Reprinted from JOURNAL OF THE WASHINGTON ACADEMY OF SCIENCES
Vol. 17, No. 8, April 19, 1927

PROCEEDINGS OF THE ACADEMY AND AFFILIATED SOCIETIES

GEOLOGICAL SOCIETY

423D MEETING

The 423d meeting was held at the Cosmos Club January 12, 1927, President BUTTS presiding. The Secretary announced the election to active membership of W. N. WHITE and A. M. PIPER both of the U. S. Geological Survey, and also the resignation of FRANK TWEEDY and S. W. BEYER.

Program: PROFESSOR J. HARLAN BRETZ, University of Chicago: *Channeled scabland and the Spokane flood.* That part of the Columbia Plateau which lies north of Snake River in Washington bears a remarkable system of erosional and depositional land forms. They are extraordinary in their magnitude, in their extent and distribution, and unique in their relationships. Running water is generally conceded to have caused them but the unparalleled results indicate unparalleled conditions under which it acted.

The channeled scablands constitute the erosional part of the record. They cover almost 2000 square miles, about $\frac{1}{6}$ of the area of this part of the plateau. They are elongate tracts, oriented with the gentle dip slope of the underlying basalt flows, mostly bare rock or with a thin cover of coarse basaltic rubble, commonly with canyons in them, and are bounded by steep slopes of the deep loessial soil of the plateau. They constitute a curious anastomosing pattern, the down-dip convergences inherited from an earlier normal drainage pattern and the divergencies, equally numerous, produced by crossing of divides of this older pattern. There are hundreds of tracts of the higher loess-covered areas in the scablands, from a fraction of a square mile to many townships in area, all discontinuous and bounded by the scabland areas. The steep marginal slopes in loess are in striking contrast to the gentle slopes of the older drainage pattern surviving within each isolated loessial tract. Canyons in the scablands are multiple and anastomosing, amazingly so in some tracts; deep canyons and shallow ones uniting and dividing in a labyrinthine fashion about bare rock knobs and buttes unlike any other land surfaces on the earth. Certainly but few of these canyons are inherited from the older pattern.

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

The depositional land forms associated with channeled scabland are chiefly great mounded masses of little worn basaltic gravel. They occur on the down-gradient side of eminences and in other protected places in the scablands, and in the Snake and Columbia valleys below the entrance of the scabland drainage routes. They are not eroded forms, they possess aggradational slopes and they inclose depressions or by their position aid in inclosing depressions between themselves and adjacent rock walls. All attempts to interpret them as dissected remnants of terraces or originally continuous gravel deposits have failed. They are gravel bars of huge size.

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

CANYONS OF THE SCABLANDS. Largely channels of huge rivers, eroded during the Spokane epoch.

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

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

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

AREAS SURROUNDED BY THE CHANNELED SCABLAND TRACTS. Residuals of a once continuous loessial cover, with maturely eroded drainage ways. 100 to 200 feet of loess removed over large areas.

A—Aligned scarps of loess facing the scablands. Slopes 30° to 35°. The bluffs left by undercutting of streams whose width was that of the adjacent scabland, from half a mile to 15 miles. They truncate minor valleys of the older drainage pattern.

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

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

DEPOSITS ON THE SCABLAND AND IN SNAKE AND COLUMBIA VALLEYS. Discontinuous originally. Their features clearly record actual building of each individual deposit. Any explanation must start with this.

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

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

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

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

E—Quincy structural basin. More than 15 townships covered with basaltic gravel in terrace-like and mesa-like forms. Channeled canyons tributary to and distributary from this settling basin. The forms, however, are bars, as field study has amply demonstrated. No interpretation as terraces will account for many significant relationships.

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

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

COLUMBIA VALLEY BELOW WALLULA GATEWAY. For 150 miles a descending series of scabland tracts and gravel deposits in Columbia valley.

