THE CHANNELED SCABLAND OF EASTERN WASHINGTON

J Harlen Bretz
University of Chicago

[With separate map, Pl. VI, facing p. 476]

NO one with an eye for land forms 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.

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.

The Thesis

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 streamways 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 streamways. 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 preëxisting 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 bed rock, and 900 square miles are buried in the débris 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 overswept 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 débris 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.[1]

General Features of the Region

In but few regions of comparable area does a single formation have so great a thickness, possess so nearly intact the original surface, and appear so consistently in the relief features as does the Columbia basalt in eastern and central Washington. The plateau is high where the basalt is upwarped, it is low where the basalt is downflexed, it is rough where the basalt is dissected, and relatively smooth where dissection has not occurred. Its main drainage lines are largely consequent on the structure of the basalt, as are its more prominent divides.

The flows of this great formation were originally horizontal. Now, however, there are but few tracts whose underlying flows are not

[1] The author's pıevious writings on this subject include: Glacial Drainage on the Columbia Plateau, *Bull. Geol. Soc. of America*, Vol. 34, 1923, pp. 573–608; The Channeled Scablands of the Columbia Plateau, *Journ. of Geol.*, Vol. 31, 1923, pp. 617–649; The Age of the Spokane Glaciation, *Amer. Journ. of Sci.*, Ser. 5, Vol. 8, 1924, pp. 336–342; The Spokane Flood Beyond the Channeled Scabland, *Journ. of Geol.*, Vol. 33, 1925, pp. 97–115 and 236–259; Channeled Scabland and the Spokane Flood, *Journ. Washington Acad. of Sci.*, Vol. 17, 1927, pp. 200–211 (an abstract and a number of criticisms); What Caused the Spokane Flood?, *Bull. Geol. Soc. of America*, Vol. 38, 1927, p. 107 (abstract presenting the idea that subglacial vulcanism may have been responsible); The Spokane Flood: A Reply, *Journ. of Geol.*, Vol. 35, 1927, pp. 461–468 (answering E. T. McKnight: The Spokane Flood: A Discussion, *ibid.*, pp. 453–460); Alternative Hypotheses for Channeled Scabland, *Journ. of Geol.*, Vol. 36, 1928, pp. 193–223; 312–341.

gently tilted or markedly folded. In general, the dip is westward in the eastern part and southward in the western part. Several sharply localized folds occur in the western part, and one in the southeast; elsewhere the warping is so gentle that the terms used for folded structures are not applicable. The drainage pattern faithfully reflects the structure, though it is obvious that not all streams can be consequent.

FIG. 1—Mature topography of the loess. (Photograph by Donald Bell.)

Though the west-flowing Spokane and Columbia rivers skirt the northern edge of the plateau for more than a hundred miles, they receive in this distance the drainage of only about 1300 square miles, so close to their route is the high edge of the gently tilted region. Structure determines the convergence of two-thirds of the entire region's drainage to the Snake and Columbia along its southwestern margin.

Rocks both older and younger than the basalt are elements in the topography of the plateau. The older rocks constitute local elevations, "steptoes,"[2] in the extreme eastern and northern parts of the plateau above the plateau surface. The younger rocks, all sedimentary, are a wide-spread mantle which originally completely covered the basalt. They are composed of piedmont waste, stream gravel, volcanic ash, lacustrine silt, and loess. The loess is much more extensive than all the other deposits. It is deepest in the eastern portion, but in all nearly level parts of the plateau it is deep enough to have been an important item in recording the episode of scabland-making. The essential fact regarding these sediments is that they are all much less resistant than basalt to erosive attack, especially by agents which erode too rapidly for weathering to keep pace and to transform the resistant basalt into incoherent soil. An essential item concerning erosion of the basalt is that, despite its hardness, it is

[2] I. C. Russell: Geology and Water Resources of Nez Perce County, Idaho, *U. S. Geol. Survey Water Supply Paper 53*, 1901, p. 22.

prevailingly cut with the close-set joints of columnar structure. Incipient decay and physical parting extend down these joints far below the depths to which the cores of the columns are decayed.

The rainfall of the plateau today is inadequate to maintain a single permanent and continuous stream from its own run-off. Yet the region is strongly marked almost everywhere by running water.

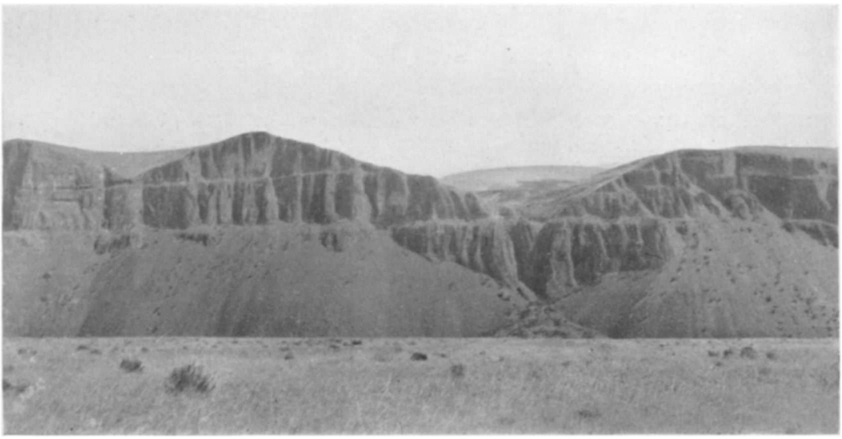


FIG. 2—Eastern wall of Moses Coulee at its mouth. Minor tributaries of the preglacial valley left hanging. Cliff summit 850 feet above coulee floor. (Photograph by L. C. Robinson.)

Aside from the scablands and the more strikingly folded tracts, this stream-determined topography expresses maturity of dissection (Fig. 1). In the eastern part of the region, where the loessial mantle is from 100 to 300 feet thick, the smaller valleys are entirely in loess. The larger ones, more deeply eroded, have their lower portions in basalt and are more youthful in appearance. Their canyon-like characters are due unquestionably in part to the greater resistance of the basalt, but evidence is not lacking to suggest that much of the mature aspect of the plateau may antedate uplift.

In addition to the mature slopes of the loess mantle and the canyon-like larger valleys on and bounding the plateau, the marks of running water include the scablands. These scabland tracts are exceedingly youthful features and are distributed along almost every drainage line from the northern high edge of the plateau sufficiently important to bear a local name. Yet in large part the scablands are not valleys. Some scabland tracts are completely lacking in valleys; some include several valleys, the separating divides themselves definitely scabland; some scabland tracts which for miles follow valley courses have margining scabland above the valley walls as wide as, or even wider than, the valley itself.

With but one exception, all valleys in the scabland have some tributaries from adjacent maturely dissected loess-covered country.

Except at and near their entrance to the greatly eroded scablands, these tributaries lack all trace of either the erosional or depositional modifications that produced the scablands. Their almost unvarying accordant junction with the valleys in the scabland indicate that those severely scoured valleys existed in present dimensions before the ravaging glacial waters entered.

All of the scabland drainage ways are united in a most remarkable anastomosing pattern. The convergences in this pattern clearly were inherited from the preëxisting drainage system. But the divergences, equally numerous, are the consequence of a flooding of the preglacial valleys so great that the minor divides, even some of the major divides, of the plateau were crossed, and adjacent routes were entered. Some of the routes thus entered were carrying glacial water from the ice edge. Others did not head far enough north and, without this flooding, never could have shared in the episode. Pronounced divergences took origin more than 50 miles in a direct line from the edge of the ice. It is nothing short of amazing to find that some of these divergences required rivers 200, 300, and even 400 feet deep: not ponded conditions of that depth, but vigorously flowing rivers.

Four Major Tracts of Scabland

In terms of separate origin on the northern high part of the plateau, the youthful scabland areas are resolvable into four different portions. The greatest of these is the easternmost. It heads in the general region of Cheney, 20 miles southwest of Spokane, and enters Snake River Canyon with the drainage of the Palouse River system. It may therefore be termed the Cheney-Palouse River tract. The next spillway group to the west, the Telford-Crab Creek tract, heads in the vicinity of Telford station, about 40 miles from Cheney. The third is Grand Coulee, a single great canyon across the divide, 40 miles west of Telford. The fourth and westernmost is Moses Coulee, also a separate canyoned route but heading on the southern slope of the plateau instead of crossing the divide.

The Cheney-Palouse River tract is 75 miles long and about 20 miles wide. Not one-fifth of it is occupied by loessial islands, though it was all covered with loess before the glacial discharge occurred. Several streams enter it from loess-covered country to the east, and one stream, Cow Creek, has its entire drainage area within the scabland tract. The wide spreading of the glacial waters is strikingly shown by this extensive scabland and its seventy-odd loessial islands. Yet more striking is the existence of eight well-marked subsidiary spillways which diverged from the west side of the Cheney-Palouse River tract at distances from the ice edge ranging from 3 to 60 miles. All these required operation of the major dischargeway for their own functioning; all were unquestionably contemporaneous at their initiation; no succession of operation could possibly have occurred by change in position of the glacial margin.

The Telford-Crab Creek scabland tract, next to the west, is as wide as the Cheney-Palouse River tract, but it loses its unity about 15 miles south of the plateau divide because of the number and capacity of divergent channels. However, convergence of all these (and of all but one of the Cheney-Palouse River divergences) occurs in a wide shallow structural sag (Quincy Basin) in the western part of the plateau. In this basin is the largest single area of gravel left by the glacial waters. It covers at least 24 townships. That all the channels of this Telford-Crab Creek spillway were in operation at one time cannot be gainsaid. There is continuous scabland northward from all channel heads of this tract across the plateau divide to the limits reached by the ice sheet. Some 40 to 50 square miles of this drain northward to the Columbia at present and did so in preglacial time; yet they clearly carried a wide, south-flowing sheet of glacial water to supply all the divergent channels.

Both Grand Coulee and Moses Coulee are canyons with maximum depths of 900 to 1000 feet (Fig. 2). The canyon character of these tracts is due to greater structural gradients of this part of the plateau. In both, there were preëxistent stream canyons (except in the northernmost 20 miles of Grand Coulee), but in both there was great deepening and widening by the glacial waters. Grand Coulee discharged a broad divergent sheet of water southeastward from its southern portion, but Moses Coulee had no divergences.

Causal Conditions Obtaining Over the Area

The anastomosing habit of scabland tracts over the entire area demands causal conditions that likewise existed over the whole region. These conditions were essentially:

1. A volume of glacial water too great for the existing valleys to carry.
2. A marked contrast in erodibility of the loess and basalt.
3. A high gradient for streams of the volume indicated by the abandoned channels.

Nowhere does the field evidence suggest any other cause, nowhere is it inconsistent with this explanation, and almost nowhere does it fail to show several mutually corroborative phenomena in support of this explanation.

More than 50 well-defined cases of divergence across loess-covered divides are known and at least three cases where such divides, parallel with (instead of transverse to) the direction of flow, were destroyed for 15 to 45 miles between the preglacial valley courses. In eight

FIG. 3

FIG. 4

FIG. 5

FIG. 3—Palouse Canyon between the two falls across the former Palouse-Snake divide. Cut about 400 feet deep. Looking north into the preglacial valley.

FIG. 4—Upper Palouse Falls. Close to the divergence from the preglacial valley.

FIG. 5—Palouse Canyon below the lower falls. Portion modified from a short preglacial tributary of Snake River. Rounded relict hill of loess on sky line.

places the divide crossings in the anastomosis were notably eroded in basalt. The most striking case is the diversion of Palouse River from its preglacial valley (Washtucna Coulee) to a very narrow canyon (Palouse Canyon) and the consequent shortening of the river by about 40 miles. Palouse Canyon (the lower ten miles of the river) is 400 to 800 feet deep in basalt (Figs. 3, 4, 5). Part of it is modified from a short preglacial tributary to the Snake, but the very narrow straight portion across the old divide clearly is a product of the Cheney-Palouse River discharge. A waterfall 196 feet high still survives in this canyon (Fig. 6).

Palouse Canyon is not the only record of the breaching of the divide. The whole summit for ten miles from east to west (transverse to the canyon) is marked scabland. It reaches 350 feet above the floor of the abandoned valley and 800 feet above the bottom of Snake River canyon to the south. Yet both valleys are preglacial. And in both the water flowed vigorously westward and southwestward toward the Columbia.

All scabland areas descend toward Snake River or Columbia River and enter these large valleys. Here the effect of the glacial waters might presumably be indistinguishable from the work of these two rivers before and since the scabland-making episode. Such a presumption would be based on the conception of these river valleys as valleys also for the glacial streams. The river-channel characters, the key to scabland interpretation, would give place to normal valley characters. It should then follow that the extraordinary anastomosis on the plateau was the consequence of shallow streams (for their widths cannot be disputed) or that there was sequence, not synchrony, in their operation. If the great widths and great depths actually existed contemporaneously in all channelways, both the Snake and the Columbia should similarly have become channels. They should have developed some cases of divergence in consequence of the flooded condition, and their tributary valleys which did not head in the scabland should have been notably ponded by the great volume. This is a crucial test of the writer's thesis.

