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VALLEY DEPOSITS IMMEDIATELY EAST OF THE CHANNELED SCABLAND OF WASHINGTON. I

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ABSTRACT

Forty-one valleys whose drainage enters the eastern margin of scabland spillways are known to contain deposits made by glacial waters. Thirty-nine of these valleys never have carried drainage from glaciated areas, and the glacial waters in them must have been backed up from the scabland. These deposits possess such extraordinary features and relations that they, like the scabland topographic forms, are considered unique.

1. Each separate area of backwater is recorded by a widespread mantle of silt containing abundant grains of unweathered basalt (the country rock) and pebbles of foreign rock.

2. In each, this mantle extends up to a definite upper limit on the valley slopes and along the valley lengths.

3. These upper limits in each case agree closely with the upper limit of scabland where the valley enters.

4. The altitudes of the upper limits, constant throughout any one backwater area, vary with different pondings, forming a descending series from north to south along the scabland gradient.

5. Remarkable large mounded gravel deposits in the tributary valley debouchures possess foreset strata which dip *out* of the scabland and *up* the valleys. The composition, topography, topographical relations, structure, and size of these deposits are inexplicable without great *reverse currents*.

6. In no case could these reverse currents continue through and escape from the valleys they entered. They are simply a record of the rapid backflow into these valleys.

It is concluded that these glacio-aqueous deposits cannot be explained by conditions associated with ordinary glacial ablation or by a sequence of several Pleistocene epochs. They require the volume and rapid rise of glacial rivers across the plateau, which the writer has previously read from the scabland itself.

INTRODUCTION

About forty different stream valleys draining westward into the easternmost of the channeled scabland tracts of the Columbia Plateau in Washington are considered in this paper. Many of them are tributary to others, so that the total number of separate entrances into the scabland is twelve. The northernmost and southernmost of these entrances, measured along the scabland margin, are about 125 miles apart.

The deposits studied are thickest and coarsest close to the entrance of these valleys into the scabland. They extend up on the valley slopes as high as the loessial scarp bases along the adjacent scabland. They also extend back up these valleys approximately to the crossing of the contour which marks both their upper limit and the scarp bases at debouchure into the scabland. In all but three of these valleys, essentially the full length was examined, and the absence of these deposits farther upstream than the contour crossing was established for all but two. But the distance upstream to such crossings and the altitude of these crossings vary in different valleys.

Although the deposits are prevailingly coarser nearer the scabland, there are great variations in character and structure in any one portion of a valley. The diversity much exceeds anything ever previously reported for stream-valley deposits, so far as the writer is aware. A classification might be attempted on the basis of textural gradations; it might also be constructed on a basis of sedimentary structures. Either method may give the impression that these sediments are much like other silt, sand, gravel, and boulder accumulations, or that the genesis of their bedding structures is similar. The only terms available for description of these deposits have genetic associations, and it will be difficult to avoid an erroneous mental picture despite caution on the part of both writer and reader. The printed page cannot convey the picture which field acquaintance gives, for there probably is nothing in the reader's experience sufficiently resembling the structural, textural, and topographic features of these deposits. All gradations and interminglings possible exist. One must not think of the textural types as distinctly separated from each other. To do so is to miss one of the most significant facts regarding them.

The region will be treated areally, and the distribution and relations of the deposits will be considered valley by valley, beginning in the north and progressing southward along the eastern margin of the scabland. The area involved is shown in Figure 1. Three of the twelve separate valley entrances into the scabland are major streams. Palouse River has one tributary sharing in the record, Snake River has eleven with three subtributaries, and Walla Walla River has four tributaries and seven subtributaries which carry the deposits. In addition there are eight separate minor valley entrances, and among

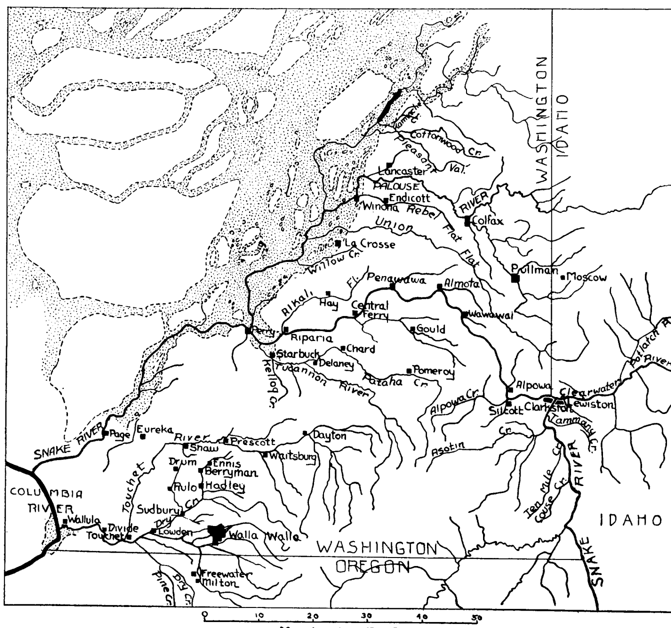

FIG. 1.—Valleys immediately east of channeled scabland

them four tributary valleys to be considered. This total of forty-one distinct valleys is only the total of those examined. Because of limitation of time, at least a dozen more tributaries and subtributaries of Snake River, joining below the known upper limits of loessial scarps and valley deposits, had to be left for later examination.

PALOUSE RIVER DRAINAGE

KAMIACHE CREEK VALLEY

The northernmost valley involved in this study is that of Kamiache Creek which enters the scabland just south of Rock Lake in northwestern Whitman County. The valley is only 7 miles long, though the stream flows 2 miles beyond the valley mouth across scabland before it joins Rock Creek at the foot of the deep rock-basined lake. The contrast between the 7 miles of normal stream valley and the 2 miles of scabland can hardly be appreciated by one who has not seen it. Probably nothing like this has ever been described. Above the entrance to the scabland the valley is wide and flat bottomed, with alluvial deposits and low terraces on the floor, and with stream-etched slopes descending to it from the divides surrounding it. Through this valley the creek flows with a gradient normal to such minor streams in a mature topography. But out on the scabland there is no valley at all. Bare and rugged rocky buttes are distributed very irregularly among the rock basins and rock-bottomed spillways which separate them, making the anastomosing pattern which is typical of scabland. The extreme youthfulness of slopes here is emphasized by the cliffs, the blocky talus, and the unfilled basins. The utter unlikeness of this anastomosing pattern to stream valleys has been repeatedly pointed out by the writer as indicating that scabland is stream-channel topography. The impossibility of these channels recording a succession of routes has also been shown. They are contemporaneous and constitute simply the highly diversified rock floor of a very great glacial river whose surface was higher than the tops of the buttes.

Another topographic feature unique in the scabland system is the lines of steep loessial scarps which truncate the mature topographic forms to the east and overlook the scabland to the west. The base of the scarp immediately north of Kamiache Creek entrance is 1,880 feet A.T. Scabland descends thence down to Rock Lake, 145 feet lower, and in the rock basin of the lake to a reported depth of 250 feet. The total vertical range, therefore, is nearly 400 feet. The loessial scarps belong to the scabland forms, not to the older slopes along the creek valley.

If, then, Kamiache Creek above the scabland is much older than the scabland itself[1] and its bordering scarps, and if the volume and

[1] Kirk Bryan, in *U.S. Geological Survey Bull. 790-B*, clearly recognizes the existence of two kinds of drainage ways on the Columbia Plateau in Washington, one group (scabland) containing those "that were deepened and modified by the great streams diverted across the plateau during glacial time" and the other group, those "developed by normal erosion before the diversion of the glacial waters." He notes that some normal valleys "formed in a cycle of erosion that antedates the great coulees produced in the diversion of the glacial waters" are tributary to scabland spillways.

depth of the glacial rivers were as great as the writer has argued, the lower part of this creek valley must have been flooded with glacial water back from its entrance into scabland. Whatever may be expected or interpreted as a record of this flooding must not occur higher on the valley sides or higher upstream than approximately 1,880 feet, and it must be well marked below that altitude. These restrictions, set forth for Kamiache Creek valley, are applicable equally and are equally required for the forty other valleys considered.

Kamiache Creek valley is remarkably constricted at its debouchure into scabland where the stream crosses the line of loessial scarps. The bottom width in the valley itself is about 1,000 feet for 3 or 4 miles above the mouth, but in the mouth there is no bottom width. Instead, the stream enters a narrow gulch about half a mile long and 50–100 feet deep, through which it descends 100 feet in passing from the normal valley to the scabland. The south wall and the bottom of this gulch are of basalt; the north wall is of gravel.

If one climbs this northern gravel wall of the gulch, he finds himself on a remarkable spur which projects southward completely across the valley (save for the gulch itself) from the northern valley slope. This spur is 1,000 feet long (across the valley mouth) and about half a mile wide (measured with the stream length). Its summit is 150 feet higher than the scabland immediately west and 50 feet higher than the valley floor immediately east. This summit is irregularly rolling and has undrained depressions on it. On the east it descends steeply to the flat valley floor.

The spur which thus transforms Kamiache Valley at the mouth into a narrow gulch is composed of very angular and poorly sorted basalt pebbles, cobbles, and boulders. A pit on the west side of the spur near the base shows only foreset beds, dipping 21°–23° southward across the course of the valley, along the scabland length, and along the direction of the aligned loessial scarps. The top of this singular deposit is 1,865 feet A.T., 15 feet lower than the scarp base about half a mile to the northward. Between them are bare, or nearly bare, knobs and ledges of the highest scabland.

The flat floor and gentle slopes of Kamiache Valley afford only one adequate section in the first 4 miles east of this abnormal gravel deposit. The material exposed is sandy silt, poorly stratified and poorly sorted.[1] Unweathered pebbles scattered irregularly through this material are composed of various rocks which certainly do not outcrop in the creek's drainage area. A small unweathered granite boulder was found at 1,850 feet A.T. East of this point, only alluvium of reworked loess, containing some basalt gravel, was found on the valley floor, and only loess on the valley slopes. There is no gravel deposit between the basalt and the loess and, therefore, no possibility of deriving the fresh granite, quartzite, etc., from the creek's drainage area. There is no possibility whatever that the great deposit of angular basalt gravel, containing boulders 3 feet in diameter, rising abruptly 50 feet above the flood plain, containing long deltaic foresets dipping southward across the valley, and clearly once completely blocking the valley, has been made by the creek. Just above the summit altitude of the gravel deposit are loessial scarps facing scabland to the west. This gravel mound, lying along the margin of the scabland and extending throughout almost its whole exposed vertical range, is a unit deposit with a definite topographic form modified subsequently only by erosion of the narrow gulch. It is a torrential deposit of some sort, built originally from the north completely across the mouth of the valley, and definitely related to the genesis of the scabland. The silt and erratic material up the valley do not occur higher than the summit level of this barrier.

[1] This silt was shaken through a series of ten sieves ranging from 1 mm. opening down to 0.074 mm. Material stopping on the 1 mm. sieve yielded recognizable particles of granite, quartzite, schist, mica, feldspar, clear quartz, and basalt. The quartz is abundant, its grains mostly sharp angular pieces with hackly surfaces, though some grains are rounded. Grains partly of quartz and partly of feldspar, and others of quartz with mica only partially embedded in it, tell of mechanical disintegration without weathering. The mica occurs in thick pieces, essentially broken mica crystals, instead of mica flakes. The percentage of basalt, the country rock, is low. It occurs as angular broken particles of fresh black rock and also as crumblike bits of reddish weathered rock. Material stopping on the 0.71 mm. sieve has a higher percentage of fresh broken bits of basalt, though down through the finer sieves the proportionate amount of basalt decreases rapidly while the proportion of quartz increases to 75 per cent on the 0.147 mm. sieve. Many of the particles of quartz on this sieve are shaped like splinters, two or three times as long as wide or thick. More than 50 per cent of the silt stops on or passes the 0.074 mm. sieve (200 meshes to the inch). In texture and in color it is identical with the loess of the nearby higher slopes.

COTTONWOOD CREEK VALLEY

This much larger stream enters the scabland 1½ miles southwest of the mouth of Kamiache Valley. The same striking contrasts between the topography upstream and downstream from its entrance exist as in Kamiache Creek. The interpretation of scabland as channel topography demands the same corroborative evidence in this valley. It is here but differently expressed.

The valley-mouth bar depending from the north and constricting the valley is much less definitely shown. It apparently never completely crossed Cottonwood Valley. There is no gulch across it and no steepened gradient comparable to the Kamiache features. But there is another bar, just south of the mouth of Cottonwood Creek valley, and its relations to scabland on the west and to loessial scarps on the east are clearly shown. Its upper surface falls but little short of the scarp base, its slopes are broadly convex and it partially buries scabland knobs. Bar deposits, therefore, testify to the depth of water in the glacial river at the mouth of Cottonwood Creek and indicate the necessity for silt deposits back in Cottonwood Valley pond.

Such silt is exposed in many places in the mature valley, extending back at least 6 miles from the bar. Since the valley-mouth bar does not appear ever to have constituted a dam, the silt can hardly be interpreted as deposited in a local pond. That it is not wholly from local drainage is abundantly shown by the presence of many pebbles of varied foreign materials.

The silt occurs in definite terraces near the junction of Pleasant Valley with Cottonwood Creek. Both streams have re-excavated their valleys to a depth of 30 or 40 feet in this silt, and many minor drainage furrows have been eroded across the terraces. Two miles or so farther up each valley, the silt deposit constitutes a fairly complete floor, only slightly trenched by streams.

A 30-foot clean section of the silt shows distinct stratification. Some strata are composed of the local loess, rehandled by water and largely free from other material. Other strata have abundant grains and small pebbles of basalt scattered through the dominant loess. Much less numerous are the angular grains and pebbles of foreign rock. They are rarely grouped together in laminae, lenses, or pockets. The undisturbed stratification shows that the widespread dissemination of coarser material through the loess-silt is a result of original transportation and deposition together.[1]

This association of grains and small pebbles of foreign rock and of both fresh and weathered basalt in the reworked loess is consistently present in all the silt deposits described in this paper. Whatever the cause of ponding in these valleys, it did not allow the degree of sorting and segregation that occurs in essentially all water-laid deposits. Glaciers and mud flows leave unsorted valley deposits but obviously did not make these.

The silts in Pleasant Valley were identified within 2 miles of St. John at an upper limit of 1,940 feet A.T. None was found higher on the slope or higher up the valley, a feature indicating transportation up-valley rather than down-valley.[2]

PALOUSE RIVER VALLEY

This stream enters the scabland about 8 miles south of the entrance of Cottonwood Valley and at an altitude approximately 200

[1] Three samples of the silt in Cottonwood and Pleasant valleys were sieved, as described for the silt of Kamiache Valley. One sample came from the highest of the deposit, 1,940 feet A.T., and in all respects was like the other two. Material stopped on the 1 mm. screen was about 50 per cent basalt, all in small pieces. The larger fragments, ranging up to 1 inch in diameter, consist of granite, quartzite of several colors and textures, vein quartz, phyllite, muscovite schist, broken feldspar, and muscovite crystals. One mica fragment measured $\frac{1}{4}\times\frac{7}{16}$ inch. Part of the basalt present is in unweathered or but slightly weathered angular pieces whose surfaces are cleanly broken, part consists of much weathered pellets and crumbling pieces. In material stopped on the 0.71 mm. sieve and examined under a magnification of ten, some of the weathered pieces break when compressed in small tweezers or yield a claylike material when scraped. Yet some of the clean-fractured basalt particles are so hard that their sharp edges will take a steel mark from a knife blade. Sharply angular quartz grains are found in all the coarser sieves, though such sizes are unknown in the loess above the glacial water level, as are the bits of foreign rock. The material stopped by, and passing, the 0.074 mm. sieve amounts to 58 per cent, 60 per cent, and 85 per cent in the three samples.

[2] This altitude of 1,940 feet is 60 feet above the highest scarp bases in this latitude. If there is no error in measuring, it seems to indicate that the glacial waters in the scablands reached well up on some of the scarps and that scarp bases, therefore, are not the upper limits of the glacial rivers in the scablands. More evidence indicating this is found in a minor valley entering the scabland about 2 miles south of the entrance of Cottonwood. The scarp bases here are 1,865 feet A.T., and the silt occurs for half a mile back in it and 20 or 30 feet higher. It is the same type of deposit, carrying abundant coarse angular grains of black basalt with a few granite and quartzite particles.

feet lower. The profile of the floor of Palouse Canyon continues out into the scabland without interruption; the canyon walls, though scoured into scabland forms, are traceable for some miles out into the glacial drainage way; and the normal canyon for $1\frac{1}{2}$ miles above the scabland is clogged with thick gravel deposits. Though the gravel is now dissected, there are extensive remnants of the original surface, and these consistently descend toward the east, or up-canyon. The bar profiles are unmistakable. A large remnant on the south side of the canyon also slopes down toward this wall, creating a broad fosse between the gravel mound and the north-facing cliffs. The maximum thickness of this gravel is more than 75 feet. Sections are few and unsatisfactory. One exposure in the eastern and lower part of the deposit shows irregularly bedded basaltic gravel, coarse basaltic sand, and fine brown sand and silt, with a total thickness of 40 feet. Cobbles and pebbles of various kinds of foreign rock are present.

There is no road or railroad along Palouse Canyon for nearly 20 miles, and no examination was made for silts up-valley from the significant gravel deposits. But Lancaster Creek, a tributary entering from the northeast, contains this silt for at least 4 miles above its junction with the Palouse, or 5 miles by valley from the scabland margin. A section 15 feet thick at 1,615 feet A.T. showed disseminated coarse grains and pebbles of fresh basalt, and a few foreign fragments.[1]

REBEL FLAT CREEK VALLEY

The preglacial course of Palouse Canyon makes a right-angled turn to the south less than a mile out in the scabland and another right angled turn back toward the west about 5 miles farther downstream. At this latter angle, where the town of Winona stands, Rebel Flat Creek enters Palouse River from the east. Scarp bases just south of Winona, marking high-level divergences southward

[1] Seventeen per cent by weight of the total sample of this silt stopped on the 1 mm. sieve. Half of this consists of 6 angular pebbles of foreign rock. Seventy-five per cent of the remainder is basalt. By the mechanical tests outlined in describing silts of Cottonwood and Pleasant valleys, most of this basalt is but slightly weathered, though some is friable and soft. The little weathered basalt looks perfectly fresh in color; the crumbling particles are dark red in color and commonly do not show the clean-broken chiplike shapes with sharp edges. Seventy-one per cent of the total sample is essentially loess in texture and color.

across the preglacial divide toward Union Flat Creek, are 1,605 feet A.T. The floor of Rebel Flat is adjusted to the Palouse Valley floor at Winona. Its tributary valleys and all its slopes show that it is but a part of the general maturity east of the scabland, far older than the youthful scabland. Silt deposits for a few miles east of Winona show that, like the valleys thus far described, Rebel Flat was here in essentially present proportions before the glacial discharge eroded the scablands.