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

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

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

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

Discussion: W. C. ALDEN: Professor Bretz frankly points out the difficulties met in applying his explanation of the origin of the remarkable features of the Columbia plateau. It is not easy for one, like myself, who has never examined this plateau to supply offhand an alternative explanation of the phenomena. I have read Professor Bretz's papers on the subject with great interest but I am left with the feeling that some things essential to the true explanation of the phenonena have not yet been found. The "channels" appear to be due to stream erosion. The main difficulties seem to be: (1) The idea that all the channels must have been developed simultaneously in a very short time; and (2) The tremendous amount of water that he postulates as coming from the melting of the ice sheet in so short a time to do the work. It seems to me impossible that such part of the great ice fields as would have drained across the Columbia plateau could, under any probable conditions, have yielded so much water as is called for in so short a time. It also seems as though the estimated capacity of the Wallula Gateway, when fully opened, is too great for this gorge to have served as a bottle neck to hold above it a flood of such dimension to the level called for in the explanation offered. It appears that ice sheets of three distinct stages of glaciation invaded the borders of this region and may have afforded conditions of repeated floodings of much smaller volume. It would seem that a more extended study of the glacial phenonena is required about the heads of the scabland "channels" to determine, if possible, more exactly just what sort of glacio-fluvial discharge actually occurred. Perhaps the explanation of the phenomena does not actually necessitate contemporaneous development of all the "channels," nor in so short a time. The problem would be easier if less water was required and if longer time and repeated floods could be allotted to do the work. The conditions of repeated glaciation in the basins of Clarks Fork and the Columbia are not yet well enough understood to afford very sure bases for postulations as to stream flow therefrom. It is important and highly desirable that means may be provided for a more extended study of the Pleistocene phenomena of these basins and of the adjacent mountains.

JAMES GILLULY: The question of the existence of a Spokane flood rests on the interpretation of many highly abnormal field facts. The evidence presented by Professor Bretz is assuredly convincing as to (1) the anomalous, indeed unique, drainage features of the Columbia Plateau, (2) their direct dependence upon glacial waters, and (3) the necessarily large volume of many of these streams. However, certain criteria used to determine the actual quantities of water involved appear somewhat questionable. Both Russell and Jenkins have recognized a ponded condition of the Snake River at Wallula Gateway, but Russell has attributed it to monoclinal deformation rather than to a flood, and, while Jenkin's views are not clear, he presumably agrees with Russell. Presumably then, without definite evidence to negative this theory, scoured basalt at high levels here is not conclusive of a sudden deluge of Spokane waters. The overflow may well be much older than Spokane glaciation. The evidence presented by Professor Bretz to fix the Wallula cutting as Spokane and not earlier is the height of talus. In an article published in 1925 he pointed out that "most of the talus (at Wallula Gateway) is higher than three-quarters though some is typical." Thus the date of the overflow is not fixed accurately as the date of the Spokane glaciation, even if we grant that the three-quarter talus criterion of age elsewhere applied by him is valid.