FIG. 6—Lower Palouse Falls, 196 feet high. (Photograph by L. C. Robinson.)

The valley system of southeastern Washington is older than any scabland. This is amply attested by the graded slopes, the development of tributary systems, the relations of loess to scabland, and the presence of old stained gravels in valley bottoms. In many places on the plateau it is clear that the scabland features are superposed on this older drainage pattern in loess and basalt. Palouse Valley, for example, was as deeply entrenched in basalt east of the scabland as it is today; and, if a dam 100 feet high were built at the head of the canyon through the divide, the abandoned route (Washtucna Coulee) would be resumed. This abandoned preglacial course, now without drainage, is more than 40 miles long and 200 to 350 feet deep in basalt (Fig. 7). Minor tributaries from a large loess-covered tract to the north join it at accordant grade, yet belong to the pre-scabland mature drainage system.

There were eight different entrances of the scabland rivers to the Snake and Columbia valleys, one of them multiple. Three of them, entering the Columbia, are over precipices 200 to 400 feet high (Fig. 8), and two of them, entering the Snake, are very narrow canyons across the preglacial Snake-Palouse divide (Fig. 9). Judged by the criteria of an accordant junction and a system of pre-scabland tribu-

FIG. 7—Washtucna Coulee at Washtucna Lake. Scabland walls well shown. Compare this abandoned valley of the Palouse River with the canyon it now occupies. (Photograph by Robert Landon.)

taries, the only scabland routes entering the master valleys that were inherited from the older drainage system are Moses Coulee, Crab Creek, and Palouse River (via Washtucna Coulee).

Deposits in the channeled scabland system constitute another remarkable feature. There are two kinds; the channel deposits, prevailingly of pebbles, cobbles, and boulders, and the pond deposits back in valleys entering the scabland from unglaciated areas. This classification is not a rigid one, however, for in some places a ponded condition succeeded current flow.

The gravel deposits in the channels depart as much from conventional valley fills as the scablands do from valley forms. They are so situated with reference to the canyoned channels and the rock basins that they cannot be remnants of valley trains or similar deposits unless two episodes of enormous discharge be postulated. Their shapes are such that by no possibility can they be erosional in origin. They are local deposits, built beneath the surfaces of the great rivers. As channel deposits, they are contemporaneous with the erosional forms in basalt and in loess. Many of them are hills a hundred feet in height, some of them are 200, 300, and even 400 feet above their lower base. There is no term in geological literature for them except that of "bars" (Fig. 10). Their locations are all in conformity with the genesis implied by that term, as also are their structures, their shapes, and their composition. But if they are bars, the glacial streams in which they grew far exceeded any other glacial streams in depth. Were this conception of great depth based alone on these so-called bars, it could command but little respect. Rivers of this character must have left other evidence. Some of that evidence has already been briefly reviewed. The great widths shown on the map are undeniable, the physiographically recent great scouring of the basalt over hundreds of square miles is almost startling, the scarped islands of loess still carrying the mature topography of pre-scabland time are indisputable. And such divide crossings as Palouse Canyon, formed while the preglacial valley a mile wide and 350 feet deep was carrying a great stream away from the threatened divide, offer strong corroborative evidence. But there is still more evidence of the flooded condition of the valleys of eastern Washington. It lies in the other type of deposit noted, the silt and sand of the ponded tracts.

A generalization to which no exceptions have yet been found is that every non-scabland valley entering the scabland contains débris carried back into it from the scabland. This débris may consist of scattered erratic boulders, cobbles, and pebbles; or of stratified silt and sand; or it may be a gravel deposit partially blocking the entrance. All three types are found in many of these valleys. The erratic character of some of the débris is not limited to the larger fragments, it is to be recognized even in the sand deposits. And some remarkable lenses of berg-laid till in the stratified sand and silt have been found.

These features are common in valleys that receive and always have received their run-off entirely from loess and basalt. In each valley the records above listed occur only up to an altitude corresponding to the upper limit of the glacial waters where that valley opens into the scabland complex (Fig. 11). The two most notable cases of ponding yet found are in Snake[3] and Walla Walla valleys. In Snake Valley, the upper limit of erratic cobbles and boulders and of stratified silt and sand is 1350 feet A. T., and the altitude reached by the glacial flood across the Palouse-Snake divide is 1325 to 1350. At the entrance of the adjacent Walla Walla Valley, 40 miles farther down the Snake, the upper limit of the glacial waters was about 1100 feet A. T., and the deposits under discussion are known up to 1080. Maximum depths of the two ponds thus recorded are about 800 feet each.

These records of ponded waters are not topographically expressed except at the very entrance of the tributary valleys into the scabland. Gravel deposits here commonly have the form of embankments which, when built, partially or even completely blocked the tributary valleys. Elsewhere the materials generally constitute a mantle on all slopes below the upper limit, thicker on lower slopes but easily overlooked if one passes through by train or automobile. In contrast, the great mounded channel deposits are almost as spectacular as the associated basalt scabland.

[3] East of the entrance of Palouse River.

FIG. 8

FIG. 9

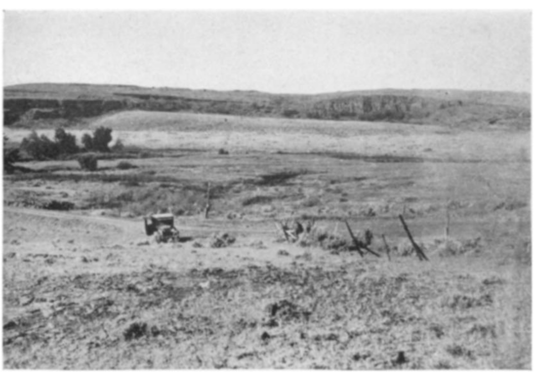


FIG. 10

FIG. 8—Frenchman Springs Cataract. A western spillway from Quincy Basin. The total height of the irregular cliff is 400 feet.

FIG. 9—Devils Canyon. A narrow gash across a preglacial divide. No stream other than local run-off has used it since it was formed.

FIG. 10—Bar in Crab Creek Valley, south of Downs. Except at the left, a partially enclosed depression lies between the bar and the cliff.

The junction of the two master valleys, the Snake and the Columbia, in the southwestern part of the river-scarred plateau is 120 miles by direct scabland routes from the head of the Cheney-Palouse River spillway and 140 miles from the Telford-Crab Creek spillway head. All glacial waters of the anastomosis converged here and escaped thence to the Pacific along the lower Columbia. The junction occurs in a wide structural valley where there is very little scabland but a large area carrying huge gravel mounds. Nineteen townships are covered deeply with this débris. The criteria by which the mounded gravel deposits in the scabland are adjudged glacial river bars lead to the same conclusion here. The relations between these bar deposits and their basin differ somewhat from the relations in the Quincy Basin up on the plateau. These 100-foot to 400-foot gravel mounds, though clearly having constructional profiles, have steeper slopes and better-marked river channels among them. They more nearly approximate river bars in appearance, as a scrutiny of the generalized contour lines on them (Pl. VI) will show. And they almost nowhere approach the upper limits or the outer limits of the glacial waters. In Quincy Basin, along the Telford-Crab Creek spillway group, they closely approach or actually reach both. This basin had but one outlet; the Quincy Basin had four. Scabland on the walls of this outlet (Wallula Gateway) is perfectly definite up to 1150 feet A. T. and probably extends to 1200 (Fig. 12). This gap is cut across an asymmetrical fold 12 miles south of the Snake-Columbia junction, a fold which constitutes the south wall of the structural valley. If Wallula Gateway was approximately as deep in preglacial times as at present[4] the waters flowing through it during the scabland-making episode were nearly 900 feet deep.

Obviously, another explanation is at hand

FIG. 11

FIG. 12

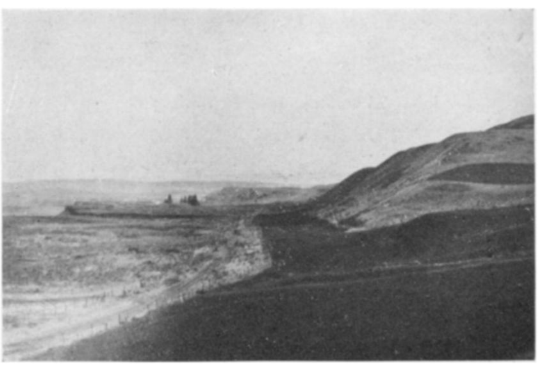


FIG. 13

FIG. 11—Terrace in Touchet River valley, tributary of the Walla Walla River. (Photograph by Robert Landon.)

FIG. 12—Scabland on east wall of Wallula Gateway. Smaller butte 300 feet, larger butte 450 feet above river.

FIG. 13—Near Celilo, Ore. Scarp eroded in ancient gravel formation; scabland at base a rock terrace 500 feet above the Columbia.

[4] New data seem to show this. Earlier interpretations called for considerable deepening by the glacial waters.

for the 900-foot vertical range of the marked scabland of the Gateway—that the upper scabland is older; so much older that it antedates the present depth of the canyon across the anticline. The evidence for a full development of the valley system draining the plateau before the glacial flood occurred has been outlined. The alternative hypothesis apparently cannot be harmonized with it.

FIG. 14—Steamboat Rock, in the middle of upper Grand Coulee. The largest mid-channel butte of the scabland. (Photograph by C. L. Beane.)

But before the matter be considered closed, the valley of the Columbia beyond the Gateway should be examined. Its character must have an important bearing on the problem.

CHANNELED SCABLAND BEYOND THE PLATEAU

From Wallula Gateway to the Willamette River, west of the Cascade Range and 200 miles beyond the Gateway, the Columbia basalt is the physiographically dominant formation. The plateau is generally considered to extend westward to the Cascade Range, but it is considerably more warped and folded than in eastern Washington. In a general analysis three portions may be recognized along the river: two downwarped areas separated by an area of upwarp. The river valley in the downwarps is wide and without notable walls; across the upwarp it is a canyon with maximum depth of a thousand feet. Across the folds of the Cascade Range farther west it is a great canyon or "gorge" 4000 feet in maximum depth; and still farther west, about Portland, there is a great widening which probably is largely structural.

The "wides" and "narrows" along 200 miles of Columbia River below the junction of the Snake have almost the same modifications that are found in similar situations above that junction. The wides carry great gravel deposits with bar forms almost intact. The stratification in these bars dips prevailingly away from the Columbia. The material is commonly but little worn, is poorly sorted, and is almost all local in origin. Striking contrast exists between present Columbia River gravel and this bar material. The bars are not all spread out in the structural wides, many are built in reëntrants in the walls of the canyoned portions. Some are built high above the river, some extend almost from river level up to heights as great as 400 feet. Mouths of tributary valleys are favorite places for them;

FIG. 15—Head of Spring Coulee, a divergent canyon leading southeastward out of lower Grand Coulee. (Photograph by L. C. Robinson.)

their form, composition, and structure indicating clearly that they were built by the greatly swollen Columbia, not by the tributary streams. Not one of these deposits can be explained as old stream gravels left during the deepening of Columbia Valley, or as recording former valley trains, without doing violence to the field evidence. No other river valley in the world possesses such features, so far as the writer has been able to learn. Like those on the plateau above the junction of Snake River they are channel forms, not valley forms.

As with the depositional part of the record, so with the erosional part. There are channels, rock basins, and buttes of very youthful character, eroded in basalt, at high levels above the Columbia. They are river bottom features. They assuredly do not date back to the original cutting of the Columbia Valley. Their occurrence as actual divergences from the Columbia across divides to tributary valleys, and the building at such places in the tributary valleys of great bar dams or partial dams, demand the same extraordinary relations of volume to capacity as in the scabland system on the plateau.

The erosional features are most pronounced in the narrows. Where the contact of weaker formations on basalt was reached by the immense glacial river the overlying material was swept off to produce a broad basalt terrace, etched with the characteristic vigorous strokes and margined by a youthful scarp in the superjacent formation (Fig. 13). To build these great bars in the lower Columbia Valley, to erode the high-level scabland and its margining scarps, and to allow the divergences into the lower courses of tributaries demand depths but little less than those at Wallula Gateway and in Snake River Canyon. A remarkable combination of all these features near the mouth of John Day River records 750 feet of flowing water in the Columbia.

The record of the great glacial river has been found as far down the Columbia as Portland, Ore. Here it appears to end in a deltaic gravel deposit which covers about 150 square miles. The surface of the deposit ranges from river level (which is nearly sea level) up to 360 feet A. T. Most of it lies above 200 feet. It is not a plane surface, and its irregularities are not due to erosion since the deposit was made. Though the structure everywhere is foreset, the direction of dip is so diverse in some places that, taken with the absence of a plane surface, it does not conform to the conception of a delta. A specific explanation for the ensemble would be difficult if one had no acquaintance with channeled scabland and its bars. But for the requirements of that explanation, the Portland Delta is ideal. It is a great assemblage of bars and channels, correctly disposed and constructed for the aggraded floor of a huge river here losing its current at the head of a broad drowned valley. The detailed relations to certain rock hills which are surrounded by the deposit are incapable of any other explanation than that of subfluvial origin of the whole deposit.

