State of Washington
ALBERT D. ROSELLINI, Governor
Department of Conservation
EARL COE, Director

DIVISION OF MINES AND GEOLOGY
MARSHALL T. HUNTTING, Supervisor

Bulletin No. 45

WASHINGTON'S CHANNELED SCABLAND

By
J HARLEN BRETZ

STATE PRINTING PLANT OLYMPIA, WASH., 1959

State of Washington
ALBERT D. ROSELLINI, Governor
Department of Conservation
EARL COE, Director

DIVISION OF MINES AND GEOLOGY
MARSHALL T. HUNTTING, Supervisor

Bulletin No. 45

WASHINGTON'S CHANNELED SCABLAND

By
J HARLEN BRETZ

For sale by Department of Conservation, Olympia, Washington.
Price, 50 cents.

FOREWORD

Most travelers who have driven through eastern Washington have seen a geologic and scenic feature that is unique—nothing like it is to be found anywhere else in the world. This is the Channeled Scabland, a gigantic series of deeply cut channels in the erosion-resistant Columbia River basalt, the rock that covers most of the east-central and southeastern part of the state. Grand Coulee, with its spectacular Dry Falls, is one of the most widely known features of this extensive set of dry channels.

Many thousands of travelers must have wondered how this Channeled Scabland came into being, and many geologists also have speculated as to its origin. Several geologists have published papers outlining their theories of the scabland's origin, but the geologist who has made the most thorough study of the problem and has examined the whole area and all the evidence having a bearing on the problem is Dr. J Harlen Bretz.

Dr. Bretz started his field work in the Columbia Basin in 1922 and continued his studies there for 7 years. His somewhat unorthodox theory—that the channels were cut in a relatively short time by enormous floods of water—was published in a series of reports, and this theory has been a source of argument in geologic circles ever since. Dr. Bretz re-examined the scabland area in 1952 and published another very detailed report that confirmed his earlier work.

The Division of Mines and Geology was fortunate in being able to obtain the services of Dr. Bretz to write the present report, which briefly summarizes the results of his many years of study. This report will be of value to geologists who are interested in the problem of the origin of the Channeled Scablands, and it will also be of interest to travelers who may want to know how this channeled area came to have its peculiarly sculptured shape.

MARSHALL T. HUNTTING, Supervisor
Division of Mines and Geology

April 15, 1959

CONTENTS

ILLUSTRATIONS

WASHINGTON'S CHANNELED SCABLAND

By J Harlen Bretz

Unparalleled in the whole wide world, scarcely even approached by any other landscape of similar origin, are the Channeled Scablands on the Columbia Plateau in eastern Washington. Four contrasting theories have been proposed for this unique topography, at least three of which cannot be correct. None of the four can point to specific processes now in operation, nor to any combinations of observed processes, that yield more than feeble comparisons for the extraordinary features of the Channeled Scablands. Understanding the Scablands involves imagination and courageous departure from accepted views. Two of the four theories possess this qualification. Two are conventional and inadequate. Although the same agencies are called for in each theory; i. e., glacial ice and glacial rivers, the differences among these theories are in time and space relations and in quantities.

Visualize a fairly plane tract, a plateau surface 125 miles across. Cover its basaltic rock foundation with a thick, powdery soil, the famous Palouse wheat soil. Bound this part of the Columbia Plateau on north, south, and west by the deep valleys of the Spokane, Snake, and Columbia Rivers. Tilt the plateau down toward its southwest corner. Allow normal rainfall for many thousands of years to collect into streams that flow along the direction of tilt, small streams converging to make larger ones. Admit that these plateau-born streams must make valleys in the deep soil—converging valleys. Permit some part of them to erode down into the bedrock.

Now change the climate so that the British Columbia and northern Washington highlands become buried in glacial ice. Thicken that ice until it buries most mountain peaks and spreads slowly toward the south. Visualize the advancing margin reaching and then crossing the canyons bounding the north side of the plateau. Realize that the field evidence records the advance as reaching only a few tens of miles out on the plateau, the ice melting at that margin and its meltwater escaping along the larger streamways in the thick soil, deepening and widening them. Conceive that the arctic climate continued for a long time, so that ice continually flowed southward, only to waste away along the northern margin of the plateau, its meltwater using the minor valleys across that plateau. Nobody adequately conversant with the area questions any of the above requirements for a successful theory for the origin of the Channeled Scabland.

Now examine a map showing the extent to which the old drainage system became invaded by meltwater streams (pl. 1). Compare that pattern with any other drainage system on the earth. The map

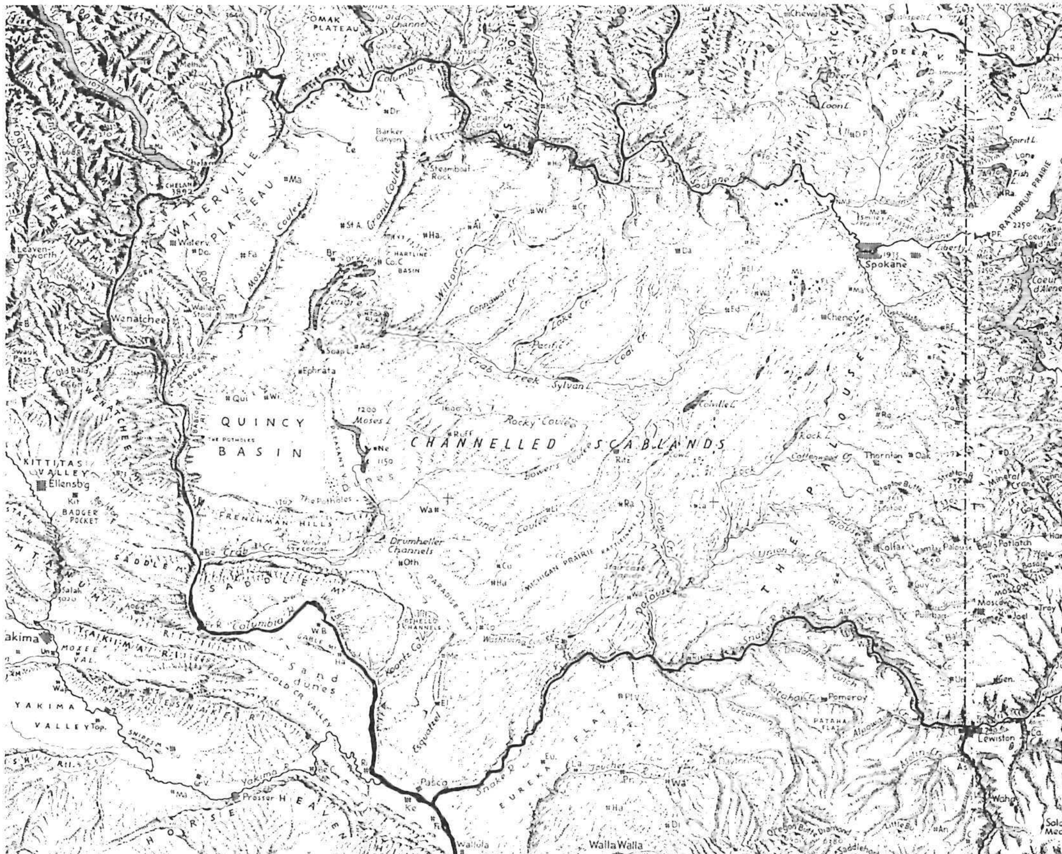


FIGURE 1. Physiographic diagram of the Channeled Scablands and environs. (From Erwin Raisz, 1941)

shows a feature that never existed before the meltwater invasion occurred, a feature that no other comparable drainage system in the world possesses. Many streamways of this pattern *diverge* downstream, only to *converge* again. A network of drainage channels was made out of the original treelike converging pattern. Travelers by air report that from altitudes of, say, 20,000 feet, the scorings left by the glacier-born streams look about as definite as the depiction in plate 1. The network is vivid to the man in the air because the deep soil was cut through, and many channels were eroded into the black basalt beneath. These long attenuated strips and belts of bare or nearly bare rock outline the unique pattern of Washington's Channeled Scabland.

At this point, theory-makers go four different ways almost as divergent as the cardinal points of the compass. Before one can critically examine and judge any one of the four theoretical routes indicated on our imaginary guidepost, he must know the general facts that demand explanation.

GENERAL FEATURES OF THE CHANNELED SCABLAND

Anastomosis.—This outstanding feature has been outlined above. In the 50 or more single glacial streamways that split downgrade to make 2, about 25 definitely involve crossing a divide of the preglacial drainage pattern. Some overflowed the transgressed divide "broadside" from one channel to the other. Most of them were spillovers from the side of a large channel to the head of a smaller one. Among those divergences, the majority ended by rejoining the larger streamway they had left. But the discharge of more than a dozen offshoot meltwater strands did not mingle with water from the parent stream until after reaching the Columbia southwest of the complex.

This anastomosis (or plexus or network or complex) involved divide crossings as much as 300, even 400, feet above present bottoms of the parent plateau river course. Many of the pre-existing valleys headed miles south of the ice margin, and only by these spillovers could they ever have obtained the stranded erratic boulders derived from bedrock far north of the plateau. Only berg ice could have carried such boulders across the violated divides.

None of these divide crossings south of the known limit of the ice sheet can be explained by direct glacial damming. Here is a challenging problem for the hydrologist and the geomorphologist.

This interlaced glacial river pattern with its divide crossings has been explained as the consequence of:

(1) enormous flooding in the preglacial valleys (Bretz, 1923a-1956),
(2) damming of these valleys by jams of berg and river ice (Allison, 1933),
(3) filling of the early valleyways with gravelly outwash from the glacial margin (Flint, 1938), and

(4) a glacial advance (the "Scabland Glacial Lobe") far beyond the limits accepted by everybody but the author of that theory (Hobbs, 1943).

The proposed floods, ice dams, and ice sheet have vanished, of course. The great gravel deposits of the third theory are less readily disposed of, yet they also are gone.

The flood theory shocked and displeased many geologists, especially when it demanded that every channelway be flooded simultaneously. This demand was based on a near-coincidence of altitude of upper ends of all channels heading at the margin reached by the ice sheet.

Rock basins.—Another outstanding feature of the Channeled Scabland is the existence of hundreds of undrained basins along the channelways. Under the semi-arid climate of the lower southern and southwestern part of the area, these rock-walled and rock-bottomed basins are empty or contain alkaline lakes. Swamps and fresh-water lakes are numerous in the northeast. Depths of the basins may exceed 100 feet. One (Scooteney Lake, Othello Channels, fig. 21), on the very summit of a channeled divide, is 135 feet in depth. Admitting the existence of the rock basins (without an extinct waterfall at the upstream edge to explain them as plunge basins), one doubter of the flood theory suspected that they might be collapsed lava caverns lying in channelways only by coincidence. Other skeptics minimized their magnitude or ignored their existence. The fourth theory which, because of serious internal and external disharmonies, has never had followers, saw these rock basins as glacially plucked. The flood theory accepts plucking but considers that the tremendous volumes and velocities of its rivers, operating on the closely and vertically jointed basalt, made plucking possible in favorable places.

Scarps in loess.—As readily recognized as the rocky ledges and cliffs of the glacial river routes are steep margining bluffs above the scabland basalt. They are developed in the overlying Palouse soil which is actually a thick dust deposit, known as loess. Much of the Channeled Scabland is dotted with "islands" of this loess, also sharply outlined by steep bluffs and commonly with sharp prows pointing upstream. Indeed, all the loess-covered tracts enclosed by the channel divergences and convergences are "islands." Above scabland level the islands have only the gentle slopes of the pre-scabland topograpy, definitely untouched by glacial rivers, definitely much older in erosional development.

That the steep bluffs were made along the margins of glacial rivers is accepted by all.

Butte-and-basin topography.—Where the loess was swept off wide scabland tracts, the bare or nearly bare basalt is in some places (Palouse-Snake divide, and Drumheller and Othello channnels, figs.

18 and 21) amazingly scarified with anastomosing channels and rock basins surrounding buttes and small mesas of rock. Such tracts may have a relief of 100 to 300 feet, the erosion logically imputable to no agency other than glacial rivers. Two such tracts measure 9 miles across. The fill theory interprets such wildernesses of labyrinthine canyons as eroded into subjacent bedrock during removal of the theoretical gravel cover by glacial streams "no larger than Snake River of today." A better term for this theory is fill-and-cut. The flood and ice-jam theories presuppose an abundance of water for doing the work.

Cataracts.—Dozens of extinct cataracts and cascades exist along the glacial river courses. They constitute the Scabland's most impressive scenery. They range from a quarter of a mile wide and a few tens of feet high to 3½ miles wide and 400 feet high (Dry Falls in Grand Coulee, figs. 2, 3, and 4, and pl. 2). They commonly possess plunge pool basins, with or without lakes. Like the Niagara prototype of a retreating cataract, they migrated upstream by undercutting from the points of inception and thus left recessional gorges or canyons up to 5 miles wide and 900 feet deep (Upper Grand Coulee, fig. 8). The maximum retreat has been about 20 miles.

A repeated criticism of the flood theory has been the obvious impossibility of maintaining any tremendous discharge long enough for the cataract retreat recorded in these longer gorges. No theorist or critic has denied their waterfall origin, but significantly located examples have unfortunately been overlooked and their views invalidated thereby.

Three most challengingly located extinct waterfalls (Potholes, Frenchman, and Crater, figs. 13-17) were developed where glacial meltwater escaped across the rim of a broad basin (Quincy, fig. 20), whose bottom was too low to be eroded down to bedrock, and spilled over high cliffs bordering the Columbia River valley. The challenge lies not only in the great width of the discharging streams (therefore, huge volume) but, most important, in the fact that their channel upper limits are so nearly the same as to make almost impossible any rational concept of a sequence in operation. (See p. 26.) The flood theory has made these three contemporaneously operating cataracts one of its most strongly emphasized arguments. The rival theories have failed to give them a hearing.