This talus criterion, however, is very doubtful as an accurate time gauge on several counts: (1) The range in rainfall from point to point on the plateau is from 5 to 20 inches. If three-quarters talus is found at both places it appears then that the height is probably a relatively stable stage in topographic development, rather than a measure of total elapsed time since the cliffs were formed. (2) The validity of the criterion depends on the assumption that all fragments falling from the cliffs remain in the talus heaps. This assumption is assuredly unwarranted, for in the formation of talus rock is disrupted into finer fragments, which waste by weathering and are subject to removal by wind and by even the most ephemeral streams. The Colorado Plateau offers numerous examples of cliffs which have retreated scores of miles yet still have vertical faces. Similar tendencies must prevail here, although basalt is decidedly more resistant than those sandstones. (3) The well known differences in rate of weathering of canyon walls dependent on their directional trends also give one pause in accepting uniform talus heights as more than a very rough measure of the age of cliffs. If the talus is of uniform height in both east-west and north-south canyons it strengthens still farther the suggestion that the three-quarters stage of talus is relatively stable, rather than a good time measure. (4) Even disregarding these three points which appear to me of great cumulative importance as tending to throw doubt on the validity of the talus age criterion and accepting Professor Bretz's analysis, elapsed time since a cliff was formed varies as the square of the proportional talus heights. Seven-eighths talus then means 49/36 as great age (or 134 per cent) as three-fourths talus. Wallula Gateway, a narrow gorge for a great river, is likely to have had its talus sapped from time to time in its history, so that even granting that three-quarters talus is ordinarily valid as a time measure (which for the reasons stated above is very doubtful), the flooding of the top walls of the Gateway is probably pre-Spokane, and the deepening of the canyon a much longer process than granted by Bretz. This idea is strengthened by considering the quantitative factor. According to Bretz's old measurements the discharge at Wallula Gateway was 38.9 cubic miles per day, or over 50 times the present flood volumes of the Columbia and, proportionally to drainage basin, over 200 times as large as the greatest recorded floods of the Mississippi. Now he believes the water reached even greater height and hence must have produced a still greater flood. To explain this great flood without retreat of the ice front, he has suggested—(1) a very sudden climatic amelioration (only to rule it out as very improbable) and (2) that subglacial volcanism resulted in sudden melting of large quantities of ice which formed the flood. This mechanism is wholly inadequate as, even allowing most generous thermal properties for basalt and perfect efficiency of transfer of this heat for melting the ice, even a 10-day flood would require 17 cubic miles of basalt or a layer about 9 feet thick over 10,000 square miles. Further computations show that the rate of cooling of basalt is so slow that if we assume the subglacial surface replaced by molten basalt it would require over 9,700 square miles of basalt exposure beneath the ice to produce only 350 cubic miles of water which would only maintain the flood postulated by Bretz for ten days. But the areal geology of the Columbia basin is sufficiently well known to completely eliminate any possibility of late Pleistocene volcanism of such magnitude. Even this preposterously low estimate of flood duration is eliminated by the physical factors (such as resistance of basalt, depth of channels above Wallula referred to that constriction and others) involved. How much less competent then, must we admit is the jokullaup hypothesis to furnish the tremendous flood volume postulated by Bretz. The incompetence of the postulated mechanism to furnish the flood volume required by Bretz's interpretations of the field evidence seems to call for a reinterpretation of that evidence. That, as suggested by G. O. Smith, Meinzer, and Ferguson, such a reinterpretation is apt to be considerably more complex than the suggested flood hypothesis, seems exceedingly probable. That the actual floods involved at any given time were of the order of magnitude of the present Columbia's, or at most a few times as large, seems by no means excluded by any evidence as yet presented.

E. T. McKnight: Three dry coulees cut southwestward from the "Othello channels" at the east end of the Saddle Mountains in central Washington across the aggraded surface of the Ringold formation and debouche at varying elevations as hanging valleys along the White Bluffs of the Columbia. All are markedly U-shaped in cross section. The master channel of the three is Koontz Coulee which debouches at Ringold at an elevation of 150 feet above the river. It is $1\frac{1}{2}$ miles wide in its lower and better defined portion and its bed lies from 200 to 300 feet below the flat undissected Ringold plain which borders it abruptly on the northwest. In its upper half it has cut through the soft Ringold sediments and has exposed the underlying basalt in the form of scablands. The two remaining dry coulees are of comparable size, averaging less than half a mile in width and from 75 to 150 feet in depth, much smaller than Koontz Coulee. They head at essentially the same point in the west rim of Koontz Coulee, 10 miles above its mouth, at an elevation of 250 feet above its bed, and after following divergent courses reach the bluff of the Columbia at points 2 and 15 miles, respectively, above the mouth of Koontz Coulee and at elevations of 425 and 300 feet, respectively, above the Columbia. Both in turn show remnants of still shallower braided channels at higher levels, appearing as short shunts off of the primary channels. The southernmost dry coulee maintains its U-shape practically up to the point where its profile breaks off abruptly to the level of the Columbia; the enclosing walls of the northern coulee, on the contrary, begin to recede diagonally and to flatten at a point 5 miles back from the river so that the incised character of the coulee is soon lost, though the old drainage line can still be traced through to the bluff overlooking the town of White Bluffs.