Erosional Forms in Basalt

The realization that a remarkable episode of glacial history was recorded in eastern and central Washington first came from an attempt to map and explain the bizarre erosional forms on the plateau surface. Running water, not of local origin, was clearly indicated as the map grew. Surviving areas of the earlier topography, a normal drainage pattern, were available everywhere for comparison. Certain unusual forms in the scabland and certain relationships in its pattern early led to the conception of prodigious streams. This conception demanded the existence of other features and relationships which had not yet been recognized, and it afforded a clue to the origin of some features which in themselves did not so strikingly tell of great volume. The development of the hypothesis has continually led to the finding of new field relations and new criteria, all of them consistent with the explanation, none of them pointing to any other interpretation. Furthermore, essentially every kind of evidence required by the hypothesis has now been found.

In the remainder of this paper, a genetic classification of the physiographic forms of channeled scabland will be presented.

CANYONS: GRAND COULEE

The empty canyons and dry cataracts of the plateau are easily the most conspicuous scabland forms. Among the canyons Grand Coulee takes precedence, followed by Moses Coulee. Grand Coulee has many times been explained as a former course of the Columbia across the plateau.[5] For a time it was considered to have been initiated by a great fissure,[6] and this idea was built into the first interpretation of the coulee as a glacially diverted Columbia.[7] Grand Coulee is nearly 50 miles long. It has an upper canyoned part about 28 miles long, a short stretch in mid-length across a structural sag (Hartline Basin), and a lower canyon about 20 miles long. At least four definite upfolds in the basalt are recognizable across the coulee, their existence conditioning the variations in character and the divergences.

Upper Grand Coulee is a simple canyon whose average depth is perhaps 900 feet. The width of its floor is nowhere less than a mile and a half and in one place is nearly five miles. In the middle of this wide place stands Steamboat Rock, a butte of basalt a square mile in summit area and 800 to 900 feet high (Fig. 14). Its summit is a part of the original plateau surface, now trenched by this glacial river canyon. Like the margining cliff summits, its top is marked by scabland buttes and channelings in basalt.

Lower Grand Coulee begins with a very irregular abandoned waterfall, 400 feet high, over nearly horizontal basalt flows. Most of the lower coulee, however, is eroded in tilted flows, along a monoclinal fold whose eastward dip is responsible for lower cliffs on that side. At least five pronounced divergent canyons lead southward and eastward out of the lower coulee and the mid-length structural basin (Fig. 15). All cross the minor upfolds of the basalt here. The head of the lowest of these is about 200 feet above the adjacent floor of Grand Coulee.

Grand Coulee is a part of the Crab Creek drainage system, but today it is a closed basin. Its lowest place, Soap Lake at the south end of the lower coulee, is shut in on the south by extensive gravel deposits. The lower coulee is made over from a preglacial drainage line out of the structural sag. Tributary furrows on the monoclinal slope to the west, expressing the general maturity of the plateau, hang hundreds of feet above the surface of the lakes on the coulee floor. The preglacial eastern wall, however, has been almost completely overrun by glacial waters and is striking scabland.

The upper coulee apparently is a glacial river canyon *de novo.*

[5] The earliest published suggestion of this appears attributable to Samuel Parker, who crossed the Grand Coulee in 1835. In his "Journal of an Exploring Tour Beyond the Rocky Mountains," Ithaca, N. Y., 1838, he speaks of the "Grand Coulé, which was undubitably the former channel of the river [Columbia]," p. 294.

[6] Probably first suggested by T. W. Symons in "The Upper Columbia River and the Great Plain of the Columbia," *47th Congr., 1st Sess., Senate Ex. Doc. No. 186*, 1882.

[7] I. C. Russell: A Geological Reconnaissance in Central Washington, *U. S. Geol. Survey Bull. 108*, 1893.

Unlike the lower coulee, its walls have no notches where preglacial drainage furrows hang above the bottom and therefore no rounded gable-like headlands in the upper profile. It is also unlike the other two scabland channel routes across the plateau divide (Cheney-Palouse River and Telford-Crab Creek) in that it is deeply entrenched. The others show scarified basalt over wide tracts, but the chief result of

FIG. 16—Part of "Dry Falls," the abandoned cataract in Grand Coulee. Summit of cliff is 400 feet above the plunge basin lake. This cataract was in use during a later episode of glacial diversion. Looking northeastward into Hartline Basin. Battleship Rock on right. (Photograph by C. L. Beane.)

glacial waters in them was to carry away the overlying loess. The upper limit of glacial water at the head of the Grand Coulee route is essentially the same as in the other two (2500 to 2550 feet A. T.), but the floor is nearly a thousand feet lower than in either of them. There are at least two reasons for this. The original spill across to the mid-coulee structural sag descended the monoclinal slope already noted. This afforded an initial descent of nearly a thousand feet in a very few miles, and the great river probably sloped back rapidly to cut the canyon. Furthermore, the coulee was in use in a later glacial episode than the one to which the rest of the scabland is ascribed. The ice of this later episode did not cross the Spokane and Columbia valleys east of the head of Grand Coulee, though to the west it advanced farther than the earlier ice sheet. Apparently Grand Coulee had already been deepened considerably in excess of the other routes and thus functioned alone across the plateau divide during this later episode. Some deepening probably occurred at this time.

The upper part of Grand Coulee, therefore, shows the following characteristic features of the canyons eroded entirely by glacial rivers on the plateau.

1. It crosses a preglacial divide. Though not an essential character, this is the prevailing relation to divides.

2. It possesses scabland on the "rim rock," above and behind the brink of the cliffs. Every canyon shows this, though not necessarily along its entire length.

3. It has steepened slopes in the loess or other sediment overlying the basalt. These are present wherever scabland occurs above the brink of the canyon walls.

FIG. 17—Head of lower Grand Coulee looking south from the brink of the old cataract. Pothole Lake at right, Battleship Rock in middle left of the view. The monocline which constitutes the west wall of the lower coulee determines the sky line. (Photograph by E. J. Evans.)

4. It has islands of loess on this upper scabland. They are found on all such scabland.

5. It has island buttes of basalt in mid-canyon.

Lower Grand Coulee lacks only the location on a preglacial divide. It shows some additional features that surely were not inherited from the preglacial drainage route.

1. Rock basins on the floor are numerous. All glacial river trenches in the scabland possess these features, except perhaps upper Grand Coulee.[8]

2. A large trans-coulee cataract exists. Most of these glacial river canyon trenches have more than one, though large cataracts also exist outside of the canyons.

3. There are several striking canyons diverging from the main canyon. These are really minor divide crossings in themselves.

Moses Coulee best illustrates one feature of these canyons, the remarkable deepening and widening locally produced in the preglacial routes. Douglas Creek, an affluent which enters the coulee 15 miles above the Columbia, may well be considered the major streamway, not the tributary, of the preglacial pattern; but its headwaters were not

[8] The floor of the upper coulee is covered with gravel and silt; and, if there are rock basins here, they are buried.

entered at the time the coulee carried a glacial river, and as a consequence the deepening and widening of the coulee left Douglas Creek Valley hanging 350 feet above the gravel fill in the coulee bottom. Wells show the fill to be more than 200 feet deep, and the amount of "hang" is correspondingly increased. Widening of Moses Coulee is responsible for perhaps a hundred feet of this total of 550 feet. Douglas Creek, though a permanent stream, has gashed the lip of the hanging valley for less than a mile back during all post-trenching time. Since the later ice sheet discharged but little water through Moses Coulee, the slow rate of normal valley deepening, compared with the rate of glacial stream canyoning, is obvious.

Cataracts and Cascades

Their name is legion. Scarcely a scabland area is without ledges transverse to its length. In some places, whole series of them are in sight from well-chosen viewpoints. Most of them have rock basins at their base, commonly empty basins. Those less than 20 feet high are almost negligible in developing the argument, so common are those of larger dimensions. Sheer descent of their full height is rare, though Palouse Canyon has one 196 feet high (now carrying Palouse River), Grand Coulee's abandoned falls (Fig. 16) are 400 feet high, and Quincy Basin has three such spillways out of the western part, with vertical transverse cliffs 200, 400, and 400 feet in maximum height. In most cases the glacial rivers descended in gigantic cascades, Moses Coulee having a complex one a mile wide and a mile long, in which the descent was 400 feet.[9]

Recession of these cataracts and cascades left canyons that may be mere niches or recesses in the basalt wall over which the water fell or that may be miles in length. Many of the smaller ones came into existence only through the sweeping off of the loess and the uncovering of buried basalt ledges of the pre-loessial topography. Staircase Rapids, near Washtucna, is an example.

Among these cataracts there were a few double falls each member of which receded at approximately the same rate, so that the island in mid-channel became very much elongated, like a great blade, as the falls receded and the canyons lengthened. Potholes Cataract, one of the three western spillways out of Quincy Basin, has the most striking mid-cataract blade. It is a mile and a half long, a quarter of a mile in maximum width at the base, and its cliffs are from 100 to 275 feet high (Fig. 18).

It seems entirely probable that upper Grand Coulee was cut through the divide by the stoping of cataracts or cascades down the steep monocline north of the structural Hartline Basin. Steamboat

[9] Not 600 feet, as previously reported by the writer.

Rock thus would be explained as a Goat Island around which both falls retreated to unite again as one and thus to isolate it. An actual case of this sort is Battleship Rock which stands just in front of the great cataract at the head of the lower coulee (Fig. 17). Another illustration of canyon-making by cascade-stoping is Devils Canyon, a short spillway from Washtucna Coulee to the Snake, 15 miles west of Palouse Canyon.

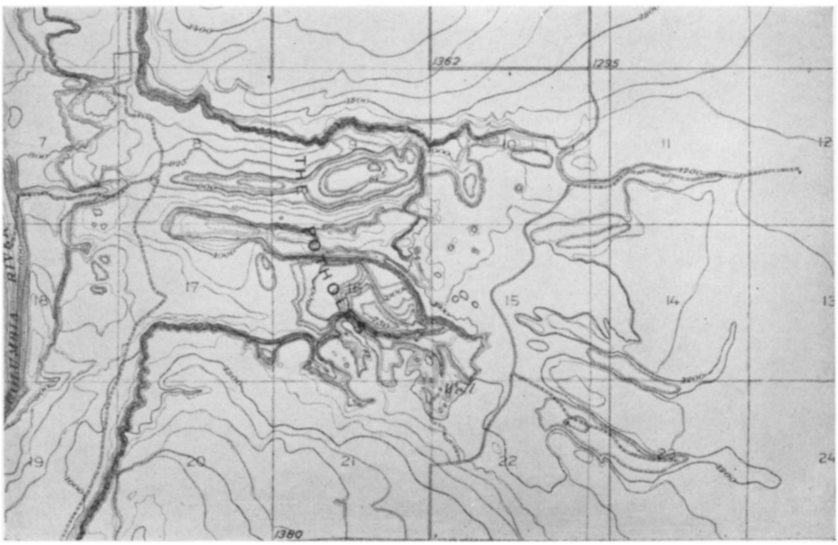


FIG. 18—Potholes Cataract, one of three cataract spillways from the west side of Quincy Basin. (From Quincy sheet, U. S. Geological Survey.)

ROCK BASINS AND MID-CHANNEL BUTTES

There is no feature of channeled scabland more challenging than the rock basins. There are thousands of them, from shallow saucers to the great canyoned basin of Rock Lake on the eastern margin of the Cheney-Palouse River spillway, more than seven miles long and having a reported depth of 250 feet near its northern end. The rock basins are not limited to the canyons and the cascade chutes or the foot of cataracts. They occur in great profusion on the broad uncanyoned heads of the two eastern scabland tracts. They occur on the torrent-swept summit of the Palouse-Snake divide, on the slopes of the preglacial valleys involved in the scabland discharge, and on the scabland benches above the rim rock of these preglacial valleys. Though not the only closed depressions left in the area after the scabland-making episode, they are the most common.