Broad gravel deposits.—Plate 1 shows two large areas and many smaller ones as gravel-covered. All such places were sites of relatively slack current because of decreased gradient or actual ponding or overloading of the stream in shallow marginal situations. Exposures in some of these scabland gravel deposits reveal foreset bedding that dips in the direction of current through a maximum of more than 200 vertical feet (mouth of the Palouse River, fig. 28) and thus apparently records a growing delta front or a growing

FIGURE 2. Fall Lake, great cataract group, Lower Grand Coulee, looking northeast from Vista House in Dry Falls State Park. The lake is 380 feet below the camera. The cataract cliff has a maximum height of 400 feet above the lake, whose basin is 80 feet deep. The white area near the right side of the view is a desiccated lake flat in the eastern of the two recesses of Dry Falls. (Photograph by Frank Guilbert)

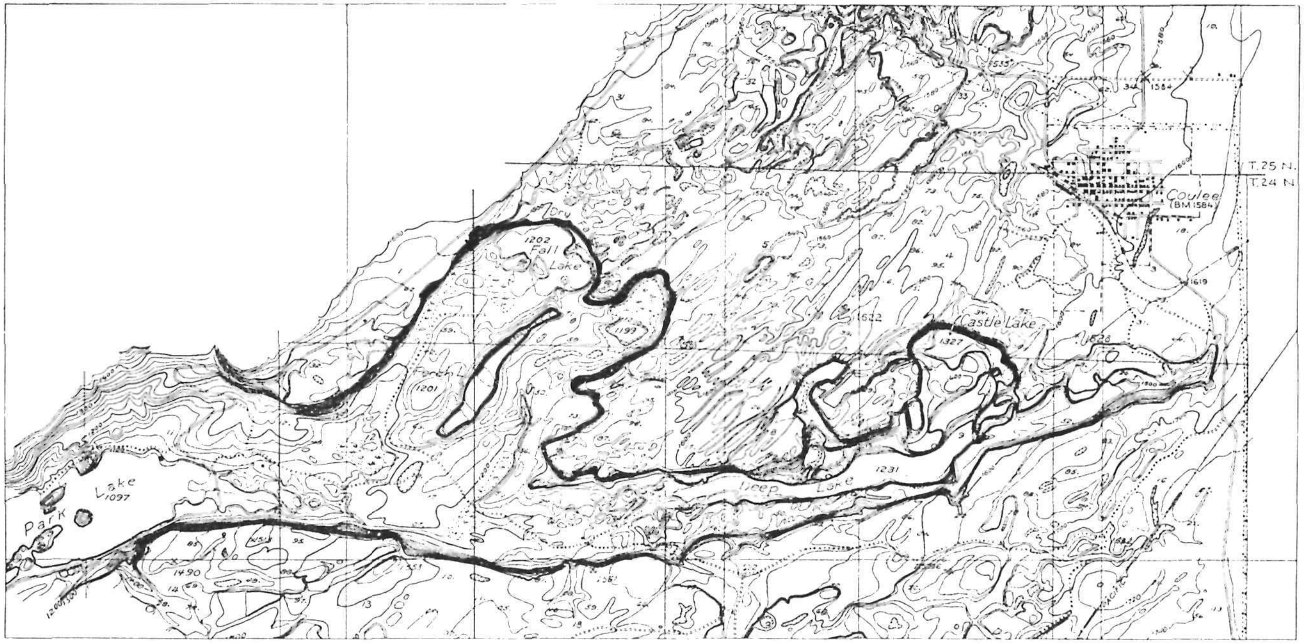


FIGURE 3. The great cataract group in Hartline Basin. Contour interval in T. 24 N. is 20 feet; in T. 25 N. it is 5 and 20 feet, changing on the 1,560-foot contour. (Reduction of a part of sheet 4, Grand Coulee topographic map, U. S. Geological Survey; scale approximately 1 inch to the mile)

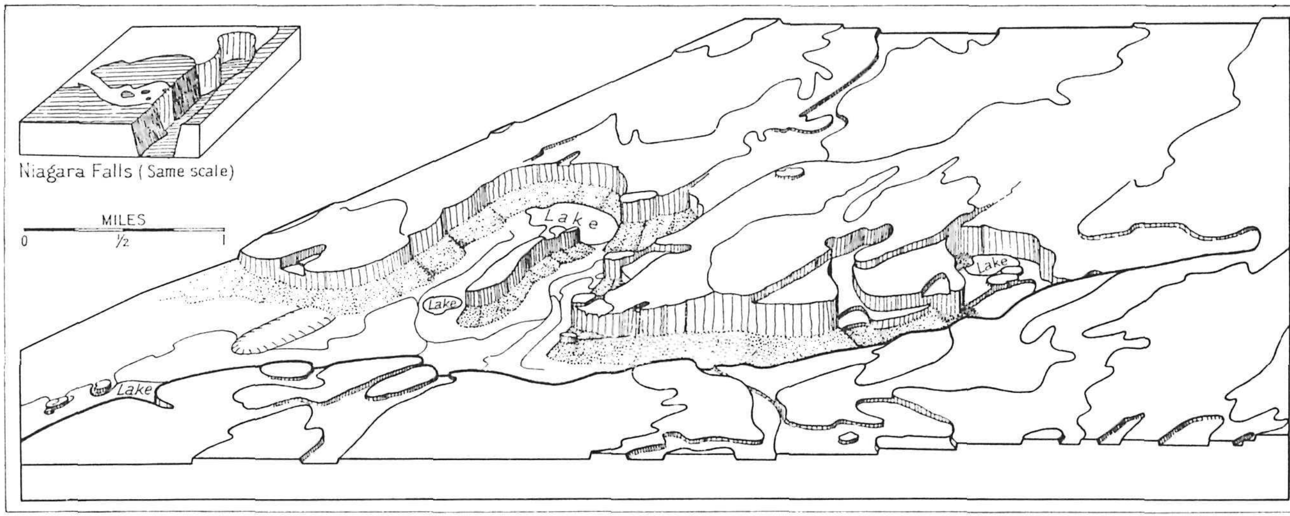


FIGURE 4. Block diagram of the great cataract group, looking north. Compare with topographic map (fig. 3) and the photograph (pl. 2). The walls of Niagara Falls and gorge, having no talus, appear higher proportionately than those of the cataract with talus halfway up the original cliffs. (From American Geographical Society Special Publication No. 15, p. 11)

giant river bar. The flood and ice-jam theories can take such inferences in their stride. The other two find different interpretations, such as morainic gravel deposits or a denial of the continuity of such inclined stratification through large vertical intervals. Imperfect exposures can mislead a geologist into incorrect inferences, especially if he already has a pet theory. This comment applies to all four ways shown on our imaginary guidepost!

Bars.—Proponents of the fill-and-cut theory point to hills of outwash gravel here and there along the streamways as remnants surviving later glacial stream erosion. Defenders of the theory of enormous flooding call these hills giant river bars, averring that they were built up where they stand. But the flood theorists are challenged to show an adequate source for all that water. It admittedly never could have come from daily summer melting along the ice margin. Adherents of the ice blockade theory incline also to call these gravel hills river bars. They get the necessary local flooding by abrupt failure of dam after dam.

The fourth theory ignores the stream deposit character of the gravel hills, erroneously calls them "mutilated moraines" and thus has to bring the ice sheet far south across the plateau. As we linger at the fourway guidepost, this theory seems the least in accord with the field evidence.

Giant current ripples.—A number of publications on the four theories appeared before the U. S. Department of Agriculture had completed its photographic coverage from the air, although vertical views had already been made for the U. S. Geological Survey in mapping Upper Grand Coulee. These U. S. D. A. overlapping verticals allowed stereoscopic viewing of any part of the region. A truly startling discovery resulted from study of photographs of some of the scabland gravel surfaces. The photographs showed a recurring pattern of parallel ridges and swales oriented at right angles to the known direction of flow in a dozen or so of the glacial rivers. Because of a strong suspicion that these corrugations were current-made ripple marks, several examples, widely separated on the plateau (Palouse-Snake junction, Upper Crab Creek, and Columbia Valley opposite Crescent Bar, figs. 24 and 27-31) were examined in the field in 1952. The ridges were so low and widely spaced that no earlier study had more than noted their existence. Their significance now became apparent, for every one of the ridges was 2 to 4 times as steep on the downstream side as on the upstream. This, plus the approximate parallelism, the dying away of the ridges toward the margin of the glacial streams, and the uniform spacing, was, to all geologists who to date (1956) have commented on the published photographs, convincing evidence that these ridges and separating swales were gigantic current-made ripple marks in the gravel bed of the glacial streams. Sizes justify the term "gigantic."

Ridges stand as much as 15 feet higher than the swales and are spaced from 175 to 300 feet apart. The larger the ridges, the wider the spacing. Some groups are nearly a mile across. They are clearly constructional forms made in favored places at the close of deposition of the gravel.[1]

When certain gravel hills, called bars in the flood and ice-jam theories and erosional remnants in the fill-and-cut theory, were found to have these gravel ridges not only on the summits but also descending the lateral slopes of the current-elongated deposits, the flood and ice-jam theories gained perhaps their strongest supporting evidence. No comment on this interpretation has yet come from confirmed skeptics of those theories.

Backwater Deposits.—Least conspicuous of all significant features of the scabland are deposits made in preglacial valleys that entered the complex from areas untouched by the northern ice sheet or its meltwater. Turbulent water flowing *up* the lower stretches of these valleys, especially along the east side of the scabland, is recorded by deltaic and bar gravel accumulations at entrances to the denuded scabland. Foreset bedding inclines upvalley, erratic berg-drifted boulders occur far up the valleys, and a largely unstratified and unsorted pebbly silt mantles the gentler valley slopes. These give a record of glacial water as high as, but no higher than, the bases of loess scarps margining the scabland. Because of the southwestern slope of the plateau, the altitudes reached by these records decrease southward.

Proponents of the flood theory argue that the upvalley foresetting in silt, sand, and gravel can mean only that an adequate current flowed *against* the valley bottom slope, that it could not have been a through current and that the gradient which caused the current was the slope of the intruding water's surface. Thus an adequately rapid rise, a flood with turbulence enough to suspend and transport the sediment, is recorded. It must have been a very brief experience. Perhaps a succession of floods occurred.[2]

The ice-jam and fill-and-cut theories quietly neglect adequate consideration of the evidence for strong upvalley currents back out of scabland.

[1]The steep, downstream slope of any current ripple, large or small, is initially determined by debris dropped in the lee of the crest. Inclined bedding at the angle of stability results, and as the ripple grows the downstream-dipping strata come to constitute the structure of the entire ripple. This is beautifully shown in exploratory excavations made in 1958 by the Corps of Engineers, U. S. Army, at the site of the proposed Monumental Dam in Snake River just below the mouth of Devils Canyon. Here the giant ripples on a large scabland gravel bar stand 25 feet or more above their associated troughs and are spaced roughly 400 feet apart. The exploratory pits show that stratification of the gravel in the ripple ridges consistently dips downvalley at an angle of 25° ± for the full thickness of a ridge.

[2]The most extensive records of this back flooding of tributary valleys from the scabland are in the Snake River canyon above Riparia, in the Walla Walla River valley and the Yakima River valley.

Scabland of different ages.—In the dozen papers (1923 to 1932) supporting the flood theory, there is only one suggestion that such flooding occurred repeatedly. Not until the 1952 studies, based largely on data from new excavations, new aerial photographs, and new topographic maps of the great Columbia Basin irrigation project, did the idea of recurring floods find adequate field evidence to support it.

The evidence lies in a variety of relations among the river channels and their bars and in scabland buttes and basins definitely more weathered in the older, higher channels that were abandoned after main channels had become sufficiently enlarged to contain later floods. By this picture, the anastomosis was at its maximum in the earliest recorded flooding, and the latest flood was confined to Grand Coulee alone. An adequate presentation of the evidence for successive deepening of main channels and abandonment of some earlier, higher lying river routes will exceed the space that can be devoted to it here. A few cases will be considered in following pages.

This section on "General Features of Channeled Scabland" constitutes a prologue only. The appended list of references contains only the important titles that deal primarily with our topic—the origin of Washington scabland. From them are taken what detailed descriptions and interpretations seem desirable in this bulletin. A complete account of the scabland's features and a complete history are yet to be written. Indeed, a complete history awaits further field studies also, and from them will come additions to, emendations of, and perhaps subtractions from the treatment bound between these covers. All too briefly for a thoroughly critical appreciation and appraisal, we shall now look at some outstanding places in the Channeled Scabland.

GRAND COULEE

The longest and deepest of all scabland canyons, with the lowest floor at the head and the widest and highest dry falls cliff in midlength—this is Grand Coulee (Bretz, 1932; Bretz and others, 1956). It has the longest gorge made by cataract recession, a record of a former cataract twice as high as its existing Dry Falls, the largest lake (Lenore) and the most saline one (Soap), the most elaborate distributary system in its lower terminal portion, the greatest accumulation there of pebble and cobble gravel and the largest stream-rolled boulders, and it functioned from the beginning of scabland history to become at last the only surviving flood dischargeway. It merits its name, Grand Coulee.

Grand Coulee is a tandem of two canyons, separated by an uncanyoned portion in midlength (pl. 3). The Upper Coulee, whose floor is largely covered now by the Equalizing Reservoir, is 25 miles long and has essentially continuous walls approximately 800 to 900 feet high. It leads southward out of the Columbia River valley at

Grand Coulee Dam, its head a great notch cut in that valley's wall. The floor of the notch is 650 feet above the river. Often described as a Glacial Columbia River course, it came into being because the northern ice sheet pushed a lobe (Okanogan) across onto the plateau and thus blocked the preglacial Columbia farther downstream. Glacial dams at this place were the cause of all scabland river invasions of the plateau.

The detour at Grand Coulee found no pre-existing valleyway to follow for the full length of the Upper Coulee. It is the grandest example of a divide crossing in the whole complex.

The tilted plateau of our introductory picture has some marked departures from a simple plane; huge wrinkles or upfolds of the basalt caused by deep-seated earth movements long before the scabland history began. Grand Coulee is intimately related to one of these, the Coulee monoclinal flexure, a steep warping up of approximately 1,000 feet toward the northwest.

The initial spillover along Upper Grand Coulee was across the higher side of the flexure as far as that upper canyon extends. Encountering the steep slope of the monocline, the glacial river must have originally cascaded about 800 feet down, to spread out considerably in the broad uncanyoned portion where Coulee City and Dry Falls State Park are located. The spectacular Dry Falls are a part of the head of the Lower Grand Coulee canyon. The entire head is the Great Cataract.

This Lower Coulee follows the monoclinal flexure almost to Soap Lake at the mouth of Grand Coulee into the broad, gravel-filled Quincy Basin. It is eroded *in* the bent and broken basalt flows, following an impossible course for any preglacial stream; hence is, like the Upper Coulee, wholly of flood origin. Hogback islands in Lake Lenore and tilted flows (figs. 6 and 7) along the highway from Dry Falls to Park Lake and in other places repeatedly demonstrate this fact along about 10 miles of Lower Grand Coulee's 17-mile length. The great gravel deposits of Quincy Basin represent only a third or a fourth of the estimated 11 cubic miles of rock excavated in making Grand Coulee and its smaller distributary coulees (Dry, Long Lake, Jasper, Lenore, and Unnamed). All that enormous task was accomplished by glacial floods during the scabland-making. Most of the debris was carried on through and beyond Quincy Basin.

Upper Grand Coulee's excavation began at the 800-foot cascade a little north of Coulee City. This cascade shortly steepened to become a waterfall and, as such, it retreated upstream until it finally cut through the divide into the preglacial Columbia Valley, thus destroying itself and leaving the great notch by which water, which is pumped up about 280 feet from Franklin Roosevelt Reservoir back of the Grand Coulee Dam, now enters the Equalizing Reservoir. Thence by a canal using eastern distributary coulees, this water for

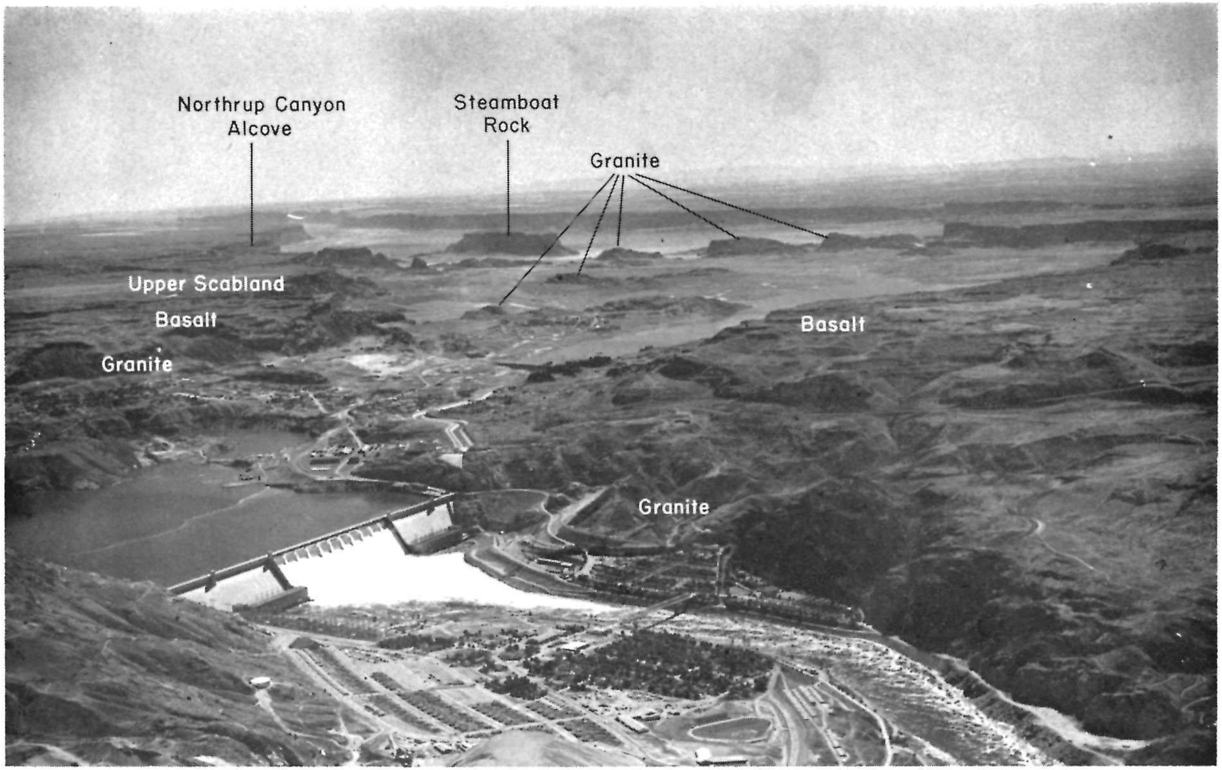


FIGURE 5. Grand Coulee Dam and head of Grand Coulee. (U. S. Bur. Reclamation photograph)

irrigating more than a million acres bypasses Dry Falls and the Lower Coulee to reach Quincy Basin.

