BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 34, PP. 573-608 SEPTEMBER 30, 1923

GLACIAL DRAINAGE ON THE COLUMBIA PLATEAU [1]

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(Presented before the Society December 30, 1923)

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INTRODUCTION

Only the northern part of the Columbia Plateau is concerned in this study and only waters from the Cordilleran ice-sheet. Two glacial epochs are involved—one the Wisconsin, the other as yet undated. Besides contributing to the geological history of the region, this article endeavors to show that glacier-born streams, under proper conditions, are erosive agents of great vigor over large tracts far from the front of the melting ice.

[1] Manuscript received by the Secretary of the Society January 10, 1923.

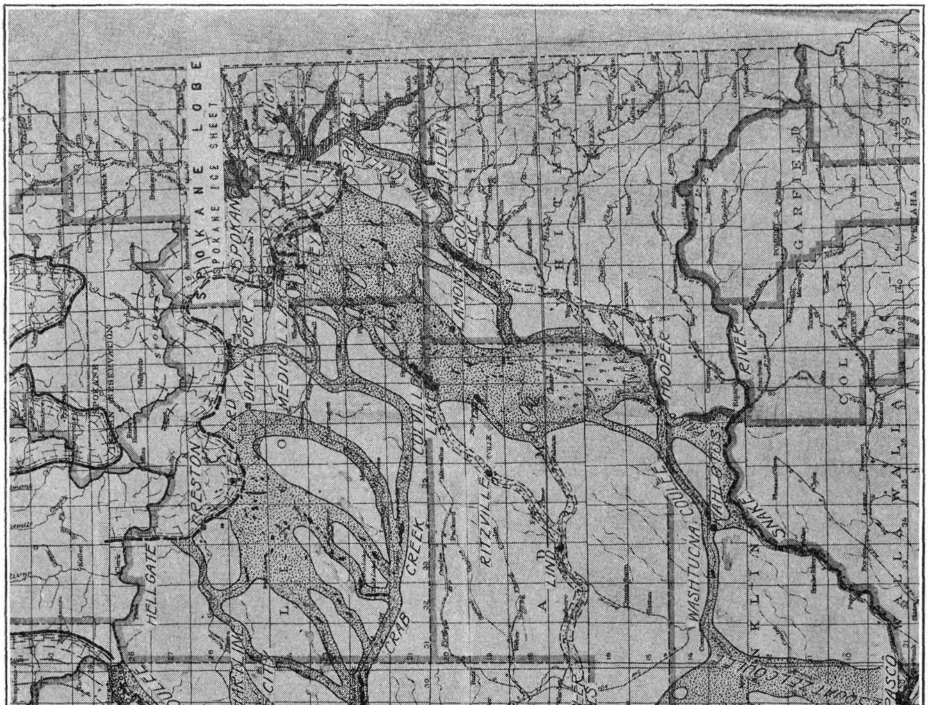

FIGURE 1.—*Glacial drainage Features of east-central Washington*

Topography and Drainage

The Columbia basalt plateau is separated from several mountain ranges on the north and from the Cascade Range on the west by the trench in which flows Columbia River. On the east, the plateau abuts against and interfingers with the Cœur d'Alene Mountains of Idaho. When the Miocene basalt flows of this region ceased, the lava plain abutted in a similar fashion against the mountains on the north and west. The cutting of the Columbia Valley between mountains and plain in the great arc known as the "Big Bend" has partially isolated this portion of the former lava plain and thus given it the character of a plateau. The Columbia Valley north of the plateau is a great canyon, 1,500 to 2,000 feet deep, its bottom less than 1,000 feet above the sea. It does not, however, serve for the complete northern boundary of the plateau. Spokane River, its tributary from the Cœur d'Alene Mountains on the east, may be considered as marking the northern limit of the pleateau east of the Columbia in Washington. The canyon of Snake River in Washington marks the southern margin of that portion of the plateau with which this study is concerned.

Widespread, gentle warping of the Columbia basalt flows in Washington has made a great shallow, structural basin, the rim of which is roughly the margin of the plateau on the west, north, and east. The flows, originally horizontal, are 2,500 feet above tide about the eastern and northern margins and 4,000 to 6,000 feet above tide in the Cascade Range, along the western margin. The lowest tract in the basin is the general vicinity of the junction of Columbia and Snake rivers. Here the basalt flows dip below the Columbia, perhaps below sealevel. Drainage escapes to the Pacific through the Columbia Gorge, cut in the Cascade Range, the greatest water gap on the North American continent.