Most of the basins in the eastern and northern higher part of the plateau contain lakes and swamps today. Farther southwest, where the rainfall is less, many are empty most of the year. Some of these empty rock basins are 200 feet deep, though they have been receiving wash ever since the glacial flood subsided. Many are so steep-walled that they can be entered only at favorable places, and the bottoms of a few are accessible only by rope or ladder. The steepness of their walls is comparable to that of the associated canyon walls

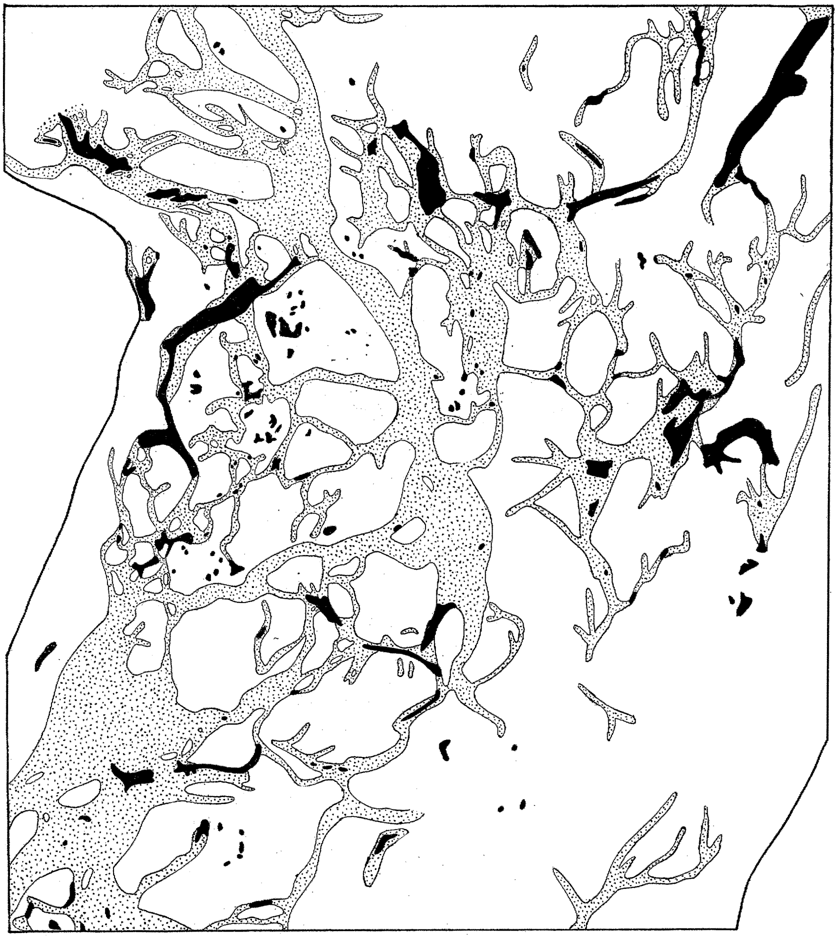


FIG. 19—Channels, rock basins, buttes, and general scabland of a part of the Drumheller Channels. Rock basins black, channels stippled, buttes and general scabland blank. The beginning and ending of many channels in the plexus is better shown here than on the contour map, Figure 21, as also is the extreme irregularity of the channel pattern. The larger rock basins are notably linear and are largely in channels. It must be understood, however, that the highest scabland is itself channel floor of the great spillway. Scale approximately 1:120,000, slightly more than half an inch to a mile.

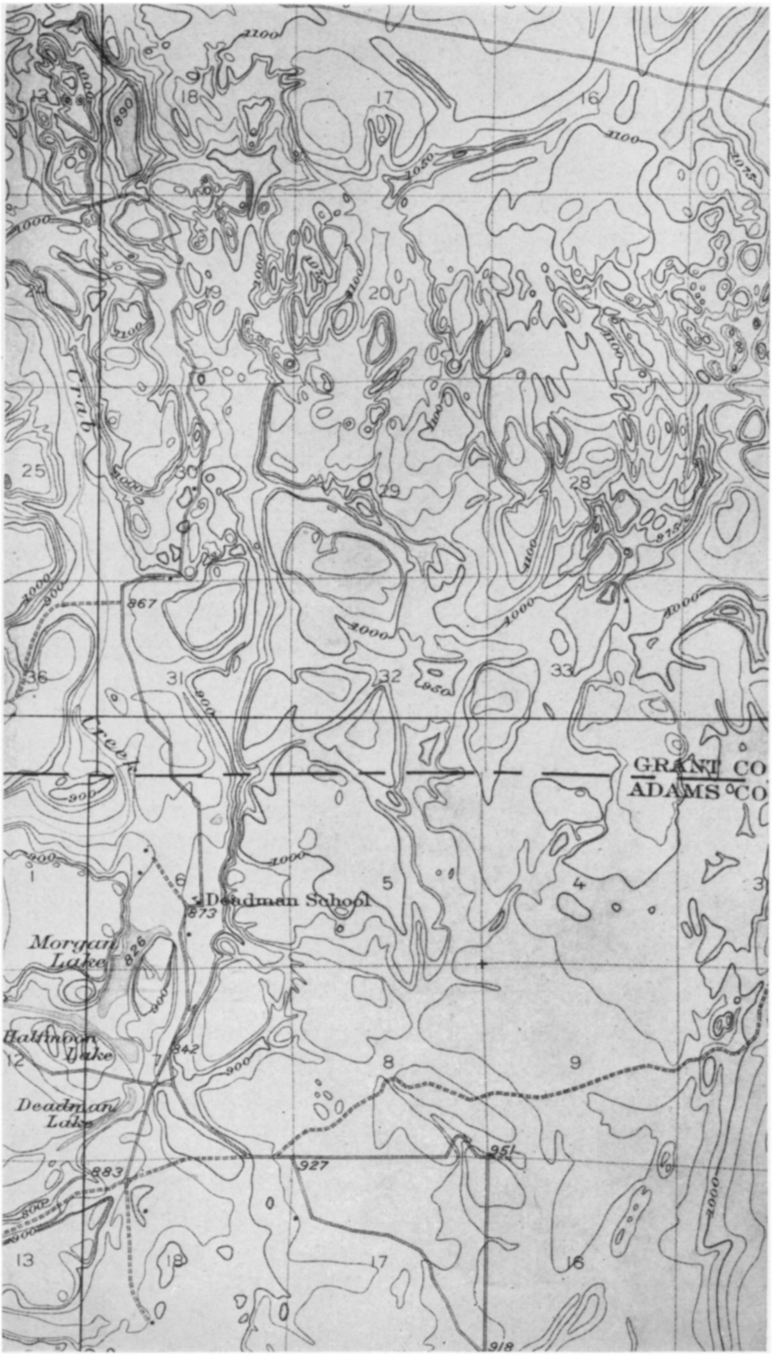
and butte walls and has the same explanation. Both have their slopes determined by the character of the basalt. Where that has large, well-developed columnar structure (and where glacial rivers had adequate gradient) slopes are steepest: where this structure is absent or poorly developed, the rock basins have gentler slopes.

Buttes in mid-channel are far more numerous than abandoned cascades and cataracts, and most of them cannot have been formed by cataract recession. The association of isolated hills and hillocks of basalt with rock basins in the scabland channels is characteristic. Where the rock basins are deep, the buttes are prominent. Though one

FIG. 20—Hypsometric map of a part of Drumheller Channels. Distribution of higher and lower tracts is more graphically shown than by the intricate and unusual contour pattern of the map, Figure 21. The contour interval is 100 feet. The highest areas (blank) are over 1200 feet; the lowest (solid black) less than 700 feet A.T. Comparison with Figure 19 will show the location of several of the largest (including the deepest) rock basins and many of the channels on the higher part of the scabland plexus.

is the reverse of the other, they are genetically associated forms. The conditions that gave rise to one produced the other. The maximum depth of erosion by glacial waters in any one place is the sum of butte height and basin depth. In such tracts the spacing of buttes and basins is very close.

FIG. 21—A part of the Drumheller Channels, the southern spillway from the Quincy Basin. (Reproduced from the Corfu (above) and Othello (page facing) topographic sheets of the U. S. Geological Survey.)



The area shown is slightly less than that of Figures 19 and 20 with which it is to be compared. The scale is one inch to a mile, nearly twice that of Figures 19 and 20. The contour interval is 25 feet.

Widely spaced buttes also occur on broad scabland surfaces which have no other marked relief (Fig. 22). The summits of some of these are higher than the loess-basalt contact in adjacent marginal scarps. They appear to be remnants of pre-loess elevations on the surface of the basalt and are not a record of great erosion by glacial water. But the closely associated buttes and basins have no adequate explanation other than the one proposed.

Plexus Groups: The Drumheller Channels

There are a few tracts of scabland where all the erosional features above described exist in a closely related group, in sharp contrast with the adjacent higher preglacial topography. The most marked of these is Drumheller Channels, the southern dischargeway from Quincy Basin (Figs. 19, 20, and 21). This spillway is a labyrinth of abandoned channels and rock basins among buttes, hills, and higher scabland surfaces of the basalt. The maze is eroded across the nose of a plunging anticline in the basalt. Its total width is nine miles, and in a single cross section the total vertical range of the scabland is 375 feet. It is difficult to count the channels because of the anastomosis and the indefiniteness of some of them, but nearly 150 definite channelways can be identified. They range from less than a mile to more than ten miles in length, and their floors are as much as 200 feet below adjacent butte tops. Almost every butte top has channels across it or heading on it, almost every large channel has buttes in it, and in many cases assignment of definite boundaries must be arbitrary. Most of the channels have continuous descending gradients, but there are many whose floors rise in places in what was undoubtedly the downstream direction.

Relations among these channels are instructive. The larger ones can be traced continuously through the maze, but many smaller ones and some large ones flare out downstream and lose their channel character in the generalized scabland. A larger number head in the scabland plexus 200 to 300 feet above the adjacent deeper and continuous channels. Junctions of small channels with the larger ones are but rarely accordant. The numerous small channels are on butte tops or on the higher tracts among the buttes. Their divergence from, or entrance to, the larger channels is almost invariably hanging.

Another remarkable feature of Drumheller Channels plexus is its rock basins. One hundred and eighty-two of these are shown by the 25-foot contour interval of the Corfu and Othello topographic sheets of the U. S. Geological Survey. The larger ones are in the more prominent channels and are elongated with the channel shapes. Many of the smaller ones are on butte tops, unassociated with definite channel forms.

FIG. 22

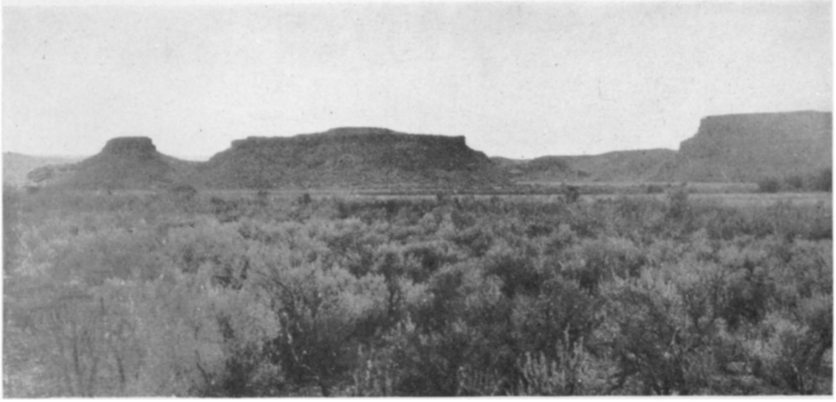


FIG. 23

FIG. 24

FIG. 22—A mid-channel butte. Absence of other basalt buttes or ledges at its level indicates that it records a hill of pre-loess topography. (Photograph by L. C. Robinson.)

FIG. 23—Trenched spur buttes in Crab Creek valley near Wilson Creek station.

FIG. 24—Scarp in loess three miles northwest of the mouth of Palouse River. Base of scarp 1320 feet A.T., about 800 feet above Palouse. A valley in the loess left hanging by erosion shows on the right. (Photograph by Donald Bell.)

Drumheller Channels constitutes one of the most peculiar groups of topographic forms to be found anywhere. It suggests karst topography, which it is not. The discontinuity and irregularity slightly resemble those of a morainic region or a tract of dunes. But the field evidence is convincing; the topography is the result of running water. For its development the tract must be covered with a current deep enough and vigorous enough to erode these channels and rock basins where there previously had been nothing remotely resembling them. It is permissible to think that, as erosion progressed, the glacial waters were concentrated in the deeper continuous channels across the ravaged anticline. But the deepest rock basin of the plexus, lying in the east-central portion, is two miles and a half from the nearest of these continuous channels, its rim 150 feet above that channel floor, and its bottom not 25 feet above. The demand for an initial great volume is obvious.

Trenched Spur Buttes and Junction Buttes

The deeper preglacial valleyways entered by the glacial streams possess a type of scabland eminence that closely resembles the mid-channel butte but has a somewhat different genesis. This type, the trenched spur butte (Fig. 23), occurs on the inside of curves of the original valley. The great glacial rivers, filling these valleys to the brim and even overrunning them, could not tolerate the leisurely preglacial curves. The submerged slip-off slopes were the most exposed places in the extemporized channelways and were most vigorously attacked. A common mode of attack was the cutting of a gorge or trench across the slip-off spur. This provided a more direct route and left a scabland butte, the terminal part of the spur, isolated in the widened watercourse. Widening by a method peculiar to this region and this episode is recorded by the buttes of this type. They are not common forms, for they require a particular setting and a particular behavior of the glacial river. They are not limited to the plateau scablands. Snake River Valley possesses two remarkable trenched spur buttes, well shown on the Wallula topographic sheet of the U. S. Geological Survey, and there is an equally remarkable situation involving trenched spur buttes in the Columbia Valley 115 miles by river below the mouth of the Snake.

