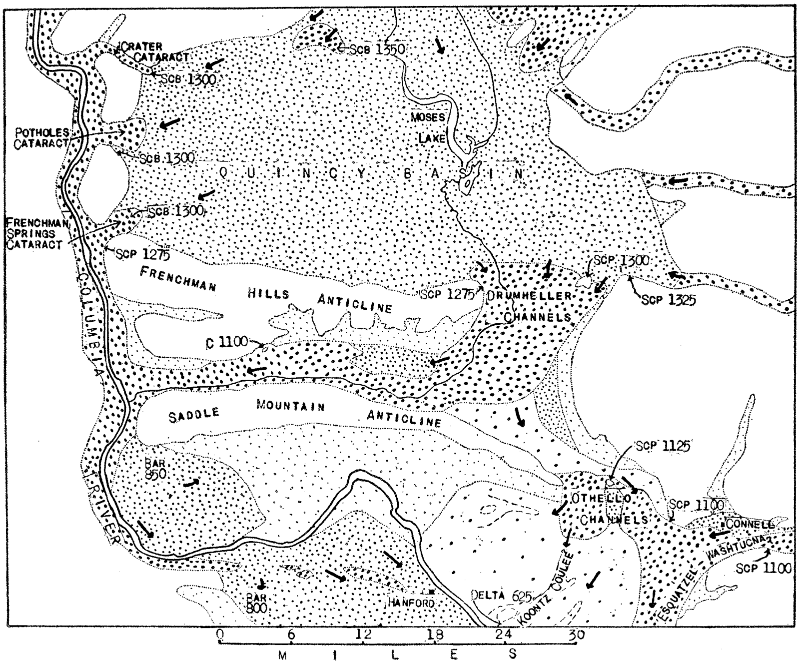

Fig. 2.—Sketch map showing discharge ways from Quincy Basin. Heaviest stippling indicates scabland; intermediate indicates gravel deposits; and lightest represents ponded areas without much current. Channeled tracts without much scabland are shown by widely spaced heavy stipple marks. Abbreviations with altitude figures as follows: *Scp*=scarp base; *C*=channel floor; *Scb*=highest scabland. Heavy arrows indicate direction of flow.

it on the south. Its western edge, close to the brink of Columbia Valley but about 800 feet higher, is determined by a gentle westward rise in the slightly warped basalt flows. Less definite upwarpings lie east of the basin. All of these structures are topographic features. This basin received all glacial drainage from the north for more than 60 miles along the ice front and also received all but one of the large divergent rivers from the great eastern scabland tract. Into this basin was carried an enormous amount of basalt gravel and sand. Only two occurrences of scabland are known in it. All else is deeply buried by this débris.[1]

Four discharge ways from the basin have operated at some time or other during the deposition of the great gravel fill, three crossing the western rim and descending over the bluff of Columbia Valley. They are Crater Cataract, Potholes Cataract, and Frenchman Springs Cataract. One, following the preglacial discharge route, opens out from the southeast corner of Quincy Basin, crossing the tip of Frenchman Hills anticline in Drumheller Channels and leading thence westward to the Columbia. The westward course is along a synclinal valley, between this anticline and a higher one (Saddle Mountain) parallel with it and 6–10 miles farther south.

Of these four discharge ways the three breaches in the western rim are divide crossings. Probably short, steep, preglacial tributary canyons to the Columbia existed here, but they carried only the drainage of the western rim itself. The bottom of the very much larger southeastern route, Drumheller Channels, is today 300–400 feet deeper in basalt than the channels leading to the three western cataracts. Stream-formed scabland in Drumheller Channels, below the altitude of the cataract heads, is fully 9 miles wide. Only a small part of this great channel width can be termed preglacial. It is almost wholly a product of glacial water. This must be granted by such critics as Dr. Mansfield who, to avoid the inference of great volume in spillways both wide and deep, remarks as follows:

> It does not seem to me necessary to assume that all the scabland channels, or even that all parts of the same channels, were occupied by water at the same time. Mr. Bretz notes that deep and shallow canyons unite and divide in labyrinthine fashion. Perhaps some of the shallower channels were formed earlier than some of the others and now hang on the sides of more favorably located channels.

If his suggestion be correct, then preglacial drainage here had made no valley or canyon across the nose of the anticline. This is saying either (1) that Quincy Basin had remained an undrained basin or

[1] There are lake sediments under much of the débris. The Quincy Basin gravel does not, therefore, follow the prevailing rule of lying on scabland surfaces of basalt.

flat while most of the plateau had developed a mature topography, or (2) that the basin-making was later than the mature topography of the plateau.

Despite its improbability, let us grant this view. The basin then had no adequate discharge way when glacial water arrived, but during glacial discharge four spillways were formed. They operated either simultaneously or in some sequence. The combined width is $12\frac{3}{4}$ miles. This is too great, let us say, to permit the idea of simultaneous functioning. If in a sequence one may hold that the "more favorably located" Drumheller channels eventually obtained all the discharge. But this requires initial contemporaneity with that unheard-of width of $12\frac{3}{4}$ miles. However, we may have a sequence with Dr. Meinzer who argues[1] that "tilting and folding of rocks have in this region occurred in recent geological time, probably during and since the cutting of the Pleistocene channels." Such a tilting applied here would require operation of only the three western spillways at first (again no preglacial drainage out of the basin allowed), then later by raising the western rim or by depressing the nose of Frenchman Hills anticline, or both, the discharge would be shifted to the southeast, the cataracts thus becoming abandoned. What is the field evidence for or against a shift of this kind?

The evidence lies in the upper limit records at each of the discharge ways and in the depths of the three notches across the western rim. Above the upper limits of glacial water is a loessial mantle with smooth slopes overlying Ellensburg (?) and basalt; below is scabland and associated gravel. At the contact there may be a scarp in the loess or other weak material on the basalt. Unless the weak material was thick enough and the current at its base was vigorous enough, no scarp may be expected. And even if a scarp exists, one cannot be sure that its base was the water's surface. The water may have been somewhat higher, though the error involved cannot exceed the height of the scarp.

A careful field study, aided by the excellent topographic maps of these spillways, has shown that the upper limits do not range more than 25 feet above or below 1,300 feet A.T. though they are

[1] Discussion in proceedings of the Geological Society, *Journal of the Washington Academy of Science*, Vol. XVII, No. 8.

35 miles apart east and west and distributed through 18 miles of distance north and south. The short channels leading to the two southern cataracts are almost 100 feet below these upper limits, i.e., 1,200 feet A.T. No shift to Drumheller Channels would occur until that tract had been tilted down to about 1,200. The record of initial spill there, however, is actually as high as at the cataracts. There is only one possibility of retaining the conception of shift by tilting; it is that reverse tilting later has raised the Drumheller upper limits just high enough to coincide with the cataract upper limits. This alternative has not yet been urged.

Another fact to consider while dealing with Quincy Basin discharge is that the combined width of the three cataract channels is $3\frac{3}{4}$ miles while Drumheller is 9 miles wide. By the alternative we are considering, it should not be half of that.[1] The reader will keep in mind that this argument of sequence by tilting is built on the assumption that there was no preglacial drainage route through the Drumheller tract and that this assumption is of doubtful value.

[1] Dr. Meinzer comments that "Quincy Valley (or Basin) into which the waters of Grand Coulee discharged evidently became the scene of a lake in which sediments were deposited and which at first discharged westward into the valley of Columbia River, forming several cataracts that retreated some distance in normal fashion before they were abandoned." *In Water Supply Paper 425*, Schwenneson and Meinzer have described a part of these lake sediments as clays containing volcanic ash, shells, bones, petrified wood, and certain dark layers charged with organic material. How do these characteristics agree with the conception of Grand Coulee River in which a waterfall 400 feet high and $2\frac{1}{2}$ miles wide existed, the retreat of which fall made the lower part of the coulee? Was most of this basalt ground to clay before it reached the lake? Was the shallow lake undisturbed by an inflow certainly greater than the present Columbia (plus the great glacial streams from the northeast and east, not considered by Dr. Meinzer) and by an outflow which maintained the three cataract rivers $\frac{1}{4}$, $1\frac{1}{2}$, and 2 miles wide? Would such a lake maintain three cataracts simultaneously while recession as great as 2 miles occurred? Would it maintain two of these cataracts while 100 feet of channel deepening in basalt above the falls occurred for almost the full width of $1\frac{1}{2}$ and 2 miles? Would it possess these organic remains? It seems far more probable that the lake took origin as soon as the basin began to be formed. It is much more probable that Grand Coulee River is recorded in the coarse and very little-weathered gravel which is as much as 90 feet (Schwenneson and Meinzer's figures) thick above the lake sediments. Indeed, older and considerably weathered stream gravels are known in a few places beneath the scabland gravel of the basin. Do they not record a long interval between the time of the lake and that of Grand Coulee and the four great discharge ways? Do they not record establishment of drainage across an obliterated lake before the scabland-making episode?

However, the whole history of glacial discharge from Quincy Basin has not yet been told. What is perhaps its most striking feature now will be considered. It is a small edition of Drumheller Channels lying on the eastern nose of Saddle Mountain anticline. The discharge here also was southward across a labyrinth of rugged buttes and deep basins carved from the tilted basalt flows. The character of the group (Othello Channels) is well shown in Figure 3. Like Drumheller Channels, also, it has a relict island of weak sedimentary material standing among the channels on the axis of the uplift. In two features, however, it differs. There clearly was no preglacial drainage across the anticline here, and the channel floors (not considering rock basins in them) are from 100 to 300 feet higher than the tract just to the north, whence came the water.

Othello Channels is a divergence from the great spill out of the southeast corner of Quincy Basin, taking origin several miles south of the main Drumheller plexus. At its head it is a hanging valley to the main synclinal valley but with reverse gradient. This reverse hanging valley leads southeastward for 8 miles before the labyrinth or plexus is reached. The plexus group is about 6 miles wide on the axis of the gutted fold and about 3 miles long with the canyon-channel lengths. The largest channel, the easternmost, is shallowest. The floor of the canyon containing Scooteney Lake is more than 200 feet below that of this eastern channel. So with the canyon west of Scooteney.

Let us try Dr. Mansfield's idea of sequence here.[1] The floor of the wide channel is below 950 A.T. at the col. Abandon this in favor of the two narrow canyons west of it whose floors are below 725, but whose combined width is hardly half that of the easternmost channel and whose walls reach to 950 and 1,000 feet A.T. This seems a bit difficult. But if unwarily insisted on in order to avoid occupation of all channels throughout the whole episode, the disconcerting fact comes to light that the deepest parts of these canyons

[1] Dr. Meinzer will be interested in this also for he says: "Unless there is conclusive proof, it should not be assumed that along any drainage line the erosion work at high and low levels was done simultaneously. It would seem more probable that the work of erosion proceeded during a long time and that the high level channels were abandoned as the stream cut down to lower levels."