The evidence for this interpretation of the origin of Upper Grand Coulee is manifold. A plunge basin at the foot of the initial fall, found by the U. S. Bureau of Reclamation, contains at least 300 feet of gravel below the level of the scabland floor immediately downstream in the Coulee City uncanyoned tract. The glacial river above the falls was relatively shallow and much wider than the gorge it made. Subsidiary lateral falls operated successively and were successively abandoned as the great cataract retreated. Northrup Canyon (fig. 9), on the east side, contains one subsidiary dry cataract as wide as Niagara and three times as high. Barker Canyon, on the west side, is but a little smaller. Steamboat Rock (figs. 5 and 10), 880 feet high and a square mile in area, stands isolated out in the Upper Coulee as a "Goat Island," where for a time the cataract was divided into two. Steamboat's broad summit is as high as the tops of the Coulee's adjacent margining cliffs and is typical scabland.

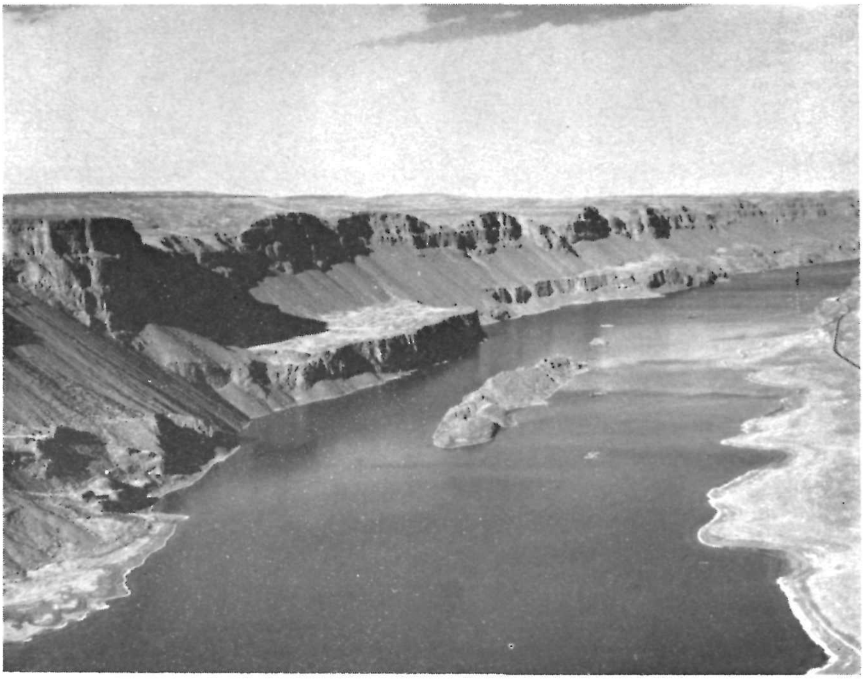


FIGURE 6. Lake Lenore, Lower Grand Coulee, looking northward. The lake basin has been excavated in the elongated belt of tilted basalt flows which constitute the Coulee monocline. The line of cliffs is on the high side of the flexure, and the ravines that preglacially descended the monoclinal slope have all been left hanging by the glacial river's erosion along the tilted flows. A very similar profile of gabled headlands exists along the east side of lower Moses Coulee. (U. S. Bur. Reclamation photograph)

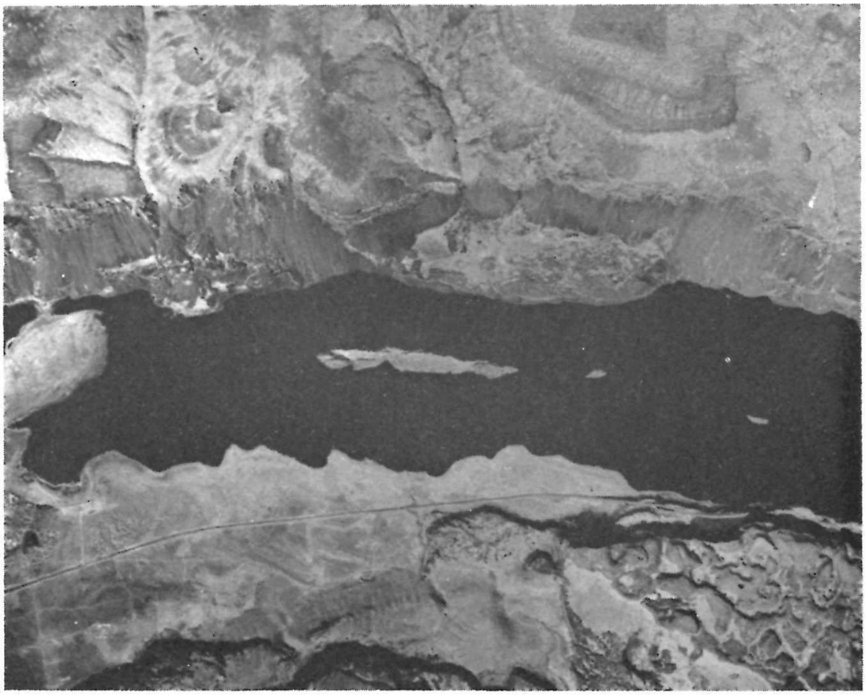


FIGURE 7. Lake Lenore, Lower Grand Coulee, and its hogback islands along the axis of the eroded Coulee monocline. Cliff summits on left stood above all flood water and carry small preglacial drainageways now hanging between their gable-like truncated divides. Cliffs on east side of lake are considerably lower, and their summits were floodswept and made into scabland. Dip of basalt in islands is 45°, whereas the flows shown in all bordering cliffs are nearly horizontal. (U. S. Dept. Agriculture photograph)

FIGURE 8. Scabland floor of Grand Coulee in Hartline Basin. The southern end of the western wall shows along the left edge of the picture. Above it are normal erosional gullies, hanging far above the scabland channel floor. The relief among these channel buttes and basins is more than 50 feet. This vertical aerial photograph was taken at an altitude of about 11,000 feet. (Grand Coulee Series, 33, U. S. Geological Survey)

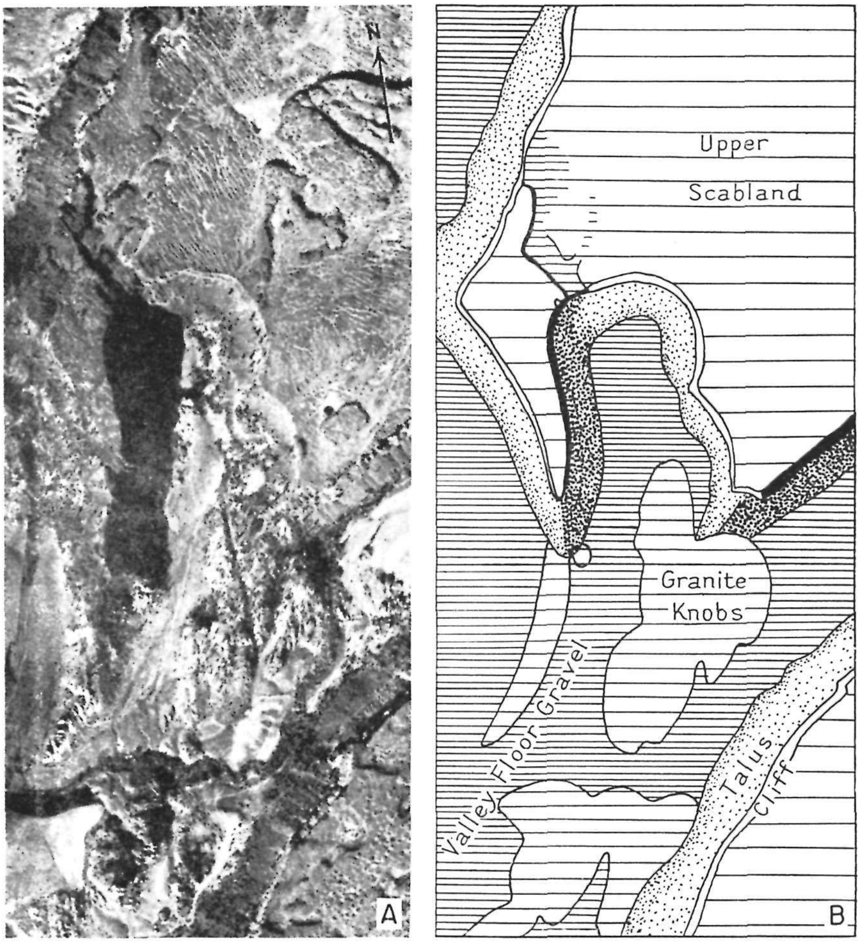


FIGURE 9. Middle alcove of Northrup Canyon group, Upper Grand Coulee.

A. The cliffs facing north and east are in shadow. Grand Coulee floor and cliff show in the northwest corner. Summit scabland occupies most of the northern half of the picture and a little of the southeastern corner. The main Northrup Canyon crosses from the southwest corner to the middle of the east side. The alcove is in the center. Note channels leading to it from the brink of the Coulee wall. Granite hills form the angle between the alcove and the main Northrup Canyon. (Photograph is mosaic of vertical aerial photographs, Grand Coulee Series, Nos. 112-116, U. S. Geological Survey)

B. Line drawing of area shown in *A*.

FIGURE 10. Northwest side of Steamboat Rock. The cliff possesses a hanging valley niche, identical with those margining the upper coulee where summit scabland occurs on each side. It was not made by postglacial drainage from the summit, nor can the valley be interpreted as a preglacial valley and the Rock as a preglacial divide. The channel enters *from the air* on the eastern side. (Photograph by Simmer)

This vanished Upper Coulee cataract, named for Steamboat Rock, found granite hills buried beneath the basal flows north of Steamboat (figs. 5 and 10). Lacking the close vertical joints of basalt, the granite was less readily attacked by the cataract's plunge, and its hills still stand, somewhat reshaped, on the broader floor of this part of the Coulee. A part of the unusual widening here is probably caused by these numerous unyielding pre-basalt hills.

Some excellent exposures of gravel-bar deposits have been made in relocating the highway along the Upper Coulee. Foreset bedding is very obvious and in places records great eddies in the lee of rock shoulders, the foresets dipping *upstream.*

Grand Coulee's system of distributary canyons begins at the broad uncanyoned place in midlength and spreads out over a width of 15 miles before entering Quincy Basin. Very respectable scabland characterizes this system of distributary canyons. One cataract in the group (Unnamed Coulee, fig. 12) is 150 feet high and had three retreating alcoves spanning a head width of more than a mile when the last glacial flood subsided. There is no channel leading to it. The discharging water arrived in a broad sheet across a minor preglacial divide.

FIGURE 11. Bar in Grand Coulee.
A. Looking east. Crest of bar is 150 feet above Coulee floor.
B. Looking south. Crest of bar is 50 feet above the fosse between it and the cliffs.

FIGURE 12. Unnamed Coulee. Oblique aerial photograph, showing unchanneled scabland leading to the northernmost cataract alcoves. Shadows fall to the right. Looking northeast. (Photograph by H. T. U. Smith)

QUINCY BASIN AND ITS OUTLETS

Grand Coulee water, entering Quincy Basin via Soap Lake, Dry Coulee, and Long Lake Coulee, was joined by the discharge of 10 to 15 glacial rivers from the east and northeast. (It is difficult to count rivers that repeatedly divide and reunite.) About half of these were supplied directly from Columbia Valley across the high northern margin of the plateau, the dominant preglacial divide. Half were born of overflow out of the largest scabland tract which the scarred plateau possesses, the enormous Cheney-Palouse tract.

All these rivers eroded their bedrock valley floors, and some garnered great quantities of gravelly and bouldery debris from undercutting their channel walls. The structural Quincy Basin was filled nearly to the brim with this gravel; approximately 500 square miles of it.

The "brim" had irregular heights, and the flooded basin overflowed in four different low places, gravel spilling over with the escaping water and cutting into the rim to a maximum depth of 300 feet. Three of the spillways created great waterfalls (Bretz, 1923a, p. 547; Bretz, 1928b, p. 464; Bretz, 1928c, p. 329; Bretz and others, 1956, p. 984) into the preglacial Columbia Valley on the west —scenic features almost unequalled outside of the scabland. One of these cataracts (Potholes, figs. 13, 14, and 15) was 1½ miles wide, 400 feet from brink to bottom of plunge basin, and its recessional gorge became 2 miles long before the flow ceased. U. S. Highway 10 climbs along a winding route up another of these extinct cataracts (Frenchman Springs, fig. 16) from Vantage bridge to the floor of Quincy Basin. The Great Northern railroad utilizes the notch made by the third (Crater, fig. 17) to climb from the Columbia River to the Basin floor. Plunge-pool basins at the foot of each of the twin Potholes cataracts were dry until leakage and waste irrigation water from the West Canal filled them. The larger one now contains a lake 125 feet deep and 1½ miles long (fig. 14).

Notches for channels to these three cataracts were cut 20 to 90 feet deep in Quincy Basin's western rim, and correspondingly decreased the Basin's capacity for retaining a gravel fill. The most challenging fact, however, is that each spillway began at very close to the same altitude. According to the flood theory, they were contemporaneous in origin and two of them ran neck and neck in the downcutting whereas one cataract was early abandoned.