In a few places where large glacial streams, occupying preëxisting valleys in basalt, joined to become one, the tip of the separating divide was severely eroded and cut into buttes much like a trenched spur series except for situation. The erosion seems to have resulted because one of the confluent rivers had superior volume and a part of it poured across the divide tip into the other valley. The junction of Crab Creek and Coal Creek, a few miles east of Odessa, possesses four such buttes in line.

Erosional Forms in Overlying Sediments

The erosional forms of channeled scabland are not limited to the basalt. Bearing their own distinctive characters, they occur in loess and other sediments that overlie the basalt. They may be classified under the terms scarps, relict hills, and channels.

By far the most common form is the scarp, a steepened slope in the overlying formation (Fig. 24). It is almost invariably parallel to a glacial river course, very seldom transverse. It invariably is marginal and almost invariably rises above the highest limit reached by glacial water at that place. It is analogous to the basalt cliffs of the scabland but always occurs at a higher level, its base essentially at the altitude of the highest rugose basalt surfaces.

Scarps commonly truncate the slopes of the mature topography. Their relations to it are like those of sea cliffs to older erosional slopes. Their heights may be as great as 200 feet, their slopes as steep as 35°. Their

Fig. 25

Fig. 26

Fig. 27

Fig. 25—Relict hill of loess, 180 feet high, surrounded by scabland. Near Hooper, Wash.

Fig. 26—Cluster of relict hills, remnants of a minor divide. Near Hooper, Wash. The hill shown in Figure 25 is one of this group.

Fig. 27—Channel in loess, looking north into Washtucna Coulee, whose preglacial floor is 350 feet lower. Nunamaker School, southwest of Washtucna, Wash.

alignment along the margins of scabland river routes, their consistent development whether the glacial river was a quarter of a mile wide or twenty miles, their formation in piedmont waste or gravel material, their orientation in various directions, their absence at the summit of loess-capped basalt cliffs in non-scabland valleys, and the occurrence of rock basins, cataract ledges, canyons, and gravel bars close to their bases—all these circumstances debar any other interpretation of them than as integral parts of the scabland system.

The "islands" of loess which make striking features on many broad scabland tracts are almost invariably elongated with the gradient of that tract and are almost invariably scarped on the sides and upgradient end (Fig. 25). Convergence of the lateral scarps to this upgradient end in many cases produces a definite prow, like the conventional pilot of a locomotive. Small "islands" may have their summits determined by the upward convergence of the lateral scarps. Larger ones commonly carry the mature topography that characterizes the loessial mantle east and south of the scabland system. Many such hills or hill groups are separated by narrow scabland channels. Some stand alone in the scabland, miles from any others of their kind. There are more than 350 of them that do not exceed five miles in length. They are commonest in elongated clusters close to the margin of a much larger tract of loess hills (Fig. 26). These clusters record one or more minor divides, the valleys among them having been completely destroyed and the divides themselves narrowed by marginal sapping until cross channels through them appeared. All gradations can be found between a group of channeled valleys in a loessial tract to a group of isolated relict hills with wide scabland separating them.

It is not difficult to see in these island hills the residuals or relicts of a once complete mantle of weaker material. The difficulty lies in explaining them by any other hypothesis. If the glacial waters diverted across the plateau had been in volume comparable to that which made the spillways from Labradorean or Keewatin ice in the northeastern and central states, only a few preglacial valleys would have been demanded to care for the discharge. The fact that two of the four source routes were stripped of their loess (except for a few relict hills) over a width of 20 miles is very significant. It is in harmony with the other phenomena of scabland, all of which call for an extraordinary volume and depth, despite the notable gradients that existed.

Glacial spillways without scabland floors exist in the anastomosis (Fig. 27). All are small features. The divides crossed by the water entering them stood too high and too far from the main routes to allow any great volume. In some of these there is good basalt scabland at the head where the divide was crossed. Most of them have definite margining scarps. Gravel deposits on their floors, typically containing a few foreign cobbles and boulders, are also common. In large part, they are still the preglacial minor valleys, though most of them are clearly set off from adjacent valleys of this category by the features above noted.

Groups of such channels, closely spaced and nearly parallel, cross some of the relict hill areas. They are taken to represent the initial violation of the whole of the vanished loess cover. Where the broad scabland areas now exist, this initial stage was succeeded by deepening and, especially, widening until lateral planation had destroyed many thousands of these hills of the preglacial dendritic pattern.

This conception is not especially difficult to accept if no capacious preglacial valleys existed among them. Such was undoubtedly the case in the northern uncanyoned scabland tracts. But the same groupings of closely spaced channels are found farther south where there clearly were preglacial valleys 300 feet to 400 feet deep in basalt. The same flooding across minor divides to make the minor channels in loess occurred here also, despite the presence of capacious valleys below the upland loessial topography. The need for great volume is nowhere set forth more strikingly.

Depositional Forms of Channeled Scabland

It has been pointed out that all the peculiar features of channeled scabland knit together into a harmonious scheme on the thesis of tremendous volume of the escaping water. Should one, however, argue that the scabland denudation can be explained by assuming smaller streams and allowing more time, he must logically test this interpretation by the deposits of these streams. They afford probably a more crucial test of any hypothesis than do the erosional forms. As befits this paper, only the deposits with definite topographic expression will be considered.

All scabland channels possess discontinuous mounds, hillocks, or hills of stream gravel. Essentially none possess gravel terraces. The mounded deposits may occur in rock basins or perched high on channel walls. In form they are characterized by a rounded crest or summit which is commonly elongated with the channel, an enclosed or partially enclosed fosse between the crest and the adjacent channel or basin wall, and the complete absence or only the incipient stages of gullying (see Fig. 10). They are constructional forms; as definitely so as kames, eskers, cones, or deltas, though differing from all of these.

In situation they commonly lie either on the downgradient side of mid-channel buttes, trenched spur buttes, relict hills, or other eminences in the scablands; or in alcoves and recesses of the channel courses. Not a single prominent non-scabland valley entering the complex is known to be without them at the place of entrance.

In distribution they occur all through the scabland complex, from the summit of the plateau divide near the head of the channel groups to the great gravel deposit at Portland west of the Cascade Range.

In structure they are prevailingly current-bedded. Many of them possess long foreset strata like those of delta fronts, paralleling a steep slope in the mound. Their steep faces, like delta fronts, were growing faces. Débris that was swept over them came to rest in quieter places in the great rivers.

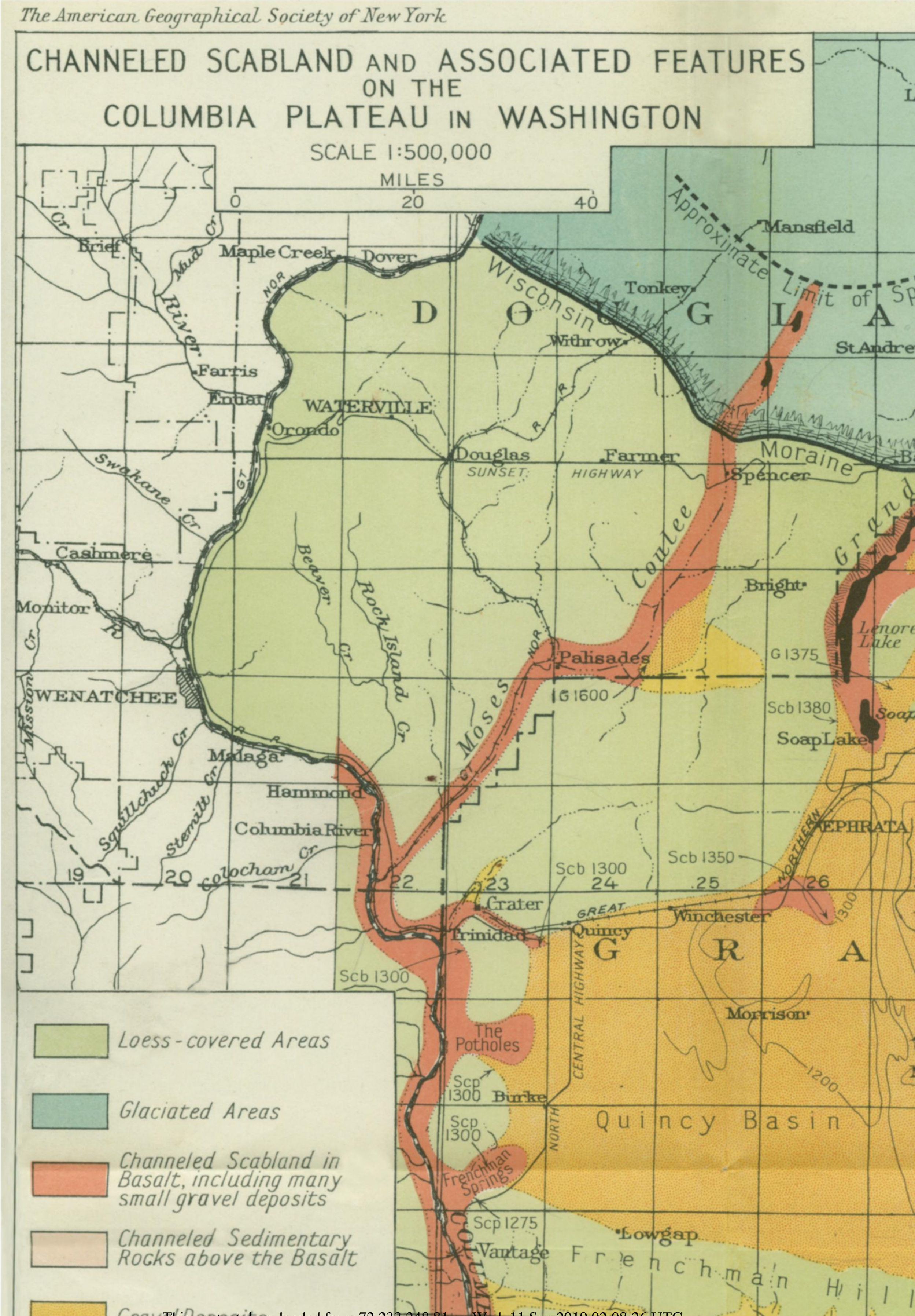
In composition these hills of gravel are dominantly of local material. Many along the Snake and Columbia have 75 to 90 per cent local material, though the present river gravels in close juxtaposition may have this ratio of local and foreign material completely reversed. Some have abundant pebbles, cobbles, and even boulders of loess, of silt, and of soft calcareous material associated with the hard basalt. Many sections show a large percentage of angular decayed basalt, well mingled with fresh "bright" fragments of the same rock. Decay of the deposits as a whole has extended but a foot or two below the surfaces. No differences have been found in amount of decay of the higher and lower deposits.

In magnitude these hills range from low mounds covering an acre or so to huge piles measuring a hundred to four hundred feet from lowest base to crest and covering a square mile or more. A few of them extend through the entire vertical range of scabland in their neighborhood. Their magnitude, both in actual size and in relation to the valleys in which they occur, is the most arresting feature among all their surprising characteristics.

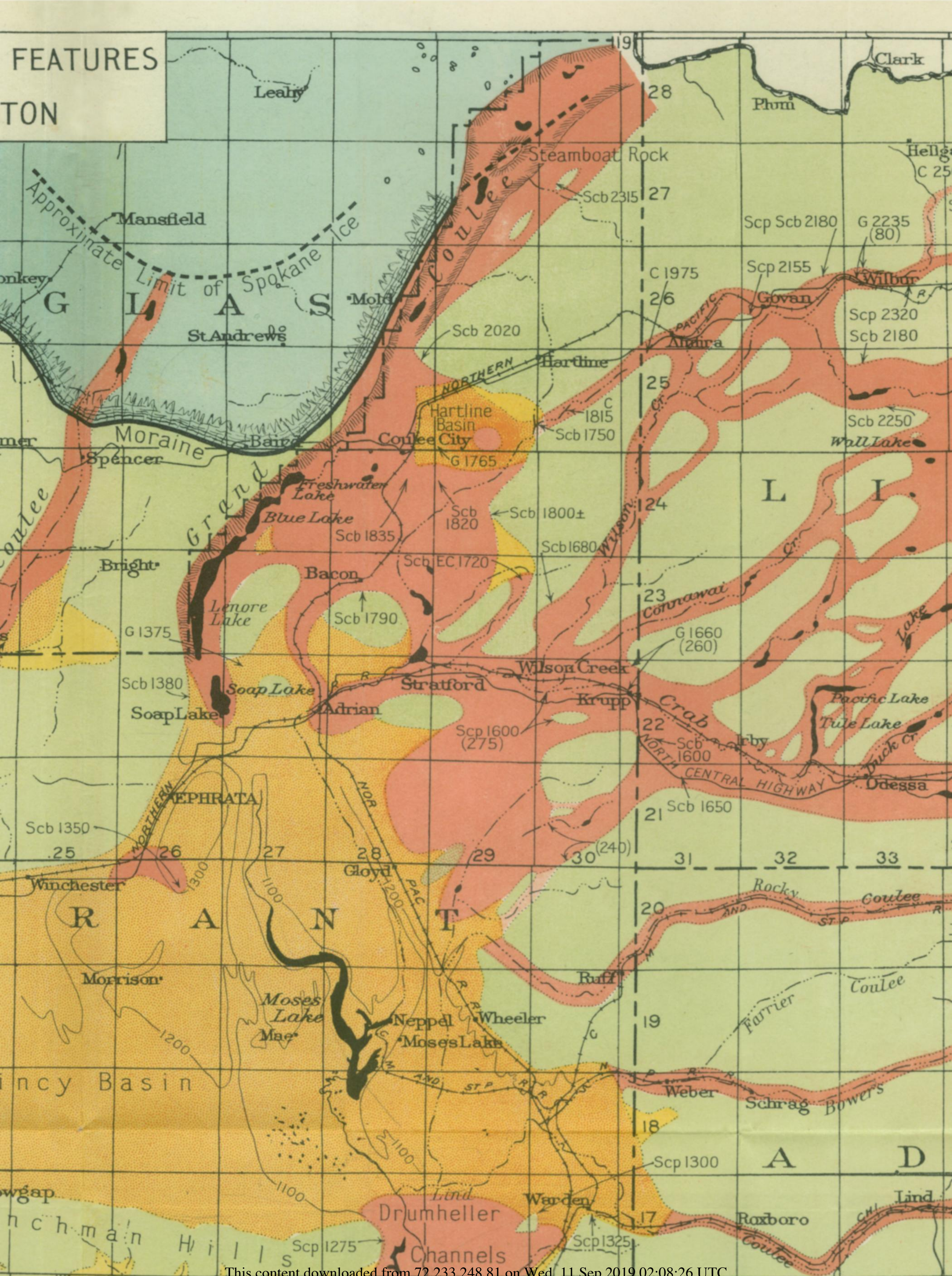
They are unlike any other detrital accumulations except the much smaller features of river channels commonly called bars. With these there is exact parallelism except for size. When considered in their setting in the scabland system, with all its other evidence for great volume and great erosion, they are seen to be an integral part. They should exist! And if they are bars, the great scoured channelways should exist! Again this assemblage of unique land forms in the Pacific Northwest is seen to be a genetic group. A lively imagination is required for the acceptance of the hypothesis, but a scientific imagination withal.

