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Chapter 1

The Spokane Flood Controversy

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ABSTRACT

The Spokane Flood controversy is both a story of ironies and a marvelous exposition of the scientific method. In a brilliant series of papers between 1923 and 1932, J Harlen Bretz shocked the geological community with his studies of an enormous plexus of proglacial channels eroded into the loess and basalt of the Columbia Plateau, eastern Washington. This region, which he named the "Channeled Scabland," contained erosional and depositional features that were unique among fluvial phenomena. With painstaking field work, before the advent of aerial photographs and modern topograhic maps, Bretz documented the field relationships of the region. He argued that the landforms could only be explained as the product of a relatively brief, but enormous flood, which he called the "Spokane Flood." Considering the nature and vehemence of the opposition to this outrageous hypothesis, the eventual triumph of that idea constitutes one of the most fascinating episodes in the history of modern geomorphology.

INTRODUCTION

The inimitable words of J Harlen Bretz (1928c, p. 446) describes the scene in eastern Washington:

> "No one with an eye for landforms can cross eastern Washington in daylight without encountering and being impressed by the "scabland". Like great scars marring the otherwise fair face of the plateau are these elongated tracts of bare, or nearly bare, black rock carved into mazes of buttes and canyons. Everybody on the plateau knows scabland. It interrupts the wheat lands, parceling them out into hill tracts less than 40 acres to more than 40 square miles in extent. One can neither reach them nor depart from them without crossing some part of the ramifying scabland. Aside from affording a scanty pasturage, scabland is almost without value. The popular name is an expressive metaphor. The scablands are wounds only partially healed—great wounds in the epidermis of soil with which Nature protects the underlying rock.
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> With eyes only a few feet above the ground the observer today must travel back and forth repeatedly and must record his observations mentally, photographically, by sketch and by map before he can form anything approaching a complete picture. Yet long before the paper bearing these words has yellowed, the average observer, looking down from the air as he crosses the region, will see almost at a glance the picture here drawn by piecing together the ground-level observations of months of work. The region is unique: let the observer take the wings of the morning to the uttermost parts of the earth: he will nowhere find its likeness.
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> Conceive of a roughly rectangular area of about 12,000 square miles, which has been tilted up along its northern side and eastern end to produce a regional slope approximately 20 feet to the mile. Consider this slope as the warped surface of a thick, resistant formation, over which lies a cover of unconsolidated materials a few feet to 250 feet thick. A slightly irregular dendritic drainage pattern in maturity has been developed in the weaker materials, but only the major stream ways have been eroded into the resistant underlying bed rock. Deep canyons bound the rectangle on the north, west, and south, the two master streams which occupy them converging and joining near the southwestern corner where the downwarping of the region is greatest.

Conceive now that this drainage system of the gently tilted region is entered by glacial waters along more than a hundred miles of its northern high border. The volume of the invading water much exceeds the capacity of the existing stream ways. The valleys entered become river channels, they brim over into neighboring ones, and minor divides within the system are crossed in hundreds of places. Many of these divides are trenched to the level of the preexisting valley floors, others have the weaker superjacent formations entirely swept off for many miles. All told, 2800 square miles of the region are scoured clean onto the basalt bedrock, and 900 square miles are buried in the debris deposited by these great rivers. The topographic features produced during this episode are wholly river-bottom forms or are compounded of river-bottom modifications of the invaded and over-swept drainage network of hills and valleys. Hundreds of cataract ledges, of basins and canyons eroded into bed rock, of isolated buttes of the bed rock, of gravel bars piled high above valley floors, and of island hills of the weaker overlying formations are left at the cessation of this episode. No fluviatile plains are formed, no lacustrine flats are deposited, almost no debris is brought into the region with the invading waters. Everywhere the record is of extraordinarily vigorous subfluvial action. The physiographic expression of the region is without parallel; it is unique, this channeled scabland of the Columbia Plateau."

A mere glance at a modern LANDSAT photograph of the Channeled Scabland (Fig. 1.1)