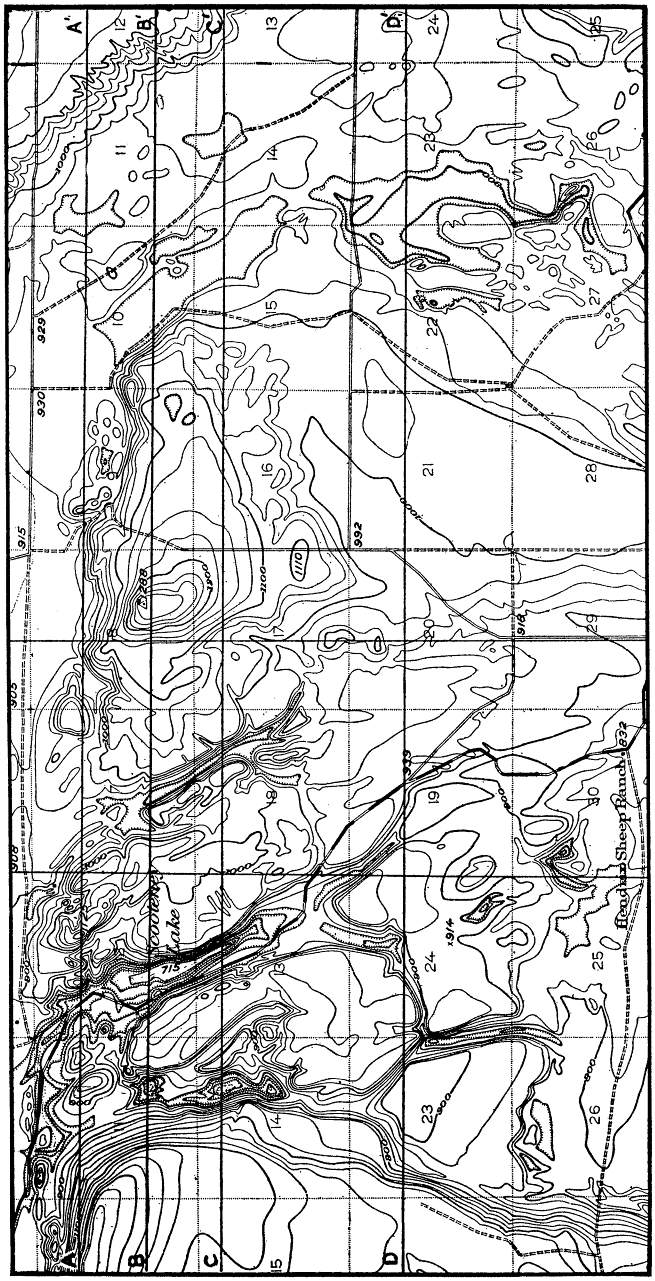

FIG. 3.—Othello Channels. Part of Scooteney Lake, Washington, topographic map, U.S. Geol. Survey

are closed depressions more than 100 feet deep.[1] Water to flow through them had to cross floors 850 and 875 feet A.T. about a mile farther south (see Fig. 4, sect. *D–D′*). And only a very narrow stream could get out at these altitudes. To get a width comparable with the rock-basined parts of the canyons, the waters had to rise at least to 900 feet A.T. To get an erosive ability adequate for the basin-making (see Fig. 5), a stream depth equal to basin depth can

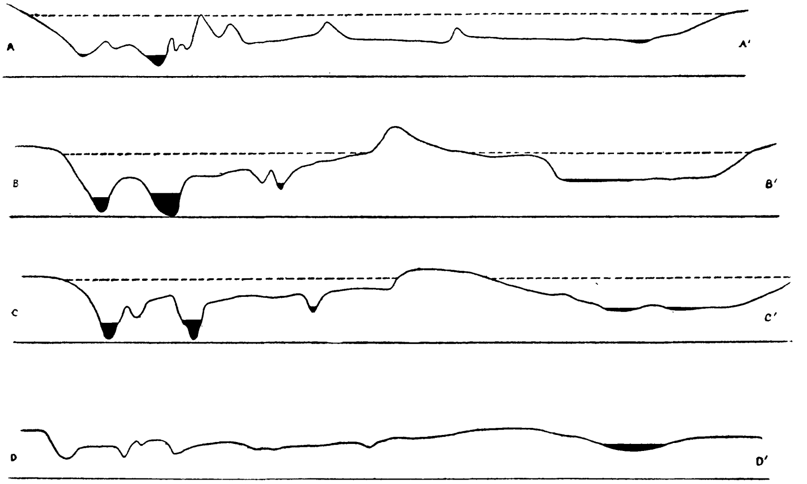

FIG. 4.—Cross-sections of Othello Channels. Base line in each is 700 ft. A.T. Dashed line, indicating upper limit of glacial water, is 1,125 ft. A.T. Basined portions of the channels are black.

hardly be denied. Since about half the canyon depth is rock basin, such a stream surface would be up to the top of the canyon walls, higher than the floor of the channel which we are endeavoring to abandon. Since a stream fully as wide as these two canyons together would have continued to flow through the broad eastern channel if the glacial river surface had been but a trifle over 950 feet A.T., it is obvious that the alternative idea of succession in use never was constructed from a careful study of the Scooteney Lake topographic

[1] The 825 contour in the western canyon, shown on the Scooteney Lake topographic map of the U.S. Geological Survey, should be hachured. It is a closed contour.

map. All parts of the Othello Channels plexus must have functioned simultaneously during their whole history.[1]

But how did these western canyons in basalt originate? The eastern channel has been eroded but little in basalt, has no conspicuous basaltic knobs on its floor, and has the relatively weak Ringold or Ellensburg for most of its eastern wall. With an "orderly and long-continued" episode of stream erosion across this divide all the water would have gone around the anticlinal nose, as the eastern broad channel essentially does. The answer is found in the upper limits record at Othello Channels. This is clearly preserved on the relict hill of sedimentary material in the plexus. Scabland extends up to about 1,100 on the sides exposed to the current (north and west sides). The scarp base is 1,125. This would put water over all the scabland buttes separating the canyons. It would provide the only means of *initiating* these canyons. If this level were maintained or approximately maintained to the close of the episode, it would have required water 400 feet deep over the rock basins in these canyons. Whether or not that depth was required for their production, something more than streams 30–40 feet deep obviously is demanded. Yet this is all that can be allowed by Dr. Mansfield's hypothesis of succession.

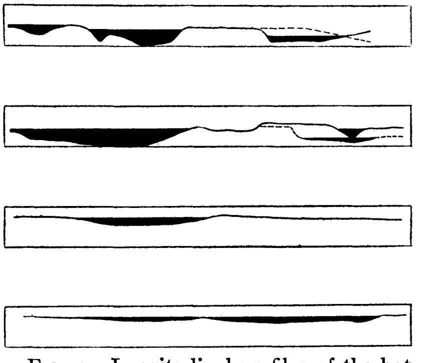

FIG. 5.—Longitudinal profiles of the bottom of four of the Othello Channels. Base line in each box is 700 ft. A.T.; top line is 1,000 ft. A.T. Westernmost channel is at the top; the broad eastern channel, at the bottom. Basined portions in black. Downstream bifurcation of two channels is shown.

The remaining question concerning Othello Channels may now be considered. It is the extraordinary height reached by the glacial

[1] Perhaps it will aid in visualizing the aberrancies of these labyrinths to consider the eastern divergence of the western rock basin. It lies in the northeast corner of sec. 14 and the west central half of sec. 13. It is more than 75 feet deep yet it *ends* at the south, its floor rising 100 feet in less than 1,000 feet of horizontal distance. The water which made it flowed south.

streams across this divide. The upper limit is scarcely 200 feet lower than at the head of Drumheller Channels, 22 miles distant by drainage routes. Water certainly had to go through the Drumheller tract before it could use the Othello route. This 200-foot descent was not bottom gradient for Othello Channels was above preglacial drainage routes. Did the enormous streams called for by the Spokane-flood hypothesis have *surface* gradients of 10 feet to the mile? The answer for this particular case should be found along the main synclinal route westward from Drumheller to the Columbia. If this syncline was not a preglacial drainage line, its floor at the inception of the flood might have been essentially as high as the eastern plunging end of Saddle Mountains anticline. If it was a preglacial valley, it might have been blocked in some way to cause the southward discharge through Othello Channels, though an "orderly and long-continued" blocking would be difficult to defend.

Dr. J. P. Buwalda has suggested[1] that the profile of both Ellensburg and Ringold remnants in the region be considered. Perhaps such sediments filled the syncline at the beginning of the discharge, though basalt certainly did not. Large remnants of what will be considered Ellensburg do occur in the syncline today. Lower Crab Creek in the scabland channel hugs the south side of the asymmetrical downfold. Along the northern side of the syncline there is a dissected terrace of Ellensburg 3–5 miles wide and 500–700 feet above the creek. Much of it lies above 1,100 A.T. There are numerous short valleys eroded in it, draining the southern slope of the Frenchmen Hills upwarp (Fig. 6). They do not have the maturity of valleys in the loess-covered tracts farther east. This may be due to greater resistance to erosion of the sandy and calcareous Ellensburg material or to less rainfall in this western part of the plateau, or to both. But their capaciousness and the development of their tributaries requires a long preglacial history. The upper-limit scarps all over the plateau record very little post-glacial erosion in loess, a weaker material and generally under a heavier precipitation. With this evidence should be considered the strong probability that the preglacial Crab Creek drainage, more than 4,000 square miles in area, left Quincy Basin through the site of Drumheller Channels instead of over one of the three cataracts. A syncline so near the Columbia

[1] Oral communication.

FIG. 6.—Part of Red Rock, Washington, topographic map, U.S. Geol. Survey

and opening into it could not escape becoming a drainage route. The idea that the syncline was filled with Ellensburg when Drumheller Channels first operated is therefore dismissed.

But other suggestions are at hand, calling for a dam of some sort in the preglacial lower Crab Creek Valley, a dam which shall be high enough to produce the Othello Channels divergence and which shall endure long enough for 250 feet of erosion at the channels in basalt, "a hard rock and very resistant to corrasion." Glacial ice as a dam is barred. Trustworthy observers have long since shown that no glacial ice on the plateau got within 50 miles of this valley. River-borne ice may be permitted, however.[1] M. R. Campbell blocked the old Kanawha (Teay Valley) with it, making several dams 100–150 feet high where the valley was a mile or two wide. These lasted long enough for the trenching of new courses, necessitated by the dams, deeper than the old.