Alternative interpretations have been offered in an endeavor to make these spillways sequential and thus avoid such unbelievable quantities of water at one time. One suggestion is that earth movements, after one cataract had been formed, depressed another place in the rim (and then another one) so that discharging water was drawn off from one cataract to make another. Then, of course, more

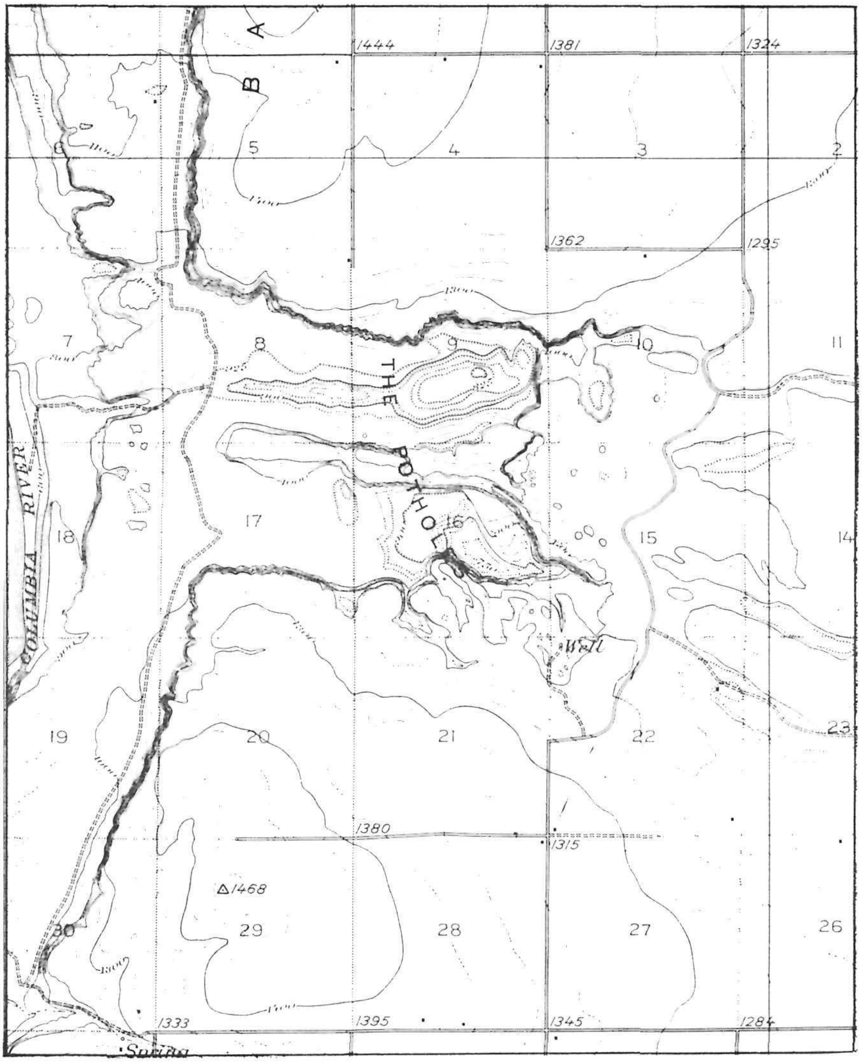


FIGURE 13. Topographic map of The Potholes cataract, one of three cataract spillways from the west side of Quincy Basin. (From U. S. Geological Survey Quincy quadrangle map)

FIGURE 14. Northern alcove of The Potholes cataract in 1954. Water is waste and leakage from West Canal about 2 miles distant and 75 feet higher than cataract brink.

Magnitudes involved: Lake in plunge basin is 125 feet deep. Top of bar on north side of alcove is 50 to 75 feet above lake surface and 175 to 200 feet above bottom of plunge pool. Bar fosse is largely filled with talus. Cliffs back of bar are, including talus, 300 feet high. Scarp of gravel terrace along the Columbia is 150 feet high, and its summit is approximately 250 feet above river. Nearer cliff, across which lake discharges, is 150 feet high above gravel terrace.

Sequences involved: Cataract originated approximately at the near end of the plunge basin. Its total retreat was nearly 2 miles. Tip of the ridge separating the two alcoves is about an eighth of a mile back from the prescabland line of cliffs. Basalt bench below this cliff (part of bench south from Crater cataract) is gashed by glacial-river chutes, recording cascades rather than cataracts and presumed to be of subfluvial origin. Gravel of the terrace overlaps a little on scabland of this bench.

Correlations proposed: Gravel terrace has right altitude above the Columbia to be correlative with West Bar and Bevery Bar. The inconspicuous but recognizable, very bouldery, flattish mound buried under this gravel is a dump from early cataract retreat, comparable to that at Vantage bridge. Scabland beneath terrace gravel is older than the terrace. Cascade chutes are later than the initial Potholes cataract. They and the bar north of the plunge basin may date from a late flood out of Quincy Basin. (U. S. Bur. Reclamation photograph P-222-177-35237)

FIGURE 15. Southern alcove of The Potholes cataract, looking east into Quincy Basin. Outline of lake in plunge basin is determined in part by gravel bars made in last stage of cataract's existence. Two lakes in channel floor leading to the falls are in rock basins of that channel, capacity of which has been increased by dams at near ends. (U. S. Bur. Reclamation photograph 40207)

FIGURE 16. Frenchman Springs cataract and Columbia River. Vantage bridge on U. S. Highway 10 is just out of the photograph (at bottom). Highway climbs diagonally northward up a postglacial scarp cut in scabland gravel, swings eastward, and then makes another diagonal climb up the south wall of the northern alcove of the double cataract to the floor of Quincy Basin. Plunge basins exist below the cataracts but have not yet (1956) received leakage and waste water from the West Canal as have the comparable basins in The Potholes cataract. (U. S. Dept. Agriculture photographs AAR-8F-187 and 9F-42)

FIGURE 17. Crater cataract and channel, looking east into Quincy Basin. The beginning of a double fall, like The Potholes and Frenchman Springs, has left a spur or peninsula which the Great Northern railroad utilizes for part of its climb from Columbia Valley to Quincy Basin. The plunge basin, Willow Creek draw, is filled with boulders below the cultivated surface shown in the photograph. (U. S. Bur. Reclamation photograph 40208)

earth movements had to occur to bring all channel upper limits to their present close correspondence. After that, no further movements would be permissible.

A second idea is that a westward-sloping gravel plain once existed in the Basin up to these upper limits. On it, escaping water behaved as it does on a delta; i. e., it developed shifting distributaries, three in number. This procedure could produce a sequence.

A third idea is here proposed for the ice-jam theorists to consider; namely, that the three channels became successively blocked by berg and river ice to make a sequence.

For none of these ideas is there any supporting field evidence. For one, there is positive evidence against it. Solution of the problem of the three western cataract channels becomes still more difficult, except for the flood theory, when the fourth spillway is considered. Although 35 to 50 miles distant, the elevation at its upper limits are the *same* as those of the cataract channels! And the width at its upper limits is 9 miles!

FIGURE 18. Drumheller Channels topography. Looking southward from O'Sullivan Dam. (U. S. Bur. Reclamation photograph DX222-117-142)

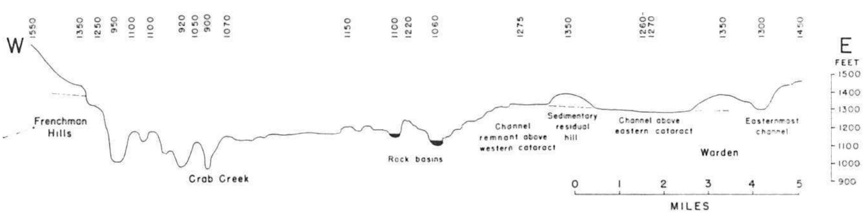


FIGURE 19. Profile across Drumheller Channels. Looking northward. Profile follows a slightly zigzag course across the head of Drumheller Channels, between Warden and the nose of Frenchman Hills anticline. The easternmost channel has been but slightly deepened or scarped, and the Warden cataract channel floors have been cut but little into basalt. The three deep notches, by one of which Crab Creek escapes from Quincy Basin, were made simultaneously. No preglacial drainage course across the anticline could have been deeper in basalt than the 1,100-foot flat between Crab Creek and the two rock basins. (From Geological Society of America Bull., v. 67, p. 976)

This enormous spillway, Drumheller Channels (figs. 18 and 19) in the extreme southeastern corner of the Basin (Bretz, 1923a, p. 595; Bretz, 1923b, p. 636; Bretz, 1928b, p. 466; Bretz and others, 1956, p. 975) was deepened more rapidly than the western channels and eventually captured all their share of the flood water. Its deepening continued through successive floods until it had been cut 300 feet into a previously intact divide. Drumheller is the most spectacular tract of butte-and-basin scabland on the plateau. It is an almost unbelievable labyrinth of anastomosing channels, rock basins, and small abandoned cataracts. Only one channel in the plexus, the route now followed by Crab Creek, has a continuous gradient across

Drumheller's 50-square-mile area; and this route almost surely has rock basins leveled up by the creek's sand and gravel in postglacial time. The average descent across the tract is between 30 and 50 feet per mile. Drumheller was a gigantic cascade rather than a unit waterfall, because the basalt beneath had been flexed, broken, and faulted in one of the plateau's strongly accented upfolds, the Frenchman Hills anticline. Although higher and earlier rock-bound channels were abandoned as the deepening progressed, no marked central channel and no dominant cataract developed.

Drumheller has an erosional record of at least three successive floods. Two are recorded in a cataract ledge, with a separating "Goat Island," 3 to 4 miles southwest of Warden. Alongside it is a gorge-like channel 150 feet deeper. Obviously the making of that gorge was later than the functioning of the cataract and brought its

FIGURE 20. Quincy Basin distributary channels. Showing the three channels leading from Soap Lake across the gravel fill and the ∧-shaped heads of minor channels. (From U. S. Bur. Reclamation topographic map R4-5720, sheet 1. Contour interval, 50 feet)

history to an end. The recessional gorge below the Warden cataract is cut off by, and hangs 100 feet up on the side of, the later gorge.

The topography of Quincy Basin's gravel fill is intimately related to the downcutting in Drumheller. Three distributary channels, Ephrata, Rocky Ford, and Willow Springs (fig. 20), reaching bedrock in but few places, cross from the mouth of Grand Coulee to the head of the great Drumheller cascade. Their excavation followed the initial filling of the Basin with waste from its dozen contributing rivers. Concentration of flow and erosion in the gravel succeeded the earlier deposition because of deepening in the Drumheller part of the Basin's rim. Many of the gravel hills and ridges are also identified as bars made during this channel development in gravel. Only one of the channels (Rocky Ford, containing Moses Lake) has any of the characters of a normal river course superimposed on its torrent-made form. These are imputed to a postglacial river from Grand Coulee and Crab Creek, now vanished because of increased aridity.

LOWER CRAB CREEK AND OTHELLO CHANNELS

The further course of the Drumheller discharge presents more difficulties for any conventional interpretation. The water divided, for a time at least, in an elongated downwarp of the basalt (the Othello basin or syncline), a few miles to the south. Part flowed westward along the north limb of Saddle Mountain, another anticlinal fold, and followed the Othello structural valley between this mountain and Frenchman Hills to reach the preglacial Columbia Valley at Beverly. Scabland marks the entire course and is worthy of more attention than can be given here (Bretz and others, 1956, p. 990 +).

Another part of the Drumheller discharge continued southward to cross the preglacial water parting made by the eastern tip of the Saddle Mountain anticline. Othello Channels (Bretz, 1923b, p. 636; Bretz, 1928c, p. 214+; Bretz and others, 1956, p. 995+) (fig. 21), resulting from the discharge across this divide, is a small copy of Drumheller. Its largest rock basin, now containing Scooteney Reservoir, is 135 feet deep, and the entire group of basins and channels is about 3 miles wide. As with Drumheller, this Othello discharge failed to clean off all the sedimentary rock that topped the preglacial divide. Each complex has an isolated residual hill of the weaker rock, entirely surrounded by the wilderness of bare basalt hills and interlocking channelways.

Basalt boulders so large that blasting was necessary before earth-moving equipment could handle them are strewn over the 8 miles of channel between the place of divergence and the entrance into Othello proper. They could have come only from Drumheller, and they must have traveled 10 miles or more on a gradient not exceeding 15 feet per mile. Volume alone could produce the required velocity in the water that carried these boulders.

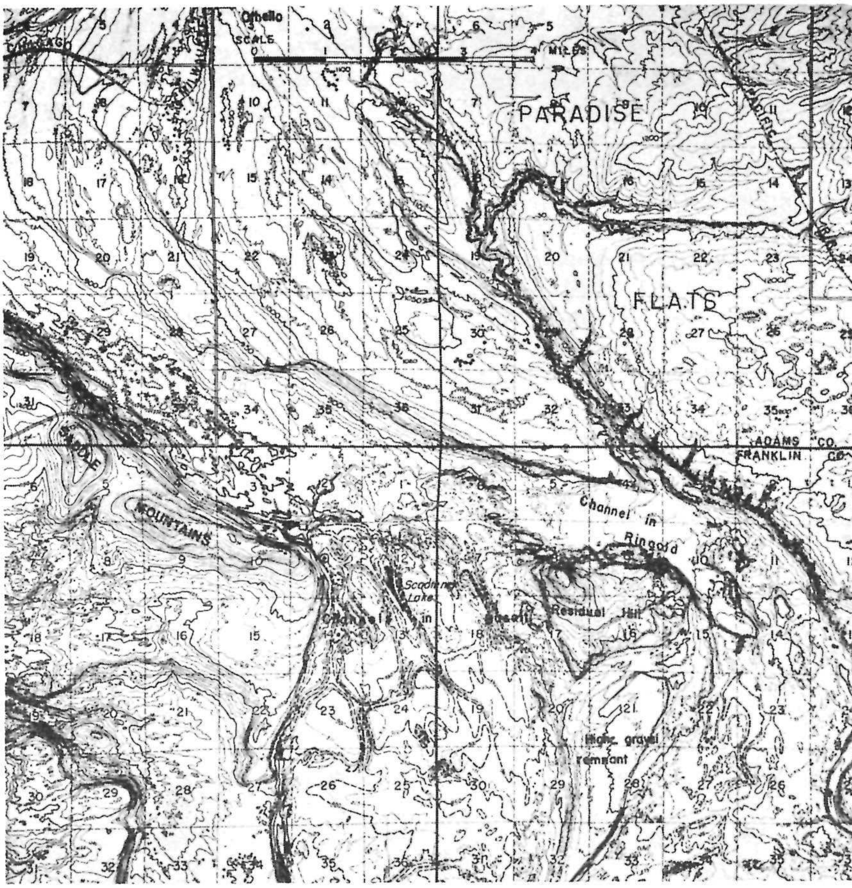


FIGURE 21. Map of Othello Channels. Interval for continuous contours, 10 feet; for dashed contours, 25 feet. (From U. S. Bur. Reclamation topographic map R4-5720, sheet 2)

Part of Othello's discharge reached the Columbia Valley via the Koontz Coulee group of channels across the Ringold plain, a flattish upland determined by a superbasalt sedimentary formation. The Koontz channels did not, in their deepening, reach basalt. Three successive glacial water discharges are recorded on the Ringold plain. Part of the Othello discharge joined, at Connell, a distributary strand of flood water from the great Cheney-Palouse glacial river. This is the only place where any Grand Coulee-Quincy Basin water united with the eastern discharge before reaching the Columbia River valley.

MOSES COULEE

In addition to the two main channel systems of the scabland complex, a third and truly magnificent scabland channel was made west of the Grand Coulee system. Moses Coulee (Bretz, 1923a, p. 600+; Bretz, 1923b, p. 634; Bretz, 1928a, p. 673+; Bretz, 1928b, p. 463; Bretz and others, 1956, p. 988) is a smaller copy of Grand Coulee, with a great ragged compound cataract (The Three Devils, fig. 22) in midlength, beetling cliffs 800 to more than 900 feet high, and a welter of butte-and-basin topography in a central tract. The lower stretch of Moses Coulee is deeply aggraded with gravel, so it has no rock-basin lakes. It has two features lacking in Grand Coulee: a record of a preglacial valley for the lower third of its 50-mile length, and a massive transverse glacial moraine in its northern third. Waterville Creek, the precursor of lower Moses Coulee, now spills some hundreds of feet down into the canyon from a hanging valley that is but little altered from its preglacial condition. Minor tributary valleys on the upland margining lower Moses Coulee also hang far above the great coulee's aggraded floor.