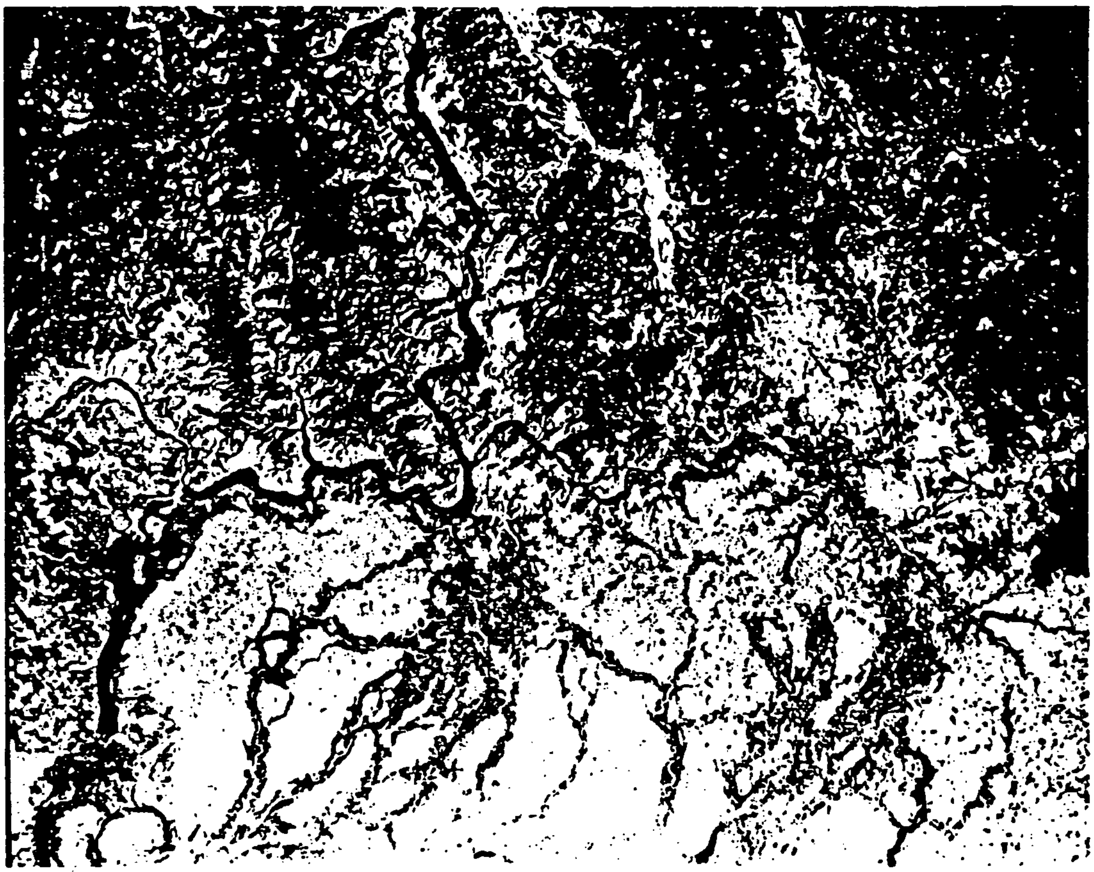

Figure 1.1. LANDSAT photograph of the northern part of the Channeled Scabland. Scabland channels form the dark-toned anastomosis that contrasts with the wheat farms on the light-toned Palouse loess. The Columbia and Spokane Rivers occur at the top (north) of the photograph. The far left scabland complex is the Grand Coulee-Hartline Basin-Lenore Canyon tract. At the center is the Telford-Crab Creek Scabland complex. At the right (east) is the Cheney-Palouse scabland tract (LANDSAT E-1003-18150 composite, 26 July 1972).

will show the features that Bretz, studying from the ground, developed as the basis of his flood hypothesis. The extensive wheat cultivation on the loess presents a vivid contrast to the flood-scared basalt exposed in the channel ways.

The unique character of the dry river courses ("coulees") of the Channeled Scabland was appreciated by the first scientific observers of the region. Rev. Samuel Parker (1838) provided the first published statement on the Grand Coulee: "[it] was indubitably the former channel of the river [Columbia]." Lieutenant T. W. Symons (1882) of the U.S. Army traversed the Grand Coulee, stating that he, "went north through the coulee, its perpendicular walls forming a vista like some grand old ruined roofless hall, down which we traveled hour after hour." Symons (1882) initiated the widely held notion that during glacial episodes of the Pleistocene the Columbia had simply been diverted across the Columbia Plateau. Variations on this general theme were standard in the early literature (Russell, 1893; Dawson, 1898; Salisbury, 1901; Calkins, 1905).

The Grand Coulee gained international fame in 1912 when it was traversed by the American Geographical Society's Transcontinental Excursion. Karl Oestreich (1915) of the University of Utrecht described the coulee as "eines mächtigen Flusses Bett . . . ohne jede Spur von Zerfall der frischen Form." He provided an excellent description of significant features that required a special origin: exhumed granite hills, perpendicular walls, and the hanging valleys marginal to the upper Coulee. He ascribed these hanging valleys to glacial erosion and to deepening of the coulee by the glacial Columbia River. Moreover, he recognized that the upper Grand Coulee was carved through a preglacial divide, which he correctly located just north of Coulee City.

Another foreign observer on the American Geographical Society excursion was H. Baulig, University of Rennes. Baulig (1913) described the loess, coulees, dry falls ("cataracte desséchée de la Columbia"), rock basins, and plunge pools. The origin of these features was ascribed to a glacial diversion of the Columbia. Nevertheless, he marveled at the scale of erosion (Baulig, 1913, p. 159): "peutêtre unique du relief terrestre,—unique par ses dimensions, sinon par son origine."

Dr. O. E. Meinzer, the eminent hydrologist of the U.S. Geological Survey, took an early interest in the western part of the Channeled Scabland. He observed (Meinzer, 1918) that the glacially diverted Columbia at Grand Coulee "cut precipitous gorges several hundred feet deep, developed three cataracts, at least one of which was higher than Niagara, . . . and performed an almost incredible amount of work in carrying boulders many miles and gouging out holes as much as two hundred feet deep." He implies that the great erosion occurred because the Columbia River was diverted across the steeply dipping basalt surface of the northern Columbia Plateau.

It was not until the studies of J Harlen Bretz (1923-1932) that the scientific study of this region began in earnest. Bretz interpreted the erosional and depositional features of the region as the product of a brief but enormous flood, which he called the Spokane Flood. For geology in the 1920's this was clearly an outrageous hypothesis. Olson (1969) has described the reception of the idea. "During its not always calm history, the story of the development of the Channeled Scabland was thought by some to have brushed beyond the dividing line in flaunting catastrophe too vividly in the face of the uniformity that had lent scientific dignity to interpretation of the history of the earth." The reaction of the scientific community was predictable, "this heresy must be gently but firmly stamped out" (Bretz and others, 1956, p. 961).

AN OUTRAGEOUS HYPOTHESIS

Because the Spokane Flood controversy is so tied to Bretz as its central figure, this review will consider part of his professional career during the years of his formulation of the flood hypothesis. The ensuing debates were not always marked by scientific objectivity, but their recounting is a fascinating example of the triumph of an outrageous hypothesis. Only in the last two decades has the flood hypothesis gained general acceptance. It is a measure of scientific maturity that in current studies of the Channeled Scabland, "the idea, but not the man has become central" (Olson, 1969).

While teaching at the University of Chicago, Bretz began conducting a summer field course in the wilds of the Columbia Gorge between Washington and Oregon. The idea for a study of the Channeled Scabland came during the summer of 1922. As he relates the story, "One summer I was out in Spokane. I saw a section of a topographic map of what is now called the Channeled Scabland, and from that I got the idea" (Quotation from Seattle Times, Sunday Magazine, July 11, 1971, p. 13).