The silt deposits extend up this valley for at least 3 miles east of the scabland. One section, a mile east of Winona, shows 15 feet of material, well stratified and well sorted, mostly rehandled loess. Near the bottom of the section are two or three layers containing coarse black basaltic sand. A very few small erratic pebbles were found.

Near the up-valley limit of the silt are dissected terraces, 25–30 feet high, cuts in which show poorly stratified and poorly sorted pebbly silt. No deposits and no terraces of this character were found farther east. The highest altitude in which the silt is known to occur in this valley is 2 miles west of Endicott, 1,500 feet A.T. and 105 feet below the scarp bases at Winona.[1] But shallow road cuts are the only sections available, and in these the overlying loess or dust generally is not cut through. No gravel deposit has been identified back in the mouth of Rebel Flat Valley.

UNION FLAT CREEK VALLEY

The lower 15–18 miles of Rebel Flat and Union Flat are nearly parallel, with an upland about 5 miles wide separating them. The southern valley is much longer, however, and its gradient near scabland is lower than that of Rebel Flat. Correspondingly, silts recording glacial backwater extend farther east in Union Flat. They are exposed in road cuts along approximately 14 miles of this valley,

[1] The material stopped by the 1 mm. sieve, 8 per cent of the total sample, is dominantly of basalt, most of which is but little weathered, though a few particles are much decayed. Foreign rock is represented by bits of granite and quartzite. Ten per cent of this coarsest material is quartz. On the 0.71 mm. sieve a larger percentage of the basalt is unweathered, and 35 per cent of the total is composed of quartz grains, most of them nearly 100 per cent angular. The material stopped by the 0.5 mm., 0.35 mm., 0.25 mm. and 0.177 mm. sieves is 50 per cent quartz grains. Sixty-seven per cent of the total sample is reworked loess.

highest at the easternmost exposure, where they are 1,680 feet A.T.[1] Foreign pebbles are abundant in the silt at 1,500 feet A.T., about 8 miles above the mouth.[2]

No localized gravel deposit was seen at the mouth; but the valley is a mile wide, and the glacial river channel it enters here is wide and shallow. The conditions favoring a marked valley-mouth bar were not present.

WILLOW CREEK VALLEY

Glacial waters crossed the divide between lower Union Flat Creek and the minor subparallel Willow Creek valley on the south, entering the latter in no less than five places. More than half the length of this valley was traversed by glacial streams, only the upper 6 miles of its course escaping the great changes wrought by the invading flood from the north. Yet the volume which followed the Palouse, swinging around the western end of the original divide, was so much greater that a bar was built in the mouth of Willow Creek valley close to its junction with Palouse River. It is a larger and even more striking feature than that in Kamiache Creek valley.

This strictly local great mound of gravel has a total vertical range of 200 feet. It originally completely blocked Willow Creek valley, and out in the middle of this valley was 100 feet thick. The bar is nearly a mile wide (along the valley length). The length of the bar lies across Willow Creek valley and extends somewhat up-valley on the south side. At the north end the bar form is lost on the upper slopes, where the deposit is a thick mantle of gravel that rises north-

[1] The coarser constituents of this sample are almost entirely of basalt, and almost all of this basalt is weathered. Yet coarse, angular quartz particles and one particle of quartzite are contributions from glacial water backed up this valley. Some of the basalt is but slightly weathered. Less than 4 per cent of the total sample was stopped on the first two sieves; 70 per cent passed all sieves; and 12 per cent passed all but the finest sieve (0.074 mm.). This fine material, as in previous sievings, is essentially loess. The altitude here is 140 feet higher than the scarp bases on minor loessial islands in scabland about a mile below the entrance of Union Flat Creek, and 75 feet higher than scarp bases at Winona, 5 miles north of the entrance. This is further evidence that the surfaces of the glacial rivers were somewhat higher than the bases of the loessial scarps. Though this makes more difficult any precise reconstruction of the surface gradients of these scabland streams, it strengthens the case for great volume.

[2] Fifteen per cent of this sample is stopped on the 1 mm. screen. More than half of it is foreign material, granite and greenish quartzite predominating. Much of the basalt is weathered. Seventy-three per cent of the total may be called loess.

ward to 1,380 feet A.T. about 100 feet below the nearby scarp base. On the south side the gravel deposit extends up to about 1,420 feet A.T.

Two distinct ridges with a constructional sag between them stand on top of the bar where crossed by the highway. Cuts through these ridges show complicated depositional structures that are very difficult to explain in detail, though they clearly record a tumultuous flow of water out of Palouse Valley and back up Willow Creek across the top of the bar. The material is mostly angular basalt cobbles and pebbles with subordinate amounts of coarse, black or gray basalt sand. There are some definite strata and irregular lenses of fine sand and silt. Some of the finer material is cleanly sorted and stratified, but some is charged irregularly with grains of coarse basaltic sand.[1] Beds of well-stratified gray sand in one place dip eastward up Willow Creek at angles ranging from 22° to 35°. These beds rest with steep contacts on the edges of the nearly horizontal stratified basaltic gravel. Close to the contact, the stratified sand dips 35°. About 6 feet farther east, out in the sand, the dip is 30°; and in another 6 feet to the east, the dip is 22°. Overlying this foreset sand bed is a subangular basaltic gravel, also foreset and dipping about 20° to the east. Minor distortions in the sand foresets show that there was some slumping during aggradation, or soon afterward, but the inclination of the beds as a whole is not due to any slumping. Vigorous shifting currents in the great eddy back into the mouth of Willow Creek are shown in the diverse character and stratification of the débris, in the steep contact of these dipping beds on nearly horizontal beds, and in the other erosional surfaces shown in the section. It must be remembered that all this is on top of the bar deposit, at least 100 feet above the floor of Willow Creek valley.

In the upper part of this valley, east of the entrance of glacial waters across the divide from the north, silt terraces are recognizable for a mile or so. This is the same pebbly and sandy silt already described for other valleys and contains bits of quartzite, granite, and

[1] This pebbly silt appears to be identical with that in the valleys upstream from the scablands. The extraordinary mechanism that produced the intimate intermixture of coarse and fine material seems to have operated at times during the deposition of this bar.

other foreign rock.[1] None of the material was found higher than 1,550 feet A.T. The nearest scarp base whose altitude is known is about 3 miles up the scabland gradient at 1,540 feet A.T. Certainly the bar described is a constructional form which blocked Willow Creek valley; certainly its total vertical range is 200 feet; certainly its summit was swept by strong currents out of the main scabland; certainly Willow Creek contained backwater at this time; and certainly the bits of fresh granite and unweathered basalt in the terraces farther up Willow Creek did not come down that drainage way.

All the valleys thus far considered are tributaries of Palouse River, though only one (Lancaster Creek) enters that river east of the scabland. All the streams immediately south of Union Flat Creek, except Willow Creek, enter the canyon of the Snake; and only through it do they open into scabland. The huge glacial river entered the valley of Snake River across a wide tract of scabland whose eastern edge is close to Riparia. Examination of the astounding features recording glacial backwater in the Snake and its tributaries will begin at Riparia and will be extended up that drainage way as far as it has been studied.

SNAKE RIVER VALLEY AND ITS TRIBUTARIES

There are enormous mounded gravel deposits in Snake River canyon near the junction of Palouse River where the glacial flood entered from the north. They may be traced eastward up the northern side of the Snake almost to Riparia. The deposit is thickest (260 feet) near the entrance of the Palouse and thinnest (150 feet) at the eastern end, but there is no definite progressive lowering of altitudes up the valley for the 5 miles of its extent. One minor gulch draining from the northern wall of Snake River valley was dammed by this deposit to a depth of at least 100 feet and has subsequently cut a narrow ravine through the gravel. A comparison of the ravine slopes

[1] Two samples, collected a mile apart, one at 1,500 feet, the other at 1,550 feet A.T., show very similar characters. One is 75 per cent loess; the other, 67 per cent. Three and six-tenths per cent of the material in one is composed of particles larger than 1 mm; 7.4 per cent, in the other. Both contain vein quartz and greenish quartzite, one yielded a fragment of mica schist. Basalt particles dominate in the coarser screenings; some much weathered, some very little altered. In both there is an increase in the percentage of angular quartz particles down at least to the 0.147 mm. sieve.

and the broad rolling surfaces of the deposit shows how little the original topography of the gravel deposit has been modified by run-off.

The débris for this rude terrace-like deposit came from the north in considerable quantity directly over the eastern part of the basalt wall against which the deposit rests. In several places it filled, or nearly filled, pre-existing minor gulches descending this wall, making remarkable features that look more like very long narrow gravel fans than anything else. But each fill is traceable up to scabland surfaces at about 1,000 feet A.T., and each contains non-basaltic débris like that already noted in the valleys to the north. There is nothing like these gravel-filled ravines in the Snake Valley above the entrance of the scabland river.

In structure, this Riparia "terrace" is largely composed of the long deltaic type of foreset beds, and these foresets dip prevailingly up the Snake. There are erosional contacts between many members, very irregularly distributed throughout the deposit, and with no suggestion whatever of weathering of the eroded surfaces. A number of striking lens-shaped bodies of silt and sand are present, apparently fillings of channel pools. Some of these lenses are without a trace of lamination, though 18–20 inches thick.

The composition of the gravel is mostly basalt, though the percentage of non-basalt is higher than for the deposits already described north of the Snake. The non-basaltic material is almost all very well rolled, whereas that in the valleys farther north is commonly angular or subangular. Quartzite material in the plateau gravels is prevailingly bluish and greenish, whereas quartzite in the gravel of Snake River valley is prevailingly white and yellow. Very suggestive of the source of these well-rolled fragments of light-colored quartzite is their abundance in the Snake River gravel now in transit.

ALKALI FLAT CREEK VALLEY

This stream enters Snake River about a mile upstream from the eastern terminus of the "terrace" just described. For several miles back from the mouth of this tributary valley, it is narrow and deeply cut into the basalt. For about a mile back from the Snake this canyon has a coarse basaltic sand deposit in terrace remnants, 75–100 feet above the Snake at low water. The sand contains a few pebbles of angular basalt. The only foreign pebble found was a whitish quartzite. The deposit is very well bedded in foresets, the beds dipping 14° in the plane of the section across and up the canyon. No other high terrace sand or gravel was seen farther up this valley. But at Hay, which is 12 miles from the Snake, and for 5 miles farther up-valley, are silt deposits to a maximum altitude of 1,290 feet A.T.—600 feet higher than the coarse sand deposit. The depth of the silt is slight and sections are poor, but the characteristic abundant grains of basalt and a few particles and pebbles of foreign material are readily recognized.[1]

Eastward, above 1,300 feet, the valley for several miles has basaltic gravel in the streamway, and much loess has been washed down the slopes and along the valley. Yet this combination of basalt and loess in transit does not yield the tiny angular particles and coarse grains of country rock disseminated through a loessial alluvium. And of course it does not possess foreign particles. No trace of the pebbly, gritty silt was found above 1,300 feet A.T. This figure is approximately the upper altitude of the loess scarps at the junction of Snake Canyon and scabland. This same statement can be made for almost all the other valleys thus far described, though some do not have the basaltic stream gravel from which the tiny particles might conceivably originate. Where basalt fragments are mingled with loess in valley alluvium, they are larger than in the silts, are all

[1] Four samples of this silt were collected at intervals along a 5-mile stretch of the valley floor, distributed through an altitude range of 300 feet. The coarsest material, stopped by the 1 mm. sieve, ranges from 7 per cent to 18 per cent of the total; while the finest part of the samples, the reworked loess, ranges from 61 per cent to 83 per cent of each total. Basalt dominates the 1 mm. and 0.71 mm. screens; most of it rusty in color and distinctly weathered, none of it really fresh. None of the basalt is rounded. Foreign rocks and mineral fragments, all angular, include feldspar, quartz, porphyry, granite, and quartzites of whitish, greenish, and brown colors. The feldspar grains are clean cleavage fragments that show no evidence of weathering under a magnification of fifteen. There is an abundance of quartz grains on all sieves down to 0.147 mm. Since 90 per cent or more of all loess sieved passes 0.147 mm., these larger quartz grains are probably a contribution from the glacial waters, not a local derivative. The weathered condition of most of the basalt in these samples seems to indicate local derivation from slopes of weathered basalt. Associated fresh rock fragments show that the basalt has not weathered since deposition. In analyses of silts considerably nearer the Snake, a great deal of the basalt content of these silts apparently is unweathered and surely is much less weathered.

weathered, and are commonly arranged in strata. Nowhere do they have associated foreign particles.

CENTRAL FERRY

This place is at the crossing of the Inland Empire Highway, about 25 miles by river above the mouth of the Palouse. Two tributary valleys enter the Snake here—Deadman Creek from the south and a small unnamed creek from the north. The mouths of both these tributary valleys contain remarkable mounded gravel deposits, well exposed in pits opened for highway material.

The deposit in the mouth of Deadman Creek begins 1,000 feet back from the Snake and extends about $\frac{1}{4}$ mile farther upstream on the east side of the valley. It constitutes a half-mound resting against the higher basalt slope. The top of the half-mound makes a bench-like form 80 feet above the creek. There are many basalt outcrops through the thin soil immediately above the flattish top. The deposit is composed chiefly of basaltic rubble, nearly 100 per cent angular, very irregularly bedded but possessing distinct foreset strata in places, the dip of which is away from the Snake and up Deadman Creek, or partially up this valley and partially toward the basalt slope against which the deposit rests. Several angular granitoid boulders occur in the deposit. Two of them are of a rather striking granodiorite porphyry, one being 3 feet in diameter. Boulders and cobbles of this rock, or a porphyry so closely similar to it in megascopic and microscopic characters that no distinction can be made, have been found in several main scabland channels on the plateau. They are all subangular. None of this rock has been found in the rounded pebbles and cobbles now being transported by Snake River.

No other deposits of gravel well above the stream have been found farther up Deadman Creek. But the peculiar silt deposit is conspicuous in many road cuts for 9 miles up the valley, and an unweathered erratic cobble was found half a mile east of Gould, nearly 14 miles from the Snake, and 1,215 feet A.T. The silt is imperfectly stratified and poorly sorted. It is full of tiny pebbles and large sand grains composed chiefly of basalt but containing a few nonbasaltic particles, unweathered. The silt deposit nowhere shows the development of a soil profile or a weathered upper zone. This is true throughout the entire region. It is to be contrasted with the common exposure of both A and B horizons in cuts in the loess above the level of the silt.

From the terraces along the lower part of Deadman Creek it appears that the silt originally completely covered the valley floor to a depth of 10 feet or more. But it also extends up on the slopes above the terraces. Low spurs of basalt, projecting out into the terraces, carry about the same thickness of silt as is found in the terrace sections. And along the Inland Empire Highway up a tributary to Deadman Creek a few miles south of Central Ferry, the same silt with the same characteristic unweathered coarse material scattered through it and the same kind of imperfect stratification is exposed in many places. It reaches an upper limit of at least 1,200 feet A.T.[1] At this level the silty deposit lies on unusually steep slopes, 200 feet or more above the nearby valley bottom, and 600 feet above the Snake at Central Ferry. In other words, the silt is a mantle which originally lay on all slopes up at least to 1,200 feet here and whose thickness on the steep upper slopes is not much less than in the valley bottom. Its deposition was so recent that weathering has not affected it and slope wash has not removed it. Certainly there has been no deepening of the valleys east of the scabland since this mantle was deposited.

The tributary entering Snake River from the north at Central Ferry carries a mounded gravel deposit in its valley mouth. It also

[1] In the sample from this altitude, most of the coarser material is non-basalt. Schist, micaceous quartzite, green quartzite, intergrown quartz and muscovite, clear quartz, two kinds of granitoid rock, and two kinds of gabbroid rock are represented. One of the gabbro-like pebbles is clearly smoothed and striated on two sides. Some of the quartz grains contain intergrown bits of biotite projecting from the exterior. Much of the basalt in the sample is so much decomposed that it crushes in the tweezers, but some of the chiplike forms are so slightly altered that the knife leaves glistening steel marks on their sharpest edges. There are almost no rounded forms in the coarser grades obtained by sieving this sample. Angularity of shapes is very pronounced. The proportion of quartz increases in each sieve sample down to 0.147 mm., where it is 50 per cent. About 90 per cent of the total sample is loess.

In contrast with this reworked loess is the undisturbed loess about 100 feet higher. Ninety-nine per cent of it passed every sieve. The 1 per cent stopped on the sieves was composed of calcareous aggregates of the loess.

lies about 1,000 feet back in the tributary valley and on the east side. Similarly, also, it is a half-mound in shape and has a benchlike flattish top. The top is 60 feet above the adjacent stream channel and 185 feet above the Snake. It has been undercut by the tributary and gashed by several gullies, but there is no difficulty in differentiating these steeper erosional slopes from the original mound slopes.

The stratification of this deposit is very irregular. There is definite foreset bedding in some of the cobbly débris, the beds dipping up the tributary, or toward the east wall, or somewhere between these two directions. Most of the material is basaltic rubble, very little worn to 100 per cent angular. Sorting in certain parts has made a few beds of well-stratified sand; but the bedding in the sand itself is irregular, and contact of the sand lenses with angular cobbly débris is also very irregular. Some of the sand is foreset with the dip up the tributary, like that of the coarser débris. Subangular boulders of granite are present, and there is one of the porphyry. There are numerous well-rounded pebbles of non-basalt like those so common in the present gravel of Snake River.

The deposit shows weather-staining only in the upper few feet. The granite and diorite boulders are fresh and unstained. So are the more worn basalt fragments. Yet the associated very angular basalt boulders are stained on all sides. It seems possible to explain these weathered surfaces in the midst of unweathered material only by assuming that they were weathered when contributed. Their marked angularity then can only mean that they are locally derived, that they traveled a very short distance. They cannot be explained as berg-carried like the angular erratics, for none are glacially worn or abraded, none occur stranded with the erratic boulders at high altitudes or on gentle slopes, and no basalt has been found in the definite berg "nests" or patches of berg-laid till that are yet to be described. They could not have fallen into the foreset strata; they must have been carried with the rest of the débris back into the valley mouth.

No other gravel has been found farther up the tributary, except close to the valley bottom. But there are many sections showing the pebble-charged silt up to about 1,200 feet A.T. The black basaltic sand in many places is distinctly segregated into irregular pockets in which there may be as much sand as silt. They possess finger-like projections which penetrate the surrounding silt in various directions.[1]

There are no sections in unconsolidated material for about half a mile upstream from the 1,200-foot contour crossing. At 1,300 feet A.T. is a good section of fine-textured material resting on basalt, but it is simply clean loess with hardly a particle of basalt and none of any other kind of rock in it.[2] Essentially every road cut farther along the highway for 25 miles—all of it well above 1,300 feet A.T.—shows the same characters. The upper limit of the anomalous silt is close to the altitude of the scarp bases where the enormous glacial river entered the Snake near Riparia.