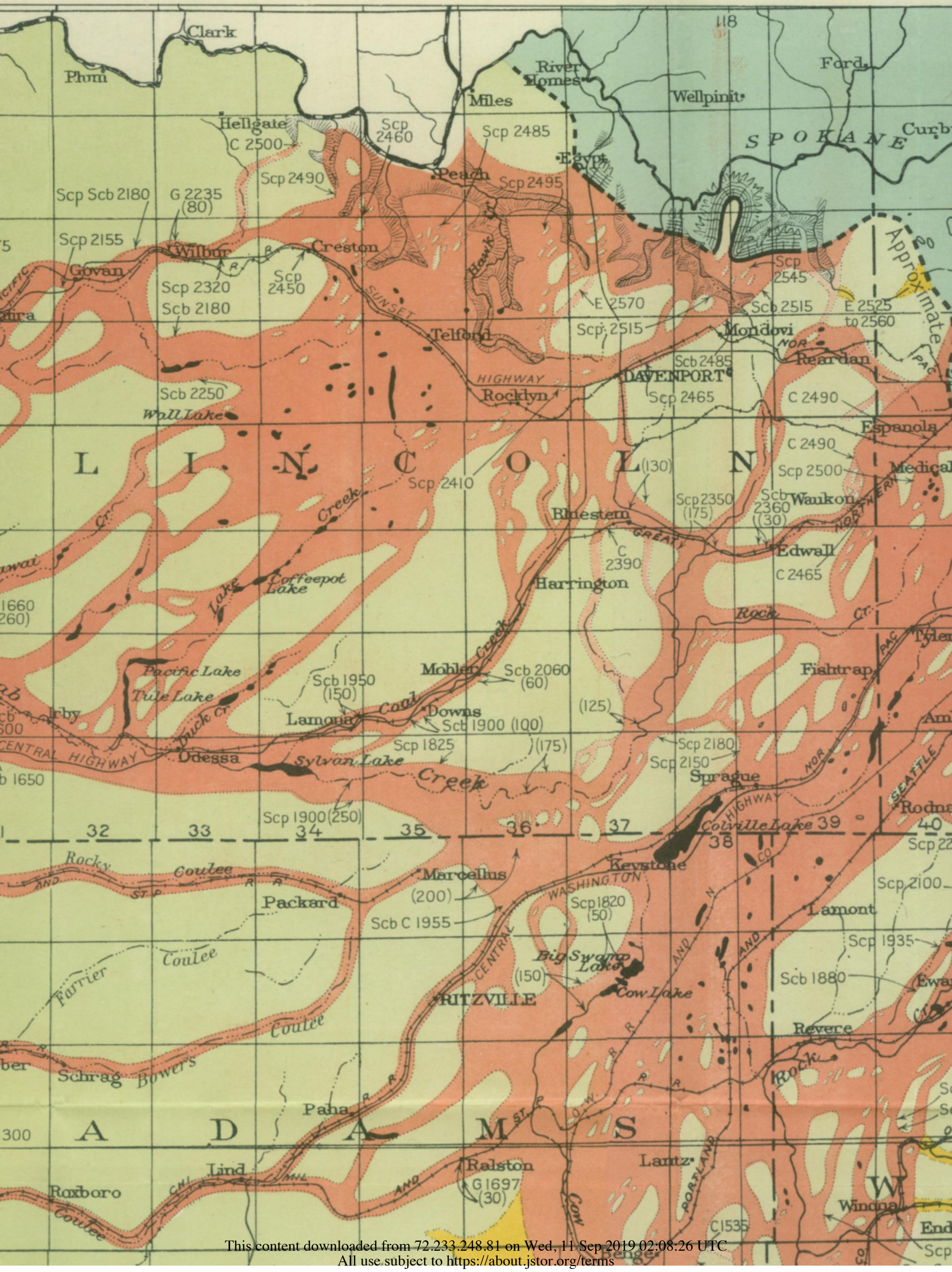
The Causal Episode

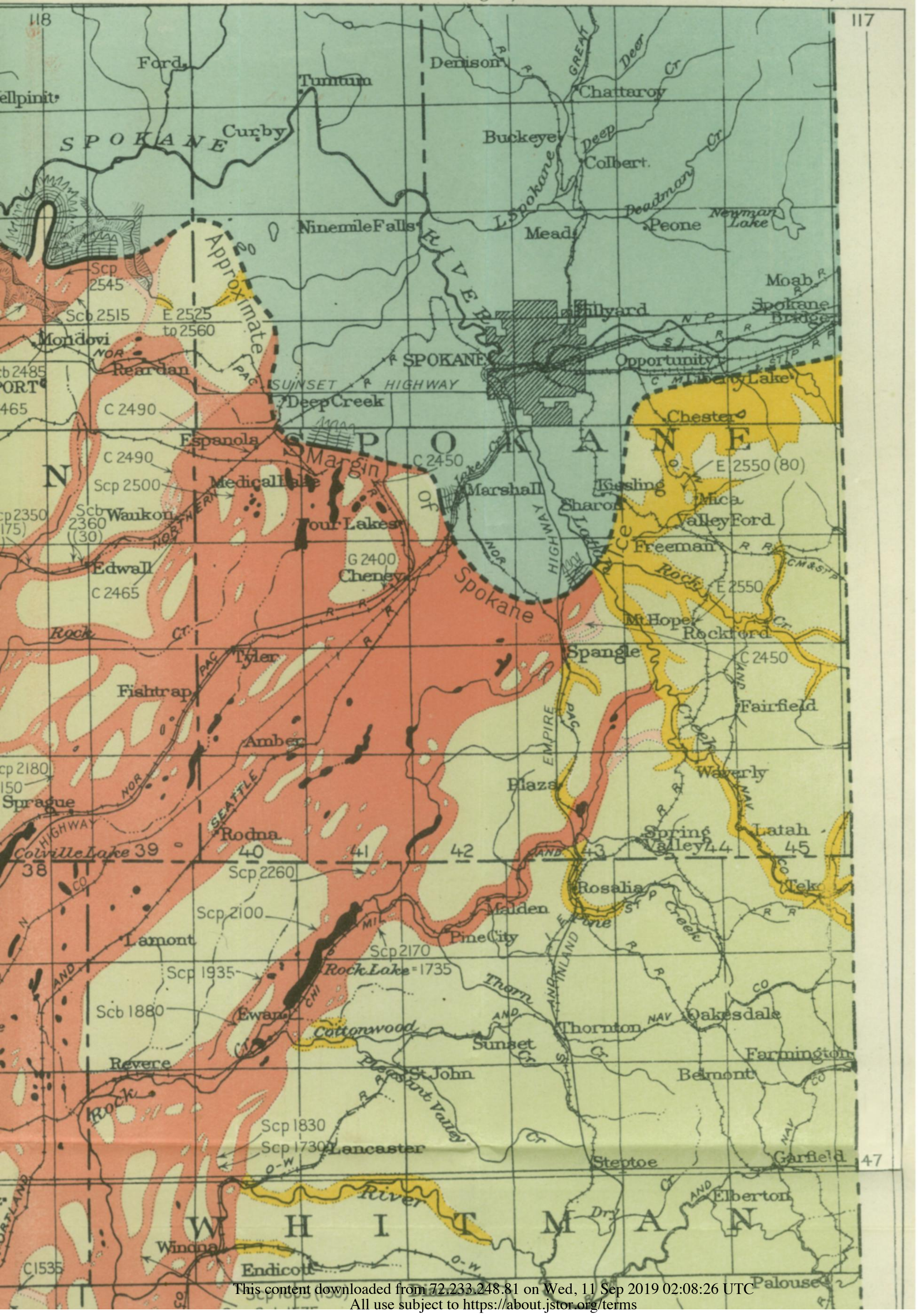
It is difficult to convey by words and pictures a visualization of the observable relationships of channeled scabland. Such terms as "canyon," "cataract," "scarp," "gravel deposit," calling up images of the usual topographic forms, suggest the usual explanation, which involves far less water and far more time than the writer's hypothesis demands. Put a glacial Columbia first in one channel, then in another, then in a third, instead of running all of them at the same time; use