The expression "the plateau" will be understood in this paper to denote that portion of the Columbia Plateau bounded by Spokane, Columbia, and Snake rivers and the mountains of Idaho.

There are many lesser basins of structural origin in the great feature above outlined and many sharp flexures, particularly in the western part, near the youthful Cascade Range. Most of the drainage lines of the plateau are consequent on its warped surface. The Columbia is the great exception. It approaches the rim from the north, but, instead of crossing and entering the basin, it swings westward and then southward in the Big Bend already described, before entering the basin. As a consequence of this, no waterway of importance enters the Columbia from the concave side of the Big Bend. Drainage of the plateau is centripetal, and the master stream finally enters the basin after it has skirted the northern and western sides in part. Only after it enters does it receive the drainage of the plateau.

The northern rim of the plateau is the highest part. It is a broad divide extending from Spokane west to the southward bend of Columbia River at the foot of the Cascade Range, parallel to Spokane and Columbia rivers and on the average only 10 miles south of them. Down its southern slope flow numerous tributaries to Palouse River and Crab Creek. These two stream systems and Moses Coulee, farther west, are intimately concerned in the glacial drainage history to be outlined.

Palouse River is the largest stream on the plateau north of Snake River. Its drainage area lies in the southeastern quarter of the plateau. Its system consists of a large number of minor centripetal streams which flow westward toward the central part of the basin. It enters Snake River in the middle of the plateau's southern margin. Crab Creek gathers the small centripetal streams from the north-central part and carries their discharge westward toward the Columbia, which it enters not far south of the middle of the western margin of the plateau.

Crab Creek has the largest drainage area of any stream on the basalt plateau of Washington, but there is so little rainfall and so much evaporation in this area that no water today flows to the Columbia. It has been otherwise in the past. The area possesses a complete system of streamways. Some of them are normal valleys in maturity, only the rainfall in some more humid times of the past having formed the streams. Others are canyons of noteworthy, even spectacular, depths, intimately related to the history of the glacial drainage of the plateau.

Stratigraphy

The dominant formation of the plateau is the Columbia lava. It has been completely covered by sedimentary deposits of silt, ash, and loess. These have suffered much from glacial and fluvial erosion, but still persist and give character to the topography and soils of more than half of the plateau. In the western part of the plateau this sediment is presumably the Ellensburg formation. It is intimately related to the basalt, its deposition beginning in some places before the great basalt flows had ceased, and in other places later and minor basalt flows occurring after its accumulation had well begun. If the sedimentary formation, or its lower part, is Ellensburg, its presence indicates clearly that the plateau is determined by the original surface of the Miocene lavas, not by any later erosional plans developed on the basalt.

PHYSIOGRAPHY

The surface of the plateau bears two strikingly different physiographic aspects. Locally, one is known as "Palouse Hills" and the other as "Scabland." Not alone are these sharply contrasted areas in close juxtaposition, but they are interfingered and interlocked. Every one of the seven counties of the plateau possesses areas of both types.

The "Palouse Hills" topography is best shown in Whitman County south of Spokane and in the eastern half of the Palouse River system. The region is essentially all in slopes, a network of drainage lines covers it, the soils are fine and deep, and ledges of basalt are exposed only on

FIGURE 2.—*Steptoe Butte and the maturely dissected Palouse Region east of the "Scablands"*

lower slopes and rarely on these. Profiles are convex only on hilltops; all valley slopes are strikingly concave. The "Palouse Hills" topography is typically mature. It is developed in the super-basalt sedimentary in large part. Its relief averages about 250 feet. The main streams now are in canyons in basalt below the floors of the mature valleys. This type of topography (figure 2), with the same soils and underlying formation, is widely distributed elsewhere on the plateau, but the drainage pattern is not so intricately detailed farther west, where rainfall since the uplift of the Cascade Range has been less.