Snake River valley itself at Central Ferry contains a gravel deposit as extraordinary as those back in the two tributary mouths. At the highway crossing, the valley floor is a mile wide. The river here is against the south wall and down in a trench about 60 feet deep. The mile-wide floor is the surface of a gravel fill. In it are cuts for 2½ miles along the Camas Prairie Railroad, which closely follows the north side of the river. Seen from the highway bridge, the gravel in the north bluff of the trench is stratified, the beds prevailingly horizontal and composed of well-worn stream pebbles and cobbles, apparently simply a fill of Snake River débris, into which the stream is now trenching. But in the next few paragraphs the reader will find that this deposit is so highly abnormal that no large valley deposit ever previously described can be cited as even similar to it.

In the first place, the surface of the deposit rises 75 feet northward from the bridge to the mouth of the unnamed tributary from

[1] A sample was taken at 1,175 feet. Eleven per cent of it stopped on the 1 mm. sieve; 62 per cent passed all sieves. Several bits of rock foreign to this tributary were found among the particles exceeding 0.5 mm. in diameter. Most of it is basalt; some fresh; some rusty red in color and capable of being scraped into a clayey powder. Quartz grains were found on all the coarser screens, some of them with intergrown mica and feldspar. The quartz content increases from 10 per cent on the 0.5 mm. screen to 50 per cent on the 0.177 mm. screen.

[2] Contrast this sample taken at 1,300 with that of the pebbly silt at 1,175. Of the total, 2.5 per cent was stopped by the first 9 screens and 10 per cent by the .074 screen; 87.5 per cent passed all screens. The material on the first 9 screens consisted of much decayed basalt with irregular shapes that can best be described as "crumbs." Though angular, they differ notably from the cleanly fractured outlines of most of the basalt in the pebbly silt. A very few quartz grains were found on the coarser screens. The color of the finest material in both samples is almost the same.

the north. Here the main valley deposit constitutes a broad ridge lying across the minor valley mouth, though 40 or 50 feet lower than the top of the semimound back in this tributary mouth. The tributary has cut a narrow gulch about 25 feet deep through the gravel ridge, just as Willow Creek, Kamiache Creek, and other streams have done where they enter scabland. It has also widely aggraded its own floor immediately upstream from the blocked entrance. The surface of the broad gravel fill, traced down the Snake Valley, descends gradually to river level in about 2 miles, so that there are no cuts along the railroad. The same descent of the surface and consequent vanishing of the cliff along the river occurs upstream also. This is no terrace profile, either across the valley or along it. The surface is decidedly undulatory, but not in terms of gullies or ravines. It is a huge, flattish half-mound, and it has been deposited as such, not eroded to this shape.

In the second place, the structure shown in the railroad cuts is almost without exception *foreset up the Snake.* The foreset structure is shared by the coarse gravel, the fine gravel, and the sand in the deposit. Not every stratum of each textural grade shows it, but most of the material (except lenses and strata of silt) does. Only two places were seen east of the bridge where the gravel has downstream foresets, and perhaps eight or ten lenses of the finer constituents possess downstream dip in their layers. The foreset gravel is arranged in nearly horizontal members, with as many as four such members in vertical sequence. One member may be only a foot in thickness; another may be 10–12 feet thick.

In the third place, the deposit, though dominantly of far-traveled Snake River gravel, contains almost unworn cobbles and boulders of local basalt. They are grayish, brownish, greenish, and reddish on the outside, typically like the weathering colors shown along joints in quarries of the region. They break readily along other joint cracks, showing similar colors when opened. Yet the material with which they are associated is essentially all fresh. The percentage of basalt among the cobbles and pebbles of the deposit is small, but it is classifiable into rounded fragments that are clean, bright, and hard, and angular fragments that are dull and decayed. The angular fragments average larger than any of the rounded basalt pieces. Some boulders are 3, 4, and even 5 feet in maximum length, very much exceeding in size any fragments of non-basalt or any fragments of well-worn basalt.

The deposit contains coarse sand or fine gravel which is almost black in color because so highly basaltic, and is apparently identical with that found in the backwater silts described in this paper. It also contains strata and lenses of buff-colored silt or very fine sand, from a few inches to a few feet thick. Both occur from the top well down toward the base of the railroad cuts. But the intimate intermingling of the particles of coarse black sand in the loess-textured silt was not seen.

Basalt as a constituent of this Snake Valley deposit at Central Ferry is much more prominent in the highest portion, near the northern valley wall. In road-cuts half-way between Central Ferry and Purrington, it is almost all basalt sand and gravel, with minor foresets which dip both upstream and downstream. The deposit here is piled up against the basalt cliffs like the two half-mounds in the tributaries entering at Central Ferry. Yet it is only the more pronounced upper part of the great flattish half-mound crossed by the highway at Central Ferry.

In the fourth place, there is a definite relation between the altitudes on this deposit and those at which the two tributary valley mouth deposits stand. Each of these deposits is piled up approximately 50 feet higher than the top of the nearest part of the great deposit in Snake Valley. Yet the increase in altitude of the great deposit northward across the width of Snake Valley brings the base of the northern tributary's deposit higher than the top of the Deadman Creek deposit. Each of these minor half-mounds obviously was built with reference to the nearby surface of the larger, lower deposit.

It is too much to expect that the foregoing very brief description can convey an adequate picture of these deposits in their setting. But if one will rapidly review the more striking features, such as the strictly localized half-mound constructional forms, the altitudes involved, the slight amount of erosion and weathering of the deposits, the foresets dipping upstream in three diversely oriented valleys, the large fresh boulders of granite and porphyry, the very angular, stained basalt boulders embedded in unstained gravel and sand, the associated silt mantle on higher slopes with coarse grains of fresh basalt sand and pebbles of non-basalt disseminated through it, the 650-foot vertical range of this silt, the close approximation of the upper limit of the silt with that of the scabland where the Snake enters that tremendously scoured topography, and the similarity of most of these features with those from Kamiache Creek south to the Snake, he must admit that the explanation of a great rush of berg-charged glacial water up the Snake could ask for little else in the way of record. Can any other explanation or group of explanations take care of all these items? Does any reader know of valley deposits elsewhere than on the Columbia Plateau which have similar features?[1]

VICINITY OF PENAWAWA

This town is 7 or 8 miles up the Snake from Central Ferry bridge. The station altitude is 613 feet A.T. Deposits similar to those just described are here also. The deep valley of Penawawa Creek up at least to 1,100 feet A.T. contains the silt, with bits of fresh basalt and small pebbles of granite and other rocks foreign to the valley.[2] A

[1] The glacial-flood hypothesis itself encounters difficulties in explaining this Central Ferry deposit. (1) The silt lenses tell of minor local pauses in current followed by renewed transportation of gravel up the valley. (2) A borelike wave moving up the valley would be succeeded by deepening water, and with increasing cross-sectional area of the reversed current; a decreasing velocity would maintain the same advancing wave. The gravel deposit, therefore, should be the product of only the vanguard of the flood. Could it conceivably have been so produced? (3) It seems questionable that a body of water adequate to make this up-valley current could, in terms even of the scabland-flood hypothesis, be poured across the Palouse-Snake divide near Riparia. (4) Most of the foresets are composed of Snake River débris, which by this explanation represents a pre-existing deposit torn up and relaid. Since no remnants of such older deposits show beneath the anomalous foreset-bedded gravel, and since it is impossible that older gravel could be completely torn out and its material rearranged and redeposited where the preflood gravel lay, it must be assumed that (*a*) a large basal part of the half-mound is of older débris, (*b*) the reworked material with added basaltic boulders covers the edges of the earlier deposit, partially filling the trench or inner valley of the preflood Snake, and (*c*) the dominant basaltic material constituting the apex of the broad mound is a contribution from valley-wall erosion and covers the surface of the older deposit.

[2] Six per cent of the sample from 1,100 feet A.T. was stopped by the 1 mm. sieve; 64 per cent passed all sieves. Though there is plenty of non-basalt in the three coarser grades, they are dominantly of very sharply angular basalt particles. Some particles are from two to five times as long as they are wide or thick. The sharp edges of many are hard enough to take a steel mark from the knife blade. The proportion of quartz, also with marked angular outlines, increases to 60 per cent in material stopped by the 0.177 sieve.

quartzite pebble was found at about 1,200 feet A.T., but nothing except loess and basalt were found above this altitude. The silt is thicker in the lower part of the valley, and in some sections the deposit is clean basalt sand. No mounded form of gravelly débris was seen in the valley mouth; but about a mile west of the railroad station, in a small gulch at Penawawa High School, there is a remarkable deposit of this character with foreset strata dipping back into the tributary out of Snake Valley. This deposit extends at least 325 feet above the Snake and originally must have nearly filled the gulch. Some parts of the deposit are composed wholly of cobbly débris, very little worn, all basalt, all with vari-colored surfaces of the original joint-plane weathering, all rudely foreset back into the little gulch. Other parts are composed of well-sorted, worn pebbles, also foreset toward the walls of Snake River canyon, i.e., back into the gulch. Thirty feet below the top of the deposit is a large cobble of the porphyry, definitely in place as a part of the extraordinary fill. In the lower part of the sections is 20 feet of coarse basaltic sand with shallow foresets arranged much like a huge pile of overlapping saucers tilted in the same direction. These dip out toward the Snake but surely are not a deposit of the local drainage. They record an eddy in some deep current flowing along the master valley. The débris of the fill is almost wholly basaltic and, though indubitably deposited by river currents, is quite unlike the normal Snake River gravel. The angular stained cobbles clearly were derived from the slopes and not from the bottom of the Snake Valley.

Cuts along a road up the south wall of Snake River canyon, 2 or 3 miles east of Penawawa, show the silt with numerous black basalt grains, some of them grouped in pockets, and with a few non-basalt pebbles and grains up to 1,200 feet A.T., about 600 feet above the river. No trace of such material was found above this altitude.[1]

[1] Two samples were taken here—one from the common phase of the pebbly silt at 1,200 feet and one from a pocket containing coarser material at 1,175 feet. The higher sample contained only 5.7 per cent of material larger than 0.5 mm.; while 9 per cent of it stopped on the 0.074 mm. sieve, and 73 per cent of it passed all sieves. The varied foreign material is unweathered and unstained, though the associated basalt particles are soft enough to scrape down readily under the knife blade. There is the increase in percentage of quartz with increase in fineness of material (40 per cent on 0.177 mm. sieve) common to the coarser screenings of all this silt. The sample from altitude 1,175 feet has

At the foot of this road-grade is Rice Bar, a large fill of gravelly waste in Snake River valley. It is half-mound in shape, its profile along the contact with the valley wall being a rude vertical arc, each end coming down gradually almost to river level. Its surface against the wall is nearly 100 feet higher than at the brink of the 20-foot river scarp at its northern margin. In this scarp the material is largely or wholly of well-rolled Snake River gravel. The section does not show structure. The surface of Rice Bar is undulatory. One undulation is a broad ridge paralleling the Snake and standing about 25 feet higher than the surface between it and the valley wall to the south.

In the highest part of the deposit, essentially against the basalt walls, a 10-foot excavation shows only well-stratified, black, fine gravel, more than 99 per cent basalt. It contains no slope-wash débris of loess or of fragments of weathered basalt, such as should occur if this half-mound were an alluvial fan in part. It is a river deposit, though certainly not composed of typical Snake River débris or dating back to a time when Snake River canyon was 100 feet less in depth. In the dominance of basaltic sand on top and the dominance of Snake River gravel in the basal part, Rice Bar duplicates Central Ferry Bar.[1]

Another half-mound deposit, known as Miller Bar, lies a few miles downstream from Rice Bar. It is very similar to Rice Bar and also stands about 100 feet higher along the southern wall of the canyon than at the brink of its low river-cut cliff. Here, as in Rice Bar, its higher portion cannot be interpreted as talus or alluvial-fan ma-

7.7 per cent of its material exceeding 1 mm. in diameter and has percentages ranging from 2.9 to 8.3 for the next eight finer sieves. Twelve and a half per cent was stopped on the 0.074 mm. sieve and 43 per cent passed all sieves. Chiplike forms of the basalt particles are common, some with hard edges and black color. Grains of quartz increase in proportion to other constituents through the first six sieves, amounting to 40 per cent on screen 0.177 mm. Grains of unweathered feldspar were found, also grains of quartz with hornblende and biotite partially embedded.

[1] The shapes of fragments are extraordinarily angular. They include sharp-edged chips, and splinters in which the conchoidal fracture surfaces are unworn. A few bits of quartzite and flakes of mica were found. Quartz grains are more common in the finer grades of this sand, but their percentage is low. Half of the sample was stopped by the 1 mm. sieve; about a half of the remainder was caught on the 0.71 mm. sieve; and about half of what passed this sieve was stopped by the 0.5 mm. sieve. Nothing reached the 0.104 mm. sieve.

terial. Several small tributary gulches from the canyon wall mouth along its upper margin, but between them the deposit is as high, or is even higher, though not of talus débris or with talus forms. There are talus piles everywhere along here for comparison, and they are easily distinguished from the high edges of these bars.

ALMOTA CREEK

No mounded deposit constricting the mouth of this tributary was identified, but for a mile or so back the pebbly silt shows in road-cuts, associated with pockets and lenses of clean sand. The silt contains foreign particles and angular bits of fresh basalt. Along the serpentine road up the canyon wall, north of Almota, are numerous foreign pebbles and cobbles. They are most abundant close to 1,250 feet A.T. One flattish cobble was delicately but definitely striated on both sides. A large cobble of the granodiorite porphyry lies at about 1,000 feet A.T.

In the canyon of Little Almota Creek, a small erratic boulder at 900 feet A.T. is the highest record of glacial water found well back from the Snake.

WAWAWAI CREEK

A deposit composed largely of basaltic sand has been opened on the lower slopes back in the mouth of this valley. Its summit is about 230 feet above the Snake. Only the upper 10–15 feet are exposed in the section. It has no characteristic Snake River débris, though foreign particles are present. Though now constituting a spur out into the valley mouth, it is probably but a remnant of the fill which is recognizable in rude terraces farther back up Wawawai Canyon. These terraces are composed of the pebbly and gritty silt, with associated well-sorted sand layers up to about 900 feet A.T. Unsorted or but poorly sorted silt occurs up to about 1,200 feet A.T. It contains pebbles of granite, gneiss, schist, quartzite, etc. A fragment of the porphyry was found at 1,160 feet A.T., and a three-foot boulder of coarsely crystalline basic lava still higher.

ALPOWA AND SILCOTT

At Alpowa there is a definite half-mound, though considerably cut away by the Snake along the upstream side. It has an alluvial fan built out on it, but below the fan it is composed of worn river gravel. Its summit is 175 feet above the Snake.[1]

Alpowa is just within the deep canyon-like valley that leads out of the capacious Lewiston structural valley. Silcott is just above the head of this canyon, at the debouchure of Alpowa Creek. East of Silcott for a mile extends a mid-valley hill of gravel, its summit 830 feet A.T., about 130 feet above the Snake on the north and 90 feet or so above an empty channel or fosse on the south. The elongated hill has an undulating surface which descends gradually westward and southward, being highest next to the river. If there is anything definitive in its form, it is a bar, not a mid-valley terrace remnant. The only exposure is in an old pit at the east end. The material here is horizontally bedded, well-rounded unweathered river gravel, 24 per cent Columbia River basalt. In it are large angular weathered boulders of basalt.

The drainage of Alpowa Creek, entering the Snake at Silcott, comes entirely from the basalt plateau. Yet about 10 miles up its valley, 1,125 feet A.T. and 300 feet above the summit of the mid-valley hill, is a granite boulder 2 feet in diameter, embedded in pebbly silts along the Inland Empire Highway. These silts, a few feet in thickness, contain bits of granite, quartzite, etc., though their pebbly content is chiefly angular basalt fragments.[2] One striated non-basalt pebble was found. This deposit constitutes rude terraces in the creek valley below the 1,000-foot contour crossing. It establishes the

[1] Foreset beds dipping up Snake River valley have been seen at three other places than those described: (1) at Ridpath station, about midway between Riparia and Central Ferry, (2) 4 miles east of Almota, and (3) 2 miles east of Wawawai. They were noted only from a passing train. No foresets dipping downstream were seen.

[2] The collection was made a little below 1,300 feet A.T. in the highest road-cut which showed the pebbly silt.

Twenty-two per cent of the sample was stopped by the 1 mm. sieve. Fourteen per cent passed all but the 0.079 mm. sieve, and 42 per cent passed all sieves. The material retained on the 1 mm. sieve consisted of a few pebbles and a large number of coarse grains. The pebbles (maximum diameter, 1½ inches) were all foreign and all unweathered. The coarse grains were almost wholly basalt. The knife-edge, applied under a magnification of ten, left shining streaks of steel on the sharp edges of some of these pieces. Other pieces yielded readily under the knife. Angularity of almost all fragments is very marked, though some of the larger foreign pebbles are subrounded. The proportion of bits of quartz increases from a few pieces on the coarsest sieve to 60 per cent on the 0.177 mm. sieve. As previously pointed out, this quartz is too coarse to be a derivative of the loess and surely does not come from the basalt.

presence of a water body up to this level and of berg-ice floating in that water. There were no local valley glaciers in the region. The only alternative sources for berg-ice are the headwaters of the Clearwater or the Salmon or the Snake itself. According to Lindgren,[1] the valley glaciers of the Clearwater Mountains were very limited in extent and did not descend below 4,000 feet A.T. The termini of such valley glaciers were from 50 to 100 miles farther upstream than this 1,300-foot ponding could possibly reach. According to Lindgren's map, only granite, quartz-monzonite, diorite, and gneiss constitute the glaciated tracts of these mountains. He says that the "granite shows great constancy in its petrographic character" and that the quartz-monzonite so closely resembles the granite that "the two kinds of rocks cannot easily be distinguished in the field." The erratic blocks distributed up to 1,300 feet throughout the Snake and its tributaries represent a considerable variety, megascopically, of granite and granitoids, gabbros, porphyries, fine-grained lavas, quartzites, argillites, slates, schists, and gneisses. The evidence of the porphyry has already been cited. It seems impossible that the berg-ice of the Snake Valley ponding could have come from the glaciers in the Clearwater Mountains. And bergs from glaciers at the head of Snake River would have traveled 575 miles from the mountains of western Wyoming and eastern Idaho to reach the ponded tract.