In lower Crab Creek the best place for an ice jam is near Beverly where there is a minimum width of 3 miles between the 1,100-foot contours. The scabland valley floor here is 500 feet A.T. This is not far below the upper surface of the basalt. The dam, therefore, was not much less than 600 feet high. If we endeavor to reduce the height of the dam by locating it farther up the valley, one as low as 500 feet can be had, if width of valley is not important. The lower dam would be 6 miles long. Adjust these items as one will, within the limits permitted by the field evidence, construction of a dam of river ice yet remains a formidable task. Then maintain such a dam here even for the shortest time required for the erosion of Othello Channels, being careful that the abundant floating ice does not block the shallow and interrupted new spillway also. Perhaps this is plausible to some. The procedure has good precedent. But it quickly passes into a purely fanciful idea when we consider (1) that hundreds of these high-level divergences are to be provided for over the whole scabland and for 200 miles farther down the Columbia and (2) that in every case, including lower Crab Creek, the record both above and below the divergence is not that of ponding but of vigorous flow identical with the divergence record itself. Most of these divergences could take care of but a small fraction of the main channel discharge, anyway.

[1] Personal communication from H. G. Ferguson.

However, let us examine the character of lower Crab Creek.

1. A very coarse basalt gravel deposit has been opened north of Corfu Station. In one short cut through the edge of a terrace a thousand or more boulders 3–4 feet in diameter have been rolled out along the roadside. This is 835 feet A.T., 260 feet above the creek which is $2\frac{1}{2}$ miles to the south. The stream which deposited them was more than 3 miles wide and, by the argument for a preglacial valley here, was more than 200 feet deep.

2. Natural Corral (Fig. 6) is a typical scabland coulee north of Colletta Station. It is a hundred feet deep, nearly 3 miles long, and a quarter to a third of a mile wide. Its name suggests the character of its walls. It is "tributary" to Red Rock Coulee though at the junction it is ten times as wide. Scabland on the brink of its cliffs is 850–75 feet A.T. It lies parallel with the creek valley only a mile and a half distant. Its flat floor is a third as wide as that of the main valley and in its lowest place (a closed basin) only 100 feet higher. At its head is a cataract more than 50 feet high, and the map shows clearly that, east of the head, the eroding waters came out of Crab Creek Valley. It is a subfluvial canyon and cataract, a record of the great plucking which the glacial stream performed.

3. Five miles farther west is another very similar scabland feature except that it has no cataract head. It has no head at all. It is a canyon 4 miles long and 150 feet in minimum depth, nearly half a mile wide, a loop out of Crab Creek Valley and back into it. Both ends hang, the upper end more than 300 feet above the main valley floor. The scabland brink of its walls is 1,000 feet A.T.[1]

4. Cash's Butte, a relict hill of Ellensburg, lies between these two curious canyons and a little north. The glacial water had to rise above 1,100 here to initiate the channel which isolates the butte. This channel floor is 575 feet above the creek, 3 miles to the south. And lower Crab Creek Valley, 3 miles wide, leads thence to the Columbia only 11 miles farther west. These features of lower Crab Creek tell clearly why Othello Channels functioned. They debar any hypothetical ice jam or blockade of any kind.

Another alternative for the high altitude of Othello Channels on Saddle Mountain anticline is the obvious suggestion that the anti-

[1] The contact of Ellensburg and basalt is about 200 feet higher here than at Natural Corral.

cline has undergone renewed movement since the channels were eroded. When Mr. McKnight failed to discuss the divide crossing in his scheme for the hanging valleys near Hanford, the writer listed several possibilities that theoretically were compatible with his conception. Mr. McKnight's preference was for post-channel uplift along the Saddle Mountain anticline.[1] By this, of course, the great depth in the syncline might be avoided and his hypothesis might at least be consistent with itself. But would it be consistent with the field evidence? Othello Channels' upper limit, 12 miles south of the divergence, is only 25 feet higher than the synclinal river's upper limit at Cash's Butte, 18 miles west of the divergence. There is no way of knowing just how high the water was on the steepened slopes of the relict hill in Othello Channels or just how deep it was in the channel back of Cash's Butte, but the summit of the butte is less than 1,175 and the surface of the flood here was below the top of the butte, yet above 1,100. The base of the Othello Channels' relict hill scarp is 1,125, and the flood water must have been that high. This altitude is below the top of Cash's Butte and shows clearly that there has been no detectable differential movement in the region since the channels were abandoned.

Preglacial drainage through the valley of lower Crab Creek is almost as clearly recorded as through Washtucna-Esquatzel Coulee. A very great glacial river in each valley is also well recorded. The divergences in both are due to the same cause, a brimming over and an escape southward toward lower tracts. The flood hypothesis has been built strictly on field evidence. It fits every item of the record thus far found in these valleys. No other hypothesis does. Several have no field evidence to support them; others are untenable because certain features of the region obviously disprove them. The only objection yet raised to the flood hypothesis for divide crossings is its demand "for a seemingly impossible quantity of water."

TALUS RATIOS

The writer has stated that Spokane spillways have talus deposits against their cliffs, $\frac{3}{4}$ to $\frac{4}{5}$ the original height of the cliffs, while Wis-

[1] Personal communication. An adjustment between alternatives is needed here, for Meinzer would bring the nose of Frenchman Hills anticline down while McKnight would raise the nose of the parallel and nearby Saddle Mountain anticline. It is similar

consin spillways have $\frac{1}{2}$ talus, and that this ratio may be used for identification of channels of two different episodes. This idea has been vigorously attacked, both as to accuracy of the statement and as to its trustworthiness as a criterion of age. Buwalda[1] believes that height of cliff is an important variable factor; Pardee and Gilluly, that the direction the cliff faces should be a variable, at least in talus which has not reached an equilibrium profile; Gilluly, Buwalda, and Mansfield, that rate of talus growth "is so slow that considerable time intervals would fail to register significant differences;" and Gilluly, that the range in rainfall on the plateau should be recorded in talus height unless a relatively stable stage has been reached.

Some of these points are well taken. They are additions to the variables earlier pointed out by the writer; viz., ashy and scoriaceous phases of the basalt, ellipsoidal structures in certain flows, prominent platiness in the columns of some flows, variations in size of columns, steep tilting of flows in some tracts, removal of material by streams, filling of basins at foot of cliffs, and addition of wind-blown material. But the weakest point in the argument from talus ratios was not recognized either by critics or the writer. It is the assumption of vertical cliffs. The writer has seen enough sections in the talus accumulations since his idea was published to show that this assumption is unwarranted. The buried cliff faces vary considerably in slope. Also enough departures from the $\frac{3}{4}$ to $\frac{4}{5}$ ratio have been found in the same channel to show that this ratio is realized only in a general way.

Talus ratio still remains a criterion for separating Wisconsin channels from older ones. That the older ones can by its use be classed as of the same glacial epoch may be an open question. That *simultaneous* operation can be established by its use has never been argued by the writer. His use of the term "contemporaneous," as is shown by the context, has been simply to denote the same glacial epoch. The belief in simultaneous development is based on other evidence, to be presented in the next division of this paper.

[*To be continued*]

to the adjustment needed between the ice jam in lower Crab Creek and the conception of long-continued erosion in making Othello Channels.

[1] Personal communication.

ALTERNATIVE HYPOTHESES FOR CHANNELED SCABLAND. II

J HARLEN BRETZ
University of Chicago

SIMULTANEOUS DEVELOPMENT OF ALL CHANNELS OF THE SCABLAND PATTERN

A simple alternative to the flood hypothesis is that the main routes of glacial water across the plateau were sequential in operation. The writer has described the anastomosis as possessing ten or twelve channel heads on the edge of the glaciated tract. If the ice margin could be so shifted that only one or two of these operated at one time, making them sequential in development, the flood scheme would collapse. We would still have a remarkable assemblage of "anomalous, indeed unique, drainage features" and would still have to admit "the necessarily large volume of many of these streams." But catastrophism would be avoided.

An examination of this conception is not an office task. There are five critical places to be studied in the field: the glaciated plain and channel heads,[1] the divergences in the anastomosis, the convergences in this pattern, the Columbia Valley beyond the plateau system, and the non-scabland valleys entering waterways used by the glacial streams. Features in each of these places should record definitely whether or not the different routes operated simultaneously. By either hypothesis each type of place should have its own type of record. These will be considered in the order listed.

HEADS OF SCABLAND CHANNELS

Restudy of the glaciated plain north of the channel heads has shown that earlier statements concerning morainic records of the ice edge are correct. There are essentially none. There is moraine topography on Sunset Prairie just west of Spokane. Perhaps 40 or 50 hills of very bouldery till are scattered over 12–15 square miles.

[1] Pointed out by Dr. W. C. Alden.

The total relief does not exceed 50 feet. The height of separate hills rarely is more than 25–30 feet. When mapped, they are only a circuloid group surrounded by till with even weaker topographic expression. There seems to be no hope of mapping any shifts in the edge of the ice from this evidence.

North of Davenport, 25 miles west of Sunset Prairie (Fig. 7), the glaciated tract is deeply canyoned by tributaries to Spokane and Columbia rivers. Only well down the northern steep slopes is there any morainic topography. Even if it could be traced out as a record

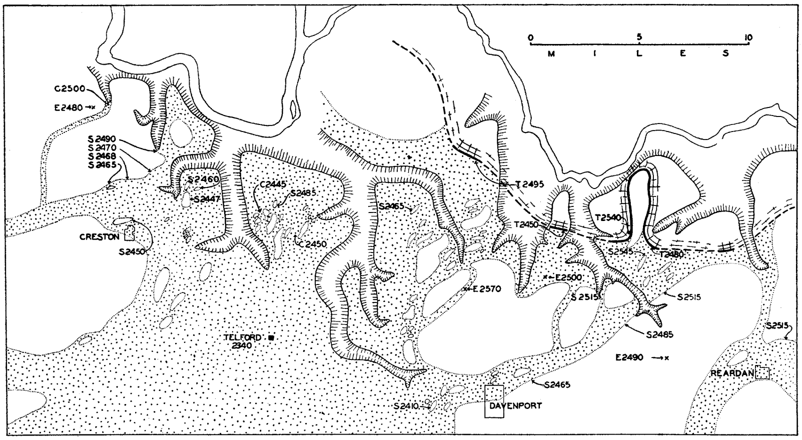

FIG. 7.—Head of the Telford–Crab Creek tract of channeled scabland. Most of the stippled area is well-marked scabland. Outlines of north-draining canyons indicated by hachures. Blank areas south of the river and the ice margins are largely loess covered. Figures are altitudes. T = Till; C = Channel floor; S = Scarp base; E = Erratic.

of ice margins, it is too far north of the channel heads and too low to bear on the question of shifting occupation.