The "Scablands" are lowlands among the groups of "Palouse Hills," plane in a general way, but diversified by a multiplicity of irregular and commonly anastomosing channels and rock-basins eroded in basalt, and containing meadows, swamps, and lakes (figures 3 and 4). The local name refers to the absence of soil over much of these tracts, the basalt outcropping in ledges and over considerable level areas. The "Scab-

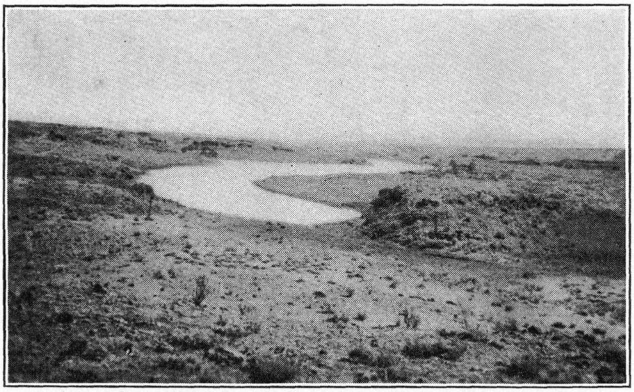

FIGURE 3.—*Channeled "Scabland" of Spokane Age*

This area is on the plateau near the head of Grand Coulee.

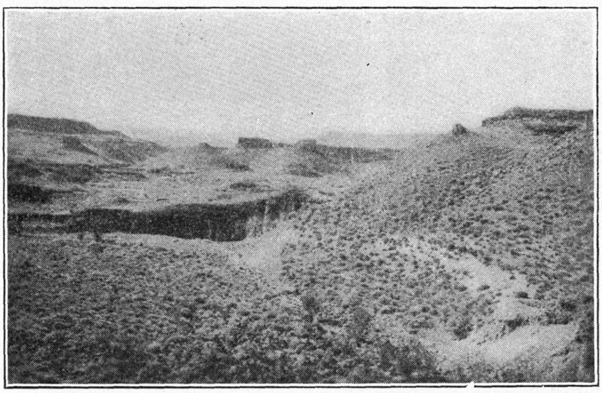

FIGURE 4.—*Spokane Drainage Channels in Mid-length of Moses Coulee*

The narrow inner channel is of Wisconsin age.

lands" are commonly elongated tracts, with their channels and rock basins elongated in parallelism. Some of these channels are canyons several hundred feet deep. Almost all of the lakes of the plateau lie in the Scablands (figure 5). None occur in the Palouse Hills.