Without the benefit of modern aerial photographs or even adequate topographic map coverage, Bretz began to take parties of advanced students into the region for month-long field studies. The work continued over the next 7 years. He soon revised an earlier notion that a marine submergence had occurred just downstream from the Channeled Scabland (Bretz, 1919). Nevertheless, the erratic granite boulders, which he had used as evidence for the submergence, were scattered about the basalt plateau far beyond the limits reached by Pleistocene glaciation. Bretz (1923a) named the glaciation responsible for these erratics the "Spokane Glaciation."

Although his first paper on the Channeled Scabland (actually the text of an oral presentation to the Geological Society of America) took care not to call upon cataclysmic origins, Bretz (1923a) provided a detailed description of physiographic relationships in the region. An example in his description (Bretz, 1923a, p. 601) of the pre-flood drainage line that was later enlarged to form the lower part of Moses Coulee: "The cliffs here are deeply notched by wide-open V-shaped tributary valleys. . . . These notches give the cliffs a striking resemblance to a series of great rounded gables in alignment. . . . Both widening and deepening in the basalt occurred and the tributaries were left hanging. They have since attained topograhpic adjustment by building large alluvial fans out on the canyon floor." He further noted that prodigious quantities of water were involved in the erosion. Referring to three outlets at the south end of the Hartline Basin (Dry Coulee, Lenore Canyon, and Long Lake Canyon), Bretz (1923a, p. 593-594) states, ". . . these are truly distributary canyons. They mark a distributive or braided course of the Spokane glacial flood over a basalt surface which possessed no adequate pre-Spokane valleys."

Bretz (1923a, p. 603) originally thought that the scabland gravels were organized into terrace remnants. However, after noting that they lacked a "sharp terrace form," this interpretation was quickly modified (Bretz, 1923b, p. 643): ". . . the evidence seems conclusive that all gravel deposits of the scablands are bars, built in favorable situations in the great streams which eroded the channels." With this conclusion he was forced to call upon catastrophic quantities of water. If the bars were over 100 feet in height, even greater water depths were required to form them. The second paper (Bretz, 1923b) also included the first detailed geomorphic map of the entire Channeled Scabland, showing the overall anastomosing pattern assumed by a great flood of water.

Bretz (1923b, p. 624-626) was the first to recognize the streamlined loess hills of the Cheney-Palouse scabland. He described them as follows: "A very striking and significant feature of the steepened slopes is their convergence at the northern ends of the groups to form great prows, pointing up the scabland's gradient. . . . The nose of a prow may extend as a sharp ridge from the scabland to the very summit of the hill. It is impossible to study these prow-pointed loessial hills, surrounded by the scarred and channeled basalt scablands, without seeing in them the result of a powerful eroding agent which attacked them about their bases and most effectively from the scabland's up-gradient direction."

Bretz knew that his interpretation would be controversial. He argued (Bretz, 1923b, p. 621), "All other hypotheses meet fatal objections. Yet the reader of the following more detailed descriptions, if now accepting the writer's interpretation, is likely to pause repeatedly and question that interpretation. The magnitude of the erosive changes wrought by these glacial streams is nothing short of amazing."

Bretz subsequently argued that the rugged scabland of anastomosing channels and rock basins cut into the basalt was the product of subfluvial quarrying. He described this process for the modern Columbia River near The Dalles, Oregon (Bretz, 1924). Moreover, he asserted that only large vigorous streams could produce such forms. The eventual conclusion from these varying lines of evidence was that so much glacial meltwater occupied the pre-existing valleys on the Columbia Plateau that it must have constituted a vast but short-lived flood, the "Spokane flood" (Bretz, 1925, p. 98). The flood spilled across pre-glacial stream divides, eroding the maturely dissected loess topography to form linear channels, and leaving a legacy of scoured loess scarps, hanging distributary valleys, and high-level fluvial deposits. It also built the huge constructional bars of gravel and then subsided so quickly that these bedforms were left almost unmodified by the subsiding water (Bretz, 1925, p. 105).

Bretz (1925) was able to trace the path of the great flood downstream through the Columbia Gorge to its debouchure into the Willamette lowland, where it built the "Portland delta." On this great subfluvial fan he recognized the significance of macroturbulence in accounting for certain flood features: "The Rocky Butte fosse is but the unfilled locus of an eddy caused by downward deflection where the current impinged on the east face of the butte. . . . The dependent terrace to the west was deposited in the slack water below the obstruction" (Bretz, 1925, p. 256).

Bretz (1925) even made the first estimate of the flood discharge. He chose Wallula Gap for this calculation because of the ponding effect of the constriction. His calculated maximum flow rate was 1.9 x 10^6 m^3/s (66.1 x 10^6 cfs), but he noted that this erred toward the low side. Nevertheless, he stated, "it represents the melting of about 42 cubic miles of ice daily" (Bretz, 1925, p. 258). He then notes that the insolation properties of ice and the total available ice mass north of the Channeled Scabland brings the whole concept into doubt. "The writer," he says (Bretz, 1925, p. 259), "has repeatedly been driven to this position of doubt, only to be forced by reconsideration of the field evidence to use again the conception of enormous volume. . . . These remarkable records of running water on the Columbia Plateau and in the valleys of the Snake and Columbia Rivers cannot be interpreted in terms of ordinary river action and ordinary valley development. . . . Enormous volume, existing for a very short time, alone will account for their existence."

Bretz (1925) then speculated on the somewhat obscure conditions that produced the Spokane Flood. He could only think of two possible explanations: (1) a very rapid and short-lived climatic amelioration, and (2) a gigantic glacier burst produced by volcanic activity beneath an ice cap. He noted severe objections to either hypothesis, but held that the great flood had occurred in spite of the problems in accounting for its source.

THE SPOKANE FLOOD DEBATE

In 1927 the Geological Society of Washington, D.C., invited Bretz to give a lecture "Channeled Scabland and the Spokane Flood." It was a purposeful invitation: a veritable phalanx of doubters had been assembled to debate the flood hypothesis. Bretz (1927a) presented the basic outline of his theory to date, citing the detailed field evidence which he could not explain by any hypothesis other than a great flood of water. The first discussant was W. C. Alden, who cautiously warned of the difficulties with the hypothesis. Lacking personal field experience in the region he suggested that the rock basins might be collapsed lava caves, but he realized that the major features indicated stream erosion. "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 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" (Alden, 1927, p. 203).