That all three of the dry coulees above described were produced under climatic conditions widely different from those prevailing at the present time is amply proved by the sage-covered depressions in the two smaller coulees, and by the scattered depressions in the upper regions of Koontz Coulee. Mr. Bretz has interpreted these dry coulees as the product of huge glacial torrents that emptied into the Columbia when its flood waters stood at or slightly above the levels of the present debouchures of the coulees. That these are at different levels is believed to be due to the different stages in which they were abandoned during the lowering of the flood of the Columbia, Koontz Coulee being the last one abandoned. The bed of the river at the time of this flood is believed to have been at essentially its present level. The writer believes that the three dry coulees were formed by glacial waters at a time when the Columbia lay several miles west of its present channel and have been converted into hanging valleys by the lateral shift of the river to the east against the soft sediments of the White Bluffs. That this lateral shift is a reality is proved by the vigorous manner in which the river is at present undercutting the bluff, producing numerous land slides, and by the fact that the Ringold formation of pre-glacial Pleistocene age, has been largely removed by lateral planation from the region west of the river although it formerly filled the basin as far west and southwest as the Yakima and Rattlesnake ranges, 15 to 20 miles southwest of the White Bluffs. The shift of the river is down the slope of the pre-Ringold basalt floor. Restoration of the profile of Koontz Coulee indicates that the Columbia lay 3 miles west of its present position when the coulee was formed. The two smaller coulees at the higher level are interpreted as distributaries formed when Koontz. Coulee lay at that level and abandoned after it had gained the mastery.

It is believed that the explanation of Mr. Bretz is inadequate to explain (1) the fact that the two smaller dry coulees previously described, although heading at the same place, reach the White Bluffs above the Columbia at different elevations; (2) the fact that a V-shaped valley along the southern base of the Saddle Mountains, which was produced entirely by drainage off of the southern slope of the mountains, also forms a hanging valley 275 feet above the Columbia, although in this case, as with the northernmost glacial coulee, the south slope of the valley breaks back several miles from the river so that the lower course of the old drainage is almost obliterated. Mr. Bretz interprets the coarse stream gravels and cobbles that cover extensive areas west of the river at White Bluffs and Hanford as the debris of the Spokane flood. The writer believes them to be the normal channel deposits of the Columbia during its eastward shift over the area in pre-glacial, glacial, and post-glacial times. The features described in this summary appear on the Scootenay Lake, Hanford and Coyote Rapids quadrangles.