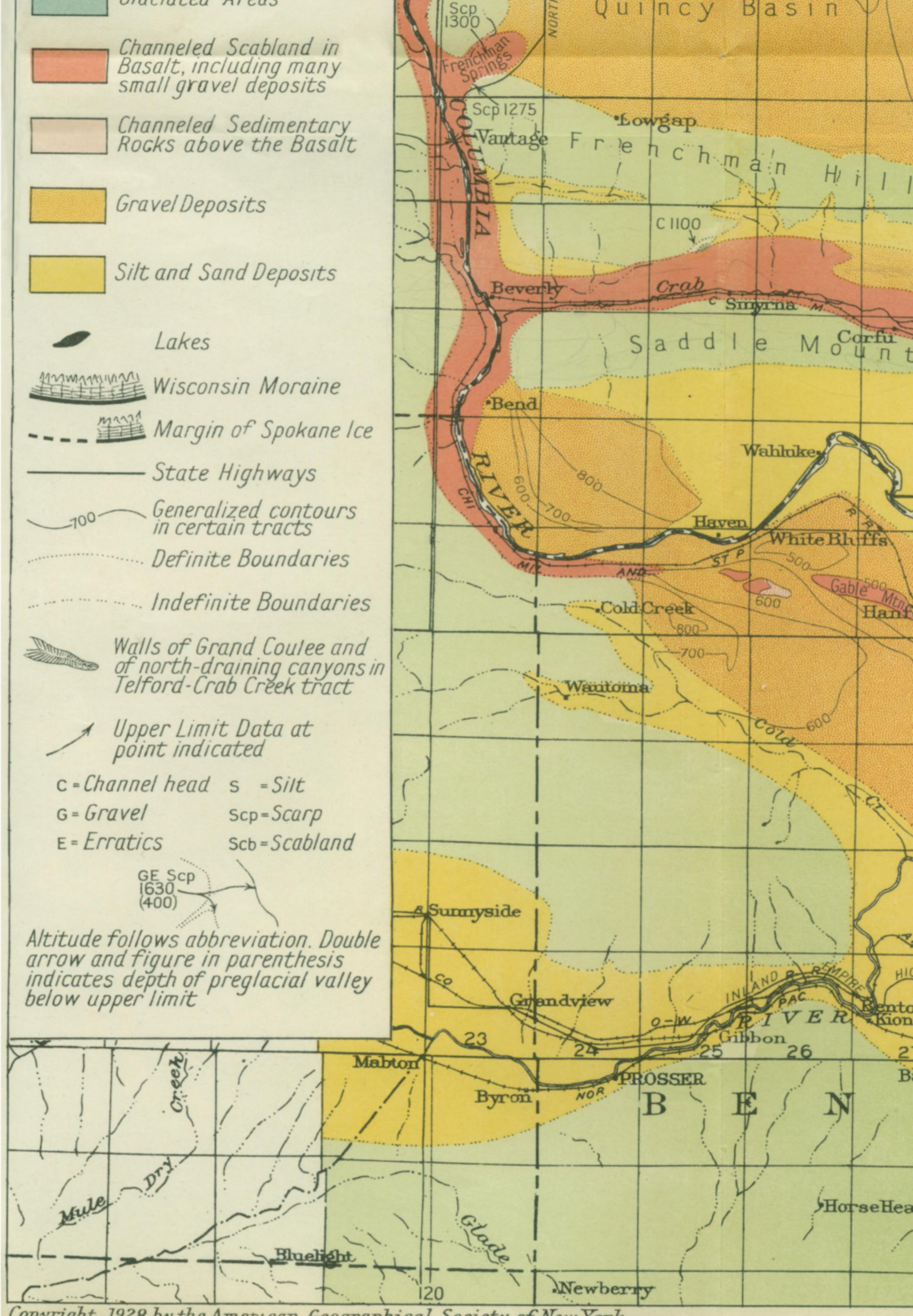


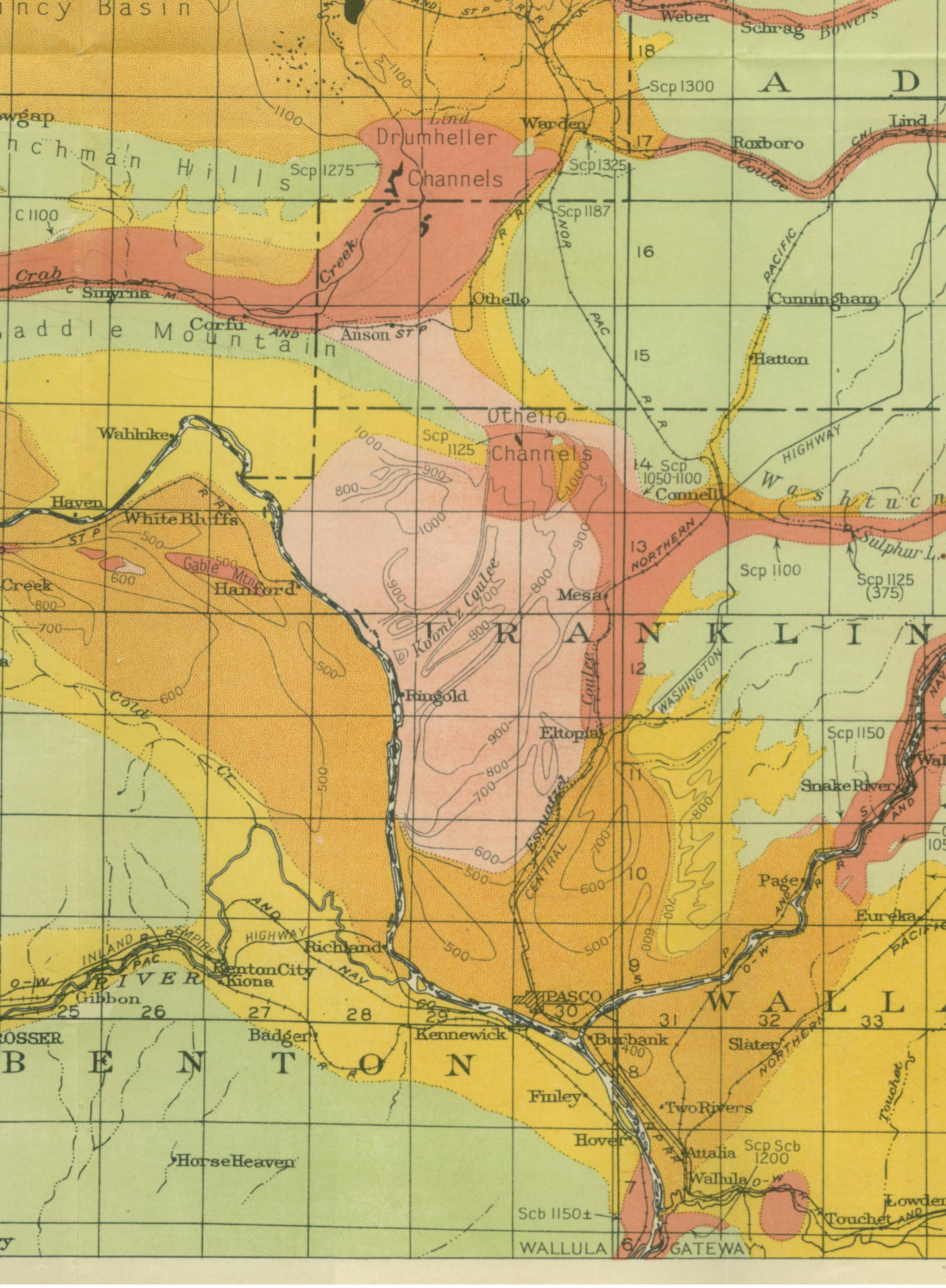
The American Geographical Society of New York
CHANNELED SCABLAND AND ASSOCIATED FEATURES ON THE COLUMBIA PLATEAU IN WASHINGTON
SCALE 1:500,000
MILES
0
20
40
Approximate Limit of Sp
Wisconsin
Moraine
Mansfield
Tonkey
Withrow
St Andre
D O U G L A
G R A
Brief
Maple Creek
Dover
Mud Cr
River
Farris
Entiat
WATERVILLE
Orondo
Douglas
SUNSET
HIGHWAY
Farmer
Spencer
Coulee
Grand
Swakane Cr
Cashmere
Monitor
WENATCHEE
Mission Cr
Beaver Cr
Rock Island Cr
Moses
Bright
Palisades
G 1600
G 1375
Lenore Lake
Scb 1380
Soap Lake
Malaga
Squilchuck Cr
Stemilt Cr
Hammond
Columbia River
Colockum Cr
EPHRATA
NORTHERN
Scb 1350
Scb 1300
19
20
21
22
23
24
25
26
Crater
GREAT
Winchester
Quincy
Trinidad
Scb 1300
CENTRAL HIGHWAY
Morrison
The Potholes
1200
Scp 1300
Burke
NORTH
Quincy Basin
Frenchman Springs
Scp 1275
Lowgap
Vantage
Frenchman Hills
COLUMBIA
Loess-covered Areas
Glaciated Areas
Channeled Scabland in Basalt, including many small gravel deposits
Channeled Sedimentary Rocks above the Basalt
Gravel Deposits

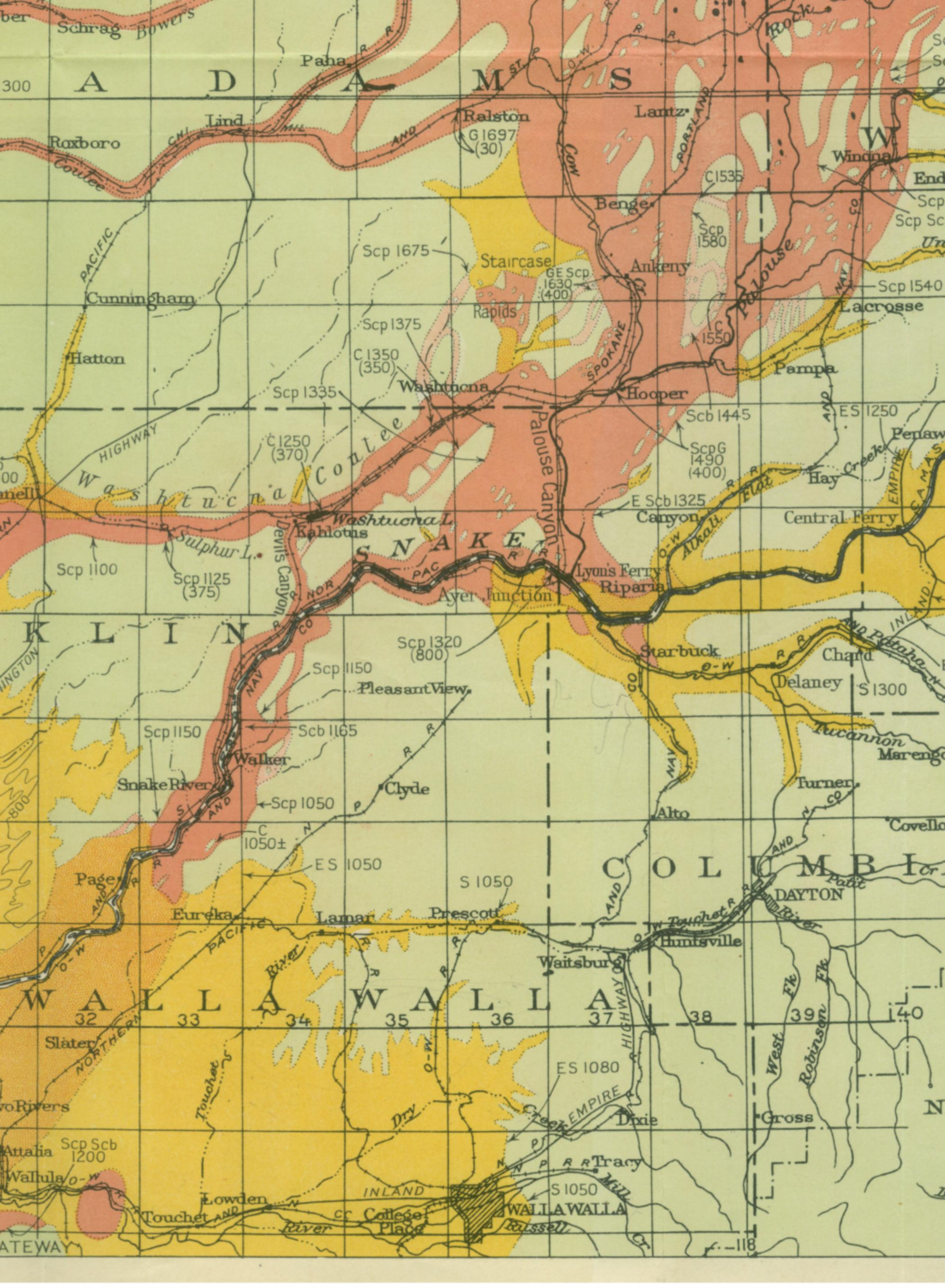

FEATURES
TON
Leahy
Approximate Limit of Spokane Ice
Mansfield
G L A S
Mold
St Andrews
Moraine
Baird
Spencer
Coulee
Grand Coulee
Steamboat Rock
Scb 2315
28
27
C 1975
26
25
24
23
22
21
Clark
Plum
Hellg
Scp Scb 2180
G 2235 (80)
Scp 2155
Wilbur
Govan
Almira
Scp 2320
Scb 2180
Scb 2020
Hartline
NORTHERN PACIFIC
Hartline Basin
Coulee City
G 1765
C 1815
Scb 1750
Scb 2250
Wall Lake
Freshwater Lake
Blue Lake
Scb 1820
Scb 1800±
Scb 1835
Scb 1680
Wilson Cr.
L I
Bright
Bacon
Scb EC 1720
Lenore Lake
Scb 1790
Connawai Cr.
G 1375
G 1660 (260)
Wilson Creek
Stratford
Scb 1380
Soap Lake
Adrian
Krupp
Crab
Pacific Lake
Tule Lake
Lake
Scp 1600 (275)
Scb 1600
Irby
Duck Cr.
NORTH CENTRAL HIGHWAY
Odessa
EPHRATA
Scb 1650
Scb 1350
25
26
27
28
29
30
(240)
31
32
33
Winchester
Gloyd
R A N T
NOR PAC
Rocky Coulee
20
Morrison
Ruff
Farrier Coulee
Moses Lake
Mae
Neppel
Wheeler
Moses Lake
19
1200
1100
1300
ncy Basin
Weber
Schrag
Bowers
18
Scp 1300
A D
wgap
Lind
Drumheller Channels
Warden
Lind
Roxboro
Coulee
17
nchman Hills
Scp 1275
Scp 1325


Clark
Plum
Hellgate
C 2500
Miles
River Homes
Wellpinit
Ford
SPOKANE
Curby
Egypt
Peach
Scp 2460
Scp 2485
Scp 2490
Scp 2495
Scp Scb 2180
G 2235 (80)
Scp 2155
Wilbur
Creston
Govan
Scp 2320
Scp 2450
Scb 2180
Hawk Cr.
SUNSET
Telford
HIGHWAY
Rocklyn
Scb 2250
Wall Lake
Scp 2545
E 2570
Scb 2515
E 2525 to 2560
Scp 2515
Mondovi
Reardan
Scb 2485
DAVENPORT
Scp 2465
C 2490
Espanola
Approximate
L I N C O L N
Scp 2410
(130)
C 2490
Scp 2500
Medical
Scp 2350 (175)
Scb 2360 (30)
Waukon
Bluestem
GREAT
NORTHERN
C 2390
Edwall
C 2465
Coffeepot Lake
Lake Cr.
Creek
Harrington
Rock Cr.
PAC
Tyler
Pacific Lake
Tule Lake
Mohler
Scb 2060 (60)
Scb 1950 (150)
Fishtrap
Irby
Lamona
Coal Creek
Downs
Scb 1900 (100)
(125)
Duck Cr.
CENTRAL HIGHWAY
Odessa
Scp 1825
(175)
Scp 2180
Scp 2150
Sylvan Lake
Creek
Sprague
HIGHWAY
NOR
SEATTLE
Scp 1900 (250)
Colville Lake
32
33
34
35
36
37
38
39
40
Rocky Coulee
Marcellus
Keystone
Scp 2100
Packard
(200)
Scb C 1955
WASHINGTON
Scp 1820 (50)
Lamont
CENTRAL
Scp 1935
Coulee
Farrier
Big Swamp Lake
(150)
Cow Lake
Scb 1880
RITZVILLE
Coulee
Revere
Schrag
Bowers
Rock
Paha
A D A M S
Lind
Ralston
G 1697 (30)
Lantz
Roxboro
Coulee
PORTLAND
Cow
Winona
C 1535
End