O. E. Meinzer voiced a commonly held view of the Channeled Scabland, ". . . 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 . . . 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" (Meinzer, 1927, p. 207). He argued that the glacially swollen Columbia could have easily cut the Dry Falls and deposited the great gravel fan of the northern Quincy Basin. He described the Quincy Basin as containing an extensive series of terraces. Moreover, the high-level channels were explained by progressive abandonment as the glacial Columbia progressively cut down to lower levels.

One difficulty that Meinzer appreciated from his field work in the Quincy Basin (Schwennessen and Meinzer, 1918) was the fact that four great spillways led out of the region where water had obviously been ponded. Bretz (1923a) had shown that the upper limits of the torrents that poured through these spillways occurred at the same altitudes. Rather than ascribing this coincidence to contemporaneous operation, Meinzer actually published the idea that the spillways had been cut one at a time, and subsequent minor earth movements had later brought them to an equivalent altitude. "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" (Meinzer, 1927, p. 208).

E. T. McKnight was also a participant in the Washington discussions. He subsequently suggested (McKnight, 1927) that a glacially diverted Columbia River was a viable alternative to Bretz' hypothesis. In response Bretz (1927b) argued that the great flood channels and bars near Gable Mountain (in the Pasco Basin) were far too large to be ascribed to the Columbia River. He made his position quite clear (Bretz, 1927b, p. 468): "I think I am as eager as anyone to find an explanation for the Channeled Scabland of the Columbia Plateau which will fit all the facts and will satisfy geologists. I have put forth the flood hypothesis only after much hesitation and only when accumulating data seemed to offer no alternative."

Bretz continued to answer various criticisms of his flood hypothesis (Bretz, 1928a, 1928b), and he established some new lines of inquiry into the problem. He (Bretz, 1929) showed that each of the valleys entering the eastern margin of the scabland spillways contained flood deposits emplaced by phenomenally deep water flowing *up* the tributaries away from the scabland channels. Along the Snake River he traced these deposits to beyond Lewiston, Idaho, more than 85 miles upstream from the nearest scabland channel. The conclusion again defied conventional wisdom (Bretz, 1929, p. 509): "Upvalley currents of great depth and great vigor are essential. . . . 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." Each subsequent study produced yet another affirmation of the flood theory. Bretz (1930b) writes: "The writer, at least normally sensitive to adverse criticism, has no desire to invite attention simply by advocating extremely novel views. Back of the repeated assertion of the verity of the Spokane Flood lies a unique assemblage of erosional forms and glacial water deposits; an assemblage which can be resolved into a genetic scheme only if time be very short, volume very large, velocity very high, and erosion chiefly by plucking of the jointed basalt."

Among the spectators at the Washington lecture was J. T. Pardee. Pardee (1922) also had written on the origin of the Channeled Scabland. W. C. Alden, who was Chief of Pleistocene Geology, U.S. Geological Survey, had sent Pardee to study the scablands. He published a brief article (Pardee, 1922) proposing that the Cheney-Palouse scablands tract had been created by glaciation of rather unusual character. Bretz later visited Pardee's field locations and found that his "glacial" deposits were flood bars (Bretz, 1974). Correspondence between Alden, Bretz, and Pardee suggests that Pardee was really considering a hypothesis that the scablands might be related to drainage from a large Pleistocene lake that he had studied in the western part of Montana (Fig. 1.2) (Pardee, 1910). It appears that Alden dissuaded him from that idea (Bretz, 1974). In his memorandum of September 25, 1922, to

Figure 1.2. Late Pleistocene strandlines of Lake Missoula at Missoula, Montana. The highest strandlines reach 1280 m (4200 feet).

David White, Chief Geologist of the U.S.G.S., Alden notes of Pardee's work: ". . . very significant phenomena were discovered in the region southwest of Spokane. . . . The results so far . . . require caution in their interpretation. The conditions warn against premature publication." David White later asked Bretz if he knew what Alden's middle name was. When Bretz replied in the negative, White said, "It's Cautious, Bretz, Cautious."

It seems clear that the source of the great scabland floods was known even as Bretz was struggling to defend his hypothesis to doubters at the Washington meeting. One story has it that during the discussion Pardee leaned over to Kirk Bryan and said, "I know where Bretz' flood came from."

Bretz finally solved the source problem for the Spokane Flood in 1928. Although Harding (1929) without consultation or acknowledgement made the first announcement of Bretz' idea, Bretz (1930a) later published the discovery that scabland flooding resulted from an abrupt failure of the ice dam that retained Glacial Lake Missoula. Bretz (1932a) clearly illustrated the relationship of Lake Missoula to the Channeled Scabland.

James Gilluly was another of those at the Washington meeting who was upset with Bretz' hypothesis. Although he had not studied the Channeled Scabland in the field, he presented an imaginative and persuasive argument for the creation of the unusual landforms by the long-continued erosion of present-sized streams (Gilluly, 1927, p. 203-205). He took exception to a minor point concerning the use of talus heights as time indicators and then attacked the major weak point in the flood hypothesis. At that time the only two explanations offered for achieving the great volumes of flood water were (1) a very sudden climatic amelioration, and (2) subglacial volcanism and a resulting glacier burst. Some simple calculations demonstrate the inadequacy of either explanation in producing the required volumes of water in so short a time. He concluded, in essence, that Occam's razor did not apply to the Channeled Scabland and called for a more complex sequence of adjustments by rivers or floods not much larger than the Columbia. In reply Bretz (1927a) asked whether the lack of a documented source for the flood was proof that the flood had not occurred. He argued that the scabland phenomena themselves required the existence of a great flood.