The Withrow moraine crossing of Moses Coulee (fig. 23) is unique in all scabland. It is a very strongly expressed ridge or series of

FIGURE 22. Compound cataract in mid-length of Moses Coulee. Three recessional gorges reach back upstream into the broad scabland. The one to the east (right) was started by a double cataract whose members united to leave a "Goat Island" comparable in origin to Steamboat Rock in Grand Coulee. Apparently all three gorges and their cataracts were contemporaneous. (U. S. Dept. Agriculture photograph AAQ-3F-50 and 51)

ridge hills of glacial drift marking the extreme southern limit ever reached by the northern ice sheet on this part of the plateau. Its course is approximately at right angles to that of the Coulee, and its descent into that great gash proves that Moses Coulee is an older feature. In the Coulee, the moraine is an irregularly mounded deposit that in places is more than half as high as the Coulee is deep and that completely conceals the eastern cliff. This latest glaciation of this part of the plateau has destroyed former scabland connections with the head region of Moses Coulee.

Inescapable conclusions from the study of Moses Coulee are (1) that early floods made and used it, and (2) that no flood water issued from the margin of the Okanogan lobe when the Withrow moraine was built. The second conclusion foreshadows an important question which we are approaching: the source of these tremendous quantities of water. The floods were not the direct product of climatic melting. A reservoir of adequate size so situated that it could be catastrophically emptied is indicated.

FIGURE 23. Edge of moraine on Waterville Plateau west of Grand Coulee. Cultivation is limited almost entirely to the smooth unglaciated surface on the left, and the hilly moraine still has its original cover of sage and other brush. The curvilinear dark pattern beyond the moraine is a drainageway still largely in brush. (U. S. Dept. Agriculture photograph AAQ-7F-129)

UPPER CRAB CREEK

Superlative showings of two flood-induced scabland features occur in this torrent-modified preglacial stream valley. One is a group of splendidly proportioned and significantly located gravel bars (pl. 4). The other is a spread of giant current ripple marks on these bars (fig. 24) (Bretz, 1928a, p. 668; Bretz and others, 1956, p. 980+). Neither find possible explanation by any alternative to the flood theory.

Five of the bars are shown by 2-foot contours on maps of the U. S. Bureau of Reclamation. All are hills of gravel with down-valley foreset bedding shown in every pit in them. Three are situated on the valley floor, almost or completely surrounded by bottom land and are streamlined in conformity with the bedrock valley

FIGURE 24. Bar No. 1 in Upper Crab Creek valley, looking southward. Vegetation pattern outlines the current-ripple marks. Fosse, with cultivated field, lies between bar top and foreground scabland. Another cultivated tract, in lower left, is in the blocked mouth of a prescabland gulch. (Photograph by H. T. U. Smith)

outlines. All reach 100 feet or more above adjacent bottom flats. One (fig. 24 and pl. 4, Bar No. 1), which is built against a scabland cliff, still is highest out away from the cliff. This one damned two small preglacial tributary valleys without completely backfilling their mouths. One of the tributaries has succeeded in cutting through the bar dam, the other and smaller one is still a closed basin back of the bar. Crab Creek, in adjusting its course around and among these bars, has not modified their outlines and has had to use the smaller of the two channelways margining the largest of the bars shown in plate 4. The Great Northern railroad uses the larger channelway.

The concept of bar growth to such magnitudes, and its corollary of a river deeper than the heights of the bars, affronted many uniformitarian-minded geologists, and an earnest effort was made to explain these gravel hills as terraced remnants of a former complete fill. This alternative may look plausible with regard to some scabland gravel deposits and, indeed, appears applicable to Quincy Basin's early, high-level gravel. It cannot apply to the Upper Crab Creek features for the reasons very briefly stated above.

Should these reasons fail to appeal, there remains the second group of features, the giant current ripple marks. Each of these bars possesses giant ripple marks on the summit and on the slope toward the larger of its bounding channels. All ripple ridges that were examined in the field are asymetrical, the steeper side facing downstream. Groups of larger ripple marks have wider spacings between the ridges. The U. S. Bureau of Reclamation map (pl. 4) does no more than suggest their existence, in part because the topographer did not know just what he was sketching. Aerial photographs, both vertical and oblique, (fig. 24) present the convincing evidence that these hills are great bars on whose last gravel accretions the generating great river left its large signature.

A short distance northeast of the bars shown in plate 4, Wilson Creek glacial river entered the larger Crab Creek torrent. In a vertical range of about 150 feet there are 2 terrace-like flats on a gravel deposit margining the tributary river's course. They are strikingly marked by giant current ripples up to 15 feet or more in height. Furthermore, the bottom of the Wilson Creek valley here is similarly marked. Erosion scarps separate the 3 ripple-marked surfaces.

This ensemble is taken to record 3 successive floods, the 2 erosional trenchings of earlier, higher gravel made possible by deepening of Drumheller Channels in the Quincy Basin's rim.

It should be said, in fairness, that these Upper Crab Creek and Wilson Creek bars have never been studied in the field by the founders of the rival theories for scabland genesis.

CHENEY-PALOUSE SCABLAND TRACT

A scabland flood route 75 miles long and in places more than 20 miles wide extends southwest from the vicinity of Cheney to Snake River canyon at the junction of the Palouse River, a little downstream from Riparia. Plate 1 shows that glacial water using this route spawned 10 prominent westward spillovers to the Grand Coulee-Quincy Basin system. All but 2 of these were preglacial divide crossings. More than 75 loessial islands are shown, and mapping on a larger scale would show more.

This is the type region where rivers with discharge "less than that of Snake River today" (Flint, 1938, p. 515) supposedly (1) built up a complete gravel fill from 90 feet thick to as much as 800 feet (in the Snake River canyon) in order to spill across preglacial divides westward out of the tract; and then, (2) reversing their behavior, eroded away almost all of the hypothetical great fill and bit deeply into subjacent basalt to make the challenging scabland topography. They are described as "leisurely" rivers (Flint, 1938, p. 514).

The Cheney-Palouse tract is also an excellent place to try out the ice-jam theory for originating the west-flowing distributary channels and the detailed channeling that isolated the loessial islands. Both the ice-jam and gravel-fill theories limit their water supply to ordinary melting of the lobe of glacial ice spanning the head of this tract. However, the bursting of local ice-jam dams could release short-lived local floods whose records might be misinterpreted as catastrophic events involving the entire scabland complex.

The Cheney-Palouse scabland tract has been superposed on a well-recorded preglacial drainage system from the head near Cheney to Hooper and Washtucna, 60-odd miles distant. Several semiparallel creek valleys converged to join Palouse River in the southern part of the tract. The Palouse itself entered the tract from unviolated eastern country about 40 miles down along the length of the tract.

FIGURE 25. Palouse Falls, 185 feet high.

From Hooper to the Snake, another 10 miles, the glacial water did an extraordinary thing. Although it sent a large distributary strand down Washtucna Coulee to join some of the Othello discharge at Connell, most of its water took a short cut *across* the Palouse-Snake divide south of Hooper and Washtucna.

There is no more significant area than this divide for testing rival theories. Streamless Washtucna Coulee was a major plateau river course of the preglacial Palouse, that did not enter the Snake until nearly 70 miles farther southwest. South of Hooper was a bedrock divide 10 miles across and, with its capping of loess, at least 350 feet higher than the preglacial Palouse valley which the glacial water left to overwhelm the divide. Here are 80 square miles of splendidly shown scabland on the divide summit. Here is the spectacular new Palouse River canyon cut 400 feet deep through the divide, leaving the old valley along Washtucna Coulee with nothing more than two alkaline lakes. (At midlength in Palouse Canyon at Palouse Falls State Park the river spills 185 feet in the clear.) Here is H U Ranch dry cataract (fig. 26), 280 feet from brink to bottom of plunge basin, and that basin 1½ miles long in the bottom of the cataract's recessional gorge. Here are 2 rock basins on the very summit of the preglacial divide, a mile apart and 80 and 120 feet deep. Here are streamlined, prow-pointed and steeply scarped loessial islands 150 feet high. These are all de nova products of the glacial overflow whose volume had been repeatedly reduced by distributaries all the way down along the Cheney-Palouse scabland tract.

Removal of the hypothesized gravel fill of this immense tract was theoretically done by "meandering" glacial streams. They left no meander scars in any bordering loessial bluffs from Cheney to the Snake. The long narrow subidiary channels separating many of the long streamlined loessial islands are no more a record of meandering streams than are the streamlined gravel bars with giant ripple marks (Staircase Rapids bar, fig. 27) (Bretz, 1928a, p. 649+; Flint, 1938, p. 878; Bretz and others, 1956, p. 1000). The scabland features just enumerated are utterly impossible erosional forms for such streams to have made.

By the ice-jam theory, the major divergences to distributaries and around islands required blockades many miles across and as much as 400 feet thick where the deep preglacial valleys still constituted trenches in the complex. The quantity of floating ice required for these dams gives one pause even if he thinks such dams would hold the head of water back of them. The failure, both by defenders and attackers of that theory, to find any topographic record of such dams or of adequate bypass channels while the dams were growing, makes the idea very speculative at best.

The "Shoulder Bar" (figs. 28-31) (Bretz, 1928a, p. 657+; Flint, 1938, p. 981+; Allison, 1941, p. 70; Bretz and others, 1956, p. 1020+) is a square mile of scabland gravel on the *south* side of the Snake nearly opposite the mouth of the Palouse and 500 feet above the valley bottom. It completely blocks the mouth of a small tributary from the south, so that in post-scabland time this stream has had to find a new route to the Snake. The long foresets of this gravel dip *northward, into* Snake Canyon. Its broad flattish summit and southern slopes are completely covered with giant current ripple marks (fig. 31). It therefore belongs to the group of constructional land forms left by the scabland rivers; i. e., gravel bars.

This huge mass of scabland gravel on the south side of Snake Canyon must have been carried across from the north side. The

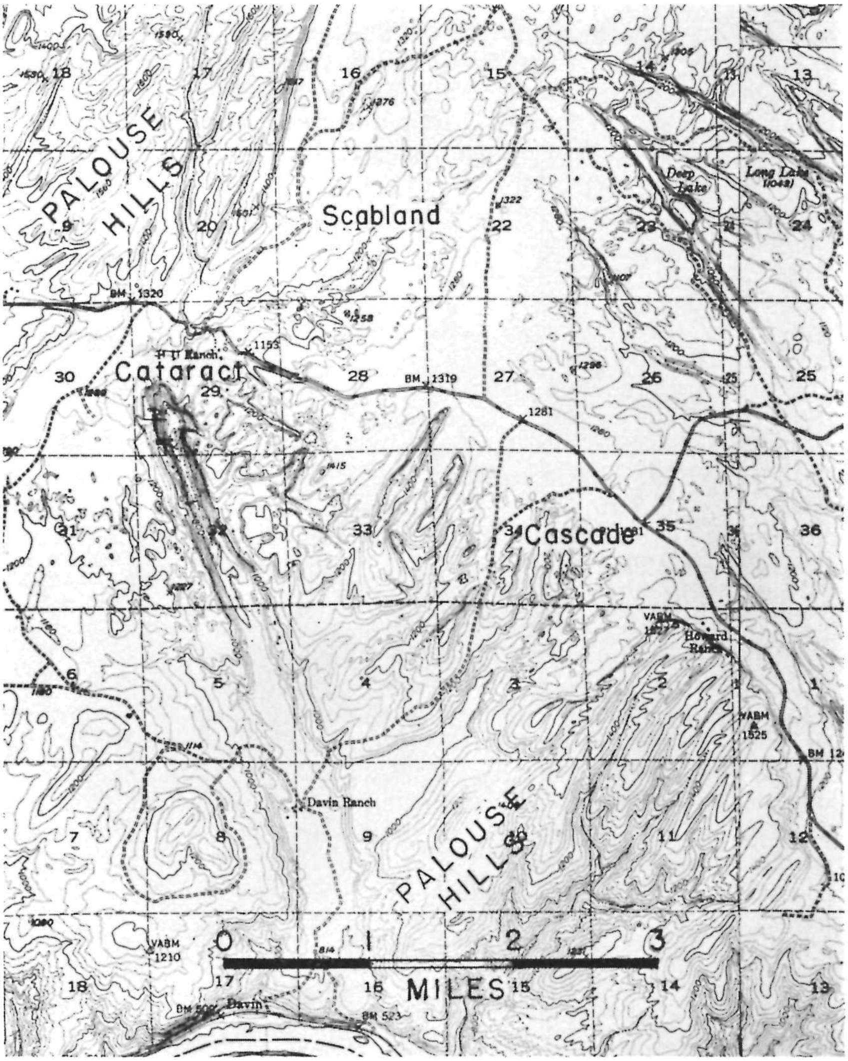


FIGURE 26. Vicinity of H U Ranch cataract. Western part of Palouse-Snake divide scabland. Loessial topography in northwestern and southeastern parts of area, loessial islands in central part. Largest island is 1 mile long and 500 to 1,000 feet wide, and its scarps are 150 feet high. Deep Lake gorge is tributary to Palouse Canyon a mile beyond eastern edge of map. (Part of Haas and Starbuck topographic maps, U. S. Geological Survey. Contour interval, 40 feet)

FIGURE 27. Giant current ripple marks. Staircase Rapids bar. Valley east of the ripple-marked surface was partially blocked by bar growth, and the tortuous stream meanders are on a silt flat. Drainage pattern east of creek is that of Palouse Hills topography. (Production and Marketing Administration photograph AAP-26-188)

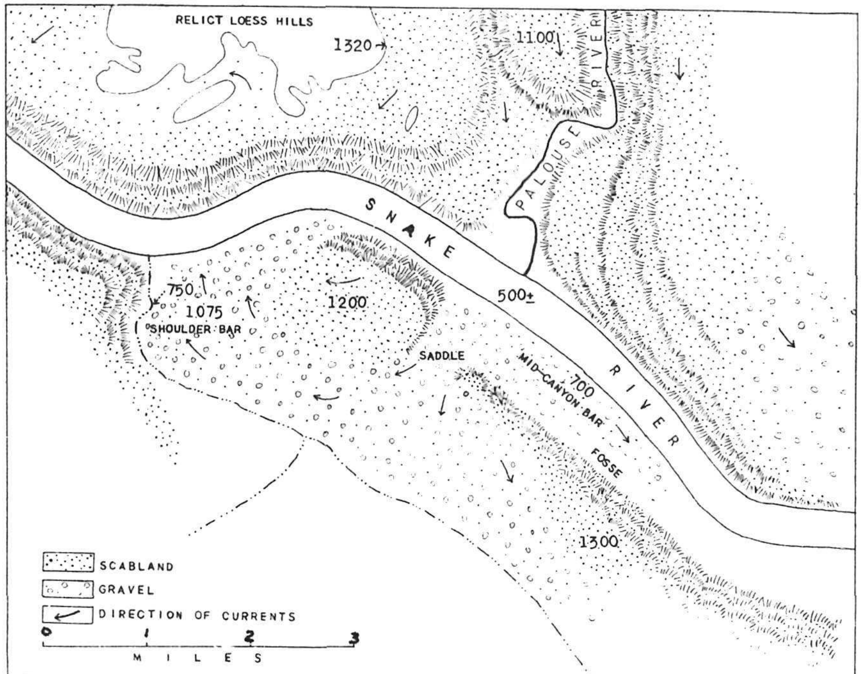


FIGURE 28. Sketch map of region at mouth of Palouse River. (From Geological Society of America Bull., v. 39, p. 656)

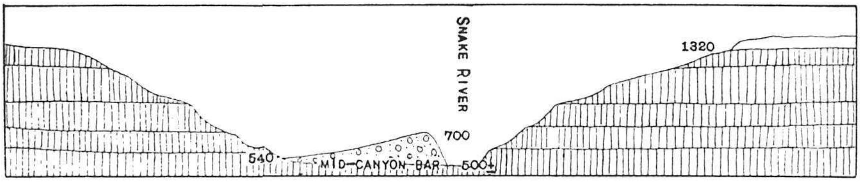


FIGURE 7.—*Cross-section of Snake River Canyon through the Mid-canyon Bar*

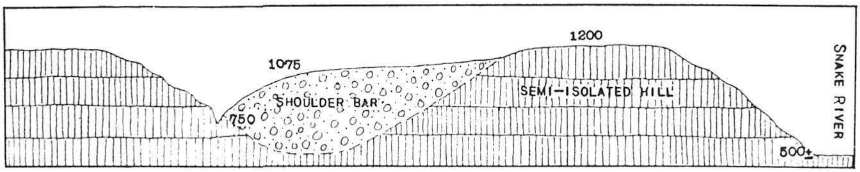


FIGURE 29. Cross-section semiparallel with Snake River Canyon through Shoulder Bar. View is near the mouth of Palouse River. (From Geological Society of America Bull., v. 39, p. 658)

ice-jam theory requires a very improbable dam 500 feet high and only 2 miles long in the canyon's width of about a mile, then neglects the evidence from the foreset beds that no ice masses were involved in their growth and that water was equally deep on both sides of the supposed dam. The fill-and-cut theory simply fills up Snake Canyon with gravel to the requisite depth. The Shoulder Bar thus becomes an erosional residual of a much larger deposit, all the rest of it removed by later erosion. The fill-and-cut theory neglects the point that, if it is correct, there would be other remnants similarly isolated on the south side of the canyon. There are none.