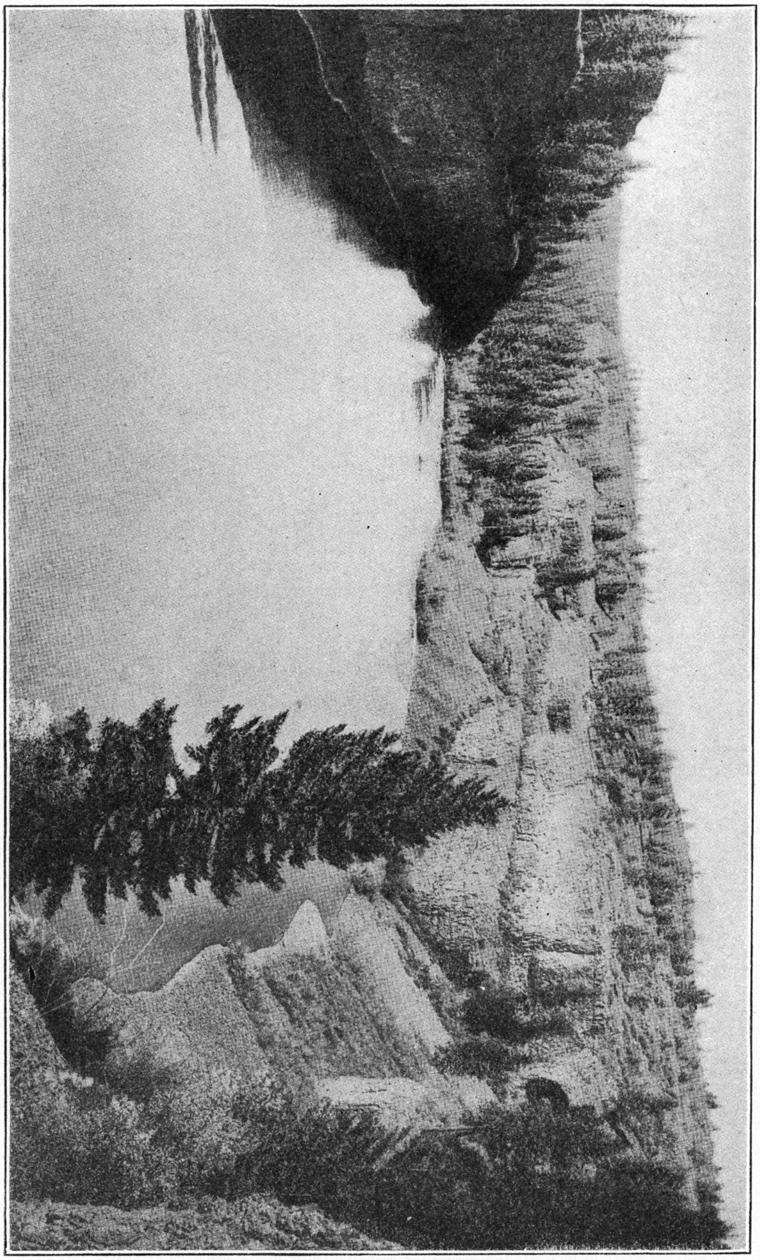

FIGURE 5.—*Rock Lake, in a glacial Drainage Channel of Spokane Age*

Glaciation

Probably the entire highland area north of the plateau was buried beneath the Cordilleran ice-sheet during the Pleistocene glaciations. At least three times the Cordilleran ice forced a crossing of the Columbia Valley and advanced onto the plateau. The latest of these, of Wisconsin age, has been described; the earlier ones thus far have been but noted in the literature. Farther east, where Spokane River serves as the boundary, only two glacial invasions of the plateau are known, both of which are pre-Wisconsin, and only brief notes exist regarding them.[2] The latter of these two glaciations is well recorded in the topography. With it and the Wisconsin glaciation on the northwestern part of the plateau this paper chiefly deals.

The Spokane Glaciation

GENERAL STATEMENT

Observers for years have been noting the existence of granite boulders scattered over the basalt plateau of Washington far beyond the limits reached by the Wisconsin ice. They are now known to belong to four categories: (1) derived from knobs of granite buried in or projecting above the basalt flows, (2) berg-drifted in a widespread ponding during late Wisconsin time,[3] (3) glacier-borne during glaciations earlier and more extensive than the Wisconsin, and (4) berg-carried in great streams born of one of these earlier ice-sheets.

The precise limits reached by the earlier ice-sheets are as yet unmapped, but enough is known to indicate that the latter of the two crossed the Columbia and Spokane valleys from the northern highlands, pushed well up on the rim of the plateau, and in the vicinity of Spokane advanced south of the rim divide as far as Spangle and nearly to Cheney. No prominent morainal margin now exists, if one ever was formed, but the till, the striated erratic boulders, the deposits of outwash material, and the drainage channels constitute adequate evidence of the glaciation. It is here named the Spokane glaciation. Details which are essential to a conception of the character of the Spokane glaciation, so far as it is now known, are here presented.

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[2] Frank Leverett: Bull. Geol. Soc. Am., vol. 28, 1917, p. 143.
M. M. Leighton: Bull. 22, Wash. Geol. Survey, 1919.
Thomas Large: Science, vol. 56, 1922, p. 335.
J. T. Pardee: Science, vol. 56, 1922, p. 686.

[3] J. H. Bretz: The late Pleistocene submergence in the Columbia Valley of Oregon and Washington. Jour. Geol., vol. 27, 1919, pp. 489-506.

SPOKANE RIVER AND PALOUSE RIVER DRAINAGE

Vicinity of Spokane.—The city of Spokane is built in a valley eroded in the basalt, not more than 10 or 15 miles from the margin of the plateau. To the east rise the mountains of Idaho—an older, higher land surface whose embayed and spurred flanks make an irregular contact between mountains and plateau. Moran Peak, about 8 miles southeast of Spokane, is one of many isolated peaks of the older mountains, standing out in the plateau. Remnants of the plateau extend perhaps 20 miles north of Spokane, separated by the valleys of the Spokane and its tributaries and terminated on the east and north by higher hills of crystalline rock. These remnants constitute mesas, such as Pleasant Prairie and Five-Mile Prairie, about 2,400 feet above tide and about 400 feet above the surface of the Wisconsin valley trains in the intervening valleys. The summits of these flat-topped hills apparently mark essentially the original surface of the Columbia lava flows. West and south of Spokane the Columbia plateau extends for many miles, interrupted only here and there, near the margins, by island-like hills or mountains of older rock.[4]