G. R. Mansfield: Mr. Bretz cites the occurrence of numerous anastomosing channels, with associated rock basins, some of which are 8 miles or more long, carved in basalt to depths of 200 feet or more, and locally on some divides as deep as 400 feet; he notes the occurrence of hundreds of abandoned waterfalls with "potholes" at their bases, also in basalt, and speaks of the recession of some of these falls; and yet he ascribes all these phenomena to a single flood of relatively brief duration. Basalt is a hard rock and very resistant to corrasion, but it possesses a well known columnar jointing, which supposedly renders it susceptible to undermining and to plucking, and Mr. Bretz relies on this property to account for the unprecedented rapidity of erosion of the basalt which his hypothesis requires. I am not convinced that so much work could be done on basalt in so short a time, even by such a flood as is postulated. The Dalles of the Columbia, which Mr. Bretz says are typical scabland channels, and the various falls in Snake River, can furnish pertinent and definite evidence with regard to rapidity of erosion and of the recession of falls in basalt if systematic observations are carried on for a few years. It does not seem to me necessary to assume that all the scabland channels, or even that all parts of the same channels were occupied by water at the same time. Mr. Bretz notes that deep and shallow canyons unite and divide in labyrinthine fashion. Possibly some of the shallower channels were formed earlier than some of the others and now hang on the sides of more favorably located channels. Mr. Bretz based much of his argument for contemporaniety of all the channel phenomena upon the relative heights of talus piles beneath basaltic cliffs along the canyon sides. Probably few, if any, direct observations are available regarding the rate at which talus piles in basalt may form. From such observations as I have made in basaltic country in the past fifteen years I should say that the rate is so slow that considerable time intervals would fail to register significant differences. Such a measuring stick should not be applied too rigidly. Again contemporaneity of erosion can not well be assumed from the identity of materials composing high level and low level gravel bars. Since all the material, high or low, may be presumed to have come from much the same general sources, identity is to be expected. Some differences in state of weathering might be looked for if the time interval between high level and low level deposits was great, but even here other factors such as texture and mineral composition of the rock fragments would enter in and mere differences in weathering would not be conclusive. The general nature of the phenomena suggests conditions similar to those attending the ice front in New York State, where temporary channels and falls now abandoned were developed. Although these were temporary, geologically speaking, some of them appear to have persisted for long periods of years. The scablands seem to me better explained as the effects of persistent ponding and overflow of marginal glacial waters, which changed their position or their places of outlet from time to time through a somewhat protracted period. Not enough is known in detail of the glacial geology and physiography of the region to furnish an adequate basis for any connected story of events here. The hypothesis of a single tremendous flood should not be accepted without further detailed regional study.

O. E. MEINZER: I have seen only the part of the region under discussion, that including Quincy Valley, Grand Coulee, and Moses Coulee. As Doctor Bretz has stated, the erosion features of the region are so large and bizarre that they defy description. However, the Columbia River is a very large stream, especially in its flood stages, and it was doubtless still larger in the Pleistocene epoch. Its erosive work in the Grand Coulee and Quincy Valley, impressive though it is, appears to me about what would be expected from a stream of such size when diverted from its valley and poured for a long time over a surface of considerable relief that was wholly unadjusted to it. The dry falls in the Grand Coulee resemble Niagara Falls and are evidently the product of normal stream work. The deep gorge of the coulee below the dry falls was apparently excavated by the same orderly and long-continued process of head-end erosion as the gorge below Niagara Falls, and it could hardly have been produced in a short time by a flood of whatever magnitude. Quincy Valley, into which the waters of the Grand Coulee discharged, evidently became the scene of a lake in which sediments were deposited and which at first discharged westward into the valley of Columbia River, forming several cataracts that retreated some distance in normal fashion before they were abandoned. Later all the water was discharged through the present outlet, the lake was drained, and the stream cut into the sedimentary deposits in Quincy Valley to a depth of about 150 feet, forming a broad stream valley with a series of extensive terraces. All these were orderly and long-continued processes of erosion and sedimentation. The features of erosion and deposition are indeed very impressive, but they are, I believe, of a kind and size that would be expected from so large a river as the Columbia must have been in the Pleistocene epoch. The rock-cut terraces of the Columbia River Valley also indicate a succession of long periods of stream erosion. The short gorges below the cataracts that discharged the overflow of the lake in Quincy Valley open upon a stream terrace that stands 900 to 1,000 feet above sea level and 400 to 500 feet above the present river level. The floor of Moses Coulee is continuous with a terrace 800 to 900 feet above sea level and about 300 feet above the river. Though the evidence is perhaps not conclusive, it seems to me that the upper of these two terraces represents the floor of the

Columbia River Valley before the river was diverted to form the Grand Coulee and the lake in Quincy Valley, the lower terrace represents the floor of the Columbia River Valley at a later time when the Moses Coulee was cut, and the gorge below the lower terrace represents the later erosion work of the Columbia.