VICINITY OF THE SNAKE-CLEARWATER JUNCTION

Lewiston, Idaho, and Clarkston, Washington, are built at the junction of the Clearwater and Snake rivers in the lowest part of the Lewiston syncline. In the bottom of the structural valley the two rivers at their junction have probably not eroded more than 200 feet,[2] and this they have done concomitantly with the erosion of Snake Canyon westward from Alpowa and Silcott.

The town and orchard tracts of Clarkston, Washington, are located on a sloping terrace-like fill composed of sand and gravel with prominent deltaic foresets. The deposit is a broad semimound resting against the southwest wall of the valley, its surface descending

[1] W. Lindgren, "A Geological Reconnaissance across the Bitterroot Range and Clearwater Mountains in Montana and Idaho," U.S. Geol. Survey, *Prof. Paper 27* (1904), p. 116.

[2] I. C. Russell, "Geology and Water Resources of Nez Perce County, Idaho," *U.S. Geol. Survey, Water-Supply Paper 53* (1901), p. 70.

from the highest part roughly 50 feet per mile, down the valley, across the valley, and up the valley. Its upstream margin has been cliffed by undercutting of the Snake. This semimound is an impossible shape for a terrace top or a delta top, and the slopes are far too steep for either feature in a valley as broad as the Snake. There is no tributary drainage entering here from the higher land to the southwest, to which it might be referred as an alluvial-fan deposit.

Pits in several places afford some idea of the nature of the material. Two different deposits underlie the tract: an older stained and weathered gravel beneath an unweathered younger deposit in which Columbia basalt constitutes about 80 per cent. A group of exposures along the Snake in the southern part of the Clarkston semimound show dominantly dark unweathered fine angular gravel (Fig. 2) whose beds are inclined at various angles, some as steep as 35°. These foresets dip south, up the Snake. There are many erosional unconformities in the deposit here, developed by shifting bottom currents during deposition and promptly filled with beds which conform to the erosional surfaces, like a stack of shallow bowls in section, the upper bowls progressively broader and flatter. The fine gravel contains large lenses and strata of yellowish silt and fine sand. Some of the silt is well sorted; some is charged with irregularly dispersed angular bits of rock; chiefly fresh basalt. In most respects, this texture duplicates the pebbly silt already described from Kamiache Creek valley south to the Snake and back in the valleys of half a dozen tributaries of the Snake.[1] Three small angular boulders and one angular pebble of the porphyry were found here.

[1] Though this mixture of coarse sand, fine sand, and silt is apparently identical in structure with the high-level pebbly silts, it differs somewhat in texture and composition. The percentages stopped on the first five sieves range from 9 to 12.4, making the cumulative curve much steeper for these grades than in any pebbly silt thus far examined. Correspondingly, the quantity passing the 0.074 mm. sieve is unusually low—only 29 per cent of the total. Most of the material on the coarser sieves is very angular basalt. Most of this basalt is unweathered, a condition to be expected, for the sample was obtained nearly 30 feet below the surface. But a considerable number of basalt fragments are well weathered, crumbling between the tweezer blades or becoming clayey material when scraped with a knife. Such weathering must have occurred before the deposit was made. There are no large pebbles of foreign rock in the sample, though nonbasalt is present. The proportion of quartz on each of the sieves increases from 1 or 2 per cent on the 0.71 mm. sieve to 50 per cent on the 0.177 mm. sieve. The finest material is essentially loess, like all the high-level occurrences.

The summit material of the Clarkston semimound is composed of the familiar pebbly silt and coarse black sand. The silt is found up to 1,050 feet A.T. on the steep slope descending from the Clarkston Heights bench to the Clarkston semimound. A "nest" of angular bouldery fragments of non-basalt was found at 1,175 feet A.T. on

FIG. 2.—Chips, splinters, slivers, and broken-rounds from the Clarkston half-mound

the eroded slopes of the bench, the material quite unlike the high-level gravel, and apparently a berg deposit made subsequent to the erosion of the bench.

The residential section of Lewiston is built on a gravel terrace which rises steeply 50–100 feet just south of the business section. Numerous excellent exposures show dominant deltaic foresets dipping northward, down the Snake or across the Clearwater. The material is grayish or yellowish but not markedly weathered. It is typical rolled river gravel and distinctly unlike the gravel, sand, and silt of the Clarkston deposit. Exposures in the top of the terrace, however, show none of this underlying gravel. There are many shallow cuts and every one examined shows tan-colored silt and fine sand, irregularly stratified, containing tiny angular fresh basalt pebbles and a few non-basalt fragments, but totally lacking in rounded pebbles and in gravelly strata. In the eastern part of the city, 20 feet or more of the light-colored sand and silt, with a few pockets and strata of coarse black sand, are shown resting on the older gravel beneath. A few layers of the sand and silt have numerous tiny angular pebbles and large angular grains of fresh basalt, partially arranged in striform fashion.

The surface of this younger deposit of the Lewiston terrace descends steeply to the south into a minor erosional valley which leads westward to the Snake. This steep margin is crenulated, and the width of the minor valley is variable in terms of the lobes and reentrants. The southern slope of the valley, however, is gentle, and its ground plan is regular. There are no crenulations in it. The flood hypothesis considers this southward slope, with lobes into an older erosional valley, as the lee face of a bar. The valley is in part a fosse.

A mile or so south of the Lewiston terrace, the surface rises in the southern wall of the structural valley to the Lewiston Orchards tract, 1,400 feet A.T. and 700 feet above the Snake and Clearwater. Cuts along the highway up this wall show the silt and sand with abundant fresh basalt particles and some angular erratics to 1,225 feet A.T.[1] A pocket of angular erratics was found at 1,200 feet,[2] and an angular granite fragment 16 inches in diameter at 1,225 feet. This is the highest known exposure of the pebbly silt in the Lewiston region. It

[1] Little foreign material was found on the 1 mm. screen, but it is varied. Both weathered and unweathered basalt occurs, the knife-sharp edges of some basalt splinters and chips being perfectly fresh. The quartz content of each sieve sample mounts from less than 5 per cent on the coarsest (1 mm.) to 60 per cent on the 0.147 mm. screen.

[2] Thirty-three per cent of this sample was stopped on the first two sieves, and 32 per cent is the sum of that passing all sieves or stopped by the finest. The larger pebbles ($1\frac{1}{4}$ inch maximum) are all of non-basaltic rock. Granite, schist, and quartzite are represented. The material on all the coarser sieves is largely of very angular fragments, in which chips, splinters, and slivers of rock are common. Quartz constitutes 40 per cent of the material on the 0.177 mm. sieve, most of it being in exceedingly angular fragments.

has basalt particles essentially as fresh as those taken from the pebbly silt embedded in the Clarkston halfmound. Yet these particles occur nearly 500 feet higher on the walls of the Lewiston Valley and only 4 or 5 feet below the surface, while the material from the pit was taken about 30 feet below the surface.[1]

TAMMANY HOLLOW

Tammany Creek is a small perennial stream entering the east side of Snake River, nearly 5 miles south of the junction of Clearwater River. It has a valley flat a quarter of a mile or so in width for several miles above the mouth. But in a fashion strikingly reminiscent of Kamiache Creek and similar to many other tributary valleys already considered, the mouth is blocked by a barrier of gravel nearly 100 feet high. Through this the creek has cut a very narrow gorge at the contact of the gravel deposit and the northern basalt wall.

This barrier is a broad ridge of gravel nearly a mile long, lying almost wholly outside the mouth of Tammany Hollow, but extending

[1] We may admit that these erratic cobbles and boulders up to 1,300 feet A.T. in Snake River valley came from the Cordilleran ice sheet, yet deny that the episode was an extraordinary flooding. It is pertinent now to inquire whether their known distribution in the Snake drainage may be a test of the flood hypothesis. The alternative explanation, it will be recalled, is that scabland was made by glacial drainage of several different Pleistocene epochs, that the earliest of these occurred when the streams east of scabland "were flowing at levels far above their present courses," and that notable valley deepening by normal stream erosion has occurred during this succession of Pleistocene epochs. The stranded erratics of Snake River drainage are highest above the valley floors nearest its entrance into scabland. It must be assumed under the alternative explanation that this height, about 800 feet, is the sum of two quantities: (1) the depth of the earliest flooding and (2) the amount of subsequent valley-deepening. By this alternative the two quantities might be estimated at 100 feet and 700 feet, respectively. How far up this early Pleistocene Snake River valley, 700 feet less in depth than now, would a ponding extend which was only 100 feet deep at the mouth of the Palouse? Only as many miles as the gradient in feet per mile is contained in 100. The present gradient of the Snake here is about 2½ feet per mile. It was probably steeper at an earlier stage in valley development. A 100-foot ponding today would produce backwater for only 40 miles up the Snake. Is it possible that the gradient of the preglacial Snake was so low that the erratics stranded at 1,225 feet A.T. above Lewiston, 70 miles upstream from the scablands, were transported here during the earliest rational flooding?

To wait for another glacial epoch will be equally difficult, for we are committed to a considerable deepening of Snake Valley in the meantime, larger fractions of the total deepening being logically assignable to the earlier interglacial epochs. Indeed, it is imcompletely across that valley mouth from one headland to the other. The summit of the barrier is nearly 1,050 feet A.T., about 250 feet above the Snake. From the summit the slope toward the Snake is relatively gentle, that facing up Tammany Hollow is steep. There are no gravel terraces in the Hollow. At mid-length this barrier consists chiefly of long deltaic foresets. They dip in that utterly anomalous fashion noted repeatedly in this study, directly out of the Snake Valley and up the tributary valley. The material is dominantly fine, dark-colored gravel; the pebbles, exceptionally angular and chiefly of Columbia basalt (Fig. 3). But there are plenty of cobbles and boulders in these foresets. Most of the boulders are composed of much-decayed basalt buried in the almost perfectly fresh finer débris.

To complete the picture, one needs only the unsorted pebbly silts and some stranded angular erratics farther back up the gulch behind this barrier. There are no good cuts to show the presence of the silt. Only loess and alluvium and basalt ledges show. But an angular granite boulder, a foot and a half in diameter, and an angular cobble of the porphyry were found about a mile east of the barrier dam.

In summary, the relatively broad Lewiston synclinal valley, at the head of the canyon that extends from Alpowa almost to the Columbia River, contains the following aberrant depositional features:

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possible to get bergs very far up the Snake at any time by this mechanism. It is impossible to carry the upper limit any farther upstream than the intersection of that high-water line (about 1,300 feet A.T.) with the vanished floor of the early Pleistocene Snake River canyon. It *cannot* intersect the present floor. By this hypothesis it is equally impossible for any but the latest high-water line to intersect the present canyon floor, though as the gradient of the deepening Snake River valley decreases, each succeeding flood will reach somewhat farther up the valley. The upstream limit of foreign berg débris must, by this hypothesis, *be a descending gradient*. This it is not. Only a Snake Valley system of full present depth at the time of glacial backwater will provide the existing horizontal upper limit of berg-carried débris to the distances up-valley that are already known.

Final establishment of this thesis will be made when the Snake and Clearwater valleys have been studied where the upper-limit contour crosses them. In most of the valleys entering scabland from the east, this flood-carried débris has already been found up to, but not above, the crossing of the proper contour.

Other serious objections to this alternative hypothesis include (1) the lack of widening of the Snake Valley during this deepening, the lack even of notable slope wash or gullying, which would remove the earliest high-line records; (2) the lack of weathering in the high-lying stranded erratics; and (3) the lack of decay in the tiny chips of basalt so abundant in the silt at all altitudes below the highest limit.

A. Silts:

1. Pebbly and coarse sandy silts occur in the bottoms and mainly on the slopes of both main and tributary valleys, extending up nearly or quite to 1,300 feet A.T., 600 feet above the Snake at the Clearwater junction.

2. The abundant particles of coarse sand and small pebbles occurring in the silts are irregularly disseminated or in pockets; rarely stratiform.

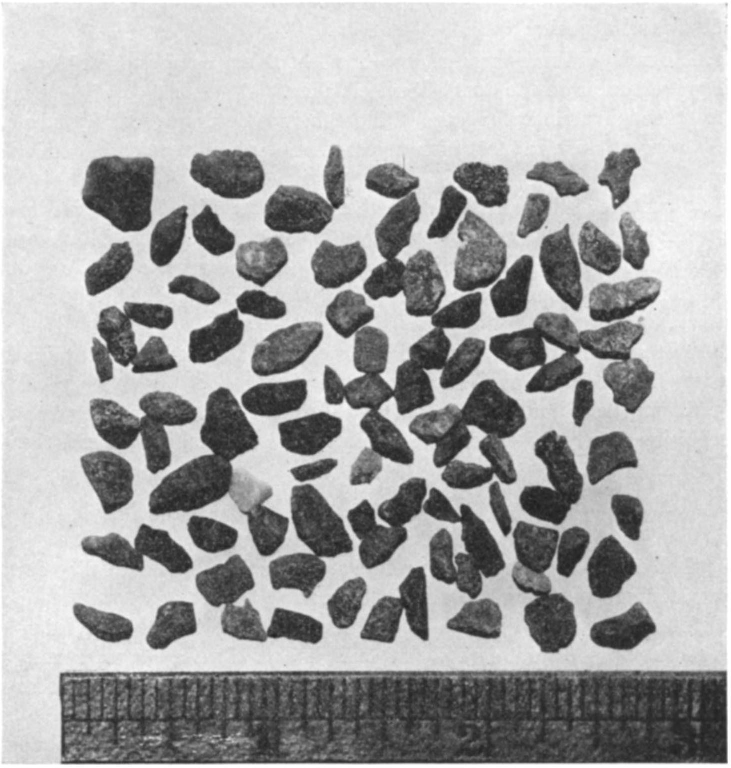

FIG. 3.—Chips, splinters, slivers, and broken-rounds from Tammany Hollow Bar

3. These larger particles are dominantly of basalt, but there is everywhere a small percentage of non-basaltic material back in valleys draining wholly from basalt country rock.

4. Most of these particles are very angular and are unweathered. The lack of weathering is as conspicuous at the upper limits as in the valley-bottom occurrences.

5. The material of this silt is identical with the loess of the plateau top and the gentle valley slopes of the region.

B. Sporadic boulders:

1. Angular boulders of unweathered granite and other non-basalts occur stranded alone, or embedded in silts, or in gravel, at all altitudes below the upper limit of about 1,300 feet A.T. The granodiorite porphyry boulders and cobbles in this class probably are derivative from the scabland glacial rivers.

2. Angular boulders of local basalt, commonly much weathered, occur in gravel deposits of fresh material in the valley bottoms.

C. Gravel deposits:

1. Mounds and half-mounds, 100–200 feet thick, composed largely of basaltic gravel, occur on the floor of Snake Valley.

2. One such mound, elongated with the main valley, once constituted a complete barrier at least 100 feet high across the mouth of a good-sized tributary valley.

3. Structure of these mounds, where exposed, contains foresets, inclining in various directions with the varying slopes of the mound. There is one marked case of foreset dip up the Snake, the location being nearer the middle than the wall of the valley. In another case, the dip is directly out of the Snake and up a tributary.

4. The material of these mounds is largely unweathered; but contains fragments up to boulders in size which are much weathered.

5. There are seams and lenses of light-brown silt in the gravel, some with the same irregularly disseminated sharp bits of basalt and non-basalt that the silts themselves carry.

D. Relation to the regional topography:

1. The silt, foreign boulders, and gravel deposits are very young.

a) They lie on erosional slopes where any notable amount of valley deepening or widening would inevitably remove them.

b) The foreign boulders, and the unweathered pebbles in the silt, lying high up on these slopes, cannot date back to early stages of valley development.

c) Gravel deposits, which once were complete barriers to tributary streams, are still almost intact.

2. The silts, foreign boulders, and gravel deposits record some abnormal episode of flooding.

a) Unweathered materials ranging from fine basalt sand to large foreign boulders cannot be distributed through this amazing vertical range, the fine débris essentially as a blanket on all gentler slopes, by any ordinary sequences in valley history.

b) The absence of such records everywhere above 1,300 feet A.T. indicates this altitude as the approximate upper limit of the flooding. Above it the surface deposits are loess or basalt rubble. The basal portions of the loess commonly have angular fragments of weathered basalt, but no foreign material and no fresh basalt particles. Nor is the loess rudely stratified; nor does its rare basaltic débris occur in pockets.

3. That abnormal episode of flooding involved strong currents in all valleys.

a) Extreme angularity of the basaltic débris records pounding and battering, rather than ordinary abrasive grinding, to produce it.

b) Erratic material in long, narrow canyons could hardly have floated back unless the episode were very long continued. Current transportation seems necessary if the time interval be short. Other evidence, already cited, indicates brevity of time involved.

4. The current of that abnormal flooding was, in every valley, exactly the reverse of the normal drainage which made these valleys and which now reoccupies them.

a) Erratic boulders were berg-floated back into tributaries from the Snake and were berg-floated up the Snake from the scablands.

b) Erratic débris was mingled in suspension with silt (the rehandled loess) and deposited in many cases without assorting.

c) Foresets of the gravel deposited during this episode in significant places dip back up the valleys. Eddies will not account for such dip.

d) If a mechanism be provided by which the flood water could have come from the headwaters of the various valleys, or of even only the major ones, there certainly should be an ascending upper limit with increasing distance upstream. If it is 1,300 feet at Riparia, it should be considerably above 1,300 feet at Lewiston and Clarkston, 65 miles farther upstream. No such rise is indicated. There is only loess and weathered basalt above this level.

5. There was *in no case any outlet* for these currents in the direction in which they flowed. The only conceivable cause for these reverse currents, in the light of all data now in hand, was an extraordinary volume in the scabland rivers and an extraordinarily rapid rise to the maximum of that volume.

[*To be concluded*]

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VALLEY DEPOSITS IMMEDIATELY EAST OF THE CHANNELED SCABLAND OF WASHINGTON. II

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TRIBUTARY VALLEYS OF THE CLEARWATER AND THE SNAKE ABOVE LEWISTON

The indicated depth of glacial flood water at Lewiston and Clarkston shows that, if the writer's hypothesis be correct, more records of this same character should be found up the Snake and the Clearwater to the crossing of the 1,300-foot contour—and no farther. The writer's study has not yet demonstrated this. There is, however, some more evidence to present.

The lower canyon of Potlatch River, a tributary of the Clearwater, contains a rude, dissected terrace whose frontal edge stands about 30 feet above the valley floor. It is composed of light tan-colored silt and sand, fairly well stratified though with undulatory contacts and some variation in thickness. In pockets and seams, and indistinctly stratified through some of the layers, are multitudes of coarse angular grains of basalt. Scattered sporadically through the silt are angular foreign pebbles and cobbles. In one section there are at least twenty fragments of the granodiorite porphyry, all grouped closely though aligned with the stratification. The largest fragment is 8 inches long. The altitude of the group of fragments is 985 feet A.T. It lies nearly 100 miles up-valley from the scablands.