The flood theory views this extraordinary deposit as bottom gravel dragged across Snake Canyon, back into the mouth of the tributary valley and up for 500 feet *above* the canyon floor by the equally extraordinary volume of flood water it envisages.[3] The giant ripple marks can have no other explanation. The long foresets record a decrease in velocity as this rush of water was swung around westward by higher basalt hills and forced to flow back into the Snake from the south side. There is, of course, no thought by any theorist that the gravel could possibly have come off drainage slopes south of the river.[4]

[3]A 20% increase in volume can double the velocity of a stream.

[4]The above explanation may be too condensed and abbreviated to carry conviction to some readers. A detailed treatment of this and other scabland problems in this significant Palouse-Snake junction area was published in 1956. (Bretz and others.)

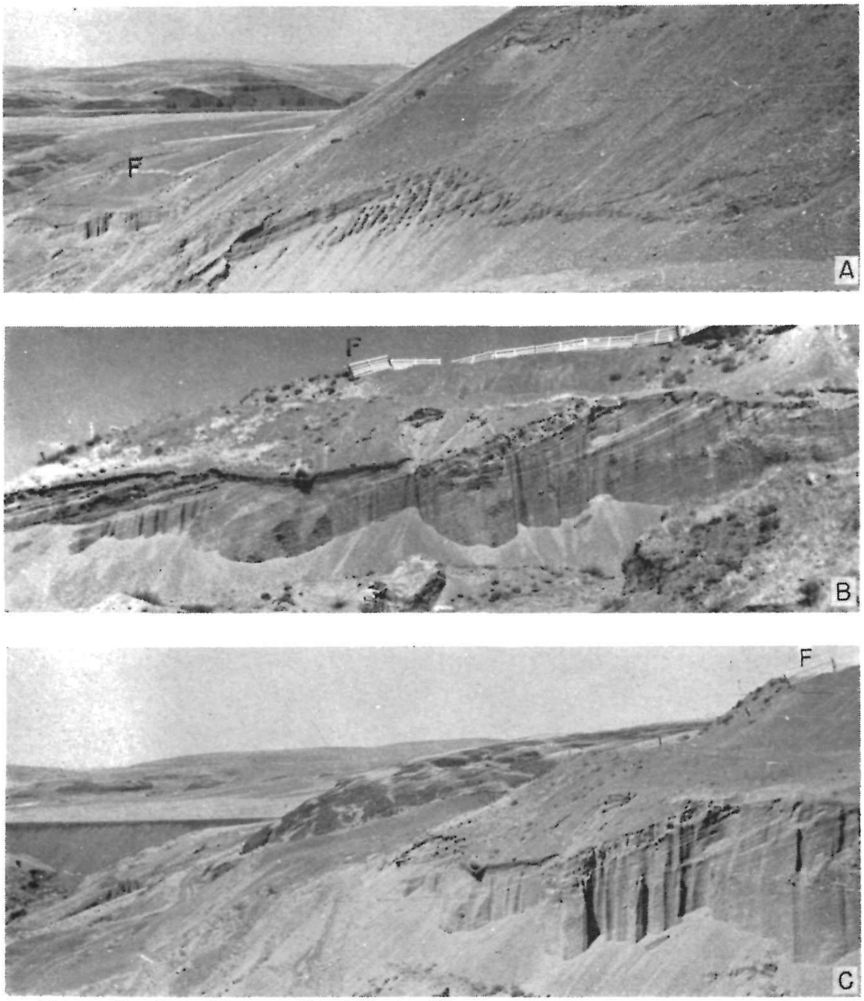


FIGURE 30. Gravel bar south of Snake River.

A. Pit section in northwest part of Shoulder Bar. False and true foreset bedding in lower left. One bevels the other. Note a fence (F) in each picture.

B. Pit section about halfway down bar front.

C. Pit section at toe of bar. (Photographs by H. T. U. Smith)

FIGURE 31. Shoulder Bar. Note parallelism of ripple marks with growing (northern) front of bar and their extension from summit down southern and western slopes. (Production and Marketing Administration photograph CCH-16-197)

PASCO BASIN

The largest downwarp on the plateau, more than 500 square miles in area, is Pasco Basin (fig. 32) at the southwest corner of the region. Here the Yakima, Snake, and Walla Walla Rivers join the Columbia. Although most of the basalt is buried under river gravel and Ringold sediments, bare basalt hills (Gable Butte and Gable Mountain) in the northern part of the Basin are island-like residuals of a basaltic upfold and stand a maximum of 700 feet above an adjacent channel in gravel.

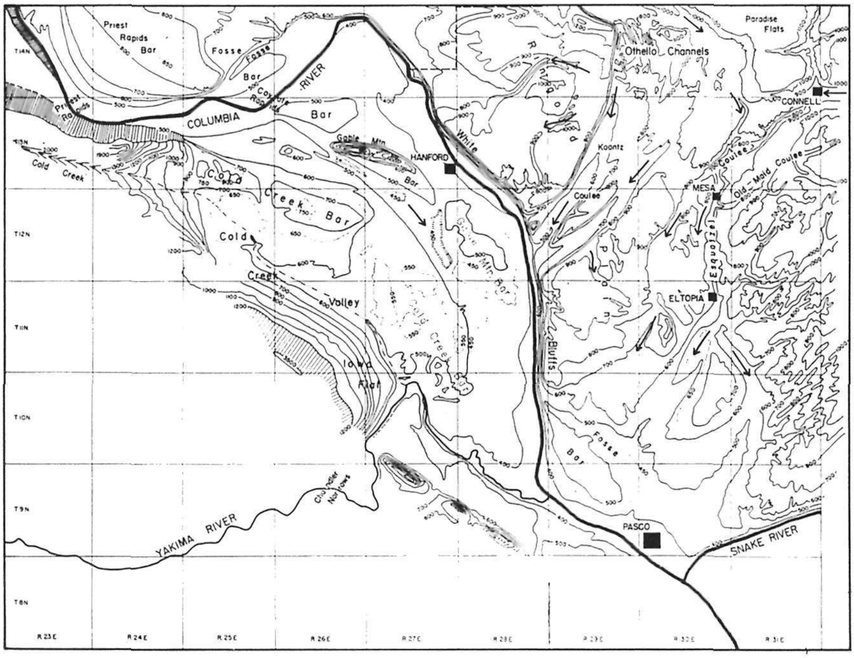


FIGURE 32. Central part of Pasco Basin. Contour interval, 100 feet; locally, 50 feet. (From Connell, Coyote Rapids, Eltopia, Hanford, Pasco, Prosser, Scooteney Lake, and Wallula topographic maps, U. S. Geological Survey)

Gravel bars are the Basin's specialty. The largest and longest bars of the entire scabland are here. One bar trails downstream from Gable Mountain for a dozen miles. Another (Cold Creek bar) is traceable for about 20 miles, although, like Gable Mountain bar, it is somewhat obscured by sand dunes. Priest Rapids bar is nearly equidimensional. It covers 20 square miles, and its summit is 400 feet above Columbia River level.

Like roads to Rome, all scabland rivers led to Pasco Basin. Had it ever been a closed depression during scabland history, it would have been filled with the huge quantities of basalt that were torn loose and broken up along the glacial stream channels. There is convincing evidence that this never occurred and therefore that the great bars are not erosional remnants as claimed in both the ice-jam and fill-and-cut theories. The best evidence for the constructional origin of these massive gravel deposits is afforded by Cold Creek bar (Bretz, 1928a, p. 678+; Allison, 1941, p. 73; Bretz and others, 1956, p. 1011+).

Figure 32 shows the relations of this broadly ridged gravel deposit to the Basin and three of its streams, the Columbia and Yakima Rivers and ephemeral Cold Creek. The higher and more obvious portion of the bar projects out into the downwarp for 13 miles, extending from the lee of the great cliffs overlooking Priest Rapids more than halfway across the broad Basin and separating the Columbia River valley portion of the Basin northeast of the bar from the 3- to 6-mile wide Cold Creek valley portion to the southwest. Yakima River, encountering the tip of the bar in the dune-infested southern part, makes an abrupt, acute-angled turn at The Horn to avoid it.

Cold Creek water rarely reaches the Yakima. It rarely flows along the length of its "valley" but is swallowed down into a growing alluvial fan of coarse debris contributed with every torrential rain from the high country immediately upstream. Gradient along the last 16 miles is 12½ feet per mile, on its fan it is 70 feet per mile, and farther upstream it increases to 150 feet per mile. Yet the rarely used, low-gradient valley is up to 6 miles wide, and the fan is from ½ mile to nearly 4 miles wide, and, farther up, the stream is in a canyon barely wide enough for a secondary road alongside it.

Clearly the lower "valley" is only an unfilled part of the Basin, partially shut off by the growth of the 100- to 200-foot broad gravel hill, the Cold Creek bar. Cold Creek never eroded this "valley" from a continuous fill up to the level of the bar top. The bar is not a terraced remnant.

Almost equally persuasive evidence is found in Priest Rapids bar. Its smooth riverward slopes are unterraced for the full 400 feet of its height, although there is no better place than along the inside of the Columbia's large symmetrical curve here for terraces to be left if the bar were really an erosional remnant. Bar structures should be found in this deposit as the Priest Rapids Dam is built.

The outlet to Pasco Basin is Wallula Gap, (figs. 33 and 34) (Bretz, 1925, p. 236+; Bretz, 1928c, p. 318+; Flint, 1938, p. 516; Allison, 1941, p. 72; Bretz and others, 1956, p. 1009), almost a squeezeway narrows where the Columbia cuts through the Horse Heaven Hills anticline. Scabland marks its cliffed walls for 800 vertical feet. All floodwater from the plateau had to escape through this constricted notch. Considering the great volumes recorded all over the scabland channel complex, the capacity of an empty Pasco Basin, the height of scab-

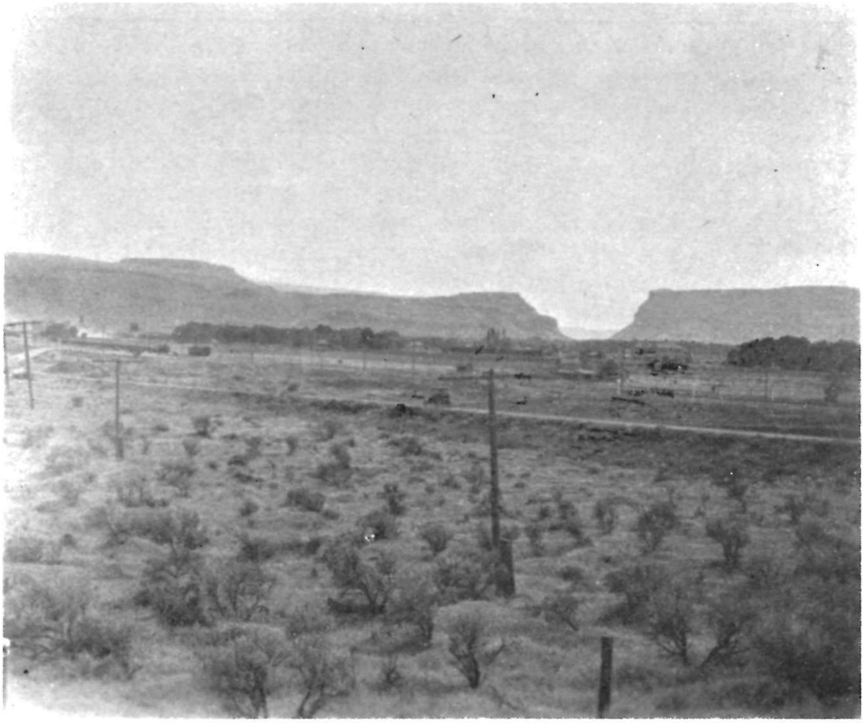


FIGURE 33. Wallula Gap and Horse Heaven uplift, looking southward. (Photograph by Bretz)

land on Gable Mountain and the narrowness of Wallula Gap, the flood theory suggests that the Gap was a bottleneck at any great flood's maximum crest. Using Chezy's formula with two wetted perimeters 15 miles apart and a surface gradient derived from their upper limits, it is computed (Bretz, 1925, p. 257) that 39 cubic miles of water escaped daily through this short gorge during a maximum flood. Is it any wonder that the flood theory aroused profound skepticism?