Having seen only this part of the region, in which I believe the existing features can be explained by assuming normal stream work of the ancient Columbia River, I am naturally loath to accept a theory of an abnormal flood for the scablands farther east. Before a theory that requires a seemingly impossible quantity of water is fully accepted, every effort should be made to account for the existing features without employing so violent an assumption. I suggest that full weight be given to the following considerations, all of which have, of course, already received careful study by Dr. Bretz: 1. The Pleistocene Columbia was necessarily a very large stream, especially in times of flood. 2. Its waters were diverted over country of considerable relief that was wholly unadjusted to it. 3. It is probably not necessary to assume that all of the region was channelled simultaneously. Is it not more probable that the water flowed successively over different tracts as the ice front changed? 4. Unless there is conclusive proof, it should not be assumed that along any drainage line the erosion work at high and low levels was done simultaneously. It would seem more probable that the work of erosion proceeded during a long time and that the high-level channels were abandoned as the stream cut down to lower levels. 5. Tilting and folding of the rocks have in this region occurred in recent geologic time, probably during and since the cutting of the Pleistocene channels. For example, there seems to be evidence that the upper terrace of the Columbia River Valley has been deformed. This recent deformation may account to some extent for channels cut through ridges that can not otherwise be well explained except by assuming excessive depths of flood water.

J. T. Pardee: Other things being equal, the amount of talus beneath a cliff would vary considerably according to whether the exposure faced toward or away from the sun. Disruption of the rock due to temperature changes and alternate freezing and thawing of water would be most effective on southern exposures.

Dr. Bretz: *Reply to Mr. Gilluly:* There are old weathered gravels down in Snake River canyon both above and below the entrance of the scabland rivers, and much lower than the upper limit reached by the glacial waters in this canyon. The canyon therefore is older than the Spokane episode or any gravel deposits in the scablands, and a canyon at Wallula Gateway must have been there in pre-scabland time. I believe that the field evidence for this conclusion would convince any of my critics. Scabland and gravel up on the walls of the Gateway do not date back to the initiation of the canyon, and some sort of ponding must be provided. Without a ponding episode, the upper scabland must be older than the tributary canyons at the Gateway. But even the map shows how the glacial waters cut up the shoulders between the small tributary canyons already in existence. A pre-scabland floor of the Gateway about 200 feet above present river level is suggested by the hanging condition of Spring Gulch. Russell's speculations on ponding in the Columbia Valley dealt with the berg-carried erratics, not with scabland, and called for a valley glacier down in the gorge at or near The Dalles, or for a subsidence of the entire region. I have believed that this second suggestion is correct. There is a possibility that final solution of the scabland problem will tie this berg-drift into the scabland story. Jenkins did not suggest any disagreement with my bottle-neck hypothesis, though his article was avowedly a discussion of the ponding. There are certain to be differences in talus height because of local variations such as I have indicated in one of my papers. But where these differences are definitely traceable to local factors, such as variations in basaltic structures or spill of local runoff over the cliff or an active stream in the valley below or other conditions, it seems permissible to so treat them and yet to draw generalizations. The blocky material on the surface of talus in the scablands indicates a rate of growth in excess of the rate of disintegration into fine material. Bryan has indicated this in one of his papers on Pedestal Rocks. Comparison with sandstone cliffs is hardly trustworthy. It is much more likely that talus accumulations in the scablands have been added to, rather than diminished, by wind action. And in the empty channels I do not believe that removal of talus material by any process has occurred in appreciable amount in post-scabland times. Furthermore, the unfilled basins of the channeled scablands, existing even close to the upper limits of glacial waters in Wallula Gateway, have lingered overlong for a region whose talus has reached a profile of equilibrium. I have not considered "equilibrium" attained until the talus covers the whole face of a cliff. A soil from disintegration of the basalt should cover a stable talus, and this is essentially lacking in the scablands or at the Gateway. The "jökullaup" sub-hypothesis I never have defended and never shall, until adequate field evidence from the required volcanic tract is forthcoming. But must it be dismissed because of Mr. Gilluly's computations? Are they conclusive? After indicating the untrustworthiness of figures, because of possible overlooked factors not represented in the computations, Gilluly moves into the very position I am scolded for taking. And the accounts of Icelandic jökullaup—are they merely early experiments in sensational journalism? Granting, however, that we must never again look toward subglacial vulcanism for a Spokane flood, must this close our minds to the flood hypothesis? I believe that my interpretation of channeled scabland should stand or fall on the scabland phenomena themselves. Perhaps, however, my attitude of dogmatic finality is proving contagious. I am glad to have convinced Mr. Gilluly that the scabland high up on the Gateway walls is stream work. I anticipated a skeptical attitude on even this point, for it is an extraordinary place for scabland, by any hypothesis for the great system on the plateau north of Snake River. The only known records for pre-Spokane ice on the plateau are about Spokane and Cheney where there is a weathered till beneath the Palouse loess. The whole record of glacial waters across the plateau and through the Gateway is post-loess! I do not yet share Gilluly's belief that pre-Spokane glacial waters are recorded in the Gateway, nor his confidence that the history can be diagnosed readily at long distance. Even a bed-side practitioner may err, I understand.