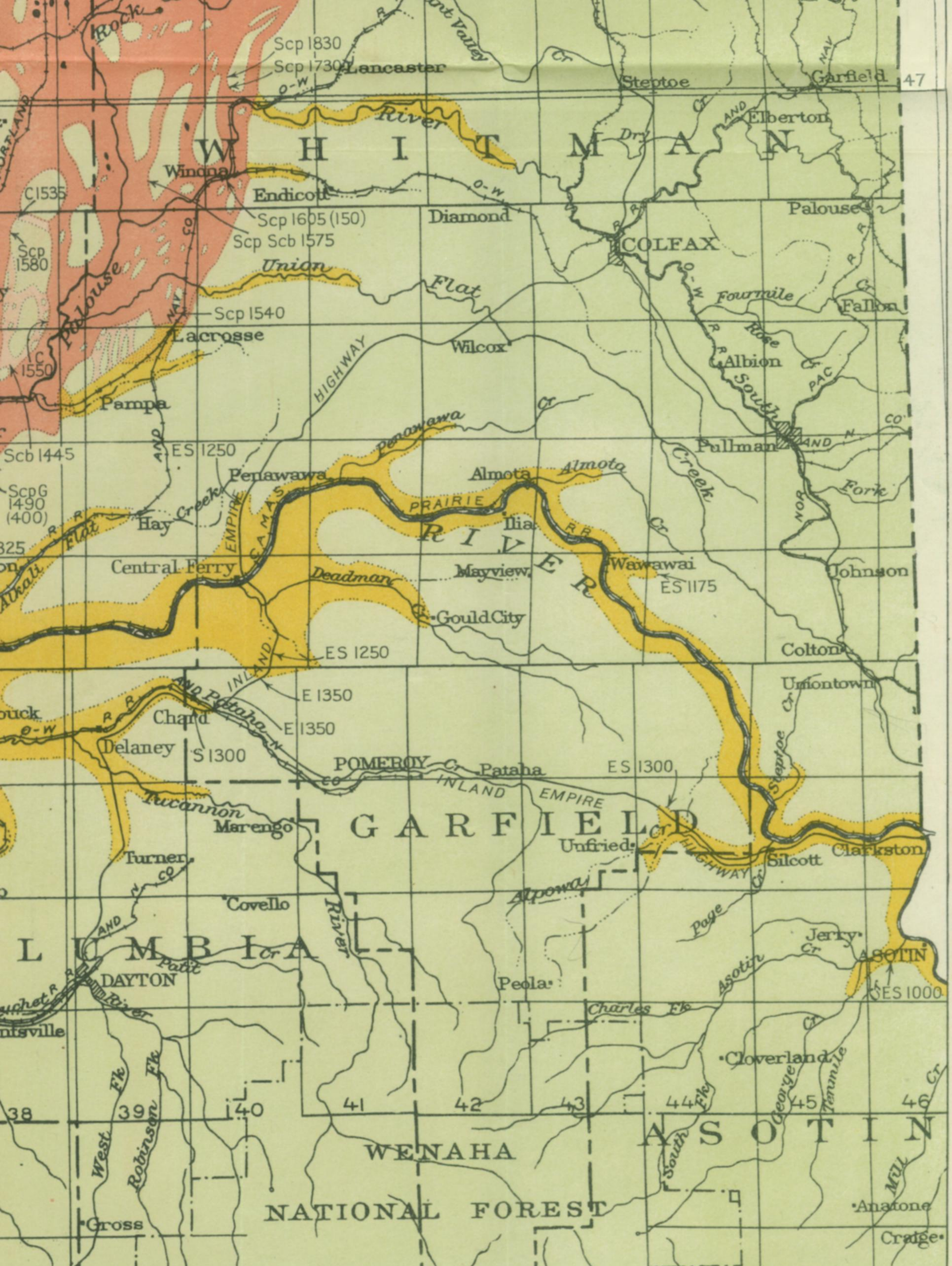

118
117
SPOKANE
WHITMAN
Ford
Tumtum
Denison
Chattaroy
Curby
Buckeye
Colbert
Mead
Peone
Newman Lake
Ninemile Falls
Moab
Hillyard
Spokane Bridge
SPOKANE
Opportunity
Liberty Lake
Chester
Deep Creek
SUNSET HIGHWAY
Mondovi
Reardan
Espanola
Medical Lake
Four Lakes
Marshall
Kiesling
Sharon
Mica
Valley Ford
Freeman
Waukon
Edwall
Cheney
Mt Hope
Rockford
Spangle
Tyler
Fishtrap
Fairfield
Amber
Waverly
Plaza
Sprague
Rodna
Spring Valley
Latah
Colville Lake
Rosalia
Malden
Pine City
Lamont
Rock Lake = 1735
Ewan
Cottonwood
Thornton
Oakesdale
Sunset
Farmington
St John
Belmont
Revere
Lancaster
Steptoe
Garfield
Elberton
Winona
Endicott
Palouse
Approximate Margin of Spokane Ice
Scp 2545
Scb 2515
E 2525 to 2560
C 2490
C 2490
Scp 2500
C 2450
E 2550 (80)
G 2400
C 2465
E 2550
C 2450
Scp 2260
Scp 2100
Scp 2170
Scp 1935
Scb 1880
Scp 1830
Scp 1730
C 1535
38
39
40
41
42
43
44
45
47
GREAT
NOR
NORTHERN
PAC
SEATTLE
HIGHWAY
EMPIRE
INLAND
CHI
MIL
ST P
NAV
CO
AND
O-W
CM & STP
Deer Cr
Deep Cr
L Spokane
Deadman Cr
RIVER
Rock Cr
Pine Creek
Thorn Cr
Pleasant Valley
Rock Cr
River
Dry Cr


Channeled Scabland in Basalt, including many small gravel deposits
Channeled Sedimentary Rocks above the Basalt
Gravel Deposits
Silt and Sand Deposits
Lakes
Wisconsin Moraine
Margin of Spokane Ice
State Highways
Generalized contours in certain tracts
700
Definite Boundaries
Indefinite Boundaries
Walls of Grand Coulee and of north-draining canyons in Telford-Crab Creek tract
Upper Limit Data at point indicated
C = Channel head
S = Silt
G = Gravel
Scp = Scarp
E = Erratics
Scb = Scabland
GE Scp
1630
(400)
Altitude follows abbreviation. Double arrow and figure in parenthesis indicates depth of preglacial valley below upper limit
Quincy Basin
Scp 1300
Frenchman Springs
Scp 1275
Lowgap
Vantage
Frenchman Hill
COLUMBIA
C 1100
Beverly
Crab
Smyrna
Saddle Mount
Corfu
Bend
Wahluke
RIVER
800
600
700
Haven
White Bluffs
500
Gable Mtn
600
Cold Creek
800
700
Wautoma
Cold
600
Sunnyside
Grandview
INLAND EMPIRE
RIVER
Gibbon
Kiona
23
24
25
26
Mabton
PROSSER
Byron
B E N
Creek
Dry
Mule
Glade
Bluelight
Newberry
HorseHea
120


Quincy Basin
Weber
Schrag
Bowers
A D
Scp 1300
Warden
Lind
Roxboro
Coulee
Frenchman Hills
Scp 1275
Drumheller Channels
Scp 1325
Scp 1187
C 1100
Crab Creek
Smyrna
Corfu
Saddle Mountain
Anson
Othello
Cunningham
Hatton
Othello Channels
Scp 1125
Scp 1050-1100
Connell
Washtucna
Sulphur L.
Scp 1100
Scp 1125 (375)
Wahluke
Haven
White Bluffs
Gable Mtn
Hanford
Creek
Mesa
Koontz Coulee
FRANKLIN
Ringold
Eltopia
Cold Creek
Esquatzel Coulee
Scp 1150
Snake River
Page
Eureka
Richland
Benton City
Kiona
Gibbon
PASCO
Burbank
Slater
Kennewick
Badger
PROSSER
BENTON
WALLA
Finley
Two Rivers
Hover
Attalia
Scp Scb 1200
Wallula
Touchet
Lowden
Scb 1150±
Horse Heaven
WALLULA GATEWAY



Schrag
Bowers
Paha
300
A D A M S
Lind
Ralston
G 1697
(30)
Roxboro
Coulee
Lantz
Benge
C 1535
Scp 1580
Winona
W
Scp 1675
Staircase
Rapids
GE Scp
1630
(400)
Ankeny
Palouse
Scp 1540
Lacrosse
Cunningham
Hatton
Scp 1375
C 1350
(350)
Washtucna
C 1550
Pampa
Scp 1335
Hooper
Scb 1445
ES 1250
Penawa
HIGHWAY
C 1250
(370)
Washtucna Coulee
Palouse Canyon
ScpG
1490
(400)
Hay
Creek
Flat
Alkali
E Scb 1325
Canyon
Central Ferry
Washtucna L
Kahlotus
Sulphur L.
Devils Canyon
SNAKE
Scp 1100
Scp 1125
(375)
Lyon's Ferry
Riparia
Ayer Junction
K L I N
Scp 1320
(800)
Starbuck
Chard
Pataha
Delaney
S 1300
Scp 1150
Pleasant View
Scb 1165
Scp 1150
Tucannon
Marengo
Walker
Snake River
Clyde
Turner
Scp 1050
Alto
Covello
C
1050±
ES 1050
C O L U M B I
Page
S 1050
DAYTON
Eureka
Lamar
Prescott
Touchet
Huntsville
Waitsburg
W A L L A W A L L A
32
33
34
35
36
37
38
39
40
Slater
NORTHERN
PACIFIC
HIGHWAY
West Fk
Robinson Fk
ES 1080
Two Rivers
Dry Creek
EMPIRE
Dixie
Gross
N
Attalia
Scp Scb
1200
Tracy
Wallula
S 1050
Mill Cr.
INLAND
Lowden
Touchet
College Place
WALLA WALLA
River
Russell
118
GATEWAY


Scp 1830
Scp 1730
Lancaster
Steptoe
Garfield
47
Elberton
W H I T M A N
Winona
Endicott
Diamond
Palouse
C 1535
Scp 1605 (150)
Scp Scb 1575
COLFAX
Scp 1580
Union
Flat
Fourmile
Fallon
Scp 1540
Lacrosse
Palouse
Rose
Wilcox
Albion
C 1550
HIGHWAY
South
PAC
Pampa
Penawawa
Pullman
Scb 1445
ES 1250
Penawawa
Almota
Almota
ScpG 1490 (400)
Hay
Creek
PRAIRIE
Ilia
Creek
Fork
Flat
R I V E R
Central Ferry
Alkali
Deadman
Mayview
Wawawai
ES 1175
Johnson
Gould City
ES 1250
Colton
E 1350
Uniontown
Chard
Pataha
E 1350
Delaney
S 1300
POMEROY
Pataha
ES 1300
INLAND
EMPIRE
Tucannon
G A R F I E L D
Marengo
Unfried
Silcott
Clarkston
Turner
HIGHWAY
Alpowa
Covello
Page
Jerry
ASOTIN
L U M B I A
River
Patit
DAYTON
Peola
Asotin
ES 1000
River
Charles Fk
Cloverland
38
39
140
41
42
43
44
45
46
West Fk
Robinson Fk
WENAHA
A S O T I N
George
Tenmile
Mill
South Fk
NATIONAL FOREST
Anatone
Gross
Cradge
Butte
Crooked
Grande
Ronde
Hanson Ferry
118
A. Hoen & Co. Lith. Balto.

more than one glacial episode if necessary; upwarp the transected divides to give the present high altitudes above valley floors. Procedures such as described here are unheard-of. Other ice sheets have come and gone and left no such record. How could such quantities of water be yielded from so small a front and with so little retreat?

It may be that there are other significant facts yet to be discovered. But the writer is convinced that the relations outlined in this paper do exist and that no alternatives yet proposed by others or devised by himself can explain them.

That unique assemblage of remarkable physiographic forms on the Columbia Plateau in Washington, described here as the channeled scabland system or complex, records a unique episode in Pleistocene history. Special causes seem clearly indicated. But what these causes were is yet an unsolved problem.