At the mouth of Asotin Creek, 5 miles south of Clarkston, is a terrace whose surface is 950 feet A.T., 140 feet above the business district of the town of Asotin. The material in the upper part of the terrace is almost wholly coarse black sand, without lenses or strata of silt or fine sand. The material of the coarse sand is largely very angular, unweathered basalt. Its bedding is of the saucer type of current foresets, the laminae dipping toward the Snake. This is close to the southern wall of the creek valley. Traced out into the Snake Valley, the bedding of this continuous deposit, lower in the section, is of long deltaic foresets which dip up the Snake. Still lower and farther out the material is chiefly yellowish silt and sand, though with beds of the coarse black sand.

The deposit lies wholly on the south side of the tributary mouth. The large creek surely has removed much of it, and there may have been, originally, a duplicate of the Tammany Hollow bar here. There is no possibility of deriving all this fresh angular basaltic sand from the Asotin Creek valley. There is plenty of old weathered basalt gravel up the Asotin which should be present in the deposit if the débris came down the creek. There is no possibility that Asotin Creek or Tammany Creek or any of the many other streams with constricting valley mouth bars could have built these forms. The shallow foresets dipping out into the Snake and up the Snake are logical structures for a huge eddy in the up-valley current, an eddy determined by the tributary mouth on the outside of a sharp curve in the course of the Snake.

Farther back up Asotin Creek valley are the characteristic silts, with an unusually large percentage of fresh angular fragments of granite, diorite, porphyritic lava, quartzite, schist, etc. A granite boulder 2 feet in maximum diameter lies at an altitude of about 1,000 feet A.T., at least 250 feet above the Snake.

The mouth of Ten-Mile Canyon, its name indicating its distance above Clarkston, contains a large portion of a gravel bar. It is 225 feet from bottom to top, and the summit is 1,025 feet A.T. It is much gullied, but its original form is still very well preserved. So far as pits and road cuts show, it is composed of foresets which dip back into the tributary valley mouth from the Snake and also dip southward down the northern wall of the tributary valley. Numerous large boulders of weathered basalt lie on the eroded slopes of the bar and are embedded in its gravel, boulders which were torn off the northern shoulder between the tributary and master valleys by the same current which built the deltaic foresets down this northern wall. This current up the Snake swept across the shoulder at an altitude certainly 300 feet above the base of the deposit to which it contributed.

About 8 miles farther up the Snake is the mouth of Couse Canyon. In it lies another one of these extraordinary local gravel deposits. It extends 175 feet from bottom to top, but rests against the sloping northern wall of the valley and nowhere is very thick. But, like the other deposits, it is a definite shoulder built out into the tributary valley. It also contains large boulders of weathered basalt buried in the much finer débris whose basalt content is largely fresh. No structure is exposed. The top of this bar is 975 feet A.T.

The discovery of Couse Canyon bar was made just at the close of the field season. With it came the discovery of a feature as extraordinary as anything yet listed, a feature whose diagnostic value obviously is great. There was no opportunity at this late date, however, to apply it to the many gravel deposits already studied.

The material of this bar is strikingly angular and at first glance appeared to contain no pebbles with rounded shapes. When sought, these shapes were found, though their percentage is very low. But three out of every four pebbles with rounded surfaces turned out to be only chips or splinters or perhaps halves of originally rounded pebbles. The remainder of the outlines are distinctly angular or subangular and sharply truncate the curves of the rounded side.

To check this feature with present Snake River gravels, two nearby bars now swept in flood time were examined—a bar composed chiefly of large cobbles and a bar without cobbles. In the cobble bar, the associated pebbles among the interstices can move only when the cobbles are in transit. They should, therefore, suffer the maximum of pounding by larger fragments which the Snake is capable of affording, except perhaps in rapids. Less than 30 per cent were broken-rounds, and there were almost no angular shapes. In the bar without cobbles, broken-round pebbles (up to $2\frac{1}{2}$ inches in diameter) constituted $12\frac{1}{2}$ per cent of the total. Essentially all else was rounded. Most of the fractured surfaces on all of these Snake River pebbles have been notably abraded subsequently. In the Couse Canyon bar, most fractured surfaces are ragged and hackly, indicating deposition promptly after the breaking.

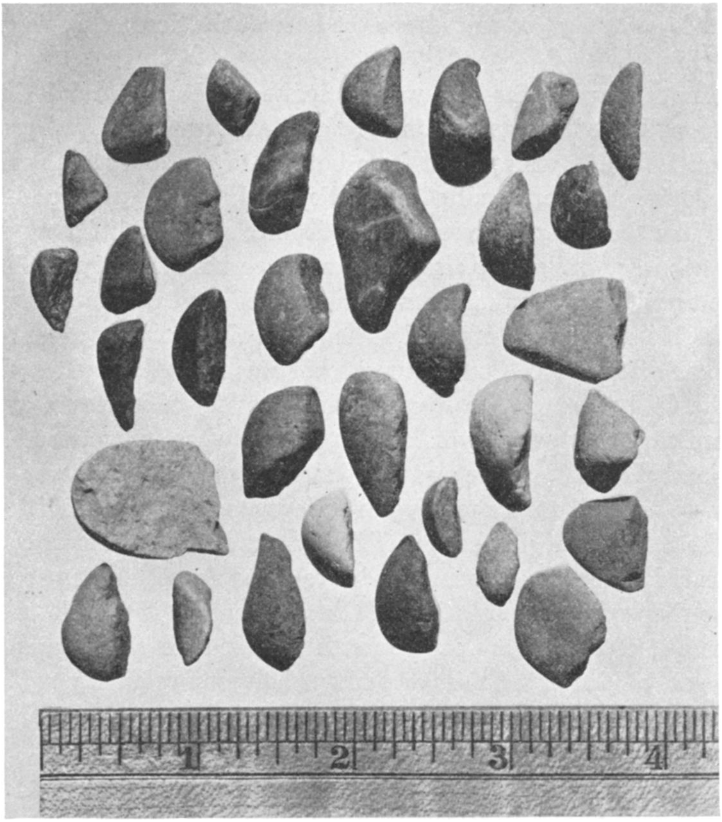

FIG. 4.—Broken-round pebbles from Couse Canyon Bar

Though this was the last gravel deposit investigated in the field study, three "mine-run" collections of angular gravel had already been made—one from the Clarkston semimound, two from the Tammany Hollow bar. These have yielded broken-rounds of identical character. In the Clarkston collection, 1.4 per cent of the pebbles are rounded on all surfaces, 5 per cent are broken-rounds, and 93.6

per cent are completely angular. In the two collections from Tammany Hollow bar, rounded pebbles constitute 0.3 per cent and 1.0 per cent, broken-rounds constitute 3.7 per cent, and 6 per cent, and completely angular forms make up 96 per cent and 93 per cent of the total.

The screening of silt samples taken from Snake River valley and its tributaries has also yielded broken-rounds in 50 per cent of the collections, some samples revealing 5 or 6 such forms on the 1 mm. sieve. Several specimens showed a dull polish on the rounded outlines and a minutely hackly surface on the fractured surfaces.

The data on these valley-mouth heaps of gravel are now nearly all before the reader. The writer believes that these deposits are unique, and that only a unique episode can explain them. Up-valley currents of great depth and great vigor are essential in that explanation. But as through currents, they are utterly impossible. If glacial water backed up the Snake from the scabland rivers, and if it possessed the current indicated, no descending gradient of the valley floor can be held responsible. The gradient must have existed in the *surface* of that flood. The writer, forced by the field evidence to this hypothesis, though warned times without number that he will not be believed, must call for an unparalleled rapidity in the rise of the scabland rivers.

TUCANNON RIVER VALLEY

This tributary to Snake River enters the larger stream from the south less than 4 miles above the entrance of Palouse River from the north. Scabland extends at least that far up the Snake, and the Tucannon therefore is considered as having a separate entrance into the glacial river-channel system. Opening directly toward the great rivers which poured into the Snake from the plateau to the north, this fairly capacious valley would, according to the flood hypothesis, receive a considerable flow back into it. There are great accumulations of gravel along its slopes near and at the mouth, but no valley mouth bar exists. Heavy gravel veneers on the west wall of Tucannon valley at Starbuck, 5 miles south of the Snake, extend up at least to 750 feet A.T. Foreset bedding in the deposit is oriented in various directions. The material is 95 per cent basalt. Non-basalt pebbles are well rounded, but the basalt pebbles are essentially all angular or subangular.

The southernmost deposit of this scabland gravel in the Tucannon is about 7 miles up from the mouth. It consists of a few feet of

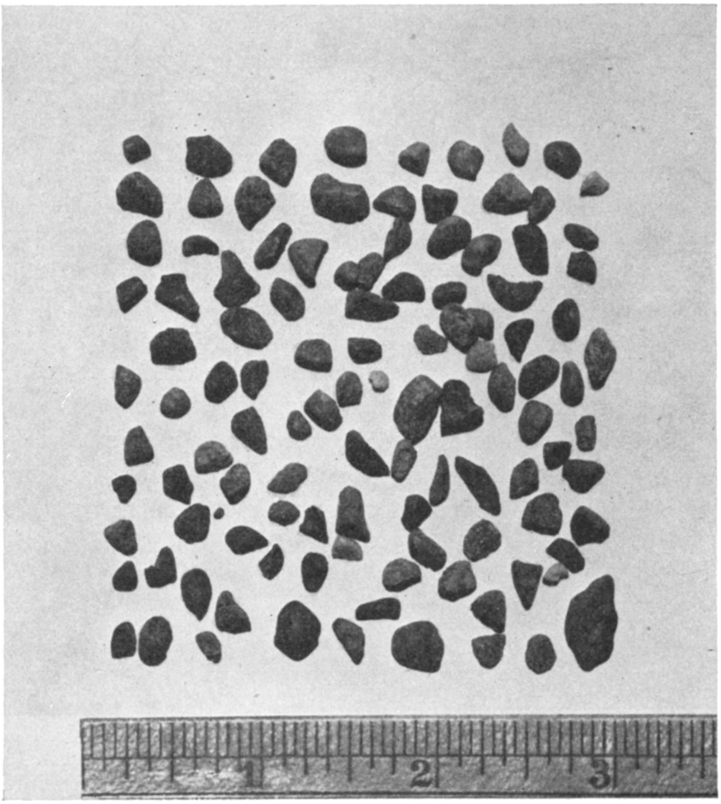

FIG. 5.—Broken-rounds from several samples of the high-level pebbly silts in Snake River valley.

black sand and fine gravel, overlying stratified silts, current-bedded up the Tucannon, and containing a few foreign pebbles. It is low on the valley walls. No gravel deposits in the Tucannon, lying above the valley floor, are known farther up-stream, and in no way can the deposits near the mouth be attributed to the local stream. They are like the great bar deposits on the south side of the Snake opposite the mouth of the Palouse and a product of the same episode. There is abundant evidence to support this statement farther up the Tucannon.

The valleys of Tucannon River and its tributary, Pataha Creek, have fairly wide floors for many miles above Starbuck. Though the streams have considerable gradients (650 feet in 21 miles along Pataha Creek from Chard to the Snake), the valley floors and the valley slopes carry a heavy silt deposit below 1,300 feet A.T. None

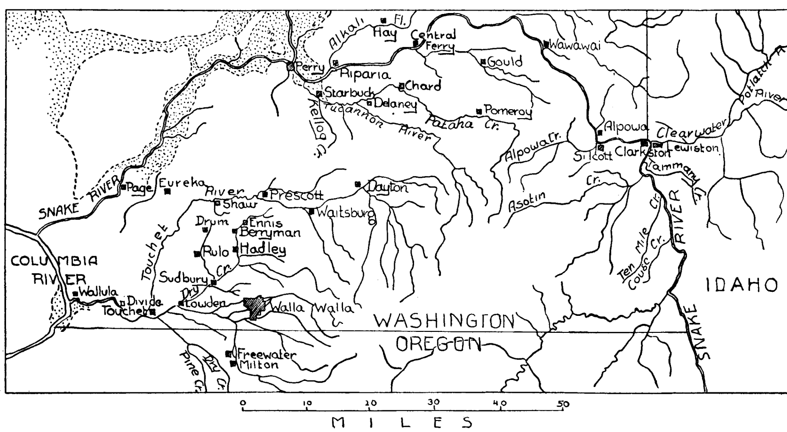

FIG. 6.—Valley deposits immediately east of the channeled scabland of Washington II.

of this silt has been found above that altitude. Fresh highway cuts are numerous from the Snake up to altitudes above 2,100 feet; and this statement is based on a careful examination of most of them, and a sampling of many.[1]

Streams have trenched into this silt until it now constitutes only terrace remnants in most places. The maximum thickness of the silt is certainly more than 50 feet. The best exposures of the silt are in highway cuts at the junction of Pataha Creek and Tucannon

[1] A sample of silt collected at 1,300 feet on the slopes of Tucannon Valley close to the junction of Pataha Creek yielded 11.8 per cent material larger than 1 mm. in diameter. Only one foreign fragment was recognized, a bit of granite. Though the basalt which constitutes this high proportion of non-loessial material is too soft to take steel markings, it is not notably weathered. Little of it is strikingly angular though a few chiplike forms occur. The particles do not have the crumblike shapes that have been found repeatedly for basalt particles in basal portions of the loess.

River. Here the upper surface of the fill is 140 feet above Pataha Creek, 1,020 feet A.T. It lies mostly in the upstream angle between the two streams. The silt deposit at this junction and in the neighborhood is not the poorly sorted or unsorted material which is common on higher slopes. Its stratification is irregular, with many lenses, with irregular contacts, and therefore with variations in thickness almost universal; but the sorting is good. In a 15-foot section, there are ten repetitions of a sequence of fine gravel or coarse sand below light-colored sand which grades upward into tan- or buff-colored silt. The fine gravel is far from clean; perhaps 10 per cent of its volume is silt. Some rhythm in the sedimentation is clearly recorded. But the silt and sand is a deposit of glacial waters, or a derivative of such deposits, for small fragments of non-basalt occur in the fine gravel and a few cobbles of foreign rock are embedded in it. The entire Tucannon drainage comes from the basalt. A little above 1,300 feet, the loessial material on the steep slope above Delaney contains pockets of fresh basaltic particles. There are no foreign fragments here, but they are common about 100 feet lower down this slope.

Many unweathered boulders of various kinds of foreign rock have been brought to light by road grading, most of them from shallow cuts. One fragment of the granodiorite porphyry, 2 feet in maximum diameter, lies in Pataha Creek valley at 1,085 feet A.T., 17 miles upstream from the Snake, and more than 500 feet above it.

The silt terraces are less pronounced eastward up Pataha, and they disappear near Chard, the whole valley floor being covered by the deposit. Here the material is but little sorted and is charged with pebbles and minute sharp bits of fresh basalt and foreign rocks.[1] The highest trace of glacial waters found in Pataha Creek valley was a cobble of granite a little east of Chard and nearly 1,300

[1] Eighteen per cent of the sample from Chard is stopped by the 1 mm. sieve. Nineteen per cent is stopped only by the finest sieve (0.074 mm.), and 35 per cent passes all sieves. Most of the larger fragments on the coarsest sieve are non-basalt and therefore foreign to this valley. To get here they must have traveled 21 miles up the Tucannon and Pataha valleys. The finer material on this sieve is almost all basalt, very angular and largely of fresh material. Knifelike edges of the chips will take a steel streak. The proportion of quartz in the coarser sieves rises from a few grains on the 0.71 mm. sieve to 50 per cent on the 0.177 mm.

feet A.T. No silt was recognized here or farther east along the highway for 35 miles. But the divide between Pataha Creek and Alpowa Creek is crossed in this distance and, descending to 1,300 again, the silts and erratic boulders of Alpowa Creek valley are encountered.

A tributary valley entering the Tucannon from the south, a little above the junction of Pataha Creek, carries the silts up at least to 1,225 feet A.T., where they constitute terrace fragments. At the junction of this tributary, the silt is 40 feet thick and the terraces are well marked. Fragments of foreign rock occur in the silt at 1,225 feet, a mile north of New Hope.[1]

Two north-flowing tributaries to the Tucannon, Kellogg Creek and Smith Hollow, enter the main valley below the junction of Pataha Creek. In the first named, a section 20 feet high occurs at about 1,150 feet A.T. The lower 5 feet is old stream rubble and gravel. The upper 15 feet is of silt or rearranged loess, showing almost no stratification but containing seams and pockets of the fine black gravel or coarse sand.[2]

In Smith Hollow, plenty of the pebbly silt is exposed in a section in the valley floor at 1,140 feet A.T.[3] Foreign pebbles were found

[1] The description for the silt at Chard might be copied verbatim for this sample except for percentages. Twenty-three per cent of this silt remains on the 1 mm. sieve, 34 per cent passes all sieves, and 18 per cent is stopped only by the 0.074 mm. sieve. The following tabulation shows the abundance of quartz grains in the coarser grades.

0.50 mm.—1.6% of total sample—20% quartz—0.32% of total is quartz
0.35 mm.—4.0% of total sample—30% quartz—1.2% of total is quartz
0.25 mm.—4.7% of total sample—50% quartz—2.35% of total is quartz
0.177 mm.—3.8% of total sample—60% quartz—3.38% of total is quartz

In these four sieve samples, more than 6 per cent of the total collection is composed of quartz grains larger than any found in the local loess.

[2] In a sample taken from one of these pockets, only two foreign fragments were found on the 1 mm. sieve, both quartzite. Much of the basalt is in sharp angular pieces whose edges will take marks from a knife blade. Associated with this unweathered basalt are a few pellets of friable weathered basalt, readily crushed in the tweezers. On the 0.71 mm. sieve several grains of quartz were found which contain partially embedded flakes of biotite. Eighty-six per cent of the sample passes all sieves.

[3] Thirteen per cent of the sample from this place was stopped by the 1 mm. sieve, 20 per cent passed all but the 0.074 mm. sieve, and 52 per cent passed all sieves. Foreign material on the 1 mm. sieve consists of quartzite, quartz-muscovite schist, feldspar, and quartz. The curious mixture of much-weathered basalt and unweathered basalt, repeatedly noted, is found here also. The sharpest edges of some of these particles are hard enough to take steel marks, yet the sample collected was only 3 or 4 feet below the surface on a gentle slope.

in the wash material along a road up the side of the valley here to 1,320 feet A.T. The highest erratic was a fresh, coarse-grained granite. Above that level there is only loess and basalt to the summit of the divide.

It is 35 miles across the divide on the east between silts and erratics in Pataha and Alpowa valleys, yet the upper limit is the same in both. This is because the glacial waters which reached back in each came from the same place, the entrance of the scabland flood into the Snake. It is only 12 miles across the divide to the west between silts in Tucannon drainage and in Touchet River valley, a tributary to the Walla Walla; but silts in the Walla Walla nowhere are known within 200 feet of the altitude reached in the Tucannon and Snake drainage. The reason is precisely the same as for the descending series of upper limits in Kamiache, Cottonwood, Lancaster, Rebel Flat, Union Flat, Willow, and Alkali valleys—the descending surfaces of the great rivers.