Boulders of various crystalline rocks, igneous and metamorphic, with characteristic glacially planed, beveled, and striated surfaces, lie scattered on the surface of the Columbia plateau about Spokane, extending as far south as the base of Moran Peak and the village of Spangle, close to the base of the Palouse Hills. They have not been found, however, in this maturely dissected country, nor at altitudes much above 2,500 feet above tide on the northern slopes of Moran Peak and Mica Peak, east to the Idaho line.

Outwash gravel deposits at similar elevations and close to the driftless Palouse Hills are known at Pantops, along the Inland Empire Highway, and elsewhere. The deposit at Pantops is at least 30 feet deep and possesses current bedding with southward dip. It lies on the basalt plateau not more than a mile west of the base of Moran Peak, at an altitude close to 2,400 feet above tide. The gravel in the deposit is not stained or cemented; it looks as fresh as Wisconsin gravel in the Great Lakes region. Scattered through it are hundreds of granite boulders averaging 3 feet in diameter, many of them exceeding 10 feet. The gravel is not coarse, there are no cobble phases in it, and the boulders are wholly out of accord with the gravel as a stream deposit. Furthermore, the boulders are subangular and show considerable decomposition of the granite on their less-rubbed surfaces. They doubtless are a local contribution, de-

[4] Named "steptoes" by Russell.

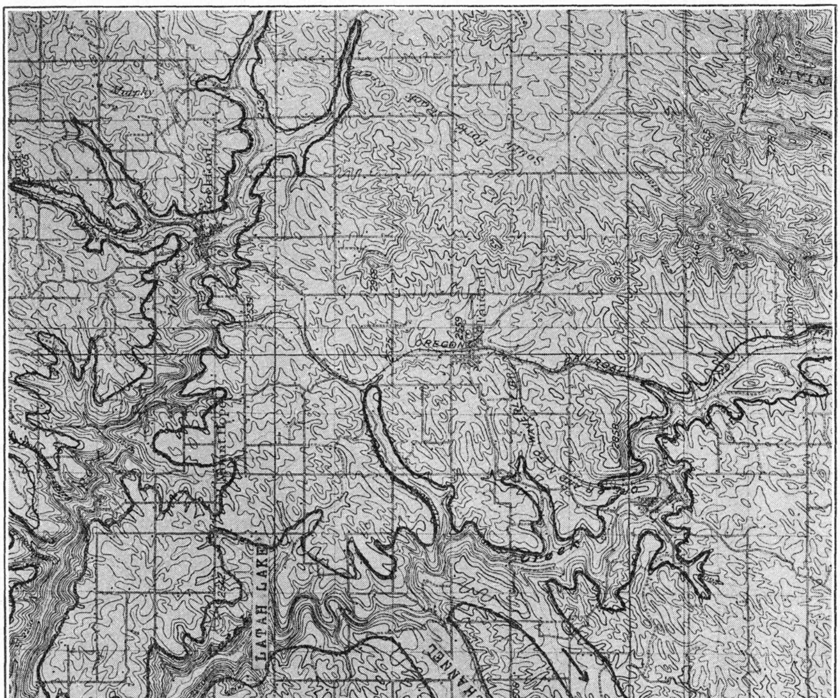

FIGURE 6.—*Glacial Ice and Drainage near Spangle, Washington*

rived by glacial plucking of the decayed granite on the northern flanks of Moran Peak and Mica Peak. They are boulders of decomposition and doubtless were easily quarried by the ice. Their abundance in the gravel and the little rubbed condition are clear indications that the front of the ice-sheet did not advance far beyond this place.

Despite the fresh appearance of the gravel at Pantops, the topography gives no clue to its presence. From what can be seen now, it is difficult to determine whether the Pantops gravel is a kamey deposit or is a remnant of a valley train or outwash plain. It blends into the lower slopes of Moran Peak and the basalt plateau.