Restudy has shown another thing regarding the glaciated tract north of Davenport. It is that the ice sheet did not reach as far south as formerly indicated. What had been taken in earlier reconnaissance for ice-laid till proves to be berg-laid. The divides between the north-draining canyons, previously unvisited, were found to carry *scarped relict hills of loess*, many of them 50 feet high, some 75 feet high, *separated by channels*, some with scabland floors. The channelways across these divides are roughly transverse to the divides and canyons. The altitudes of scarp bases, checked as carefully as possible in the absence of a topographic map, are with few exceptions higher farther north. Some channelways, when traced southward and southwestward, lead to northerly walls of canyons on which lie deposits of coarse angular basaltic rubble obviously swept out of the channels.

The combination of features here is remarkable. The loessial hills have not been glaciated. In their forms, relations to each other and to scabland, they appear to be identical with the relict hills of the scabland farther south. Floated erratics have been found among them, but not above 2,525–2,560. The associated scabland is not related to the north-draining canyons; it occurs only on the divide tops. Southward flow seems clearly indicated. The only conclusion which seems allowable is that the Spokane ice here did not reach the channel heads as formerly mapped, and that there was a broad sheet of water flowing vigorously southward across this scabland to become concentrated in the channel heads.

The revised map shows, therefore, only four separate spillway tracts from the ice. There may have been but three, though possibly there were five, separated by higher hills, against the northern slopes of which the ice sheet impinged. Since one of these (Moses Coulee) does not reach northward across the plateau divide, the number to be manipulated with shifting positions of the edge of the ice is reduced to two or three, possibly four.

Another feature of great significance in this proposed alternative of sequential instead of simultaneous occupation is the correspondence in altitudes of the northernmost channel floors, scabland-scarp contacts, and highest erratics floated back among the loessial hills. About forty such observations are available, fairly well distributed in significant places along 90 miles of the northern edge of the plateau. Almost every township here possesses all of these features. The channel floors are the lowest, but are nowhere known below 2,450. The floated erratics are the highest, but are nowhere known above 2,560. Much of this vertical range exists in virtually every township. The upper limits are essentially the same at either extreme of this 90-mile stretch.

Whatever may be the full significance of this remarkable uniformity, one conclusion clearly demanded is that irregular advance and retreat of the edge of the ice sheet could have made very little difference in operation of the different spillways. They must have operated very largely together.

One possible sequence may be pointed out. The retreat of a cascade or cataract to form upper Grand Coulee, elsewhere set forth, eventually produced a canyon through the plateau divide. Scabland above the brink at the head of the canyon, recording early discharge, is about 2,500 feet A.T., nearly 1,000 feet above the canyon floor. If the great eastern spillways had an open-water connection, along the edge of the ice, with the Grand Coulee discharge at the time this retreating cataract reached the walls of Columbia Valley, or later, they would inevitably have gone dry. By far the largest part of the 2,800 square miles of scabland of the plateau lies in these eastern spillways. Much of the episode therefore saw the whole plexus in operation.

DIVERGENCES IN THE ANASTOMOSIS

There are about thirty major divide crossings and hundreds of minor ones in the scabland pattern. They are the heads of divergent routes. Several of the more marked divergences have already been described. Othello Channels is an example, the three Quincy Basin cataracts are examples, as are Devils and Palouse canyons. The latter two are especially significant since there can be no question of the existence and preglacial depth of the capacious valley from which they diverge, nor can post-glacial folding be called upon to explain them. The basalt of the Snake-Palouse divide shows only very slight warping. This doubtless determined the location of the original divide. But both the Snake and the abandoned Palouse valleys are almost wholly erosional in origin.

Changing location of ice edge surely never could produce any sequence in operation among the divergences of any one main route. It seems impossible that critics have intended to imply this, and improbable that they have carefully considered these numerous remarkable features. Granting, then, that divergences were due to overflow of divides, and knowing that there are only three definite source routes from the ice, all at essentially the same altitude, it follows that the divergences can be explained only by the simultaneous operation of glacial streams of the magnitude which the writer has repeatedly described.

CONVERGENCES IN THE ANASTOMOSIS

As previously noted, almost every confluence of glacial rivers was determined by a confluence in the preglacial drainage pattern. There are as many of these as there are divergences, and the entire plateau scabland system is converged to one canyon about 120 miles in direct line from the ice edge. If there was sequence in operation, then converging strands from two different source routes might be expected to record the fact. If the upper limits in the two channels just above the convergence have the same altitudes, this can be so only by coincidence. Gravel deposits made by the stream last in operation should block the mouth of the earlier route.

There are three places best suited to have this record. One is the convergence of Crab Creek and Grand Coulee drainage near Adrian; another is the convergence of Washtucna Coulee and the eastern part of Othello Channels near Connell; and the third is the convergence of Snake River, Esquatzel Coulee, and Columbia River near Pasco. All these are especially significant because Grand Coulee drainage is involved in each. It was shown in a preceding paragraph that the only probable sequence among the source routes was a capture of the whole discharge by Grand Coulee at the time its deep notch was completed. The reader will recall, however, that even this sequence required contemporaneous operation of the whole system for most of the scabland-making episode.

If we follow up this idea, Othello Channels spillover might well have been delayed until the capture turned all the glacial waters through Grand Coulee. It would thus clearly post-date the Washtucna Coulee River, which, by this scheme, would then go dry. So also would Devils Canyon and Palouse Canyon, and therefore the glacial river in Snake Valley. Thus the threefold junction near Pasco should likewise record this change.

But no suggestion has been found in the field that any such shift in operation occurred. Othello Channels eastern route, if brimful when the maximum depth of channel was attained, carried about 175 feet of water, 4 or 5 miles above the junction with Washtucna.

Washtucna Coulee, if brimful (and Devils Canyon proves that it was) carried a river 375 feet deep about 6 miles above the junction. Yet the upper limits of both glacial rivers at these places are very close to 1,100 feet A.T. Washtucna Coulee does have a large gravel deposit on its floor for a few miles above the junction, but this was deposited by its own glacial stream, as its form clearly shows.

The same evidence or lack of evidence is to be found in the other two places. The record at the Crab Creek–Grand Coulee junction is complicated by another item, the Wisconsin discharge through the coulee. But a wide spill out of Crab Creek crossed the angle between that valley and Quincy Basin, entering the latter about 10 miles from the channel cut by the Wisconsin Grand Coulee. At this place the record is simple and clear. The convergences, like the divergences and the heads of scabland channels, record contemporaneity, not sequence, of operation.

COLUMBIA VALLEY BEYOND THE PLATEAU SCABLAND

Despite the evidence submitted thus far, one may have a feeling that since the plateau is so little dissected, since so many drainage lines are hardly more than through the weaker sediments above the basalt, since there is a notable dip slope everywhere, and since there have been at least three glaciations of the northern edge of the plateau, a few mistaken observations and a few misinterpretations might be responsible for the Spokane flood blunder. Perhaps there is still hope for a conventional interpretation. Dr. W. C. Alden says: "It appears that ice sheets of three distinct stages of glaciation invaded the borders of the region and may have afforded conditions of repeated floodings of much smaller volume. . . . . The problem would be easier if less water was required and if longer time and repeated floods could be allotted to do the work." Dr. James Gilluly thinks it "exceedingly probable that . . . . a reinterpretation (of channeled scabland) is apt to be considerably more complex than the suggested flood hypothesis. . . . . That the actual floods involved at any given time were of the order of magnitude of the present Columbia, or at most a few times as large, seems by no means excluded by any evidence as yet presented." Dr. G. R. Mansfield says: "The general nature of the phenomena suggest conditions similar to those attending the ice front in New York State, where temporary channels and falls now abandoned were developed. Although these were temporary, geologically speaking, some of them appear to have persisted for long periods of years. The scablands seem to me better explained as the effects of persistent ponding and overflow of marginal glacial waters, which changed their position or their places of outlet from time to time through a somewhat protracted period."

If there was one tremendous flood, if all labyrinthine canyoned tracts were brimful throughout their history, if violated divides were as high above preglacial floors as now, if the great gravel piles are simply huge river bars, if the loessial scarps are really river bluffs, if the profiles constructed from their altitudes are surface gradients of gigantic rivers, if the entire system actually does record what the writer has read from it, then Columbia Valley beyond the plateau scabland surely must bear witness to the event. It should speak authoritatively. Repeated floodings a few times as large as those of the present river might leave cumulative deposits, but not in great heaps with thicknesses equaling the sum of flood depths. Nor could floodings like those which made the Finger Lakes, Mohawk Valley, and Adirondack channels spill out of the deep Columbia Valley across divides into the lower course of tributaries, making scabland channels across these divides 600–750 feet above the river and building bars 400 feet high.

Though the writer has described features of this valley, pointing to an enormous river in it, criticism has ignored all but one of these. New data in two papers now submitted for publication, and therefore not presented here, will make the case for an enormous flood in Columbia Valley very difficult to explain away. The one feature which has received attention from critics is Wallula Gateway.

This narrow canyon of the Columbia, beginning 12 miles south of the entrance of the Snake and about 15 miles in length, is eroded across an unsymmetrical anticline, the continuation of the Horse Heaven Hills uplift. Typical scabland extends higher above the canyon floor at this place than anywhere else in the entire region. It spreads out above the canyon walls on both sides of the river. But since the upper slopes were not definitely cliffed and since the loess mantle is thin, a transitional zone must be used in most places here for the upper limit. However, two fairly definite markers are available, one on each side of the river. Each of these requires a revision of previously published descriptions.