It should now be clear that basalt grains are abundant in the pebbly silt (reworked loess) up to 1,300 feet A.T. in the Snake River drainage east of the scabland. It should also be clear from the almost universal presence of varied foreign débris that the reworking of the loess and the introduction of the high content of basalt grains was done by glacial water. Almost every sample has yielded essentially unweathered sharp-edged particles of basalt intimately associated with much-weathered pebbles or crumbs of the same rock. The relative proportions of fresh and decayed basalt, however, vary notably. The shapes of the fresh and but little-altered particles are extraordinary. The chips and splinters do not seem referable to abrasion by either streams or glaciers. Vigorous percussion would yield these shapes, as it would produce the broken-round pebbles found in 50 per cent of the silt samples and in several samples of bar gravels. The writer's explanation incorporates this idea of percussion, deriving the basaltic débris from local slopes swept by the rush of glacial backwater. Some of this débris was already well weathered, and when fragmented did not yield the riven shapes.

There are two other possible explanations for these basaltic particles in the silt: (1) they may be the product of local weathering; and (2) they may have been carried back up the Snake from the scablands. The first fails to agree with the field evidence in several vital points and is rejected. The second demands some mechanism for that transportation many tens of miles up the valley lengths and many hundreds of feet up the valley slopes. The only mechanism which seems feasible is berg-ice. Yet the definite berg deposits of the region do not contain basalt. The ice moved so short a distant over on to the basalt plateau that little, if any, of this material is to be expected. The foreign boulders and cobbles and the larger foreign pebbles in the silt samples were undoubtedly carried by floating ice, but the presence of the basalt does not seem satisfactorily explained by this procedure.

The writer is not yet satisfied with his explanation. There are two items of the field evidence that do not seem to harmonize with it: (*a*) the abundance of very angular quartz grains that obviously did not come from either loess or basalt, and (*b*) the thorough dissemination of coarse particles through the unstratified phases of the silt. An attempt to understand this latter item is outlined in the next few paragraphs.

A sample block of the pebbly silt, several pounds in weight, mixed with twice its volume of water, was stirred vigorously to get it all in suspension, and was then allowed to settle. The coarser particles settled first. Only the finer sand was found mingled with the silt. Several repetitions of this experiment, with decreasing amounts of water, gave the same result so long as the material was sufficiently liquid to take a plane upper surface when the current ceased. To keep the coarser particles suspended in the fine, and thus to duplicate the intimate mixture of all sizes in the original sample, it was necessary to so reduce the quantity of water that the material was a mud sufficiently thick to hold irregularities of its upper surface when stirring ceased. The pebbly, gritty silt of these valleys east of channeled scabland is apparently a mud-flow.

The mechanism of a mud-flow seems utterly at variance with any picture one may devise for the action of glacial water in these valleys. The mantle-like character of the deposit on valley slopes suggests at once the alternative that this intermingling of coarse and fine material is the product of soil creep and is not an original structure at all. But before one concludes that the matter is disposed of by this suggestion, he must explain the thick deposits of pebbly silt on the very gentle slopes of valley flats and even on hilltops, and must account for the undisturbed stratification of clean, fine sand both above and below the problematical silt in some sections. Furthermore, this alternative hypothesis must start with the fact that both erratic particles and sharply angular unweathered basalt particles lay on all these slopes before the postulated soil creep could mingle with the loess. It therefore offers no escape from the idea of a glacial flooding.

Experimental production of creep in the sample material has not been successful. The quantity worked with was so limited that the influence of friction on sides and bottom of a trough extended throughout the mass. A duplication of the internal stresses involved in creep was impossible, and what really was secured was a sliding. Yet with as little jarring as possible sliding in both wet and dry material promptly produced a concentration of the coarser particles in the bottom portion of the sample.

Reverting again to the writer's hypothesis, we may ask how an up-valley surge can produce the mud-flow structure of this pebbly silt. The valleys certainly were not filled with mud to the upper limits of the turbid glacial water. The silt (reworked loess) and probably the basaltic chips came from the local slopes as the water rose; only the erratic material surely had to come in with the glacial flood, and floating ice can be called on for this.

The mud mixture must, apparently, be considered a product of the agitated marginal water of the rising flood, left in the deepening water with little further disturbance. Some incipient assortment may record a little reworking, but further additions to the deposit apparently would be sorted, and pebbly silt above the stratified material seems to be debarred unless local subaqueous slumping could produce it. It seems certain that if the pebbly silt and the gravel deposits on the valley bottoms are of the same episode, the silt could not have been deposited at the maximum flooding or during recession of the water; else it would overlie the gravel.

The foregoing suggestions are very sketchy. There is no internal evidence in the characteristics of the pebbly silt to support the flood hypothesis. The most that can be said is that the silt is a product of glacial water, that battering of basalt occurred somewhere to make the included coarse, angular grains, and that the conditions of its deposition were extraordinary. The problem of its origin probably will not be solved by consideration of its characteristics alone; the silt must be studied in the light of the other extraordinary deposits of the region.

WALLA WALLA VALLEY

The main current of the glacial flood across the scablands, after entering the canyon of the Snake, followed it down toward the Columbia. About 35 miles below the mouth of the Palouse, Snake River passes to a relatively down-warped tract in which the canyon walls disappear. In this tract, the Snake joins the Columbia. Like all structural valleys with adequate outlet along the course of the glacial rivers, it is an excellent place to test the hypothesis of great volume. Without that volume there can be no high upper limit of silts and berg-borne erratic boulders, for structural valleys on the Columbia Plateau in Washington have not suffered any considerable deepening by erosion. They are today essentially only the original down folds. The hypothesis of several different epochs of great valley-deepening since the upper bars or silts or scabland were made is obviously inapplicable to a structural valley.

Flooding by glacial water occurred in this structural basin, spreading out in a huge pond 75 miles long. A large part of the Walla Walla drainage area lies in the depression; and glacial water extends eastward up the Walla Walla from the Columbia, reaching in one place within 12 miles of the Tucannon backwater. Due to the low altitude of the district and the lack of notable canyons in it, most of the divides of the Walla Walla basin were submerged by the wide sheet of water. Hundreds of observations in all parts of this drainage area show that the glacial water reached up to, but nowhere above, 1,100 feet A.T. Over the site of Walla Walla city, close to the eastern limit of the flooding, it was 175 feet deep; and at the junction of Touchet River, a major tributary of the Walla Walla, it was 650 feet deep. Since the drainage of the Walla Walla system is wholly from loess and basalt, any other material in the sediments must be a contribution from the Snake or the Columbia valleys.

EUREKA FLAT

A curious feature of the loessial hills which diversify the surface of the Walla Walla region is their elongated linear shapes, trending approximately N. 20° E., and their close spacing. Among these linear hills between Walla Walla River and the Snake is an equally curious elongated flat, several miles wide and nearly 30 miles long, subparallel with the Snake and trending about 40° east of north. The surface of this flat rises gradually from the southwest about 17 feet per mile to the northern end, from which one can see the mouth of the Palouse a thousand feet lower and 6 or 7 miles away.

Whatever the origin of these peculiar topographic features in the loessial cover of the basalt, they control the minor horizontal irregularities of the upper limit of silt and erratics. The topographic expression of this low part of the Columbia Plateau, therefore, antedates the flooding.

The lower part of Eureka Flat was inundated by water escaping directly out of the Snake. The glacial silt 3 miles north of the town of Eureka is more than 20 feet thick. It is composed chiefly of reworked loess, horizontally stratified, but contains many layers of fine, light-colored sand and many pockets and strata of coarse basalt sand, the grains angular and unweathered. The evidence of glacial origin is found in hundreds of grains, pebbles, and cobbles, and in a few boulders of a variety of foreign materials. Some of the cobbles and boulders bear good striae. There are a very few thin seams of gravel, in which foreign débris is prominent. Similar sections occur both east and west of the town. But though the flat continues for 15 miles farther northeast, rising from 1,050 feet (the highest silt) to 1,500 feet at the northern end, nothing except loess and basalt were found on its floor.

TOUCHET VALLEY

The headwater creeks of Touchet River flow northward from the northern spur of the Blue Mountains, uniting near Dayton and Huntsville to flow westward for about 30 miles to the eastern margin of Eureka Flat. The river, here 200 feet lower than the flat, turns southward along the contact of Eureka Flat on the west and the close-set linear hills on the east to enter Walla Walla River about 20 miles farther downstream.

The characteristic records of the glacial flooding occur in well-marked terraces for 12 miles along the east-west stretch, extending as far up as Prescott (1,038 feet A.T.). But east of a point about 2 miles beyond Prescott, the road cuts show only basalt and loess. The loess is reddish or yellowish in color, intimately cut by seams of lime and in some places full of closely spaced nodules of lime-cemented loess.

Sections in the Touchet valley terraces show a gray silt full of tiny black basalt grains and bits of foreign rock. Its thickness at Shaw, about 2 miles east of the margin of Eureka Flat, is nearly 80 feet, the height of the terrace above the river. At Prescott, which is essentially the upstream limit of the silt, the terrace itself constitutes the highest of the deposit, about 1,050 feet A.T. At Shaw, however, the terrace top is 890 feet[1], and the silt extends up the lower slopes as a mantle to 1,020 feet, where the highest occurrence of fresh basalt grains in the loessial débris was found.[2] Two foreign

[1] Seventy-one per cent of the sample from this terrace has the texture of loess. Six per cent is of particles too large to pass the 1 mm. sieve. In the coarser material angular basalt is dominant, some of it fresh and some weathered. Particles of granite, vein quartz, and quartzite are associated with the local rock débris. Quartz constitutes 5 per cent of the material on the 0.71 mm. sieve, 10 per cent on the 0.5 mm. sieve, 25 per cent on 0.35 mm. sieve, and 50 per cent each on the 0.25 and 0.177 mm. sieves. Very little of this quartz shows worn surfaces. A few cleavage fragments of feldspar were recognized on the 0.5 mm. sieve. In essentially all respects, this Touchet Valley silt is like that described for Snake Valley.

[2] Only 1 per cent of the sample taken here was stopped by the 1 mm. sieve, and 74 per cent passed all sieves or was stopped only by the finest one. The only foreign ma-

pebbles were found at 1,090 feet A.T., 4 feet down in the dust and loose loess.

In its southwestern course along the margin of Eureka Flat, Touchet valley was completely submerged by the glacial water, the silt deposits lying back on the adjacent upland. As far down the valley as Johnson's Bridge (6 miles upstream from Walla Walla River) almost every cut in unconsolidated material exposes unstratified silt charged with pockets and disseminated particles of rock, basalt greatly predominant. Near Johnson's Bridge are two splendid exposures of the silt, each nearly 100 feet high. In one the lower 50 feet is composed of brown silt or fine sand, rather massive, well sorted, and so coherent that it forms cliffs. There are a very few pebbles of foreign material in it. No pockets or lenses of the coarse basaltic sand were found, though there are a few lenses of angular basaltic pebbles and cobbles. The upper 50 feet consists of a weaker silt which does not maintain cliffs, which is more gray in color, and which has plenty of lenses and pockets of tiny pebbles and coarse sand grains.[1] A few cobbles and boulders of non-basalt

terial consisted of the abundant quartz grains, some large thick mica cleavage fragments, and one unworn cleavage bit of feldspar. Some angular grains of quartz on the 1 mm. sieve contain mica flakes partially embedded in them. The dominant basalt on the coarser sieves is subangular to subrounded. Much of the quartz is subrounded. Both fresh and unweathered basalt are present, some bits with knifelike edges that take a steel mark.

[1] Fourteen per cent of the lowest of this pebbly silt is stopped by the 1 mm. sieve; from 4.6 per cent to 6.8 per cent remains on each of the next seven sieves; and only 44.4 per cent passes the 0.074 mm. sieve or is stopped by it. The coarsest grade contains fully 10 per cent of foreign material, and it is in as small pieces as the 90 per cent of basalt on this sieve. Most of the basalt is wholly unweathered and exceptionally angular. A few broken-rounds occur in this sample, mostly of foreign rock, which must have been rounded, and probably were broken also, before being carried back into the Walla Walla depression. The proportion of quartz on the six coarser sieves increases from a few grains on the 1 mm. sieve to 50 per cent or 60 per cent on the 0.177 mm. sieve.

Whereas splintering and chipping of local basalt was apparently possible in the back-rush up Snake River valley, that procedure does not seem probable here. There was no opportunity for production of such a current here, nor were there numerous basalt outcrops. The very sharply angular basalt of the Touchet valley silt seems best explained as a derivation of the scablands themselves. It is difficult, however, to account for their transportation here. Even though some basalt might be included in berg-ice, it would hardly be limited to these grade sizes and these shapes, and it certainly would are scattered sporadically through the silt. There is no really good stratification in either member.

Another section, half a mile farther upstream, shows much the same things. Light-brown, rather massive sand and silt underlies brownish and grayish stratified sand and silt. Pockets and lenses of coarse sand and small pebbles are rare in the lower brownish member but common in the upper member. The stratification is irregular and undulatory in detail and in the large. It seems to record different times when the water here became more muddy and then cleared up somewhat. But how are we to explain the currents recorded by the coarse-textured basaltic sand containing particles of foreign rock? And how explain the pocket form of much of this aggregate? Some of these are as thick as they are wide; none are elongated as thin strata. They might be explained as small masses dropped from berg-ice; but lenses of such material, indubitably so, are present in other sections in the Walla Walla valley and have such strikingly different composition that this explanation apparently must be rejected. Whatever the details of a final explanation may be, it seems obvious that exceptionally turbulent and excessively turbid water must be admitted.

Sections in the silt of Touchet valley south of Johnson's Bridge show a great deal of stratification; and the extensive silt terraces out in the open Walla Walla valley, shortly to be described, possess a very uniform and regular stratification.

The area between Touchet River and Walla Walla River, approximately 15 miles wide, slopes southward toward the larger stream. The divide runs subparallel with the Touchet, 300 to 500 feet above it, and only about 2 miles south of it. Several minor valleys in this gentle southern slope will now be examined.

DRUM-RULO VALLEY

The up-valley limit of silt in this unnamed drainage way is at Drum station, 1,045 feet A.T. It has all the familiar characteristics so frequently recited. But at 1,100 feet, three-fourths of a mile north of Drum, an excellent new section yielded nothing but gray loess with

not constitute 90 per cent of berg contributions. The finer foreign material in these silts seems too thoroughly intermingled to have dropped directly from floating ice.

nodular lumps.[1] Southward from Drum, the little valley contains terraces, the pebbly silt being recognizable in dozens of road cuts. South of Thiel, this silt shows a stratification of irregular and undulatory beds, but the sorting of sand from silt is very imperfect.

ENNIS-BERRYMAN-HADLEY VALLEY

The highest record of glacial water in this minor drainage line was found on the valley bottom at 1,090 feet A.T., four-fifths of a mile north of Ennis station. The evidence consists of a few pockets of pebbles and grains containing foreign material.[2] At 1,100 feet and above, along this valley way, only clean gray laminated loess is exposed in the road cuts. Lest one think that these pebbly silts on valley slopes might be outcrops of a formation between the basalt and the true loess, it should be noted that half a mile north of Ennis, at 1,070 feet A.T., a cut shows nodular loess beneath unstratified gray silt with foreign pebbles and bits of bright basalt. Farther along this cut in the valley slope, the silt disappears and the loess

[1] Three samples were collected in this vicinity—one in the highest exposure of the pebbly silt at 1,045 feet A.T., one a mile down the valley at 1,020 feet A.T., and one of the undisturbed loess three-fourths of a mile up the valley at 1,100 feet A.T. Coarse material is most abundant in the lowest sample. The loess itself has no coarse material, and the contrast between its composition and that of the pebbly silt samples is the universal contrast throughout all the country immediately east of scabland. Foreign material in the pebbly silt includes granite, gneiss, quartzite, diorite, mica schist, and vein quartz. Many quartz grains on the coarser sieves have embedded portions of crystals of hornblende, mica, and feldspar.

[2] A sample taken at 1,090 feet A.T. has 3 per cent of its weight stopped by the 1 mm. sieve, while 78 per cent either passes all sieves or is stopped only by the finest. Another sample, taken a quarter of a mile farther down the valley, contains 10.5 per cent of material too coarse to pass the 1 mm. sieve, while 65 per cent is stopped only by the 0.074 mm. sieve or passes that. This parallels the result obtained in a similar set of samples in the Drum-Rulo-Thiel valley. Since the glacial silt of these valleys is not sorted and has pockets and seams of coarser material, different samples from any one place should not be expected to agree very closely. Collection was guided in all cases, however, by the justifiable desire to have the anomalous composition most strikingly brought out. These analyses therefore show the maximum amount of coarse material in each place. It seems fair to conclude that there is less of it in the re-worked loess at the upper limit of these narrow valleys. The sharp angular bits of basalt, common in these valleys, are well above the top of the basalt formation, the valleys being wholly in the loess. Like the foreign débris, these innumerable bits of basalt have been carried up the valleys. There is plenty of fresh material in every one of the several samples taken. There has been little, if any, weathering or erosion since the deposits were made.

constitutes the entire exposure. The silt, therefore, lies in a valley in the loess.

An instructive section a mile south of Berryman, at about 950 feet A.T., shows 15 feet of unconsolidated material above basalt. The uppermost 3 feet or so is brown soil, probably in large part a wash deposit from neighboring slopes. Below this is buff-to-brown loessial material, unindurated, containing reddish streaks and patches that are not far from horizontal. This buff-to-brown material contains scattered sharp grains of basalt and foreign rock. One seam especially well charged with rock bits is almost a coarse sand, 3 to 5 inches thick and several feet long. Below the pebbly brownish silt or loess is reddish nodular loess to the underlying basalt. Closely spaced, irregular, intersecting lime seams are especially prominent in it. There is some calcareous infiltration in the pebbly silt—a rare thing.

SPRING VALLEY

Terraces about 25 feet high, composed of the glacial silt, occur in the lower part of this valley, their surface about 920 feet A.T. along the road in section 17. A stream-cut bank here shows pebbly silt, loess, and basalt, though not overlying each other in vertical sequence. The loess is dark reddish brown, dense, hard, and highly calcareous. It contains numerous irregular pebble-sized fragments of weathered basalt, but no foreign material. The angularity is of a quite different type from that possessed by the fresh basalt in the glacial silt. The rock has been crumbled to make these pieces, and the surfaces of the fragments are much pitted; while the fresh basalt particles so frequently mentioned have been sharply and cleanly broken as though by percussion. The adjacent silt is unstratified, distinctly grayish, sandy, and friable. Numerous pebbles of quartzite, granite, etc., are associated with the particles of unweathered basalt.[1] A granite boulder lies in the stream bed near this section.