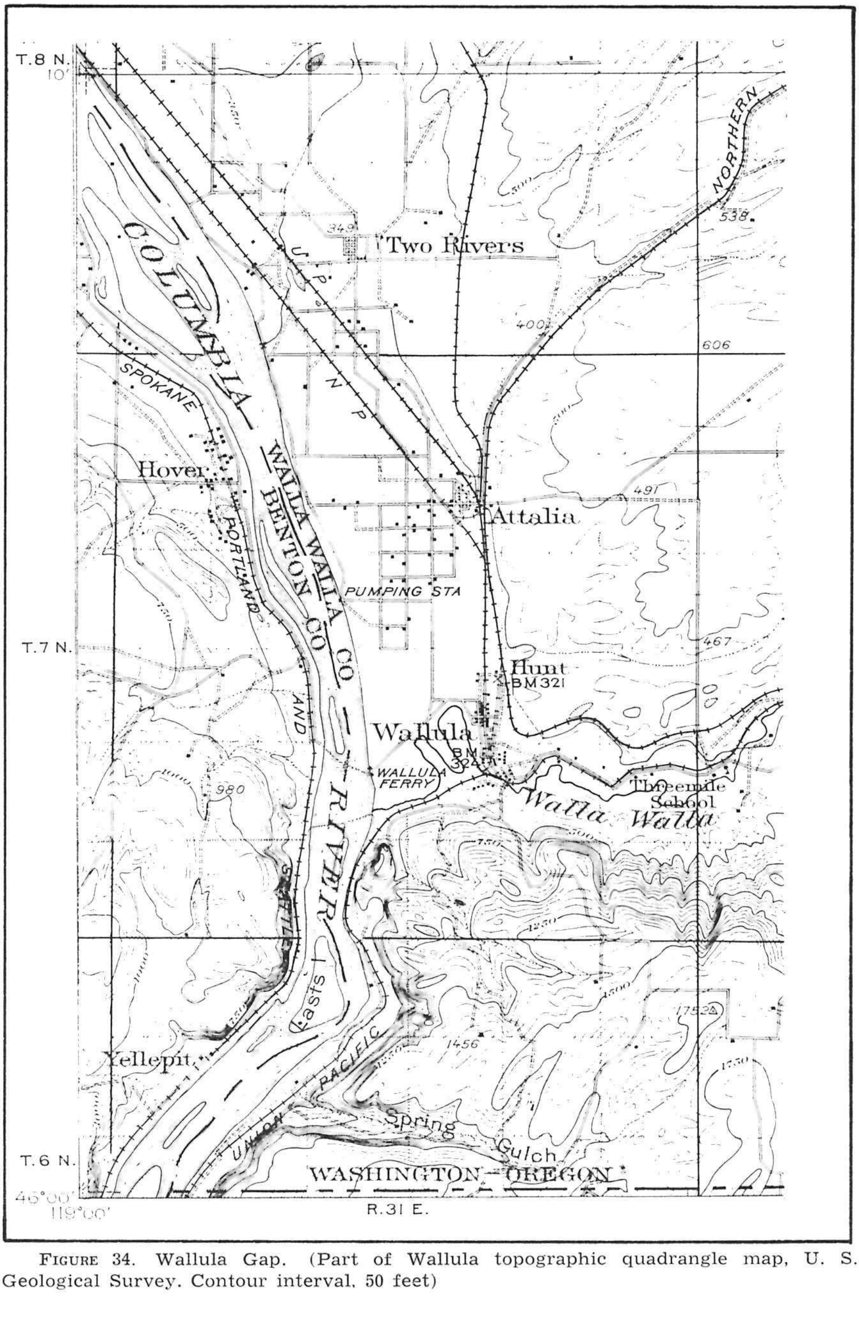


FIGURE 34. Wallula Gap. (Part of Wallula topographic quadrangle map, U. S. Geological Survey. Contour interval, 50 feet)

OTHER SIGNIFICANT FEATURES AND PLACES

(1) The records left by floods and flood-borne icebergs have been found down along the Columbia all the way to Portland and Vancouver (Bretz, 1925) and are a vital part of the epic story of the scablands. (2) Devils Canyon (Bretz, 1923b, p. 639; Bretz, 1928c, p. 206; Flint, 1938, p. 511+; Bretz and others, 1956, p. 1026) has great significance for any theory of scabland genesis. (3) Hanging mouths of the Koontz Coulee group of channels (Bretz and others, 1956, p. 995+) bear directly on this question. (4) Currents which flowed up the Snake River above Riparia, up the Yakima near Chandler, and up the Walla Walla near Reese (Bretz and others, 1956, p. 1014 footnote) are in the record. (5) Hundreds of massive icebergs that did not get caught in any jam were stranded back in Cold Creek valley (Bretz and others, 1956, p. 1012). (6) No terminal moraine now survives east of Grand Coulee. (7) A great bar at Beverly (Bretz and others, 1956, p. 993) blocks Lower Crab Creek and must be later than the last of Grand Coulee's discharges. (8) Scabland now considerably broken down by weathering occurs at high levels in channelways that functioned only during early floods (Bretz and others, 1956, p. 987+). (9) A comparison (contrast) between the non-flooded Yakima Valley's gravel terraces at Ellensburg and the flood gravel bars of scabland is illuminating (Pardee, 1910; Bretz and others, 1956, p. 979). Regretfully, these and many more items cannot be treated in this bulletin.

SOURCE OF THE WATER

Of the 4 theories for the origin of the Channeled Scabland, 3 obtain water for the channel-making from ordinary marginal and near-marginal glacial wastage. Given a forward movement in the ice sheet adequate to replace the waste, the meltwater rivers can continue flowing indefinitely. At no time, however, can they become the enormously swollen streams the flood theory asks for.

Realizing this and aware than many gravel deposits are huge river bars, the ice-jam theory endeavors to supply the necessary volume and depth by sporadic floods from abrupt failures of local dams. The flood theory asks for water enough delivered to the heads of all the main channels to initiate the entire system simultaneously. Suggestions that the glacial margin shifted sufficiently in proper places to make at least the Grand Coulee-Quincy Basin and the Cheney-Palouse routes sequential have been rejected as, of course, has been the idea that operation of smaller glacial streams through a long time could produce the great bars, rock basins, cataracts, and divergences.

What source for this unprecedented volume in a short time? The flood theory was without a plausible cause for some years, although it was constantly strengthened, in the opinion of its protagonists, by continued discoveries of more evidence for its verity. Then the addition of 2 and 2 to make 4 occurred, a simple addition that should have been made much earlier.

The source must have been a large body of water standing high enough and near enough, and with a dam of glacial ice which, failing, would catastrophically release many cubic miles of water with no way to escape except to the scabland channel heads.

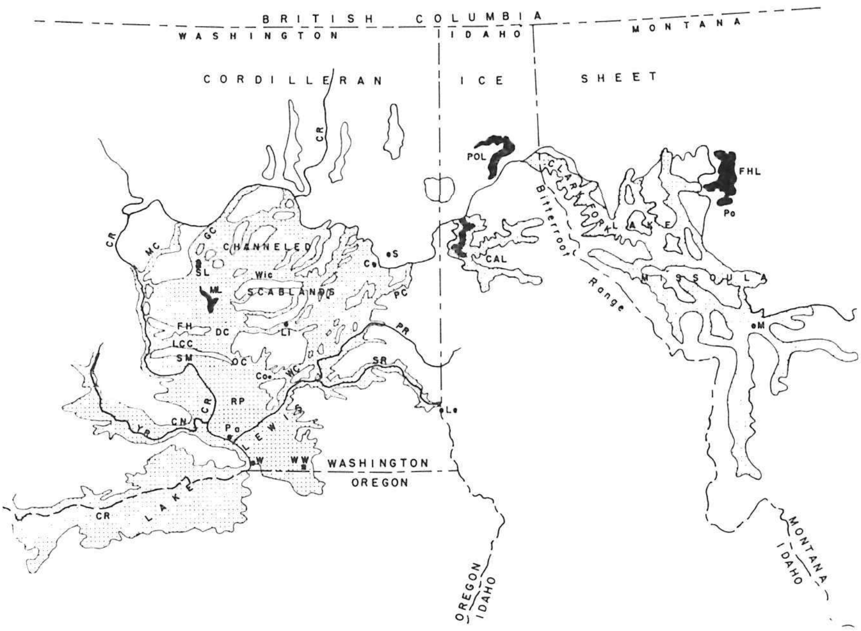


FIGURE 35. Map of Glacial Lake Missoula and Channeled Scablands. (From Geological Society of America Bull., v. 67, p. 1036)

C—Cheney
CAL—Coeur d'Alene Lake
CN—Chandler Narrows
Co—Connell
CR—Columbia River
DC—Drumheller Channels
FH—Frenchman Hills
FHL—Flathead Lake
GC—Grand Coulee
LCC—Lower Crab Creek

Le—Lewiston
M—Missoula
MC—Moses Coulee
ML—Moses Lake
OC—Othello Channels
Pa—Pasco
PC—Pine Creek
Po—Polson
POL—Pend Oreille Lake
PR—Palouse River

RP—Ringold Plain
S—Spokane
SL—Soap Lake
SM—Saddle Mountain
SR—Snake River
W—Wallula
WC—Washtucna Coulee
WiC—Wilson Creek
WW—Walla Walla
YR—Yakima River

That body of water was Glacial Lake Missoula in western Montana (fig. 35) (Pardee, 1910; Pardee, 1942; Bretz and others, 1956, p. 1034+). It was dammed by the front of the same ice sheet that rode up on the northern margin of the plateau. It had been described and mapped in a preliminary way before the Channeled Scabland problem was discovered. Altitude of its surface was

1,700 feet above the main channel heads. Its volume was estimated as 500 cubic miles. Its depth at the dam was 2,000 feet. A large deep valley led westward from the dam site to the basalt plateau's northern margin, 90 to 175 miles distant.

All the mountain valleys that held Lake Missoula led northwestward to the site of Lake Pend Oreille in the Idaho panhandle. Here the Bitterroot Range, separating Idaho and Montana in this latitude, had its northern terminus, an abrupt drop-off for thousands of feet into the large deep Pend Oreille-Spokane valley leading from the lake to the plateau. Here the rate of ice advance from the north became balanced by its rate of melting, so the glacial front pushed no farther south, and the ice made a dam that closed off these Montana valleys from their preglacial dischargeway. A lake promptly formed in front of this dam and rose as the dam thickened.

Lake Missoula's waves left a multitude of closely spaced but very faint shorelines on its enclosing mountain walls. They tell of repeated shiftings of the lake level. The highest is no more marked than any other, and no saddle in the crest of the Bitterroot Range was low enough to become an outlet. Opinion is that the only possible outlet was under or through or, most probably, over the glacial dam, whence it could flow southwestward toward Spokane.

If this Pend Oreille-Spokane valley beyond and below the site of the dam was not filled with glacial ice at the time the lake reached its highest level, and if the dam was holding back a head of possibly 2,000 feet of water, a tremendous hydrostatic pressure existed. This was a precarious situation if we assume that an almost empty valley lay immediately to the west.

Late in development of scabland theories came an illuminating discovery in one of the coalescent arms of Lake Missoula. A series of giant current ripple marks was identified on its floor (fig. 36) (Pardee, 1942). These could only indicate a tremendous current downvalley toward the site of the dam. Few geologists have doubted that this current was born of a very rapid lowering of the lake, the water escaping past a collapsed dam. These ripple marks are a record of probably the last flood to reach the plateau.

But there were several floods. The theory is elastic enough to take care of that. The margins of modern glaciers fluctuate in position with climatic change. Ancient glaciers and ice sheets have left records of marginal retreats and readvances. The history of the Pleistocene (or Glacial) epoch involves 3 very large retreats (perhaps some were complete extinctions), of the continental ice sheets, bringing on 3 long interglacial stages. The theory requires that the failure of the Lake Missoula dam occurred in part because a cycle of warmer years, centuries, or millenia had weakened it and had concomitantly filled the lake to its maximum volume. After the bursting of the dam and the cataclysmic release of hundreds of cubic miles of water, headed for the scablands, a readvance again

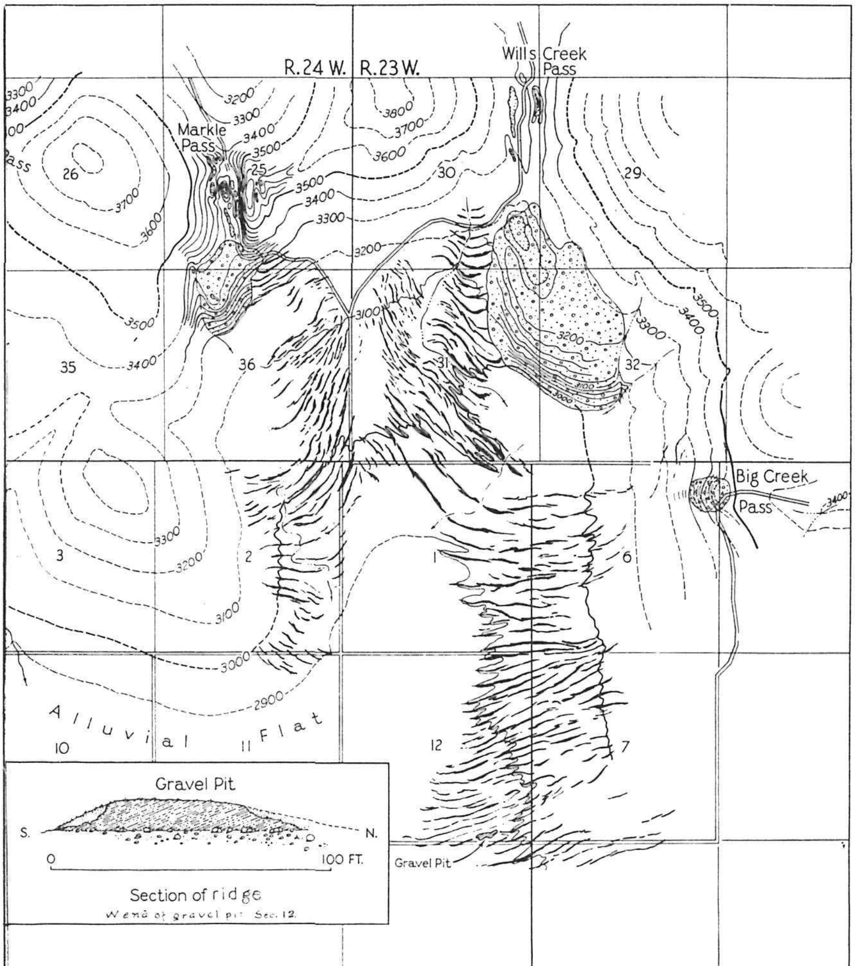


FIGURE 36. Giant ripple marks from Glacial Lake Missoula in northern part of Camas Prairie Basin. (From Geological Society of America Bull., v. 53, p. 1584)

closed the gap and initiated another Lake Missoula. As now believed, the plateau records at least 7 floods down the Pend Oreille-Spokane valley, 5 of them crossing the plateau but 2 of them finding no Okanogan lobe dam and therefore affecting only the Columbia Valley.

It was the successive return of flood water that deepened the major spillways and thus caused abandonment of many high-lying channels of earlier floodings. In this repeated experience, Grand Coulee held the winning hand. Its decent of the Coulee monocline gave it that highest of all scabland cataracts, Steamboat Falls. Retreat of this cataract needed only to reach the Columbia Valley north of the preglacial divide to provide by far the deepest channelway, nearly a thousand feet lower than the Cheney-Palouse and associated streamways.

A gravel dam in Upper Crab Creek valley at its junction with the eastern part of the Grand Coulee distributary coulee system has foresets dipping up the creek (Bretz and others, 1956, p. 982). This unmistakably records the fact that Grand Coulee outlived all its plateau contemporaries. The Beverly bar, similarly blocking the mouth of Lower Crab Creek with foreset gravel thrown back out of the Columbia Valley, tells of a post-Grand Coulee flood in the master valley alone, the last one of the series. No Okanogan lobe could have been blocking the Columbia when the last of the Lake Missoula dams broke.

CONCLUSION

Nowhere in the world is there known or suspected a story at all comparable to what we read from the scabland forms. Evidence of the magnitude of the floods has been, and may continue to be, questioned simply because the flood theory goes so far beyond any other geological explanations for past, unwitnessed events in earth history. Geologists, like most humans, tend to think in accepted patterns. The Colorado River's Grand Canyon took millenia to excavate. Why not use more time with less water and get comparable results in the Scabland?

Try that concept of moderately proportioned rivers working through a protracted time to make possible:

(1) Quincy Basin's four contemporaneous outlets;
(2) Drumheller's and Dry Falls' widths;
(3) Rock basins like Scooteney Lake;
(4) Bars like Cold Creek, Upper Crab Creek and Shoulder;
(5) Giant current ripple marks;
(6) Plucking and transportation of the boulders of Othello Channels;
(7) Back-filling as in Yakima, Walla Walla, and Snake Valleys;
(8) Divide-top scabland like that south of Hooper and Washtucna;
(9) Wallula Gap's 800 vertical feet of scabland;
(10) The anastomosing drainage pattern over an area of 15,000 square miles.

There is only one reasonable conclusion. Enormous volume alone could have been responsible. If the computed discharge rate through Wallula Gap is approximately correct, Lake Missoula would have been emptied in about 2 weeks.