Aaron Waters (*in* Bretz, 1972) relates that Gilluly was later to change his mind in this matter. Many years after the incident at the Washington Academy of Science Gilluly visited the Channeled Scabland on a field excursion. As he observed the Palouse-Snake divide crossing, a major scabland stream channel, his astonishment changed to a smiling comment, "How could *anyone* have been so wrong?" Nevertheless, the emotion of those days is evinced by the geologists who continued to deny the flood hypothesis and apparently never changed their minds on the matter: W. C. Alden, K. Bryan, W. H. Hobbs, F. Leverett, C. R. Mansfield, J. C. Merrian, O. E. Meinzer, and G. O. Smith.

The published record of the Spokane Flood debate is clear on one major point. Bretz repeatedly asked only that his flood hypothesis be considered not by emotion or intuition, but by the established principles of the scientific method. His detailed paper on the scabland bars contains the most eloquent expression of this plea (Bretz, 1928b, p. 701):

> "Ideas without precedent are generally looked on with disfavor and men are shocked if their conceptions of an orderly world are challenged. A hypothesis earnestly defended begets emotional reaction which may cloud the protagonist's view, but if such hypotheses outrage prevailing modes of thought the view of antagonists may also become fogged.
>
> On the other hand, geology is plagued with extravagant ideas which spring from faulty observation and misinterpretation. They are worse than "outrageous hypotheses," for they lead nowhere. The writer's Spokane Flood hypothesis may belong to the latter class, but it can not be placed there unless errors of observation and direct inference are demonstrated. The writer insists that until then it should not be judged by the principles applicable to valley formation, for the scabland phenomena are the product of river channel mechanics. If this is in error, inherent disharmonies should establish the fact, and without adequate acquaintance with the region, this is the logical field for critics."

THE REVISIONISTS

By the early 1930's the Channeled Scabland problem had become something of a sensation for American geology. Bretz (1932a, 1932b) had published the last of his field results, and he had embarked on new problems in Greenland and Alberta and ground-water studies in the U.S. His monumental but controversial field study was now open to the kind of attack that he himself had so strongly urged—new field studies.

Ira S. Allison (1933) was the first to enter the new foray. His view was not a denial of the Spokane Flood, but a modification. He argued that it was ice, rather than mere volume, that was the critical factor in the flood. He presented detailed evidence for the ponding of flood water all the way from the Columbia River gorge to the Wallula Gap. This ponding was produced ("in spite of the obvious difficulties of such an explanation") by a blockade of ice in the Columbia gorge. The blockade grew gradually headward until it extended into eastern Washington. As water was dammed to higher levels it spilled across secondary drainage divides creating the enigmatic hanging valleys, high-level gravels and widely distributed erratics. One of the key insights of Allison's motivation was in his last sentence, "perhap this revision will make the idea of such a flood more generally acceptable" (Allison, 1933, p. 722).

Hodge (1934) published a brief interpretation of the Channeled Scabland involving mainly glacial processes. He hypothesized a complicated alternation of ice advances and drainage changes. The basalt was quarried by glacial erosion, and channel complexes in the basalt were produced by the diversion of meltwater streams around blocks of stagnant glacier ice and jams of berg ice. The theory was never adequately supported by published field evidence.

Perhaps the most serious alternative to the Spokane Flood hypothesis was posed by Richard Foster Flint (1938b). In many ways Flint's study is one of the most ironic in the annals of geology. He presented a carefully worded argument that cited a considerable amount of field data. He stated that the scabland gravel was relatively fine: "Gravel coarser than pebble size is common only in the northern part of the tract" (Flint, 1938b, p. 472). This description was combined with the observation of relatively good size sorting and fair to good rounding to suggest, "a picture of leisurely streams with normal discharge" (Flint, 1938b, p. 472). It is obvious from Flint's sedimentological descriptions that he was giving most of his attention to the slackwater facies of the Missoula flood deposits in the various scabland channels.

One of Flint's most important arguments was that the surface form of the scabland deposits was that of "non-paired, stream-cut terraces in various states of dissection" (Flint, 1938b, p. 475). It was an idea that Bretz had introduced (Bretz, 1923a) and subsequently rejected after closer field study. Flint thought that Bretz' revised interpretation of the deposits as constructional bar forms could explain some, but not all of the field relationships. He suggested that a sequence of channel aggradation by normal proglacial outwash was followed by dissection to leave remnants of fill that occasionally resembled bar forms.

Flint (1938b) accepted Bretz's (1928b) arguments that the flood gravel often (1) occurred in the lee of island-like areas, (2) had rounded upper surfaces, and (3) exhibited a parallelism of surface slopes with the dip of underlying foresets. He argued that "terraces" had been extensively dissected by a downstream base level reduction. The "terraces" were prefentially preserved in the lee of island-like areas. In addition, the low precipitation plus the high permeability of the gravel prevented gullying, so the gravel deposits developed rounded slopes by dry creep. Finally, he showed that many of the gravel slopes did indeed truncate the underlying bedding. As specific cases, he argued that Bretz' Willow Creek bar, Staircase Rapids bar, Palouse Canyon bar, Midcanyon bar, and Shoulder bar were all simply terrace remnants. Subsequent studies have shown that three of these bars have prominent giant current ripples on their upper surfaces (Fig. 1.3).

Flint also described multiple scarps and benches on the Palouse loess. Instead of recording the high-water mark of the Spokane Flood (Bretz, 1928b, p. 701), he interpreted these scarps as evidence of lateral planation by proglacial streams. Subsequent studies in the Cheney-Palouse scabland by Patton and Baker (Chap. 6, this volume) reveal that these scarps resulted from differential erosion of Palouse Formation paleosols and from the exposure of calichified gravel underlying local areas of Palouse loess.