[1] The contrast in the quartz content of the two samples is worthy of emphasis. The loess yielded a few grains of quartz on the 0.5 and 0.35 mm. sieves, about 1 per cent on the 0.25 and 3 per cent to 6 per cent on the 0.177 mm. sieves. The silt adjacent to this loess yielded numerous quartz grains on the 1 mm. and the 0.71 mm. sieves, 10 per cent on the 0.5 mm., 40 per cent on the 0.35 mm., and 50 per cent on the 0.25 and 0.177 mm. sieves. This notable difference, repeatedly found in other samples also, indicates introduction of the large quartz grains with the glacial water. But the sum of all material on these six sieves was only 5.9 per cent of the total sample, and probably not more than 2 per cent of the flood silt consists of such introduced quartz.

On the divide between Spring Valley and Dry Creek to the south, half a mile from the section, the same pebbly silt occurs at 1,050 feet A.T.[1]

DRY CREEK

The main valley of this stream describes an arc of 120° about the northern environs of Walla Walla, its radius approximately 6 miles long, and that city lying at the center. Dry Creek receives the drainage of the three minor valleys just described. Being lower and more capacious, it has more of the silt deposited by the glacial flooding. No sections were available on the floor or lower slopes in the vicinity of the 1,000 and 1,100 foot contour crossings; but where the valley floor is about 900 feet, the slopes on both sides carry the pebbly silt, up at least to 990 feet A.T. on the south[2] and to 1,050 feet on the north. A terrace fragment constituting a low mound on the valley floor at 950 feet shows unstratified silt charged with tiny pebbles and large sand grains of angular fresh basalt. Associated with them are a few fragments of non-basaltic rock.

The deposit is much thicker a few miles farther down the valley. Near Paul School, a cut 27 feet deep is wholly in the silt. Layers of sand and silt alternate. Sharp contacts are more common than gradations. The bedding is horizontal as a whole but has many minor undulations. Few beds are more than 6 inches thick. Many layers of silt are clean and well sorted; others are highly charged with coarse, angular, black basalt grains. There are pockets of basaltic sand, some clean washed, others with a matrix of the silt. There are lenses of angular basalt gravel with many foreign pebbles.

From Paul School down Dry Creek valley, the silt deposit is so heavy that nothing else shows. The present creek flat has been re-excavated from an almost complete fill that was 50 feet or more in

[1] No pebbles of foreign rock were found in this sample. But the presence on the coarser sieves of abundant basalt, some of it angular and nearly fresh, some weathered and crumbling, and of quartz grains which reach a maximum of 50 per cent on the 0.177 mm. sieve indicate the action of glacial water. Furthermore, a cobble of the granodiorite porphyry was found at this altitude on the slope.

[2] Of this sample, 11.6 per cent was stopped by the 1 mm. sieve. It contained particles of mica schist, granite, quartz, feldspar, quartzite, and mica. The mica occurs in large, thick pieces, not in thin flakes. Some of the quartz grains have mica partially embedded in them. The proportion of quartz increases to 50 per cent on the 0.177 mm. sieve. Twenty per cent of the sample passed all sieves, 22 per cent was stopped by the 0.074 mm. sieve, and 27 per cent by the 0.104 mm. sieve.

depth. The low divide between Dry Creek and Mud Creek to the south is entirely covered with the silt. The highest sections here are 950 feet and show only the silt. Indeed, this divide is a dissected silt plain, the summits still holding flattish surfaces, a feature wholly lacking in the loessial hills above 1,100 feet A.T. to the north and to the east.

One section on this divide, near Sudbury, reveals a lens several feet long and a foot thick, very highly charged with angular foreign pebbles. Many of these fragments are well striated on different sides, the marks crossing each other in the fashion typical of glacial striae. No basalt was found in the débris. This lens certainly is not of the category of pockets and lenses dominated by sharp angular basalt grains. It is underlain by well-washed fine sand and overlain by pebbly silt. Both contacts are very sharp.[1]

The lens of coarse non-basaltic débris is interpretable only as a mass of till. Associated small boulders in this and nearby sections tell the same fact: that there was abundant floating glacial ice in the water when the heavy silt mantle was deposited. Indeed, all the coarser foreign débris back in all valleys described in this paper must have been similarly transported. But in almost all cases, the foreign material and the sharp pieces of basalt were mixed thoroughly with the silt before coming to rest. For this mingling there must have been some transportation after release of the foreign material from the ice. And there must have been some method of transportation, other than floating ice, to distribute the broken fresh basalt particles so widely and so high on the pre-existing loessial slopes.

[1] Of the sample from the lens, 77.3 per cent was stopped by the 1 mm. sieve. In all this material, not one particle that could be referred to Columbia basalt was found. Only one holocrystalline fragment was found, a granite. The material appears to consist essentially of slate, argillite, and quartzite. Quartz grains range from 30 per cent on the 0.71 mm. sieve to 50 per cent on the 0.25 mm. sieve. No basalt was found in any of these grades. The fine product consists of 3.8 per cent stopped by the 0.074 mm. sieve and 9.8 per cent passing that sieve. Both the silt immediately below and that directly above the lens are low in percentage of pebbles and coarse grains. Their coarser grades all contain basalt particles. The quartz content on the 0.25 mm. sieve is 40 per cent in the silt above the lens and 60 per cent in that below. On the 0.177 mm. sieve it is 50 per cent and 70 per cent, respectively. Fifty-eight per cent of the upper silt and 69 per cent of the lower are stopped by the 0.074 mm. sieve or pass this sieve.

VICINITY OF WALLA WALLA CITY

Before examining the great silt filling in the central part of the Walla Walla valley, the eastern and southern margins will be considered. The city of Walla Walla is only a few miles from the eastern limit of the large structural down-warp. A pronounced upwarp, constituting a northern spur of the Blue Mountains, rises to summits nearly 4,000 feet above the city, about 17 miles to the east. Numerous creeks flow down the western slope, some to Touchet River, some to Dry Creek, and some to Walla Walla River. Mill Creek, the northernmost and largest of those entering Walla Walla River, has built a large fan in the eastern part of the depression, on which it divides into several distributaries. The head of this fan is about 1,400 feet A.T., and it descends westward about 80 feet to the mile. Walla Walla is built on this fan, altitudes in the city ranging from 900 feet in the west to 1,050 feet in the east.

The glacial pebbly silts with foreign rock fragments overlie the lower part of this fan, except along the stream ways, and extend eastward to upper limits of about 1,080 feet A.T. A small cobble of the granodiorite porphyry was found at 1,100 feet, about a mile east of the city limits. But farther east, nothing except dust, reddish-brown loess, basalt and basalt gravel have been found on the slopes of the Walla Walla drainage basin.

The relations of the glacial silt and erratics to the Mill Creek fan make it clear (1) that some portions of the fan have not been worked over since the flooding, (2) that the fan in the valley and the canyons on the upwarp long antedate the flood, and (3) that the warping which made the canyons and the fan possible was still earlier. This sequence must not be neglected in evaluating any proposed explanation for the distribution of the silt and erratics in Walla Walla valley.

Another fan, built by the south fork of Walla Walla River, lies in the general region of Milton and Freewater, Oregon. It blends with the Mill Creek fan near Walla Walla. It apparently has been completely worked over since the episode of glacial water, for no traces of the silt deposit were found on it. The region, however, has a record of the episode back in the valley of Dry Creek, Oregon, a tributary entering from the south.

DRY CREEK, OREGON

This narrow valley descends a steep structural slope (the continuation of the Horse Heaven Hills uplift in Washington) to Walla Walla plain, debouching about 3 miles northwest of Freewater. A terrace composed of light-colored silt, about 50 feet high, extends northwest and southeast along the front of the uplift at the mouth of Dry Creek valley. Terrace forms continuing its profiles southward up this valley are recognizable for 2 miles back. In every one of several good exposures in this distance, pebbles of various kinds of foreign rocks were found. All were essentially unaltered by weathering, one was distinctly striated. The tiny pebbles and coarse grains of basalt are abundant. They show some tendency toward a stratiform concentration in places. There are also silt layers and fine sand layers which do not show these particles.[1]

The highest altitude at which this pebbly silt was found is 1,000 feet A.T. The next good cut up the valley is at 1,100 feet A.T. The material here has none of the characteristics of the glacial silt. There is no foreign material; and the contained basalt is weather-fractured débris, mostly in large pieces and obviously derived from local slopes.[2]

PINE CREEK

This drainage way, which is very similar to Dry Creek, debouches from the uplifted tract into the plain about 3 miles farther west. Its valley contains terraces of the silt in its lower 2 miles, the highest being 975 feet A.T. The valley farther up is walled and floored with basalt. One section is 20 feet high, with local stream gravel at the base, and all the rest of massive silt in which are a few

[1] In the sample which was sifted, taken from an altitude of 990 feet A.T., 9 per cent was stopped by the 1 mm. sieve and 50 per cent passed all screens. The largest fragments were of foreign rock. Basalt particles, both fresh and weathered, are present. The shapes of the particles are distinctly angular, though not of the extreme forms described in other samples as chips, splinters, or slivers. Quartz is unusually abundant, amounting to 40 per cent on the 0.5 mm. sieve and 60 per cent on the 0.25 mm. sieve.

[2] This silt taken from the valley floor is simply a mixture of loess and local basalt. There is very little quartz in grades coarser than 0.125 mm. Another sample, taken at 1,150 feet, is of the hill-slope loess. The amount of material stopped on each of the first six sieves ranges from 0.3 to 0.8 per cent. Quartz constitutes 25 per cent of that on the 0.25 mm. sieve but only 10 per cent of that on the 0.177 mm. sieve. Seventy-five per cent of the total either passes all sieves or is stopped only by the finest.

pockets and lenses of coarse sand and pebbles. There are plenty of foreign fragments in these pockets, though the easily recognizable "bright" basaltic débris was not found. Another section, near the upper limit in this valley, has numerous foreign pebbles and imperfect stratification and pockets in which coarse basalt sand is very prominent.[1]

A fragment of the granodiorite porphyry was found on the divide between Dry Creek and Pine Creek at 950 feet A.T. There are numerous other boulders of foreign rock associated with it.

WAYLAND ROAD

A minor gulch utilized by this road up the structural slope, a few miles west of Pine Creek valley, contains terraces of silt up to 925 feet A.T. The material of the terraces is typical in every way. The highest exposure is about 180 feet above the silt terrace that flanks the foot of the uplift. It is impossible to select a hillward contact of this terrace, for the surface of the silt mantle rises gently from the terrace flat up the lower slopes.

BUTLER GRADE

This abandoned road southward up the structural slope, nearly south of the town of Touchet, affords no cuts. But the rain-washed and wind-swept old roadway has much coarse black basalt sand concentrated in the ruts. Most of it is unweathered or but slightly weathered. Three to 5 per cent of this concentrate is composed of tiny fragments of unweathered foreign rocks. This persists up to about 1,000 feet A.T. Here the steep grade disappears across a structural flat, and little wash has occurred. The next steep grade begins a trifle below 1,300 feet. A few foreign pebbles were found here up to 1,425 feet, as far as this traverse was carried. But the finer material of the wash contains no foreign bits, and the basalt sand and fine gravel is distinctly weathered. It seems probable that

[1] In two samples of the silt, one taken at 950 and the other at 975 feet A.T., 12 per cent and 8.6 per cent were stopped by the 1 mm. sieve, while 43.5 per cent and 47.4 per cent passed all sieves. Both contain an increasing percentage of quartz down through the first five sieves, reaching 65 per cent and 50 per cent, respectively, on the 0.25 mm. sieve. Both contain unweathered subangular pebbles of foreign rock and angular particles of basalt, some of which is as hard as fresh rock when tested with a knife blade.

these pebbles were scattered along this road in the same way that the bits of crockery, glass, and iron in the wash were carried here.

VAN SYCLE CANYON

Five or 6 miles farther west is a prominent spur of basalt projecting north from the lower slopes of the Horse Heaven Hills uplift. Its summit, nearly a square mile in area, is 850 feet A.T. Walla Walla River has cut a relatively narrow valley across its northern slope, the bottom of which is 500 feet below this summit. Van Sycle Canyon, eroded along the steeply tilted, perhaps faulted, basalt flows, enters the Walla Walla just west of the prominent spur. The fine glacial silt is deep along the lower part of the stream way from this canyon. It extends westward along the foot of the uplift almost to the entrance of Wallula Gateway, the Columbia's spectacular watergap through the Horse Heaven Hills uplift. On both sides of Walla Walla River it constitutes the only material exposed between the rock-walled Walla Walla trench and the Columbia.

THE WALLA WALLA PLAIN

The large downwarp in which Yakima, Snake, and Walla Walla rivers enter the Columbia has minor structural diversities. One of these is a smaller basin in the Walla Walla drainage area. It extends eastward from the basaltic spur above-noted for 25 miles to the foot of the uplift east of Walla Walla. It is about 15 miles across from north to south. The basalt throughout this tract is below all stream grades. In the city of Walla Walla, it is 500 feet below the surface. The low tract has no loessial hills, yet it is much diversified by hills and valleys and has a maximum local relief of 150 feet in less than a mile. Almost all sections seen in this basin are in stratified silt, sand, and gravel. A very few sections show reddish calcareous loess at the base. The water-laid sediments of this plain show maximum vertical sections of 80–90 feet, and the total thickness probably exceeds 150 feet.

The plain is crossed by a multitude of minor streams. These, with Walla Walla River, have dissected the once continuous fill into its present roughness. In the higher marginal parts of the plain the material is like that in the lower parts of the tributary valleys already described. It is light-colored, sorted sand and silt with irregular and undulatory bedding, with seams and strata of dark, coarse sand and fine gravel, with scattered erratic débris present in almost every section, with pockets and lenses as well as disseminated tiny pebbles and large grains of unweathered basalt.

The restored surface of the dissected fill descends westward about 25 feet to the mile. This might be considered an aggradational slope if the material were fluviatile and had come from the headwaters of the converging streams. But there is abundant evidence that it was deposited in a body of glacial water reaching back from the Snake and Columbia and submerging the region up to the 1,100-foot contour, 600 feet above the surface of the fill in its western part. The slope therefore may be explained more satisfactorily as due to the pre-silt floor, itself perhaps fluviatile. The Mill Creek fan and South Fork fan may be portions of that floor, higher than the surface of the glacial backwater.

Walla Walla River leaves this aggraded plain by the rock-walled trench at Divide and Reese eroded in the northern slope of the basaltic spur near Van Sycle Canyon. This crooked trench has considerable remnants of the silt and sand deposit in it and therefore, in large part at least, is the pre-silt dischargeway from the basin. The trench is 300 feet deep at Reese.

If this be a correct picture of conditions before the submergence by glacial water, let us attempt to visualize the details of the flooding, assuming any normal cause and any reasonable volume for the Snake and Columbia. The rise of that water first produced reverse flow through the trench, the backwater emerging abruptly near Divide into a basin ten times as wide as the rock-walled valley. This condition would persist while the water in the western part of this basin deepened to at least 300 feet, this figure determined by the highest water-laid deposits in the valley here. Notable back-current might have poured through the trench while the water rose, but it could hardly have persisted across the expanding lake in the basin, nor would there be any more favorable conditions for current back across the flooded Walla Walla plain after the water had risen above the barrier at Divide and Reese. Thick deposits of coarse gravel and coarse sand, foreset up the Walla Walla valley, could hardly be deposited out on the broad floor of this lake 5 miles from the eastern end of the trench.

This sketch has been drawn that the reader may better appraise the character of the water-laid sediments in the western and lower part of the Walla Walla plain. These sediments will now be described.

A river cliff near Cummings Bridge, half to three-fourths of a mile south of the east end of the trench, shows about 60 feet of sand, gravel, and silt. The section in mid-length of this cliff consists of a few feet of brown sand beneath 20 feet of coarse rubble gravel containing foreign fragments. The gravel and sand interpenetrate with irregular lenses of each in the other. Above the poorly worn gravel is 30 feet of fine brown sand to the top of the section. This sand is distinctly and uniformly stratified into beds 2–4 feet thick.

Traced southward less than 1,000 feet, the upper brown sand goes beneath another gravel bed, which in turn is covered with gray sand and silt. This upper gravel member is black, prevailingly rather fine textured and irregularly bedded. It contains several large boulders. The gray sand and silt above it has undulatory and somewhat irregular stratification.

But if traced northward from mid-length of the section, the brown sand above the rubble gravel goes under gray silt and sand. The black fine gravel of the south end of the section is absent. The contact between the uniformly bedded brown sand below and the irregularly bedded gray sand and silt above is unconformable, and its descent northward finally cuts the brownish sand out of the section, the gray silt and sand resting on the rubble gravel. Its undulatory and irregular bedding conforms generally to the sloping contacts and truncates the nearby horizontal bedding of the brown sand.

Except perhaps for the two brown members, this section records deposition in glacial water or derivation from such deposits. The unconformity, which has a vertical range of about 30 feet in the entire section, may record two different episodes of deposition separated by a time of erosion. It may also be considered a product of cut-and-fill during one depositional episode, if current of sufficient depth and vigor can be shown from other evidences. By the first explanation, the brownish color of the uniformly bedded sand might be weather-staining during the erosional interval. By the second explanation, the sand was brownish when deposited. Uniformity of the color throughout 30 feet of sand, the faintness of the color, and the complete absence of leaching or of infiltration of lime suggest strongly that weathering *in situ* is not responsible for the color. But whether or not two episodes of deposition are here recorded, one may ask why coarse rubble gravel, containing foreign rock material, should be at this place in Walla Walla valley. It does not show anywhere in the trench to the west or in the wide plain to the east. By what routes could it have come to position?

This gravel might be ascribed to the minor Warm Springs Canyon mouthing here from the uplifted area to the south, though Pine Creek, Dry Creek, and Van Sycle Canyon mouths do not have such deposits and Warm Springs Canyon could not supply quartzite, granite, schist, diorite, etc., unless older glacially derived deposits were being eroded. The nearest source for quantities of little-worn basaltic débris is the upper part of the basalt spur. This is essentially scabland, though not channeled. The nearly bare rock of its broad top is quite unlike any similar basalt spurs or eminences in the region above 1,100 or 1,200 feet A.T. But it is difficult to get this material off the top of the spur and on the upstream side by any normal rise of backwater in Walla Walla valley.

Another section showing considerable gravel is afforded by a pit about a mile south of the town of Touchet and 5 miles east of the section at Cummings Bridge. It is essentially in the middle of the Walla Walla valley here, 2 miles from the nearest elevations which might contain basalt as high as the level of the deposit.