Although known glacially dammed lakes have later been drained, under observation, by failure of their dams, no lake as large as Missoula has stood so high above and so near the country swept by the escaping water. No other glacial lake has been so deep against its dam. No such lake has had its dam so favorably situated for a catastrophic quarrying out by tremendous hydrostatic pressure. No second dam, like the Okanogan lobe, has diverted those waters from a major drainage lineament capable, like the Columbia around the Big Bend, of keeping floods of any conceivable magnitude within its valley walls. No area like the broad, loess-covered, basaltic Columbia Plateau has been so favorably situated for receiving and keeping the flood records.

We do not yet date the successive glacial floods, but the freshness of the Channeled Scablands' records indicates a geological recency. They await your inspection in almost their pristine forms.

CHRONOLOGICAL LIST OF REFERENCES

Pardee, J. T., 1910, The Glacial Lake Missoula, Montana: Jour. Geology, v. 18, p. 376-386.

Bretz, J H., 1923a, Glacial drainage on the Columbia Plateau: Geol. Soc. America Bull., v. 34, p. 573-608.

————, 1923b, The Channeled Scablands of the Columbia Plateau: Jour. Geology, v. 31, p. 617-649.

————, 1925, The Spokane Flood beyond the Channeled Scabland: Jour. Geology, v. 33, p. 96-115, 236-259.

————, 1928a, Bars of Channeled Scabland: Geol. Soc. America Bull., v. 39, p. 643-702.

————, 1928b, Channeled Scabland of eastern Washington: Geog. Rev., v. 18, p. 446-477.

————, 1928c, Alternative hypotheses for Channeled Scabland: Jour. Geology, v. 36, p. 193-223, 312-341.

————, 1932, The Grand Coulee: Am. Geog. Soc. Spec. Pub. 15, 89 p.

Allison, I. S., 1933, New version of the Spokane Flood: Geol. Soc. America Bull., v. 44, p. 675-722.

Flint, R. F., 1938, Origin of the Cheney-Palouse scabland tract: Geol. Soc. America Bull., v. 49, p. 461-524.

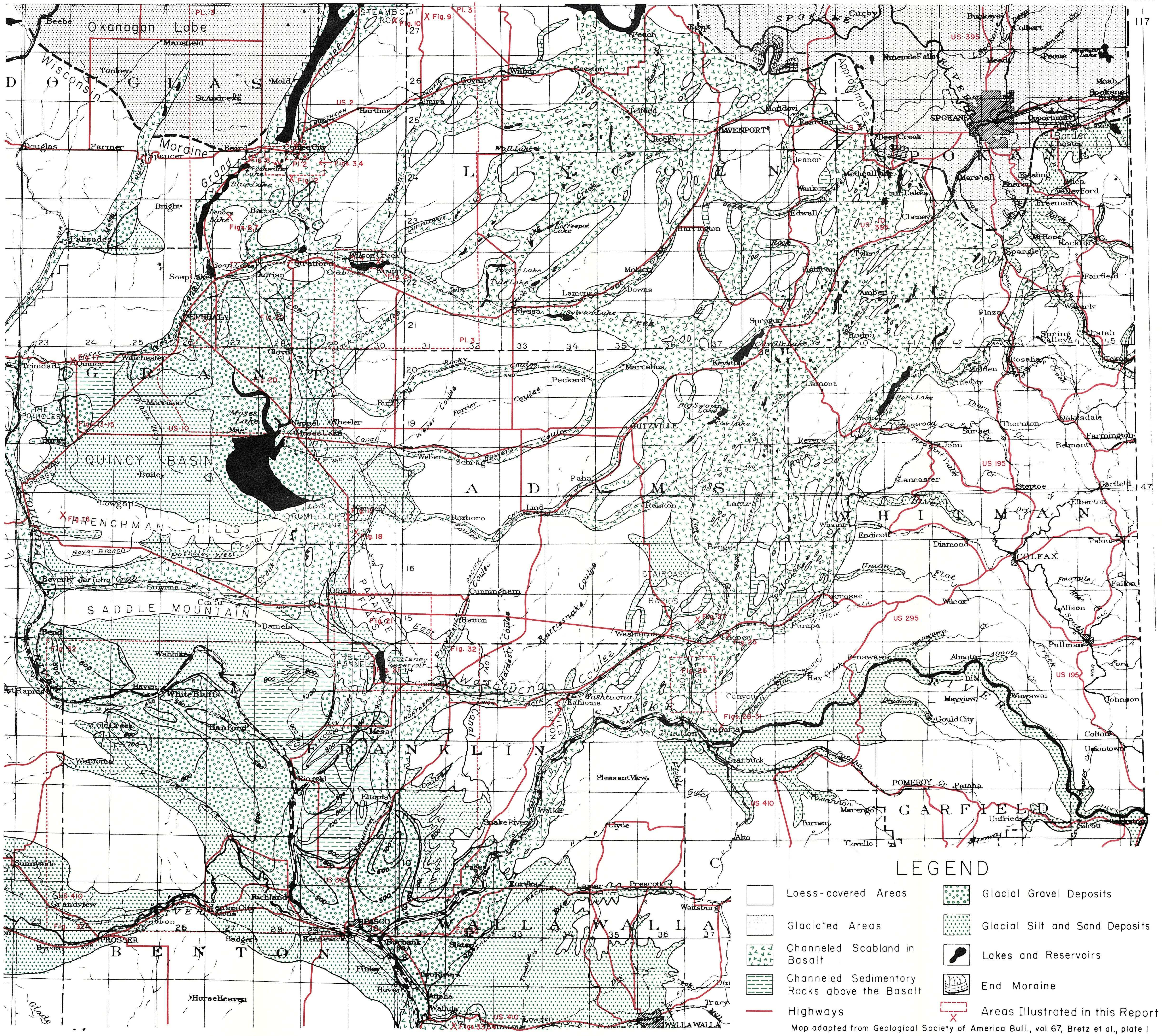
Allison, I. S., 1941, Flint's fill hypothesis for Channeled Scabland: Jour. Geology, v. 49, p. 54-73.

Pardee, J. T., 1942, Unusual currents in Glacial Lake Missoula, Montana: Geol. Soc. America Bull., v. 53, p. 1569-1600.

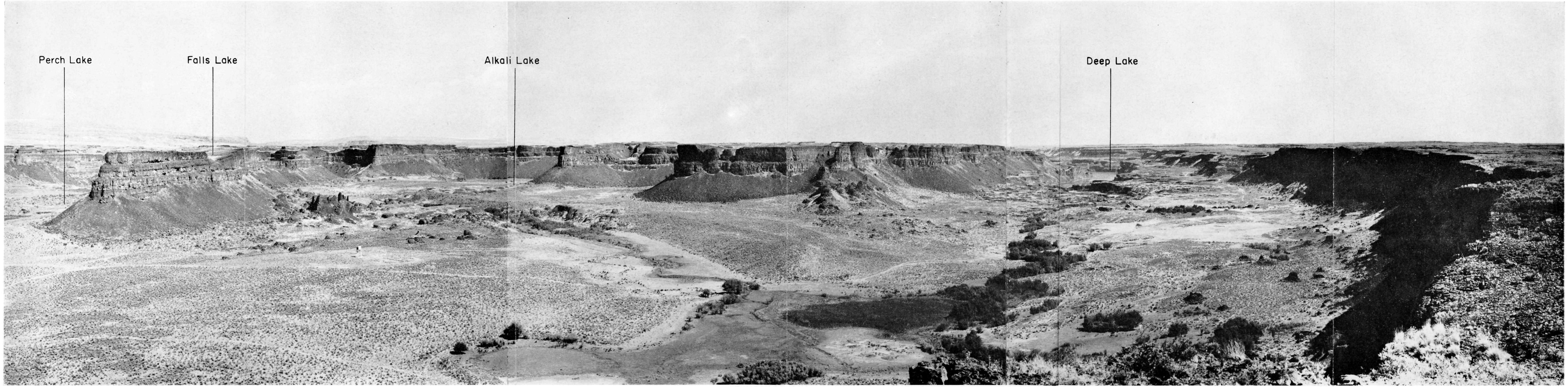
Hobbs, W. S., 1943, Discovery in eastern Washington of a new lobe of the Pleistocene continental glacier: Science, v. 98, p. 227-230.

————, 1947, The glacial history of the Scabland and Okanogan lobes, Cordilleran continental glacier: Ann Arbor, J. W. Edwards, 36 p.

Bretz, J H., Smith, H. T. U., and Neff, G. E., 1956, Channeled Scabland of Washington; new data and interpretations: Geol. Soc. America Bull., v. 67, p. 957-1047.

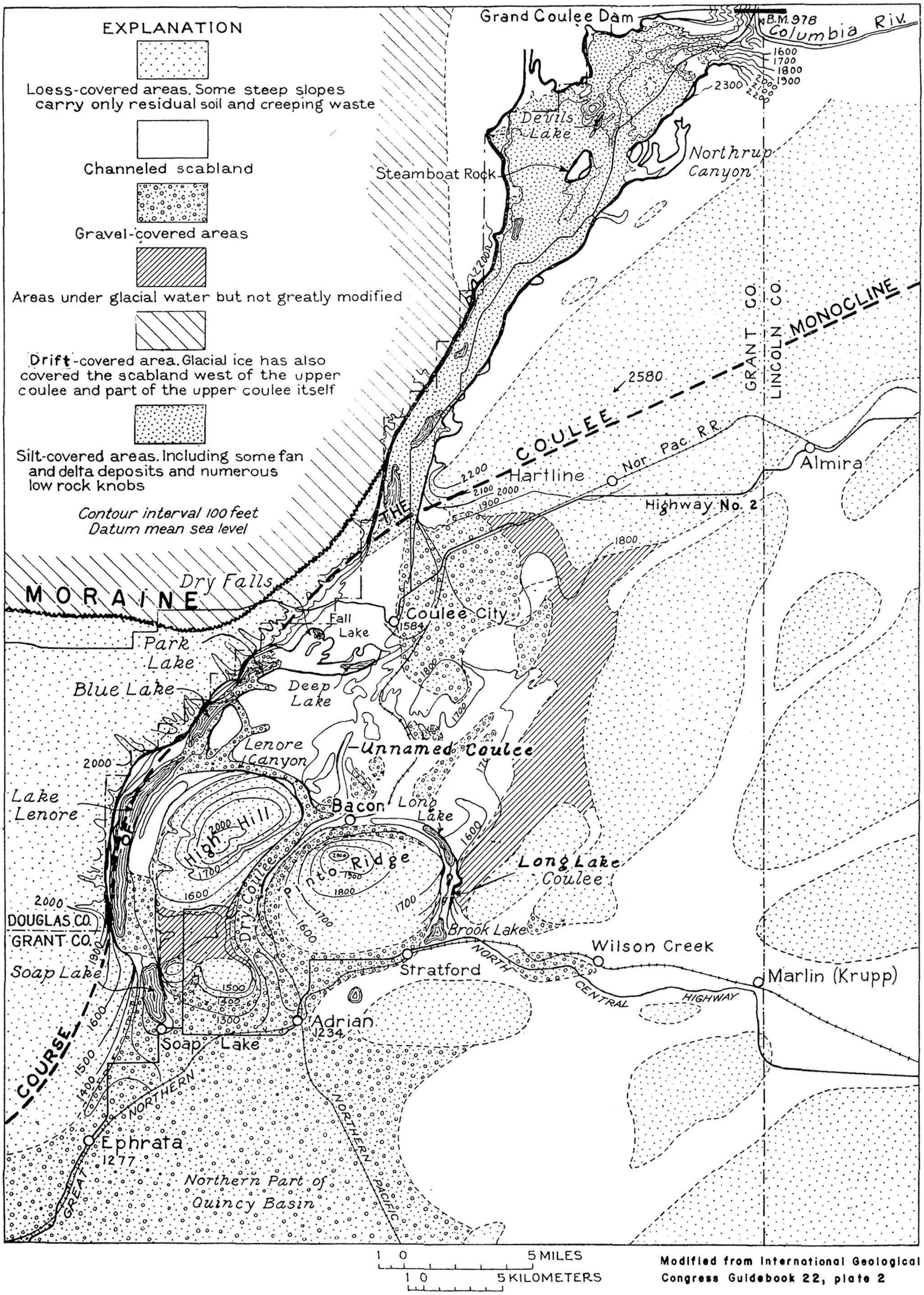


CHANNELED SCABLAND OF EASTERN WASHINGTON



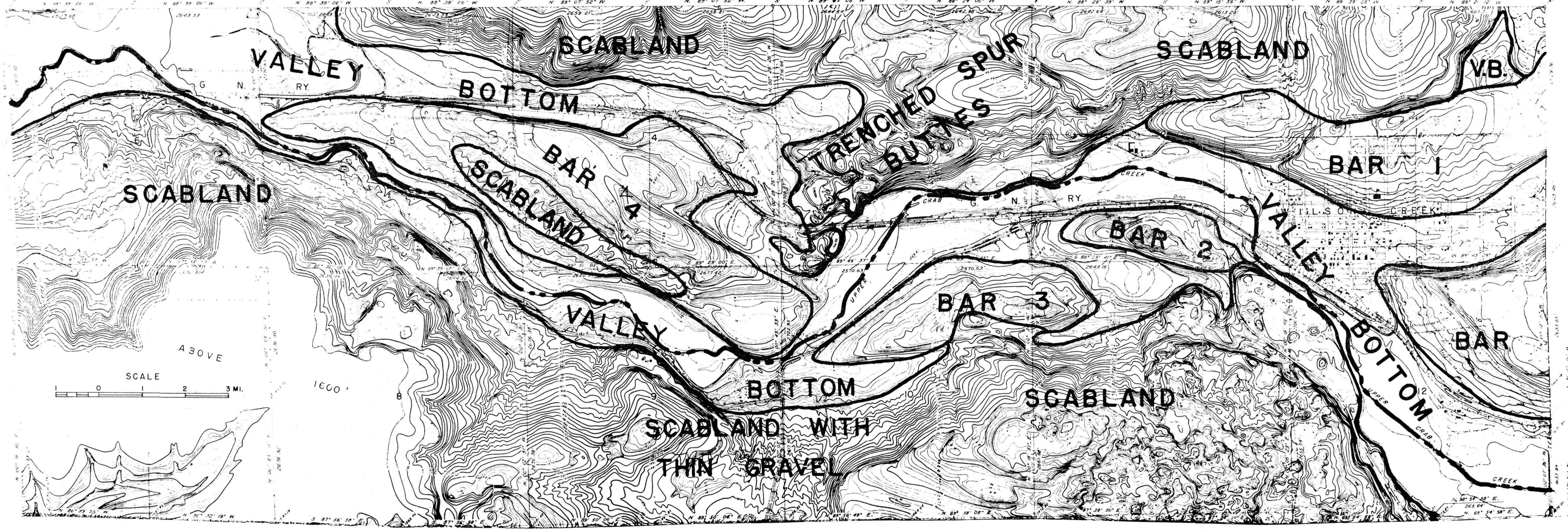
PANORAMA OF THE DRY FALLS SYSTEM

System is $3\frac{1}{2}$ miles in width. Deep Lake is 300 feet in depth and is one of the beauty spots of this system. Dry Falls Observation Point is just outside this picture on the left.



Modified from International Geological Congress Guidebook 22, plate 2

GEOLOGIC MAP OF GRAND COULEE, WASHINGTON



MAP OF BARS IN UPPER CRAB CREEK VALLEY, WASHINGTON

Below junction of Wilson Creek glacial river. Part of U. S. Bureau of Reclamation topographic map G 5883. Contour interval 2 feet.