Reply to Mr. McKnight: Undoubtedly the Columbia has undercut White Bluffs and thus shortened Koontz Coulee. But its eastward shift is not down the slope of a pre-Ringold basalt floor. The basalt is at least 100 feet below the river surface at Ringold, at the foot of White Bluffs. And Gable Mountain, a rugged eminence five miles long and at least 700 feet above the river, stands in the eastern half of the tract which the river, by this conception, has made by lateral planation. Jenkins thinks that the Ringold silt underlies the gravel of this wide part of the Columbia Valley. The 200-foot range in altitude of the gravel deposits about Gable Butte and Gable Mountain appears to be wholly in material of the same age. If the gravels of this part of Columbia Valley are normal affairs of valley or channel deepening, the older and higher portions should lie successively farther west from White Bluffs. But no succession of terraces of different ages has been found; instead, the relief appears to be a matter of great bars and abandoned channels with "holes" in them as low as present river level, all disposed with reference to the two basaltic interruptions as they should be if the entire valley at one time were a river bottom. While the main floor of Koontz Coulee hangs only 150 feet above the Columbia, three other glacial spillways, all within a mile and a half of the mouth of Koontz Coulee, hang 250 to 400 feet above, and all have approximately the same gradient. If their profiles are projected, they will reach at least twice as far out into Columbia Valley. By Mr. McKnight's explanation, there must have been as much lateral planation by the Columbia while the glacial waters were using Othello Channels as in all subsequent time. This projection of profiles assumes a Columbia River bottom, at about 500 feet A. T. at that time. How Othello Channels and its distributaries (Koontz, etc.) could have discharged across the Ringold flat at an upper limit of 1150+ while the Crab Creek syncline was undoubtedly an open route (for it also carried the glacial waters) to the capacious Columbia Valley is a puzzle for which I have found no answer save great volume and ponding at Wallula Gateway. If my information were limited to this district alone, I probably would not have arrived at present interpretations. It is in the remarkable interrelationships of the channeled scabland *ensemble* that the conception of a Spokane flood finds support.