Flint traced the coarse scabland deposits downstream into the Pasco Basin. There he found that the deposits changed from sand and gravel to silt and fine sand containing erratic stones. He named the fine-grained facies the "Touchet beds." The deposits had already been described by Bretz (1928a, p. 325-328; 1929, p. 516-536; 1930b, p. 414), who ascribed them to ponded flood water; and by Allison (1933), who ascribed them to water ponded by ice jams. The silts are recognized only to a uniform elevation of about 350 m. The stratification ranges from rhythmic parallel bedding to cut-and-fill. The included erratic stones are granite, basalt, and other crystalline lithologies. Intense folding, fracturing, and clastic dikes imply slumping and sliding of the water-saturated silt on gentle subaqueous slopes. Flint thought that these relationships were most consistent with a large lake, which he proposed was ponded by a landslide dam or glacier ice in the Columbia gorge. Following Symons (1882) he named this water body Lake Lewis.

At this point Flint had the necessary tools to erect his hypothesis. The proglacial meltwater streams of normal discharge overran the northern margin of the Cheney-Palouse tract. This flow was derived from lobes of ice at the heads of the Cheney-Palouse and Telford-Crab Creek scabland tracts. Flint thought water from Lake Missoula (Bretz, 1930a) need not be involved. Instead, he observed that the discharge "was less than that of the Snake River today" (Flint, 1938b, p. 515).

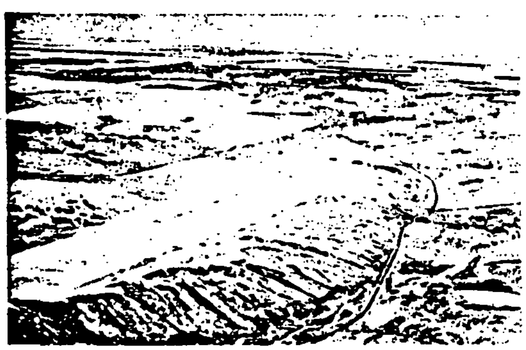

Figure 1.3. Oblique aerial photograph of Staircase Rapids bar. The bar is approximately 50 m high and composed of coarse flood gravel. The giant current ripples on the upper bar surface (left foreground) were actually first described by Flint (1938b) who did not recognize their origin. Bretz and others (1956, p. 1000-1002) later used these and other giant current ripple sets to demonstrate Flint's "faulty reasoning."

As Lake Lewis rose, the "leisurely" streams that Flint envisioned aggraded, forming a thick fill. This fill blocked preglacial tributaries to the Channeled Scabland, such as the Snake River, and formed marginal lakes which accumulated fine-grained sediments. The steep scarps on the Palouse loess were then cut by lateral planation of the streams flowing on this fill. When Lake Lewis finally drained, the streams gradually incised the fill to form terraces. Moreover, Flint was able to explain the enigmatic notched spurs and slotlike hanging canyons as the result of superposition of streams from the widespread fill rather than a consequence of divide crossing by catastrophic flood water.

Flint argued that the complex of anastomosing channel ways cut into basalt was a consequence of erosion by relatively small streams operating on various profiles. He stated that scabland-type erosion should occur wherever rock material with vertical planes of weakness is subjected to stream flow. As examples of such erosion he cited Red Rock Pass, Idaho, an outlet of pluvial Lake Bonneville (Gilbert, 1890). He also noted the scabland erosion at Twin Falls, Idaho, where the Snake River flows in a canyon nearly as spectacular as the scabland channels. He noted, "the . . . [basalt] flows yielded to the hydraulic force of the Snake River as similar flows on the Columbia Plateau yielded to the hydraulic force of proglacial streams, yet I am not aware that unusual floods have been held to have affected the upper Snake River" (Flint, 1938b, p. 492). These words were written 30 years too soon! Malde (1968) described the catastrophic outburst of Lake Bonneville that eroded the scabland forms at Red Rock Pass and Twin Falls.

In yet another ironic passage, Flint (1938b, p. 504-505) calculated the probable rate of filling for Lake Lewis at the modern discharge of the Columbia River. He stated, "the calculated time, 13 years 1 month, seems grossly inadequate for the deposition of the fill in the scabland tracts." He rationalized his interpretation, however, by referring back to the interpreted filling episode. Bretz' flood theory was so despicable that even circular reasoning could be employed to erect an alternative hypothesis.

A careful examination of Flint's (1938b) paper reveals that he observed and described the morphological feature which, more than any other, was absolutely incompatible with his elegant theory. On the surfaces of the scabland "terraces" he described an intricate microtopography of anastomosing channels, small depressions, and crescentic channels (Flint, 1938b, p. 475). In other areas he observed "mamillary undulatory topography." As an example he gives the precise location of the train of giant current ripples on the upper surface of Staircase Rapids Bar, 3 km north of Washtucna (Flint, 1938b, p. 486). Although the ripples that he describes are somewhat masked by overlying slackwater sediments, Flint (1938b, p. 499-500) even states the characteristic ripple magnitude: "The undulations are 20 to 100 feet long, and have amplitudes up to 10 feet. Their axes are generally transverse to the Snake River." How ironic that Flint was the first to accurately describe (without knowing what they were) the very feature that Bretz and others (1956) later presented as incontrovertible evidence for catastrophic flood flows (Fig. 1.3)!

It was Allison (1941) who published the first criticism of Flint's fill hypothesis for the origin of the Channeled Scabland. The first shortcoming noted was that the anastomosing channel patterns and deep rock basins could not have been eroded by "normal" streams. Second, Allison disputed Flint's correlation of the scabland gravels to the Touchet beds, suggesting that the Touchet sequence was younger than the gravels. Third, he agreed with Bretz that the peculiar shapes of the scabland deposits required extraordinary processes. The conclusion was that the complex jamming of various channels with ice was the only reasonable explanation for the unusual drainage patterns and depositional features.