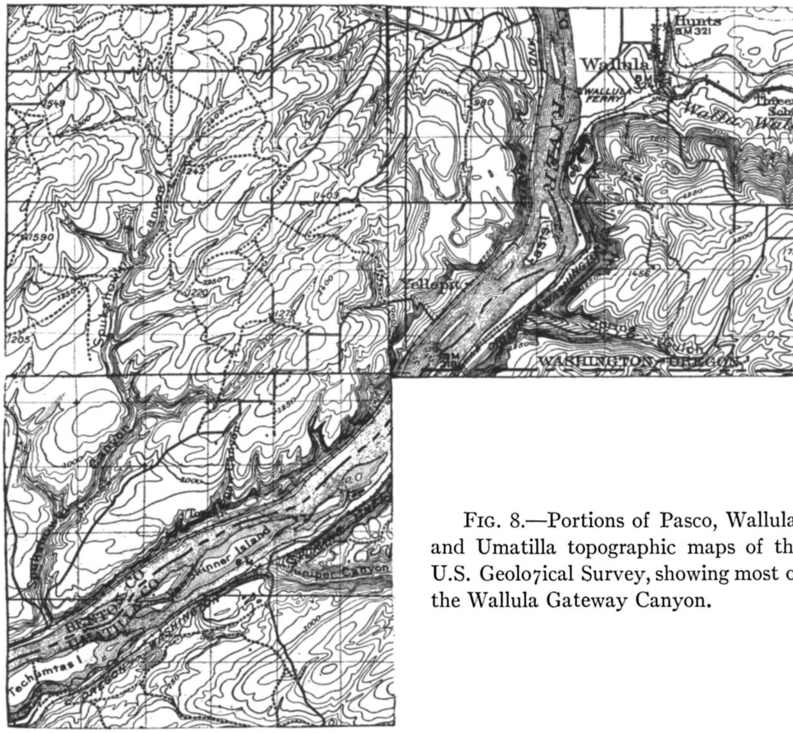

FIG. 8.—Portions of Pasco, Wallula, and Umatilla topographic maps of the U.S. Geolo7ical Survey, showing most of the Wallula Gateway Canyon.

On the west side of the Gateway Canyon (Fig. 8), a flat-topped hill nearly a mile long and elongated parallel with the canyon lies about a mile and a half west of the river. It is separated from the higher land farther west by a channel which at the head, the northern end, is more than 1,100 feet A.T. The hilltop is about 50 feet higher. This channel descends southward 150 feet in three-quarters of a mile over scabby ledges and has scabby sides farther south. At the channel head the old water course is not very well defined. Its floor has large low mounds and broad shallow depressions. There are no ledges here. Southward, where deeper, a clearly marked bar fills the entire channel. The channel floor above it is a basin 25 feet deep (now drained by a small gully through the bar). On the south side the general channel floor is 45 feet lower. Channel walls are well marked here also. The southern part of the channel has been made by modification and enlargement of an earlier minor drainage line developed by local run-off. One affluent of the preglacial valley now hangs above the bar. The channel is too deep and far too wide to belong to the preglacial pattern. Apparently the flat-topped hill was not overrun, and 1,150± may be taken as the upper limit.

There is another and more marked channel parallel with the river and above the canyon walls on the west side. It is lower and nearer the river. It also leads southward. The two join half a mile from the top of the steep slope down which their present drainage spills to the Columbia. On this slope is a great mantle of coarse débris descending 300 to 400 feet from the upper scabland to the Gateway Canyon floor. This might be considered a talus slope or a steep fan which has climbed to the top of the cliffs. But its débris has come from erosion in the two channels, which are scabland features, not normal affairs. And nowhere else have talus or fan deposits in Columbia Valley closely approached the top of canyon walls. Genetically, it is a delta which is all frontal slope.

On the east side of the Gateway are more instructive features. Definite scabland extends up to 1,100, and scabby ledges in the northern part up to 1,150 and 1,175. On the northern slope of the upland (sections 34 and 35, T. 7 N., R. 31 E.) is a shelf or shoulder at 1,150+, with the 1,200-foot contour ringing a small portion out toward the lower slopes. This whole shoulder has been stripped of its soil and now bears only broken basaltic rubble and thin wind-drift soil in places. On the south and overlooking this rude bench is a definite scarp in loess 20–30 feet high, its base about 1,150 feet A.T. Above this no basalt is exposed anywhere on the upfold. All is covered with the coarse-textured loess. The waters which made scabland on the slopes of Wallula Gateway reached 1,150, probably 1,200, here. A more pronounced spur of the upland, in the eastern part of Sec. 35, a little over 1,100 feet A.T., is all scabland on its summit.

Thus both sides of Wallula Gateway have a trustworthy record of water flowing through the canyon up to present altitude of 1,150, a hundred feet higher than previously reported. What was the depth of the canyon when this occurred?

Earlier interpretation called for considerable widening and deepening of Wallula Gateway by the flood. It was suggested that perhaps 200 feet of deepening had been produced. A part of the evidence of this was the existence of about 200 feet of "hang" at the mouth of Spring Gulch, a preglacial tributary entering the Gateway Canyon from the east. The hanging condition exists, but, like so many features of the scablands, simple map inspection is an unsafe route by which to reach an interpretation.

Spring Gulch heads in the loess-covered slopes of the basalt anticline and shows no bedrock above 1,550. It is a narrow, crooked, steep-walled but uncliffed gulch down to 1,000 feet A.T., where a level flat several hundred feet wide exists, underlain by about 25 feet of rudely stratified rubble gravel. Farther west this flat surface of the deposit grades into a sloping surface descending with the canyon and trenched by a deep gully. The basalt fragments of the fill are very little worn. They are not a contribution from the headwaters of the gulch. Several fragments of granite, one of them a foot in diameter, were found in the fill. Some basalt fragments appear perfectly fresh; others are rotten. Much silt occurs in interstices and there are some sand lenses.

The sloping surface terminates at about 700 feet A.T., there breaking off steeply, partially over cliffs in the débris, down to 550 feet A.T. The rest of the descent is over talus, slope wash, and rock ledges. At the bottom of this descent the preglacial slopes of the original gulch converge not far above present Columbia flood-plain level. The hanging condition therefore is due to a fill of rubble in the last mile of the gulch's length. This fill was introduced from the Columbia Valley, probably not so much by transit back up the gulch (though there are some foresets dipping away from the Columbia) as by lateral introduction over the northern spur between master and tributary valleys. The flat at 1,000 might record an approximation to the upper limit here, but probably is too low. The mingled fresh and decayed basaltic débris is what should be yielded if a great flood rose to sweep across long-exposed higher valley slopes.

The angular granite and diorite porphyry tell of berg-rafting across the scablands to this place. Wallula Gateway was as deep, or nearly as deep, before the Spokane Flood as it is today. And since under-cutting at the mouth of Spring Gulch, as well as downcutting, would leave it hanging, apparently there has been no notable widening of Wallula Gateway at the bottom.

Another gulch on the southeastern side of the Columbia, near Juniper switch track, a few miles downstream from Spring Gulch, possesses much the same record. It is in the unmapped area of Figure 8. It is a smaller gulch, and the steep front of its rubble and gravel fill rises to 850 feet A.T., about 550 feet above the Columbia. This steep slope is almost as far out as the truncated spurs on either side. The surface gradient of the fill is much less than that of the gulch floor, much less than the surface slope of Spring Gulch fill. It ends abruptly upstream against steep slopes of basalt. Here it is composed of almost nothing but coarse, rudely stratified, angular fragments of Columbia basalt, though at the steep front there is a considerable proportion of well-rolled pebbles of foreign rock.

Juniper Canyon is the next tributary gulch down the Columbia, and nearly at the end of the Gateway Canyon. The spur between the two, 800 feet above the Columbia, is all scabland to 1,100 at least. Here are rock basins, buttes (two of them 50 feet high), jagged bare rock surfaces, a subsidiary small gorge right along the crest of the narrow spur, and two or three transverse gashes across from the Columbia to Juniper. Bars of gravel, flung out of the Columbia, occur on the summit in one place. The gravel which covers most of the northern wall of Juniper Canyon at its mouth has foresets dipping toward the Columbia, yet containing foreign material that could only have come across the spur *out* of the Columbia at altitudes of 900–1,100. There is no good scarp in loess here, but on the south side of Juniper is one about a hundred feet high, its base at 1,000. The deep deposit of flood gravel in the mouth of Juniper Canyon, now trenched, shows that the Columbia Valley here was essentially at its present depth when the flood occurred.

This will suffice to show the nature of the new data. They are essentially like all evidences previously published or included in this paper. But they indicate a considerably deeper "tremendous flood"; 300 feet deeper in the Gateway, to be precise. This will make acceptance of the Spokane Flood hypothesis more difficult than ever. One may find, with Dr. Gilluly, that higher talus ratios in the upper part of the Wallula scabland mean pre-Spokane age, not a more readily weathered phase of the basalt, not the absence of vertical cliffs. Gilluly surely could not tolerate a pre-Spokane flood, therefore the Gateway itself was very much short of its present depths when the highest scabland was formed. But this conception is barred here, everywhere in the scablands, and down the Columbia by the consistent testimony of the valley system. It predates all scabland. Scabland surfaces, cliffs, rock basins, loess scarps—all would long since have vanished as such if they were of such physiographic antiquity. They are among the most youthful erosional features of the region. They are superimposed on the preglacial valleys and divides.

An important fact regarding Wallula Gateway is that its highest scabland levels are 100 feet, perhaps 150 feet, higher than upper limits in the Snake, 20 miles distant upstream. Since a broad structural valley lies between the end of Snake Canyon and the head of Wallula, conceivably a ponded tract here might carry the flood profile across without a drop in the surface. But the fact that it is higher seems to have but one explanation. It is that post-flood uplift of 100–150 feet has occurred along the axis of the Horse Heaven Hills anticline. Such evidence, if it existed in the proper places, would help to dispense with the flood hypothesis for the divide crossings. Wallula Gateway, however, does not belong to that category. This strong suggestion of recent uplift notably weakens the estimates on the volume of the flood, published earlier by the writer. If the record of surface gradient has been diastrophically disturbed, one essential factor for the computation is lacking.

One last point regarding Wallula Gateway. With a depth and a bottom width but little modified by the flood, the idea of "bottleneck" ponding at the Gateway ceases to have validity. Dr. Alden remarks that "it seems as though the estimated capacity of Wallula Gateway, when fully opened, is too great for this gorge to have served as a bottle-neck to hold above it a flood of such dimension to the level called for in the explanation offered." If, then, it was essentially fully opened all the while,[1] what becomes of the idea of

[1] Exception being taken for a large lateral canyon east of the river, and for considerable erosion on the slopes here.

the ponding? Again we must appeal to the Columbia Valley testimony. As will be shown in a paper on the great bars down this valley, the tremendous river was in every place, except one, much higher than earlier accounts would indicate. For that one, at White Salmon, Washington, a local uplift was suggested. But the White Salmon bar now falls into the new and higher profile recorded by many previously undiscovered bars and divergent channels. The ponding was caused by the immense volume of flowing water in the valley below Wallula Gateway.