Reply to Mr. Mansfield: I have had no success in fitting the field evidence to the idea of shifting dischargeways across the scablands. I cannot get the glacial streams to cross at Palouse Canyon, Devils Canyon, etc., without a ponding farther down the Columbia, nor to cut the canyons or canyon groups at these separated places without maintaining all dischargeways while the ponded condition is being removed. A labyrinthine group admittedly records a succession of events in that the glacial river was drawn down from original wide spreading as the canyons were eroded. But such cutting apparently must be done while the Wallula ponding was being lowered, or else that ponding must be repeated for each successive epoch of occupation. Only the Moses Coulee and Grand Coulee-Drumheller Channels plexus groups would have developed without the backing up postulated. Mr. Mansfield's idea of obtaining the rate of erosion of the basalt at The Dalles is excellent, but probably can be applied only to the features exposed at low water, and altered only during high water. The deeper and inaccessible parts of such a channel group should be the most rapidly changed. I hope that Mr. Mansfield and others of the United States Geological Survey will be able some time to study the channeled scablands in detail. These features should take their place in the literature as a group of land forms without parallel, and a genesis that can be agreed upon should be established.

Reply to Mr. Meinzer: The erosion of Grand Coulee could not have taken a longer time than the sum of whatever glacial stream occupation it has had. The margin of the ice sheet must have remained within 35 miles of its maximum advance in order to produce the Grand Coulee diversion. We may multiply whatever time interval this represents by different glaciations to get a longer period but it does not seem possible to consider this canyon a normal product of long-continued stream erosion. The scabland plexus east of Grand Coulee, from Coulee City south to the Quincy basin, is certainly not a normal affair, for three pre-existing valleys were entered and much eroded by glacial waters from the north before deepening of the lower coulee occurred sufficiently to contain the discharge. The lake sediments of Quincy Valley lie beneath thick basaltic gravel deposits which are disposed, as in so many other places in the channeled scablands, in great mounds, several miles long, with gentle back slopes and side slopes that are constructional profiles. These are separated by three wide channels of contemporaneous origin, leading from Crab Creek and Grand Coulee across the basin to Drumheller Channels. My earlier interpretations were that these channels (Moses Lake lies in one of them) were dissected out of a once-continuous gravel fill, but many features could not be harmonized with this, and I have been trying the Spokane Flood idea since. Several years ago Mr. Meinzer suggested to me that tilting or some other adequate cause had diverted discharge from The Potholes and Frenchman Springs cataract to Drumheller Channels, and I have tried since to apply this in the field. But I cannot find any evidence to support it. The rock terraces of Columbia Valley to which Mr. Meinzer refers were there in present development when the Flood occurred. The prominent one at the Potholes alcove rises northward along the Columbia about 300 feet in four miles. The surface of the southern part of it, below about 1250 A. T., is typical scabland and has a sharply defined cliff back of it. The northern part, above the level of the flood as indicated by upper limits in all three spillways out of Quincy basin, carries no such record and has no bare rock in the cliff back of it. Slope of the cliff and talus, which is soil covered to the very top, indicate a much older feature. As Professor Davis would say, the cliff in its southern part has been "refresht." This northward rise of the rock terrace is due to the warping in Babcock Ridge, a low anticlinal into which the Columbia has cut its valley. That rock terrace was here, in its present warped condition, I think, before the glacial discharge occurred. The close approximation of upper flood limit on this terrace, in the two cataracts named and in Drumheller Channels seems to indicate that no warping comparable to what the terrace shows has occurred since the glacial flood. This is also the upper limit of scabland in Wallula Gateway. The upper limits in such widely spaced features as Othello Channels, Devils Canyon and Snake River Canyon do not vary more than 100 feet from 1250. There is, of course, no precise marker in the topography for upper limits, for most of these features are river-bottom forms, but I do not think my figures miss it by more than 100 feet. Such coincidence of altitudes as I have indicated is remarkable if different episodes are involved or if the region has been warped since Spokane time. Moses Coulee below Three Devils abandoned cataract has 200 feet or more of debris, mostly gravel, on the rock floor which therefore is as low as in Columbia Valley at the junction of the two valleys.

W. P. WOODRING, W. W. RUBEY, *Secretaries*.