Another example of the strong emotions evoked by the Spokane Flood controversy involves W. H. Hobbs, an eminent glacial geologist from the University of Michigan. He spent several weeks studying the terrain in southeastern Washington and prepared a paper explaining the landforms as the product of a "Scabland Glacial Lobe." Both Bretz and Flint reviewed the paper for the Geological Society of America, and both recommended rejection. The paper was then submitted to the American Philosophical Society, which had supplied part of the funds for the study. Bretz again reviewed the paper, and again it was rejected. Although a brief statement of the hypothesis was published (Hobbs, 1943), the main manuscript had to be published privately (Hobbs, 1947). The author expressed his feelings in the "Foreword" to his paper:

> "In the winter of 1942-43 I was listening with much interest to a lecture on the late geological history of the so-called Scabland area which is southwest of Spokane and close to the supposed southern front of the Pleistocene Cordilleran continental glacier. A map projected on the screen dozens of lakes, none of which transgressed its border, an almost sure indication that this lobate area had once been actually covered by a Pleistocene glacier lobe.
>
> Surrounding this lobe on the lecturer's map could be seen a broad apron of gravels, and enveloping the gravels were heavy deposits of silt. These relationships of glacier lobe to outwash and loess duplicated what I had observed in west Greenland. The lecturer explained, however, that the deposits represented upon his map had been laid down by a great flood of water of unknown origin, the "Spokane Flood."
>
> In the belief that my Greenland observations had given me an advantage in interpreting the evidence within the Scabland region, I then and there decided to make a personal study of it on the ground. Although two other very extended studies had already been made of it by Fellows of the Geological Society of America, and their conclusions had been published *in extenso* in its *Bulletin*, the Society provided me with a grant of money which made possible a new study of the area. This field investigation was carried out during two seasons, and the results and conclusions met with unusually enthusiastic general approval when they were presented to the Society in 1945 at its Pittsburgh meeting. Following tumultuous applause in the crowded section the discussion was throughout approving."

The Hobbs paper contains so many fundamental errors that one marvels at the absurd limits that were being stretched to find an alternative to catastrophic flooding as the cause of the Channeled Scabland. Hobbs (1947) argued that the scabland was a product of glacial scour and that the Palouse loess was deposited contemporaneous to this glaciation by anticyclonic winds off the ice that lay in the various "channels." He interpreted many scabland gravel deposits as moraine remnants modified by glacier-border drainage.

VINDICATION

At long last Pardee (1942) shared his observations of Glacial Lake Missoula that firmly indicated its role as the source of catastrophic floods through the Channeled Scabland. He noted that about 500 cubic miles of water were impounded behind a glacial lobe which occupied the basin of modern Lake Pend Oreille in northern Idaho. Pardee believed that this glacial dam had failed suddenly with a resultant rapid draining of the lake. Evidence for this failure included severely scoured constrictions in the lake basin, huge bars of current-transported debris (Fig. 1.4), and giant current ripple marks with heights of 50 feet and spacings of 500 feet (Fig. 1.5). Lake Missoula was the obvious source for the catastrophic flood flows required by Bretz' hypothetical origin of the Channeled Scabland (Fig. 1.6). Pardee did not state the connection, perhaps leaving that point generously to Bretz. Even Alden remained cautious to the end. His last published report on Lake Missoula observed (Alden, 1953, p. 155): "Abrupt release of water from lowering of the ice dam . . . might result in floods of great magnitude. . . . Each may, *perhaps,* have been the origin of many violent floods that are *supposed* to have swept over the scablands."

In the summer of 1952, Bretz, then nearly 70 years old, returned for his last summer of field work in the Channeled Scabland. The purpose was to investigate new data that had been obtained in surveys for the Bureau of Reclamation's Columbia Basin project. Professor H. T. U. Smith accompanied him, acting in the field as "skeptic for all identifications and interpretations" (Bretz and others, 1956). With the aid of Mr. George E. Neff of the Bureau of Reclamation that study (Bretz and others, 1956) answered with meticulous detail all previous criticisms of the flood hypothesis.

Central to the 1956 investigation was the study of the scabland depositional features. Extensive excavations for the irrigation project and new topographic maps proved that the gravel hills called bars by Bretz (1928b) were indeed that, subfluvial depositional bedforms. Most convincing of all was the presence of giant current ripples on the upper bar surfaces. These showed clearly that bars 30 m high were completely inundated by phenomenal flows of water. Numerous examples of giant current ripples were found on the same bars which Flint had interpreted as terraces. Such features could only have been produced by the flow velocities associated with truly catastrophic discharges. Bretz and others (1956) and Bretz (1959) modified Bretz' earlier interpretations to allow for several episodes of flooding. The central theme of their study, however, was that only a hypothesis involving flooding could account for all the features of the Channeled Scabland. More recent studies of the

Figure 1.4. Large "gulch fill" formed at the mouth of a tributary canyon along the Flathead River, Perma, Montana. The deposit is an eddy bar (Baker, 1973a) formed during the rapid draining of glacial Lake Missoula. First recognized by Pardee (1942) this gravel deposit was later breached by a small stream to form the V-shaped notch visible at right. The low terrace in the foreground is composed of lacustrine silt.

Figure 1.5. Giant current ripples at Camas Prairie, north of Plains, Montana. The ripples are composed of gravel and consist of ridges up to 15 m high and spaced as much as 200 m apart. The ripples cover approximately 10 km² of the northern Camas Prairie. Faint strandlines of Lake Missoula are visible in the background.