PONDING IN NON-SCABLAND VALLEYS

There is one remaining test for simultaneous occupation of all channels. When one canvasses the problem deductively, he realizes that if the great flood ever occurred, and if the present Columbia Valley system then existed, there should have been noteworthy ponding in the lower part of Snake River Valley (above Palouse Canyon), Walla Walla Valley, Yakima Valley, Umatilla Valley, John Day Valley, Des Chutes Canyon, and all other tributaries entering from non-scabland regions. The presence of pond deposits definitely related to the scabland rivers should establish the flood beyond any further reasonable doubt. Absence of such deposits should renew the effort to find workable alternatives for the scabland phenomena themselves. The rub, however, is to show that pond records, if they do exist, are definitely related to the scabland rivers. Glacial waters backed up the tributary valleys there undoubtedly were. The striated erratics prove that. But the critical reader recalls that a late Pleistocene submergence, probably Wisconsin in age, has been described for the region. This submergence is generally accepted as due to a lowered level of this part of the continent. It was like the Champlain submergence of the St. Lawrence Valley. How can one know that foreign material back in these valleys does, or does not, belong to this submergence?

And though erratic boulders and cobbles logically should be a part of the record of the assumed Spokane ponding, they should constitute only a small part of that record. Where is the immense quantity of loess that was swept off the scablands? Should it not be very much in evidence as a stratified silt in the supposedly ponded valleys?

This pertinent challenge was introduced in the discussion which has been referred to repeatedly, but it did not appear in the printed account. The writer has been unable to learn who proposed it. At that time this challenge could not be answered with observational data, for these valleys had not yet been critically studied. Nor is there yet enough known in detail to furnish an adequate basis for any connected story of events in the ponding of such non-scabland valleys. But enough is known to show that some extraordinary episode of sedimentation has occurred in them. Data from Walla Walla Valley may be generalized as follows.

A widespread deposit mantles the Palouse loess or completely buries it throughout the entire Walla Walla Valley below 1,050 to 1,080 feet A.T. It extends back up the tributaries to similar altitudes. Almost all recent road cuts below 1,100 show it. But no such cuts above that altitude show it. Instead, they show only reddened loess with calcareous cementation in nodules and seams and a cover of unconsolidated, apparently little weathered dust 2–4 feet thick. Here and there basalt appears beneath the loess.

The sedimentary deposit in question is stratified and is varied in character. The following differentiations in material have been observed. This list is not a section. No definite vertical sequence among the different constituents has been observed.

1. Coarse, angular, black (fresh) basaltic sand and gravel. The coarse black sand seems the most widely distributed, vertically and horizontally, of all the listed constituents. It commonly occurs in lenses and pockets and is very widely disseminated in grains throughout the silt layers.

2. Very fine-textured, light-colored sand. It is almost as fine as loess in many strata. In some fine gravelly phases of the deposit it occurs as very definite but very irregular lenses. It apparently is not a derivative from basalt rock. It may represent the coarser part of the Palouse loess.

3. Grayish to slightly brownish silt, comparable to Palouse loess in color and texture. To the touch, this silt is loess. Except in some gray phases it is Palouse loess in color also. But it occurs in strata, and some of these strata show laminae.

4. Pebbles and cobbles (a few boulders) of holocrystallines,

metamorphics, and other foreign rocks. A very great variety represented. Some of these are rolled, some are bruised, facetted, and striated. Some are as angular as though directly from a rock crusher. They have been dropped from floating ice. They are not common in the gravelly and sandy phases of the deposit, but are almost always to be found in any cut where the silty phase is dominant.

5. A clayey and sandy matrix, yellowish in color, which surrounds groups of the foreign rock fragments. This phase is but rarely found and is strictly limited to these pockets of foreign angular and subangular gravel. The aggregates of matrix and larger fragments look like till. It seems very probable that they are patches of till, dropped from floating ice in masses a foot to three or four feet across, flattened into a stratiform lens because of a soft, muddy condition.

6. Various combinations and interminglings of the constituents before listed. The most common combination is a sprinkling of the coarse basaltic sand and small basaltic pebbles through the silt Another common combination is foreign pebbles scattered through the silt.

There is a definite directional variation in the composition of the deposit. In the west-central part of the valley it is mostly sand and fine gravel. Near the northern, eastern, and southern margins, closer to the upper limits, it is mostly silt and very fine sand. This horizontal distribution is to be correlated with distance from Columbia Valley. With this is a range in thickness also, the thickest portions known (150 feet maximum) being farthest west. The disseminated large basalt sand grains are less abundant near the eastern and upper limits, though foreign pebbles seem to be as common here as elsewhere.

Cross-bedding is common in the coarse sand and fine gravel. Near the mouth of the valley, foresets in fine gravel dip eastward, up the valley away from the Columbia. Cross-bedding in the finer constituents is rare. Sequences in stratification do not seem to indicate any clearing of sandy, muddy water, such as seasonal variations in glacial melting might give. All that can be said yet is that thickness and order of the strata of different materials seems variable and unsystematic. Marked irregularities in stratification of sandy phases occur. One such structure is illustrated in Figure 9. No satisfactory explanation for this is at hand.

There is virtually no weathering or cementation in any phase of the deposit. There is no brownish, yellowish, or reddish stain to the upper part. Some granitoid pebbles crumble readily, but associated with them are apparently perfectly fresh pebbles of much the same kind of rock. In some of the basalt sand and fine gravel there are distinct strata of the colored alteration products of decomposed basalt alternating with similar strata of fresh black basaltic sand and gravel. It is obvious that this decay did not occur after deposition.

FIG. 9.—Contorted bedding in silt and fine sand, Walla Walla Valley. Etched into relief by the wind.

Whatever conditions were responsible for erosion of the débris, for transportation to the Walla Walla Valley, and for the peculiarities of its deposition here, they surely involved the destruction of a great deal of well-weathered basalt. In some sections a slightly calcareous zone lies a few feet below the surface, but lime is markedly less in amount than in the Palouse loess at similar depths.

The topography of the deposit is exceedingly interesting and rather surprising. All the numerous creeks of the Walla Walla plain have cut 50 feet or more into it and have widened their valleys to the proportions of flood plains. Divides between creeks, where composed of the finer material, carry a multitude of minor drainage lines, only the tops of the divides recording the former plain of aggradation. The topography of the silt deposit in many places blends into that of the higher mature hills of loess. The coarser phases, where dominant, are less dissected and have broad aggradational slopes, descending southward, away from the open Walla Walla Valley and the nearby Columbia, almost as definite as the aggradational slopes of the bars of scabland. If the deposit is of the same age throughout the valley, the differences in amount of erosion apparently must be ascribed to differences in porosity.

The preceding generalized description for the Walla Walla Valley is equally applicable to Snake River Valley and its tributaries above Palouse Canyon. There is nothing to add, and almost nothing to subtract. The curiously contorted bedding in sand has not been found. And apparently the steeper slopes in general determined sloping, instead of flattish, surfaces in the deposit. There is one significant change to make, however. The upper limit is 1,300–1,350, not 1,050–1,080. A separate pond is recorded, its surface about 250 feet higher, though only 12 miles distant at the narrowest place in the divide. By valley route it is 40 miles distant.

The fact that the scabland upper limits at the mouth of the Snake River pond is 1,325 and at the mouth of the Walla Walla pond is 1,050–1,100 may be only coincidence. The reported difference in altitude may be an error. The abundant unweathered basalt grains scattered through the silt may have no genetic connection with scabland erosion. The floating ice recorded by the glaciated erratics in scabland channels may not have drifted back up these ponded valleys during the scabland epoch. There was probably a later glacial episode, with widespread berg-drifting. The apparent record of abundant decomposed débris associated with perfectly fresh basalt may be a mistaken interpretation. The unusual and widespread mingling of coarse basaltic sand grains through silt and fine non-basaltic sand may have some simple explanation. In short, the writer's study of these pond deposits may be too limited as yet to afford a connected story of events here. But the probability of backwater pondings by the Spokane Flood is obvious.

TESTS OF THE SPOKANE FLOOD HYPOTHESIS

The unique scabland features and unique combinations of these features should afford in their relationships a particularly valuable clue to their origin. One may think of a single scabland canyon in terms of a relatively small river working for a long time, but he is sharply checked in applying this idea by the high-level divergences, the huge channel basins, the great bars, the loessial scarps back from the edge, etc. These features are not possessed by canyons with orderly and long-continued histories. So throughout the whole category. The conception of a flood explains these features and their simpler combinations, hence is justified at least as a hypothesis. But will it explain all the relationships? If essentially correct and complete, it must. If it fails, then either fundamental error is indicated or complications of the relatively simple story are involved.

THE QUINCY BASIN CATARACTS

A test for the hypothesis is available in the relations of Crater, Frenchman Springs, and Potholes cataracts to the flood in Columbia Valley. Their upper limits are about 1,300 feet A.T., their cliffs 200–400 feet high (including plunge pools), the bottoms being 100–300 feet below the upper limit of the flood in this part of Columbia Valley. It appears that some sequence here is necessary. The writer previously used the conception of bottle-neck ponding at Wallula Gateway; enlargement of this canyon lowering the flood in Columbia Valley while the scabland rivers were still operating. But this now seems completely barred out, and what sequence did occur is not apparent. If the situation cannot be explained with good supporting field evidence, the hypothesis becomes suspect.

FLOODING IN COLUMBIA VALLEY ABOVE MOSES COULEE

Nothing has been said in the writer's publications about the flood in Columbia Valley above the mouth of Moses Coulee. That part of the valley has not yet been studied. If the hypothesis is correct, a record of the flood must exist here, either of great flow from the ice, or, less probably, of a backwater pond. In the first case we expect the huge mounded bars, the recently scarred cliffs high above the river, the buttes and basins back on high rock terraces, the scarps in overlying weaker formations if contact occurs at the right altitudes. We expect that such scarps will be distributed northward along a rising profile, starting at 1,300 feet A.T. at Crater Cataract.

In the second case there should be widely distributed fine sediments up to a horizontal plane of about 1,300. If neither of these exist, the hypothesis is fundamentally wrong.

The west side of Columbia Valley, opposite Quincy Basin, must carry a record of the flood if the hypothesis is to survive. The record here apparently must be one of flowing water, though if only Moses Coulee and the three cataracts contributed, that flow might not be especially vigorous. Upper limit data here should be directly related to the history of the cataracts.

COLUMBIA VALLEY BELOW WALLULA GATEWAY

This valley has been studied largely on the Oregon side. If the flood hypothesis is in error, the so-called upper-limit features should somewhere, presumably on the Washington side, be so far out of proper position that another explanation would have to be constructed. These features, if not due to a flood, should be absent at the altitude required; they should be found too high or too low, or in non-scabland valleys. Two or more sets of them on the same slope might exist if local conditions alone were responsible. If the many so-called bars and the several so-called divergences of the Oregon side have been incorrectly interpreted because, let us say, of absence of features which would reveal their real origin, search of the Washington side should be expected to uncover them. Trustworthy criteria of their true genesis should not be lacking everywhere. If the hypothesis is correct, the constructional bars should exist in Washington as well as in Oregon, with the proper relations to scabland upper limits, to divergences, and to mouths of tributary valleys.