The basal part of the Touchet pit section is a coarse gravel, its pebbles generally subangular, its stratification fairly regular, its composition 99 per cent basalt, its material (native and foreign rock) unstained, and its foresets dipping eastward, up the Walla Walla. There are boulders of silt in this gravel, a foot in diameter and light gray in color.

Above the coarse gravel is 12–15 feet of black fine gravel. Well-sorted, well-stratified lenses of fine brown sand appear in the upper part of this gravel and, above it, this sand constitutes a continuous member of the section. Above the brown sand occurs a few feet of fine gray sand containing abundant coarse basalt grains, poorly arranged in irregular strata. They are not segregated cleanly from the gray sand anywhere. Above this in turn is a few feet of gray silt with the same sprinkling of coarse basalt sand grains. Foreign material was found everywhere in the section except in the uppermost silt and sand.

The total thickness of the section is 90 feet. The bluff summit here is 150 feet above the river, and the 60 feet of material higher than the section top apparently contains nothing but silt and fine sand. The water-laid deposit in this part of Walla Walla valley seems resolvable into a sequence recording, first, transportation of material eastward up the slope of the plain and, later, a gradual diminution of transporting ability. Glacial water is clearly recorded.

The third section to be examined in this part of the wide valley lies about halfway between the two already described. It is the northwestern margin of the irrigated Gardena tracts, which here break off in 80-foot cliffs descending northward almost vertically to the river.

The sections in these cliffs agree in a very general way with that in the Touchet pit. There is fine black gravel, fine brown sand, and gray silt, all well stratified in the large. The silt is limited to the upper third of the sections. But the brown sand and the black gravel are interbedded, the larger part of the gravel being in the middle, not at the bottom, of the sections. The thicker strata of any kind of sediment are lower down than the thinner strata. There are a few cobbles and large pebbles in the black gravel. Current bedding in this gravel is prominent, the shallow foresets dipping eastward against the slope of the Walla Walla plain. In at least three places, all of them at the base of black gravel members, there is clear evidence of erosion of the upper surface of the underlying fine brown sand, obviously produced by the up-valley current which brought in the black gravel.

The silt which characterizes the upper third of the Gardena cliffs is definitely arranged in strata of very fine gray sand grading up into gray silt. The silt is commonly dense and hard, bending the edge of the tobacco tin into which a sample was scraped. These strata are progressively thinner toward the cliff summits. In one place near the top, there are sixteen strata in 6 feet, the thickest being 12 inches, the thinnest about $1\frac{1}{2}$ inches. All are somewhat irregular in thickness, and the fine sand at the base of each has current laminae. A sharp break everywhere separates the layers. In a few places this silt and fine sand contains coarse black sand either as scattered grains or in small lenses. Here and there are pebbles and cobbles of erratic material.

A feature not seen elsewhere in the silt deposits discussed in this paper is a pocket or lens aggregation of small pebbles of gray silt in the varvelike arrangement of silt and fine sand. Apparently a fairly coherent silt already deposited was broken up, transported, and redeposited to produce this structure.

The top of none of these water-laid deposits is much above 550 feet A.T., though on the margins of Walla Walla valley and back in tributary valleys, the upper limits of the glacial silt are 1,100 feet A.T. The basalt walls of the trench at Divide and Reese rise on both sides to a minimum height of about 650 feet, and silt in this trench shows that it was also filled while the silt plain of Walla Walla valley was being deposited.

But the silt in the trench shows no varvelike structures. Through a vertical range of a hundred feet at Reese, it is much more like the silt on the higher margins of Walla Walla valley. There is stratification, though it is irregular and undulatory. There is sorting, though much of the material is not sorted. There is much interbedding of gray sand with gray silt. Pockety aggregates or concentrates of coarse unweathered basaltic sand are present; so are thin fairly continuous strata. But there are no marked gravel members, and there is no clean-washed fine brown sand.

Though stratified gray silt and sand cover the floor of the Walla Walla plain almost as far east as Walla Walla, the Gardena type of varve like bedding in the uppermost part of the section has not been found east of Lowden, 8 or 9 miles from the head of the trench at Divide. It is limited to the western and lower part of the basin. It does not occur higher than the summit of the trench walls at Reese. It is sufficiently different from all other phases of the glacial silt to need a different explanation. Two different views may be entertained.

One is that two different deposits are shown in these sections, the silt with varvelike bedding being the younger. There is unconformity in the Gardena sections, but it occurs at different places between sand and gravel in the lower part of the sections and is not at the base of the varvelike bedding. Nor is there any break between the upper varve-bedded silt and the lower and thicker members of silt and sand. Instead, there is good gradation and the currents recorded in the lower members appear gradually to have decreased until nothing more than lake-bottom circulation existed when the uppermost silt was laid down. In the Cummings Bridge section, close to the head of the trench, there is a more marked unconformity, which may require a definite episode of exposure and erosion for its explanation. But this necessity is not yet clear; and even if required, it is the lone example of its class in the Walla Walla valley, so far as now known.

The other explanation for the well-bedded sand and silt strata in Gardena Cliffs considers that the whole Walla Walla silt deposit was made in one episode of submergence, and that the differences in character are due both to different location and to changes of conditions in one location. This explanation considers that the deposition of silt was synchronous with scabland-making and that scabland waters were of enormous volume for a relatively short time, though initial and closing stages may have been no greater than ordinary melting would produce.

This explanation is built on the strong evidence for pronounced currents of glacial water flowing back from the Columbia and up the slope of the Walla Walla plain. It requires the rock barrier at Divide and Reese. The postulated succession of conditions is as follows:

1. A preglacial, broad, low Walla Walla valley, structurally determined and drained by a narrow valley or trench eroded into basalt at Divide and Reese.

2. A rapid rise of glacial water in the Columbia and Snake valleys which poured back through the trench and finally over the basalt spur above the top of the trench walls. The up-valley currents could be produced in no other way for, as in all other valleys considered in this paper, the water simply backed up; it never flowed through and out by some other route. The scabland up to 850 on this spur was produced by such up-valley current.

3. Deposition of the rubble gravel near Divide and of the better-stratified, finer, and more-worn gravel in Gardena and Touchet sections. These locations are close to the basalt barrier.

4. Great turbidity and turbulence of this water, recorded by the

pebbly silts with berg-borne débris, persisting back to the margins of the Walla Walla valley and up in many tributaries.

5. Attainment of maximum flooding, cessation of the great turbulence, and maximum deposition of silt and sand. This silt to cover the gravel which was deposited during the time of vigorous backflow. The trench at Divide and Reese to be silted full at this time, but the deeper western part of the Walla Walla valley not to be silted up level with the top of the trench walls.

6. Subsidence of the glacial waters, leaving a local shallow lake east of the silt-covered rock sill and the silt-filled trench through it. The lowest place for discharge of this lake to depend on surface of the silt deposit over the barrier and not to coincide wholly with the course of the preglacial trench. A rock sill therefore holds up the level of the shallow lake.

7. The lower part of the silt-choked trench to be cleaned out fairly rapidly and a tributary to be developed which will erode the silt filling in the upper part of the trench where the outlet fails to follow the old trench.

8. Relatively rapid erosion by this tributary eventually to provide a place lower than the sill, for the Walla Walla lake to discharge.

9. Shifting of the outlet, establishment of drainage entirely along the pre-glacial route, draining of the lake and erosion of the lake beds and the underlying glacial silt, sand, and gravel to the present topography.

This sequence explains the varve-like structures in the lower part of the Walla Walla valley only by assuming that the rainfall which would wash silt and fine sand from the higher levels down into this lingering pool had distinct seasonal or other variations, making the lake very muddy at times and allowing it to become clear in succeeding intervals.

The rock barrier is essential. No other place in the entire region is known where varve structures exist in the silt, nor where such a combination of basin and barrier exists. One difficulty with the explanation is the presence of a few pebbles and cobbles of erratic material in the varve-bedded silt. Perhaps shore ice retransported them, but berg-ice appears more logical and is forbidden at this stage. Another difficulty is that the abandoned outlet channel across the sill has not yet been found. One unusual feature which supports the explanation is the presence of tiny pebbles of silt in the sandy part of some varves. This may record erosion of glacial silt on slopes above the lake level but below 1,100 feet.

The Walla Walla basin sediments differ from those in Snake valley and elsewhere in another item than the varve bedding. There are no gravel bars constricting valley mouths. By the writer's explanation of scabland and silt, these valley-mouth bars should be formed only where a great current in a main valley passed the mouth of a minor valley. Eddying of deep vigorous currents back into these minor valleys seems the only adequate mechanism for their locations, structure, and topography. Since the Snake Valley east of the scablands contains many striking bars of this sort, a great current along the Snake is necessary; and such deposits in this part of the Snake show foresets, prevailingly up the valley, away from the scabland. But since Walla Walla valley had only a narrow trench to carry back the first of the rising flood and a very wide valley for its higher stages to fill, and since it had no great length to fill with water, there was no opportunity for development of currents of this vigor.

Still another difference between the Walla Walla valley and the Snake valley deposits is to be found in shapes of pebbles. Although pebbles in the silt are common, very few broken-rounds have been found. Since they are common to silt deposits in almost all other valleys examined, some special conditions seem indicated. One item may be the absence of a supply of rounded gravel on the Walla Walla plain when the glacial waters invaded it. Another item may be the absence of large boulders of country basalt to serve as hammers. Another item apparently is the failure of the Walla Walla back-flow to develop adequate currents. The most favorable place in Walla Walla valley for broken-rounds to be made is near the trenched barrier at Divide and Reese, but this feature of pebble shapes had not been discovered when the gravel near this barrier was examined.

SNAKE RIVER VALLEY BETWEEN PAGE AND PERRY

Scabland erosional and depositional forms along this part of the Snake have been briefly described in earlier papers. The upper limit near Perry, at the mouth of Palouse River, is 1,325 feet A.T. This is also the altitude of the bases of loessial scarps here. Thence down the

Snake for 35 miles this upper limit descends to about 1,080 or 1,050 feet, at which altitude glacial waters could overflow the lower bluffs and enter Walla Walla valley.

Backwater tracts are amply recorded by the silts both in Snake River valley above Perry and in Walla Walla valley, and the upper limits in each agree remarkably well with the upper limit in the Snake at each mouthing into scabland. It is of great interest therefore to find that this portion of the Snake between the two great pondings contains *no* silt deposits. There are no silt terraces, or remnants of silt terraces; and no traces of any kind of this material except in the mouths of some tributary canyons that are not detailed here.

It is a remarkable thing that Walla Walla valley should have an almost complete mantle of silt 80–100 feet in maximum exposed thickness and ranging through 650 feet of altitude, a deposit conspicuous in almost every cut 5 feet or more in depth and expressed in the topography almost everywhere, while the adjacent Snake River valley, even deeper than Walla Walla valley, should have no trace of the deposit on slopes, in washes, in terraces, in mantling of the bar gravel or masking of the scabland. It is equally remarkable that the valley of the Snake does contain just such deposits *above* the mouth of the Palouse.

For this striking contrast, the following explanations may be proposed:

1. The silt deposit is older than the scabland. The glacial flood has subsequently swept away all that was deposited in Snake valley between Perry and Page.

2. The silt deposit is older than the scabland; and the erosion produced by a series of episodes of glacial discharge down the silt-free portion of Snake valley, plus interglacial stream erosion, has removed the silt.

3. The silt deposit is the correlative of the scabland and its gravel bars. The scabland is the product of enormous rivers operating during a very short time, geologically.

4. The silt is contemporaneous with scabland, but both are the cumulative result of several glacial episodes.

5. The silt is younger than the scabland but has been removed by subsequent erosion on the slopes and bottom of Snake River valley.

If the silt is older than scabland and if the scabland is a record of enormous glacial torrents, then there is no record of that flood water back in Walla Walla valley or in Snake River valley above Perry. There is also no mechanism provided for the extraordinary features of this silt and its associated gravel. The coincidence of upper limit of scabland and silt in both pondings must be dismissed as coincidence only. The difference in level in the two pondings is left unexplained. The only merit of this explanation is that it is a possible escape from the flood hypothesis.

If the silt is older than scabland and if the scabland is the product of several Pleistocene episodes during which (and during the interglacial intervals separating them) the canyons were deepened a few hundred feet, the continuity of the silt mantle must be a matter of successive overlaps from the later pondings in the deepened valleys. This erosion is impossible in the down-warped Walla Walla basin; hence the higher level of the silts there would be impossible by the proposed explanation. The unweathered condition of the highest silts in each of the two large pondings would be very difficult to explain. The persistence of an extensive mantle on steep slopes at the upper limits would be impossible, for deepening in the wide-open valleys means at least as much widening, probably much more. If there were narrow inner gorges of the required depths in these more flaring valleys, this objection to the explanation would be removed. But no such gorges exist.

If the silt is correlative with the scabland and if the writer's interpretation of scabland, scarps, and gravel deposits is correct, there are no disharmonies in the scheme. Objections to this explanation will be made on a priori grounds, not on the field evidence.

If silt and scabland are correlative but both are the consequence of several Pleistocene epochs, several objections already presented must be met. The highest of the silt deposit should be exceedingly fragmentary instead of a continuous mantle, its basalt grains and foreign pebbles should be distinctly decayed, the different soil horizons should be present in the higher silt where on flats or gentle slopes. These features are not present. Most cuts in the reddish or buff-colored loess of the plateau show good A and B horizons, but no cuts in the silt anywhere in the region have shown them. The remarkable gravel deposits of Snake valley and their remarkable setting and structure are ignored by this hypothesis. So are the less striking but significant gravel beds in the western part of the Walla Walla plain.

If the silt is younger than scabland, its absence in Snake River valley between Page and Perry must be due to still later erosion. Yet the Snake just above the scablands has the mantle, and there are hundreds of re-entrants between Page and Perry where material of such geologic recency should still be conspicuous. There are flattish uplands above the brink, yet no silt on them. There are broad, deep, and partially inclosed depressions back of the great gravel bars, in which almost no erosion has occurred since the bars were built; yet no silt occupies them.

The writer believes that a fair evaluation of these different hypotheses for the absence of silt deposits in Snake valley between Page and Perry will rule out all but the two which consider the silt as contemporaneous with scabland. A fair consideration of the unique field evidences will carry conviction that scabland-making, silt-deposition, and valley-cutting on the plateau did not extend through several Pleistocene episodes. Many of the original features of scabland and silt are impossible by that view, and their equal freshness at all levels through a noteworthy vertical range debars that view.

CONCLUDING STATEMENT

The greatest known thickness of the poorly stratified and pebble-charged silt and sand is at Johnson's Bridge on Touchet River. The section extends from 550 to 650 feet A.T. The upper limit of the water body was 450 feet above the top of the section. If all this silt was carried in during one short episode of exceedingly turbulent water, 100 feet of silt was suspended in 550 feet of water. Would the increased specific gravity of such muddy water be a factor in the transportational problem afforded by the widely scattered tiny bits of fresh basalt? These particles must come in from the scablands; they cannot be produced in Walla Walla valley (though they may have been so produced in Snake valley).

It may well be asked, also, if this method of silt transportation is supported by all the field evidence. Is the partial sorting and stratification possible by this hypothesis? Is not some kind of rhythmic pulsation in water supply and sediment supply recorded in the common irregular and undulatory strata? One might well be inclined to think the stratification impossible by the flood hypothesis, and perhaps the writer's conception should be modified to allow for minor rises during a subsidence from the maximum.

If this be correct, the stratification should be in the upper part of the deposit. Most sections are too shallow to show full thickness; but so far as now known, the stratified phases do not underlie any notable beds of unstratified silt. However, they do not occur close to the upper limits of the deposit. This upper-limit silt seems everywhere to show the minimum of stratification.

Another explanation for the stratification might be modeled on the preferred interpretation for the varve-like silts in Walla Walla valley. Later re-working on the valley floors is possible during subsidence of the flood and perhaps for some time after that. Various gravel bars would have been effective dams for a time. Perhaps irregularities in the surface of the silt deposit itself would have provided short-lived basins in which re-working of wash from adjacent steeper slopes could occur.

The flood hypothesis encounters another objection in the silt lenses occurring in gravel deposits. Such lenses demand cessation of current while they are formed. How rapidly does the finest of this silt subside? Experimentation with silt which passes the 0.074 mm. sieve shows that in a mixture of one part silt to four parts water, half of the silt settled out in 2 minutes after stirring was stopped, three-quarters in 5 minutes, seven-eighths in 9 minutes, and all but about one-fiftieth in 15 minutes. The need for constant turbulence to maintain even the finest of this material in suspension is thus evident. A very brief cessation of current essentially clears the whole water body.

If one discounts or denies the evidences of torrential up-valley currents and considers this record of glacial backwater in more than forty separate valleys as the product of a general ponding, he must then explain the progressively higher altitudes northward from Walla Walla River to Kamiache Creek as the result of subsequent warping. The amount of such required warping is slight for this region, only 800 feet in 100 miles. He must then explain the horizontality of upper limits at widely separated places in the Walla Walla valley system and in Snake valley and its tributaries as due to a lack of differential movement in each of those portions of the warped surface, though he must have 200 feet of warping in a narrow zone between them. He must next admit that, at the time of ponding, there could be essentially no gradient for the recorded upper surface of the vigorous scabland rivers from Kamiache Creek to Walla Walla River, and he must deny therefore that these river-scoured surfaces were formed as early as the ponding records. The agreement of upper limits of scabland and upper limits of ponds can then be coincidence only.

If he is willing to grant preglacial valleys essentially as now, and scabland contemporaneous with the ponding, but desires to use this conception of warping, the combined Palouse and Snake (where used by glacial streams) had a preglacial descent of about 600 feet in 100 miles, as contrasted with the present descent of 1,400 feet in that distance. On this gradient of 6 feet to the mile the glacial streams must have eroded the scabland.

If, however, while retaining the idea of warping, he prefers to think that the highest scabland and pond records and all of the loessial scarps antedate the canyon-making in the plateau, he must reduce this preglacial gradient of the plateau to something like 3 feet to the mile. In other words, the admittedly recent deformation must be interglacial. And on this gradient (for large volume is debarred by this conception) he must develop the velocities necessary for the erosion of the high scabland and the scarps. The difficulties by any of these combinations are great. And field evidence reviewed in this paper is utterly at variance with them.

The final accepted explanation for channeled scabland must be built on, limited by, and constructed to include, all the field evidence. That such evidence is of extraordinary character is obvious to any geologist. That it is unique should be clear to glacialists and physiographers. The writer is convinced that anyone who attempts to evaluate the evidence must discard the idea that glacial waters here behaved as elsewhere, the only difference being in magnitude of results. He holds that it was a difference in kind of results. The data in this paper constitute a category of facts not known when the flood hypothesis was first proposed. The relations to that hypothesis are to be decided by the reader. The writer asks only that, if his interpretation be rejected, the data herewith presented be organized to make some coherent interpretation.