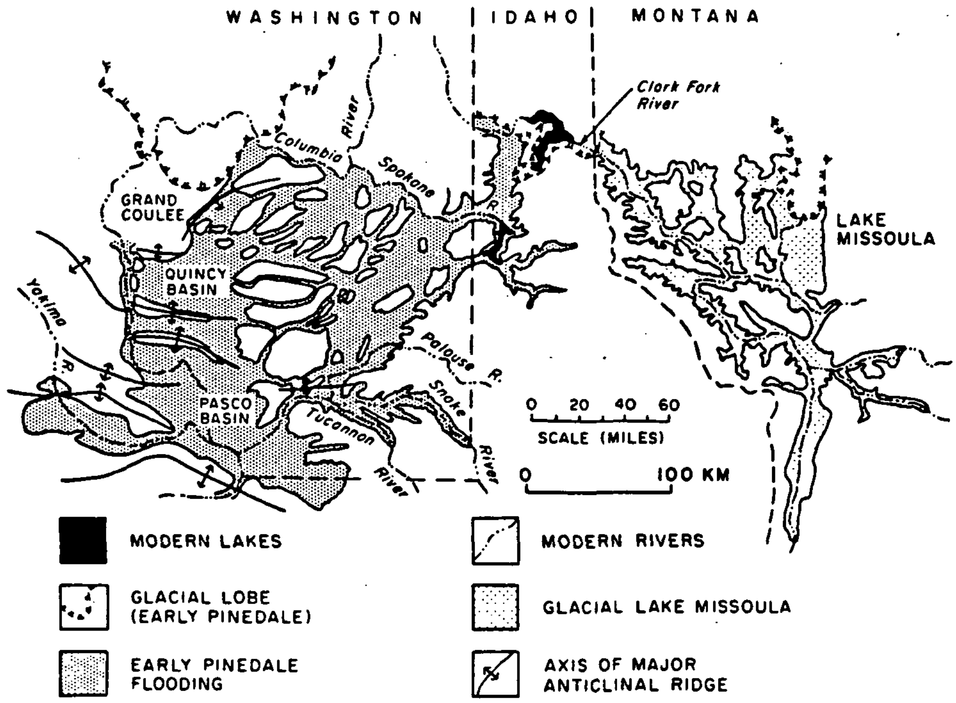

Figure 1.6. Relationship of glacial Lake Missoula to the Channeled Scabland of eastern Washington (Baker, 1973a).

Quaternary geology of eastern Washington have accepted this reasoning (Trimble, 1963; Fryxell and Cook, 1964; Richmond and others, 1965; Baker, 1973a).

Perhaps the final words on the Channeled Scabland controversy were delivered following a field trip, Field Conference E of the 7th Congress, International Association for Quaternary Research. During August, 1965, an international party of geologists observed the evidence in Montana for Lake Missoula's catastrophic outbursts. They then traveled through the Channeled Scabland studying the giant current ripples, flood gravel bars, and scabland erosion forms. Dr. Bretz was unable to attend the trip because of health. When the field party reached Pullman, they sent a long telegram to him at Homewood, Illinois. The telegram opened with "greetings and salutations" and closed with the sentence, "We are now all catastrophists" (Bretz, 1969, 1973).

DISCUSSION

When Bretz published his work on the Channeled Scabland, the paradigm of Geology was uniformity. The Spokane Flood hypothesis appeared to contradict the uniformitarian tradition that made geology a science in the nineteenth century. Indeed it was not until after 1840 that the flood theory fell into serious decline. The catastrophist idea of the Noachian debacle was finally laid to rest when Louis Agassiz showed that his glacial theory could explain erratics, striations, till, fluvioglacial activity, etc. Old ideas die hard, however, and catastrophist absurdities still appeared in the literature of the early 1900's (as they do even today). Little wonder then that Bretz' Spokane flood hypothesis appeared as an anathema to many of his contemporaries.

Simultaneously the Spokane Flood hypothesis established a conflict between two important cornerstones of geological philosophy: (1) the triumph of the glacial theory over diluvian myth, and (2) the scientific tolerance of outrageous hypotheses. It is a classic dilemma for the scientist to distinguish absurdity from outrage. A foolish idea is always self-evident, but not so with the rare, creative insight that happens to pass all reasonable bounds in the consensus of knowledge. The remarks of a former president of our society: "How narrowly limited is the special field, either in subject or locality, upon which a member of the Geological Society of America now ventures to address his colleagues. . . . I wonder sometimes if younger men do not find our meeting rather demure, not to say a trifle dull; and whether they would not enjoy a return to the livelier manners of earlier times . . . (Their) feeling of discouragement must often be shared by the chairman of a meeting when, after his encouraging invitation, 'This interesting paper is now open for discussion,' only silence follows. . . . We shall be indeed fortunate if geology is so marvelously enlarged in the next thirty years as physics has been in the last thirty. But to make such progress violence must be done to many of our accepted principles."

After speaking these words in 1926, William Morris Davis made a case for the value of outrageous geological hypotheses, even suggesting that geologists seriously consider "the Wegener outrage of wandering continents." He concluded by saying that the valuable outrage was that which encouraged the contemplation of other possible behaviors. Such outrages deserve contemplation followed not, he states, "by an off-hand verdict of 'impossible' or 'absurd', but a contemplation delibrate enough to seek out just what conditions would make the outrage seem permissible and reasonable."

Needless to say, W. M. Davis was one of the first to accept Bretz' interpretation in the 1920's. It is a commentary on those years that others were not so tolerant. "During all those years, I was fighting for my professional career." (Quotation of Dr. Bretz by the Seattle Times, July 11, 1971.) Bretz himself explored the consequences of his "outrage." His 1956 paper resoundingly confirmed the catastrophic flood theory by answering in meticulous detail all the previous objections to his grand hypothesis. It took over 30 years and the coming of a new generation of geologists for his theory to gain general acceptance.

The Spokane Flood controversy is both a story of ironies and a marvelous exposition of the scientific method. One cannot but be amazed at the spectacle of otherwise objective scientists twisting hypotheses to give a uniformitarian explanation to the Channeled Scabland. Undoubtedly these men thought they were upholding the very framework of geology as it had been established in the writings of Hutton, Lyell, and Agassiz. The final irony may be that Bretz' critics never really appreciated the scientific implications of Agassiz' famous dictum, "study nature, not books." Perhaps no geologist has understood and lived the spirit of those words more enthusiastically than J Harlen Bretz.

As the Viking spacecrafts were orbiting Mars in the summer of 1976, the cameras were trained on the great Martian channel systems. They revealed uplands streamlined by fluid flow, eroded scabland on the channel floor, and many other features that we now know to be diagnostic of bedrock erosion by catastrophic flooding. Fifty years after J Harlen Bretz' theory of scabland erosion on the Columbia Plateau was being denounced at an infamous meeting of the Washington Academy of Science, Viking scientists were using Bretz' well-documented studies of the Channeled Scabland as the major earth-analog to Martian channel erosion. Few geological concepts, born amid bitter controversy over a half century ago, have continued to have such relevance to our science.