Several significant places for such study may be pointed out. Sillusi Butte, north of Plymouth, should have the scarp-scabland-gravel combination not much below 1,100 feet A.T. The mouth of Rock Creek should carry large remnants of a tributary mouth bar, thrown back into it from the Columbia, its height not exceeding about 600 feet above the river. Other tributary valleys should have the same record, though at different altitude limits, depending on location along the Columbia. The south face of Columbia Mountain should carry the scabland-scarp-gravel combination at about 900 feet A.T. The north side of the structural valley at The Dalles should have it at about 750. This list might be multiplied indefinitely. One cannot be sure that the record will be present, but if it is, the hypothesis should be credited with having led to new field evidence, and therefore should be correspondingly strengthened. Altitude data are not yet ample enough to justify assertion or denial of post-flood warping along this stretch. This item may develop with later study.

DO THE SCABLAND PHENOMENA RECORD SEVERAL DIFFERENT EPISODES?

The suggestion has been offered by several that the record of the supposed Spokane Flood is really a much more complicated affair, that it is a product of several episodes of glacial spill, the records of which have been uncritically grouped together. This has been put into concrete form for one place in the scablands, the vicinity of Dry Falls and Hartline Basin, Grand Coulee. Presented in this fashion, it exemplifies the type of criticism by which the flood hypothesis will become established or eliminated. It is built on detailed facts instead of general opinions.

Hartline Basin (Fig. 10) carries a considerable gravel and sand fill above the coulee floor. The flattish surface of the gravel plain breaks off to the west in a steep descent to the scabland above the falls. On this western slope are two terraces. The lowest stands 1,650 feet A.T., about 100 feet above the coulee floor, and is composed of silt, possibly Nespelem (Wisconsin in age). The next terrace is 1,750 feet A.T. and is composed of gravel and sand. Bones of a camel from a well in this terrace have been reported by Dr. Kirk Bryan. Dr. O. P. Hay thinks they belong to *Camelus* or *Camelops*, and that this terrace deposit therefore is probably first interglacial in age.[1] One hundred feet still higher is the surface of the Hartline gravel plain, covering about 25 square miles. Here apparently is a record of several stages in the development of Grand Coulee, one of which may be dated from the fossil bones. Which of these episodes was the Spokane Flood? In how many places in the scabland may this sequence be unrecorded or obscure, and whatever features exist have been corraled therefore for the flood hy-

[1] "The Pleistocene of the Western Region of North America and Its Vertebrated Fauna," *Carnegie Institution, Publication 322B* (1927), p. 257.

pothesis? The challenge certainly is justifiable. But before one concludes that this series of terraces affects the hypothesis, let us examine more evidence from Hartline Basin.

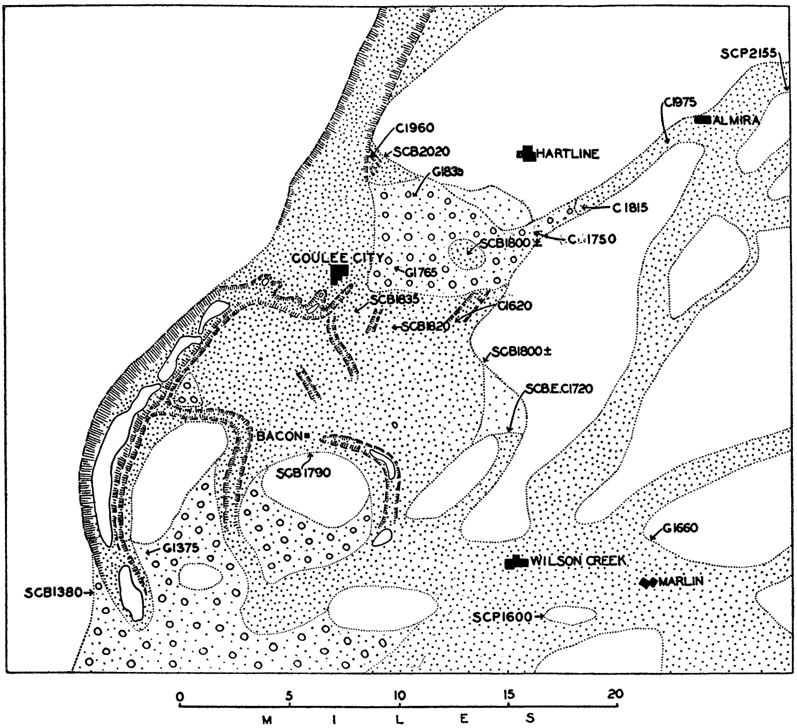

FIG. 10.—Sketch map of scabland features of lower Grand coulee and vicinity. The closely stippled areas are scabland; the tracts with stipples and circles are gravel covered; the widely spaced stipples indicate ponded tracts; the blank areas with dotted outlines are loess covered; and those with continuous outlines are lakes. Figures show altitudes. SCB = Highest scabland; SCP = Base of loess scarp; C = Channel floor; G = Upper limit of scabland gravel; E = Erratic boulders.

These terraces are all below the upper limits of scabland here! There are four places (shown in Fig. 10) which clearly record this fact:

1. The mouth of upper Grand Coulee, 4 miles north of Coulee City, has a prominent salient on the east side, jutting out about a mile between the coulee on the west and Hartline structural basin on the southeast. The 500-foot cliffs of the west side of this salient (the east wall of the mouth of the upper coulee) show the tilted

flows of the monocline only in the extreme southern part. The southeast slope toward the gravel-filled basin is not far from the dip slope. This salient is about 200 feet higher than the adjacent gravel fill, the uppermost terrace which Hay describes from Bryan's unpublished report. The top of the salient is all scabland! Across its summit, close to the higher, soil-covered slopes at the northeast, is a scabland channel 50 feet deep, 600 feet wide, and more than half a mile long. This channel leads with descending gradient *out* of Grand Coulee and *toward* Hartline Basin. Its head is a notch in the summit profile of the salient, 1,960 feet A.T., plainly seen from the highway on the gravel plain. A few hundred yards farther south on the summit of the salient lies another channel, about 30 feet deep but not notched completely across the spur. Its head is amphitheater-like, open to the southeast, and separated by a wall only 50 feet across at the head from the summit of the great cliff descending to the coulee floor 500 feet below on the west. The amphitheater records a subfluvial cataract whose plucking made the channel, but which was abandoned a little before the last of the basalt was torn out to complete a notch such as the northern channel possesses. The channeled scabland salient appears to be a record of the initial spill down the monocline from the north. It indicates that no adequate pre-scabland drainage route occupied the site of upper Grand Coulee. The oldest gravel terrace known in Hartline Basin is the flat. Its highest altitude is 1,835 feet A.T. (1,850, Bryan's figure), or 125 feet below the head of the channel notch on the salient. The highest scabland is as old as this fill. It has been modified by weathering and by deposition of dust and sand as little as any other scabland on the plateau, except that of Wisconsin age.

2. About four square miles of scabland exists out in the middle of Hartline Basin. Buttes and rock basins here with a relief of 40–50 feet stand above the aggraded plain and have mounded gravel accumulations with steep slope on the south or lee side 30 feet high. This scabland is not much less than 1,800 feet A.T. Its situation out in a broad aggraded tract, the continuation of the upper terrace, needs explanation. Running water is the explanation. To put a current of sufficient vigor across this broad flat tract requires very great volume.

3. A minor spillway of the anastomosis of the plateau, previously unmapped, diverges southwestward from the Wilson Creek channel near Almira, crossing the preglacial divide to enter the eastern end of Hartline Basin. The channel floor at the head, on the divide, is 1,975 feet A.T. Where it fades out into Hartline Basin fill its floor is about 1,750. The gradual loss of channel character in the gravel deposit at this altitude shows that it dates from the same episode that made the Grand Coulee upper scabland and the scabland and bars in the middle of the basin. All are above the terraces noted by Dr. Bryan. The initial Grand Coulee discharge was the flood discharge. It coincided with the Crab Creek flood discharge. The persistence of small rock basins on the floor of this narrow channel and of the definite loessial scarps bounding part of it seems difficult to harmonize with the early Pleistocene age suggested for the contemporaneous Hartline plain.

4. The southern rim of Hartline Basin is very significant in this problem. It is all scabland from Grand Coulee on the west almost to the mouth of this channel on the east, a distance of 7 or 8 miles. At least three distinct notches are cut into it (not counting Grand Coulee), the largest of which is Deadman's Draw, well toward the southeastern corner of the basin. The floor of this draw is 1,620, the top of its walls is 1,760, and the upper limit of scabland two miles to the southeast is 1,800±. Deadman's Draw is nearly a mile wide at the top of its walls, and in all likelihood it is a preglacial drainage line out of the eastern part of the basin. But the volume of water entering the basin, almost wholly from Grand Coulee and certainly predating the later episodes of the lower terraces, simply overwhelmed all of the southern rim. Altitudes of 1,820 and 1,835 are reached by the higher buttes of this pronounced scabland. From the unnotched portion of the southern rim the gravel floor descends northward and westward something like 15 feet to the mile. Yet this gravelly débris of Hartline Basin surely was not moved northward. Nor could it have come by way of the minor channel from the Crab Creek anastomosis. It came out of Grand Coulee in the earliest episode of glacial discharge which is recorded here. Its slope against the direction of current can be explained only by the conception of a great stream. It is river-bottom, not river-floodplain,

topography. This up-current descending slope is a consistent feature in scabland gravel deposits.

The writer does not believe that any noteworthy canyon had been developed along upper Grand Coulee at the time the Hartline scabland and gravel features were made. But he does insist that, even if there were no canyon at all, these features of the basin clearly indicate an initial episode of very great flooding, one that clearly antedates the lower terraces noted by Bryan and Hay. The extensive gravel fill of Hartline Basin was not made in backwater; it and the associated scabland tell of notable current across it from northwest to south and southeast. Four or five different stages may well be recorded in the terraces north of Coulee City. The earliest was the flood episode.

Hartline Basin may well have preflood sediments beneath the gravel, just as Quincy Basin appears to possess, and the camel bones may have come from them. That the camel became extinct everywhere in North America shortly after the first interglacial epoch is questioned.[1] For these reasons it seems doubtful that these bones may be used to date the terrace, and doubtful therefore that the youthful topography of scabland dates back to the first glaciation.

FLOODING IN STRUCTURAL VALLEYS

Since scabland high on the walls of erosional valleys might be a record of early stages in that valley's development, some may render judgment on the writer's interpretation as "not proved." But if a structural valley could be found, essentially unmodified by erosion or deposition before the glacial waters arrived, and so placed and proportioned that a relatively small glacial stream could pass through, it might afford significant evidence. Such a valley of adequate width and depth could not have high-level scabland by the alternative hypothesis. If it had high-level records at all, they would be only of ponded water.

Since such a valley is not impossible on the Columbia Plateau

[1] J C. Jones, "Geologic History of Lake Lahontan," in "Quaternary Climates," *Carnegie Institution, Publication No. 325* (1925), pp. 49–50. Kirk Bryan and J. W. Gidley, "Vertebrate Fossils and Their Enclosing Deposits from the Shore of Pleistocene Lake Cochise, Arizona," *American Journal of Science*, 5th series, Vol. II (1926), pp. 487–88. A. S. Romer, article to be published in *Science*.

in Washington, where structure is directly responsible for the major relief features, the writer kept this test in mind during the 1927 field season, hoping to find the combination required. And two valleys which appear to meet the conditions were found. Both are in Grant County, south of upper Crab Creek and east of the northern part of Quincy Basin. They are sub-parallel, oriented about northeast-southwest, lying across the downstream angle between the creek valley and the basin. The western of the two structural valleys is in open connection with the creek's erosional valley, the junction being south of Wilson Creek station. Chain Lakes, 2 or 3 miles from that station, lie in this broad structural sag, about 100 feet higher than the creek valley floor.

Though the slopes of the broad streamless valley are strikingly cliffed, there is no canyon form such as Crab Creek possesses. The cliffs are set back like great risers, and there is much channeling along the slopes. Rock basins, however, dominate in the part examined. They range from 30 to 50 feet in depth. They are so thickly set that, if topographically mapped, apparently as much area would come within hachured contours as outside of them. No dipping flows were seen. The deformation involves a sag of 200–300 feet in a tract about 5 miles wide. Crab Creek below the junction with this broad valley must have held its pre-deformation course during the warping. It cuts through land that is higher than this route.

The upper limit of scabland at the head of this divergence is 1,600 feet A.T., 275 feet above the floor of Crab Creek and about 175 feet above the floor of the sag. A wide sheet of water flowed out of Crab Creek Valley here toward Gloyd, on the eastern rim of Quincy Basin, its surface descending about 300 feet in 12 miles. Erosion was limited to etching out the cliffs and basins on the slopes of the sag.

The eastern structural valley is smaller and looks more like a stream valley. It has no open connection with Crab Creek Valley just to the north. On its floor is a string of rock-basin lakes 2 miles long, known as Long Lake or Black Rock Lake, in a setting of scabland cliffs that extend 250 feet up on the slopes. Water flows westward along the string of lakes.

A mile east of the lakes the valley is about 2 miles wide and has long gentle slopes without marked scabland, though also without a loess cover. Altitude of its floor here is about 1,550 feet A.T., 150 feet higher than Crab Creek floor at Marlin, almost directly north. The valley here is streamless and its floor is marked by broad sags and swells. This is near the head. Two miles farther east is well-marked scabland on the divide between Crab Creek and the structural valley. Upper limits on the divide are a little above 1,650 feet A.T. Glacial water indubitably flowed out of Crab Creek route across this divide and moved southwestward along this sag. Where wide enough, no scabland was produced. Where narrower, as at the lakes, erosion occurred on the slopes over a vertical range of 250 feet. No dipping flows were seen here, but the topographic relations seem to make a clear case for structural origin. The sag probably had free drainage southwestward before the episode of the flooding (for it contains no fill), but its divide at the north was more than 250 feet above the floor of Crab Creek Valley.

If these two valleys across from lower Crab Creek to northern Quincy Basin were open structural affairs when glacial diversion across the plateau first occurred, divergent streams from the glacial Crab Creek river were voluminous enough to leave the scabland record as high on their walls as on Crab Creek Valley itself. Repeated floodings of smaller volume would never do this, even if Crab Creek Valley was shallow at the beginning of the assumed series of floods.

POND OUTLETS

If the larger structural and erosional valleys of the plateau antedate glaciation, and if glacial waters ever were of the volume which the writer has set forth, then the ponding or backwater in the unexamined valleys should in some place or places have been high enough to escape through the lowest saddle in a margining divide and to enter an adjacent valley. This combination could not be expected to divert water from the Columbia system, but it might be expected to produce a local scabland channel, unconnected at its head with the rest of the system. This channel head should correspond in altitude with the highest record of ponding and with scarp bases of the particular scabland river responsible for the ponding.

Such a setting is provided by the pond of Snake Valley above Palouse Canyon (1,350 A.T.) and that of Walla Walla Valley (1,050–1,080 A.T.). But the separating divide everywhere appears to have been higher than the Snake Valley pond. Another place for this combination is Yakima Valley and Columbia Valley, with the separating Horse Heaven Hills. But here again the divide between is everywhere higher than the flood could have been in Yakima Valley. Another divide that might have been crossed by discharge from a ponded tract, had it been low enough, lies between Walla Walla Valley and Umatilla Valley. It is a continuation of Horse Heaven Hills anticline, and, had it been crossed either here or south of Yakima Valley, the crest of the flood through Wallula Gateway would have been lowered.

The most striking place for a possible realization of pond discharge lies in Idaho, in the large valley occupied in part by Coeur d'Alene Lake. Discharge should have been across its southern or western rim. This rim divides the lake basin from the headwaters of Potlatch River (flowing south to the Clearwater and thence to the Snake), Palouse River (flowing west to the scablands) and Latah Creek (flowing northwest to Spokane River). The rim is lowest on the west, there being only 2,750–2,800 feet A.T. But it nowhere shows a scabland channel across this divide to Latah or Palouse drainage, though there are many berg-drifted erratics ranging up to 2,550 all around the lake. The Spokane ice did not close the northern opening of the Coeur d'Alene Valley, and ponded water here escaped westward along the south side of the Spokane Valley to the eastern head of scabland, where scarps, erratics, and channeled basalt ranging from 2,450 to 2,550 are found.

This recital will suggest that there is little hope of finding a place to apply the proposed test. Very probably no major example exists. Two minor ones, however, have been found in the field study. One of these has been described in a paper on the bars of channeled scabland, now submitted for publication. The other will be described here. It is a small valley entering Crab Creek from the north, a few miles east of the mouth of Grand Coulee. Its scabland is limited to the bottom and lower slopes, and is not pronounced. But it has gravel deposits of the type associated with true scabland and unknown in valleys of the plateau, which carried no glacial waters. It also has erratic pebbles, cobbles, and boulders. Traced northward, upstream, these features are found to the head and on the divide at the head. (SCB.E.C. 1,720 on Fig. 10). But down the opposite slope of this minor divide there is only the mature topography with its mantle of fine material. No scabland exists here.

An earlier statement by the writer, that every scabland channel when traced up-gradient leads continuously either to another scabland tract or to the glaciated area, is not true for this place. This scabland ends on a divide top, with only the normal surface to the north and west of it. Alternatives which clamor immediately for recognition are as follows: The scabland may be a product of local run-off, or it may be an exhumed rugose surface of the basalt. The gravel may be of local stream origin or it may have come to light with removal of the loess by the local stream. The erratics may have been floated back in the later submergence, or they too may have been buried beneath the loessial cover and only locally exposed.

We are not limited, however, to these features alone. The altitude of the divide where the highest scabland and erratics occur is known. And the existence of a large scabland tract to the north and west is known, a tract lower down the western slope of this divide. It is the broad area south of Hartline Basin, the highest isolated scabland buttes of which are 1,820 and 1,835 feet A.T. The glacial waters flowed southeastward across this scabland, escaping from the main Grand Coulee route. The upper limit on an island tract, 9 miles almost directly west of the divide we are considering, and therefore somewhat upstream, is 1,790. The divide at the head of the minor scabland route is 1,720. If flowing water in the larger tract were up to 1,790 on this hill, it must have caused flooding back on the gentle western slope of the divide. A pond record should exist over this slope which lay below the flood level but out of the main currents. There has been no opportunity yet to search for it. But if it does not exist, something is wrong with the flood hypothesis. If it does exist up to this divide and no higher, only the flood hypothesis will explain the entire combination of features here.

POND DEPOSITS

There are several valleys entering scabland which have not been studied except at their mouths. If they fail to carry the pond deposits at appropriate altitudes, something is wrong in the scheme. Also, if the ponding was due to ordinary seasonal melting, varved clays and silts should record the fact. If pulsatory elements of any kind were involved, the fact should come to light from a study of the backwater deposits. It seems likely that these records of standing water will contribute more toward an understanding of the nature of glacial discharge across the plateau and down the Columbia than will the records of running water. They constitute a sedimentary record, a cumulative record. Except for the bars, all else is essentially a surface of unconformity without an overlying deposit.

FOSSILS IN FLOOD SEDIMENTS

If the writer's hypothesis be correct, the various sediments ascribed to the Spokane Flood should be unfossiliferous. To date, no fossils are known from them. Dr. Hay's lists of Pleistocene vertebrates from Washington and Oregon[1] contain no finds which, in the writer's opinion, clearly come from scabland deposits. Some discoveries are reported from scabland tracts at altitudes below the local upper limits, but burials were in other sediments in those tracts. If fossils ever are found in the so-called flood sediments, and if they were not derived from destruction of older deposits, and do not come from older deposits beneath or younger deposits above, a quite different interpretation must be devised for the scabland sediments.

CONCLUSION

The cause of the Spokane Flood is unknown. The cause of the glaciation which was an antecedent of the flood is also unknown. Many suggestions for the cause of Pleistocene glaciation have been discarded as inadequate or impossible. It is far from safe, however, to conclude that the incompetence of any particular postulated mechanism to furnish the ice sheet required by our interpretation of the field evidence seems to call for a reinterpretation of that evidence. It would be much safer first to show that the field evidences

[1] *Carnegie Institution Publication 322B.*

are inconsistent with themselves when glaciation is read from them, and that they have some more satisfactory explanation. The writer hopes earnestly that this method of approach to the problem of channeled scabland will not be neglected. Only through adequate familiarity with its features can it be judged. Only thus can workable alternative hypotheses be constructed. If and when these appear, the writer's explanation may be discarded, having to its credit only that it provoked adequate study of a most extraordinary assemblage of unique physiographic forms.