There are other gravel deposits on the plateau immediately south of Spokane, similar to that at Pantops in altitude, bedding, freshness of material, and absence of fluvio-glacial forms, but none possess the granitic boulders of decomposition.

Vicinity of Spangle.—The village of Spangle is 12 miles almost directly south of Pantops and 15 miles south of the eastern part of Spokane. Maturely dissected driftless country lies to the east and south, a scabland plain to the west (figure 6). Striated erratics have been found here as high as 2,500 feet above tide, on the slopes which face the scabland, and within 100 feet of the hill tops.

The drainage of this part of the Palouse country is northwestward, toward the scabland tract. When glacial ice stood at the limit marked approximately by the north-south line between Pantops and Spangle, this drainage was blocked and a lake was formed for which another dischargeway was necessary. The waters of Latah (Hangman) Creek and its tributaries, Rock Creek, California Creek, Mica Creek, etcetera, augmented by a great volume of water from the ice, spilled over the divide west of Latah Creek, about 6 miles southeast of Spangle, and entered North Pine Creek, a minor tributary of Pine Creek, flowing thence southwestward 20 miles across the unglaciated Palouse hill land to enter the scabland region at the north end of Rock Lake. The prominent spillways were eroded across the divide into North Pine Creek Valley.[5] The floor of each of the cols is on basalt at about 2,450 feet above tide *and is essentially a scabland tract.* The glacial waters back of this double spillway doubtless were ponded in Latah and Rock Creek valleys.

During the occupation of the spillways these waters eroded deeply in the basalt. The larger spillway is half a mile wide at the col. Both are well shown on the Oakesdale topographic map and on the Spokane County soil map. Near the junction of North Pine Creek and Pine

[5] Thomas Large: The glaciation of the Cordilleran region. Science, vol. 56, no. 1447, 1922, p. 335.

Creek and in the larger valley are great bars and terraces of coarse basaltic gravel, poorly sorted and much of it subangular. Mingled with it are a few cobbles and small boulders of granite and quartzite. The material farther down Pine Creek Valley is finer and better sorted. It seems clear that most of the debris was derived by erosion of the spillways themselves, only a small amount of foreign material crossing the lake on ice-rafts from the front of the ice-sheet.

The valley during this episode in its history was but a channel. The glacial stream filled it from side to side for a depth of tens of feet. This is shown a few miles above Malden, where the stream flooded over a low shoulder of basalt, cutting a channel in the rock at least 40 feet deep; though the main valley alongside was wide open and received gravel deposits. North Pine Creek now flows through this channel. The main current of the stream here cut across a curve in the preexisting valley. The gradient of this glacial stream was close to 30 feet to the mile in its upper part and about 20 feet to the mile in the lower part.

The character of the terraces in Pine Creek Valley below the junction of North Pine Creek is instructive. Like the Pantops deposit, there are no well defined depositional forms. The terrace tops do not abut sharply against the hillslopes, but instead waste has crept out on the gravel deposits from the slopes above, and the valleyward edges of the terraces have become rounded and notched by widened gullies until the terrace form is obscure. This is well shown at Kenova, where the Chicago, Milwaukee and Saint Paul Railroad has opened a large pit in the gravel. Furthermore, these terraces are only fragments here and there of what was once a continuous filling. Despite these evidences of considerable age, the material in the deposits appears fresh. It is unstained and uncemented.

Only one other glacial drainage route across the mature Palouse country is known, and this was but a tributary to the Pine Creek channel. Waters from glacial ice spilled southward through a low place at Mica between Moran Peak on the west and Mica Peak on the east. The altitude of the col at Mica is hardly 10 feet above that southeast of Spangle. Ponded waters of the Latah Valley must have backed up almost to the village of Mica. Whether or not a considerable lake lay to the north of the Mica col,[6] it is certain that the ice-sheet was hard against the northern flank of Moran Peak and its drainage probably passed through a settling basin before entering the short Mica channel. A few erratics, one of them striated, have been found in the channel, but no glacial

[6] "Lake Spokane" of Large.

stream gravel. Nor was the Mica channel eroded to any extent. Probably ponded waters were backed up from the south until the last stages in erosion of the North Pine Creek channel.

Vicinity of Cheney.—Cheney lies 15 miles southwest of Spokane and 10 miles northwest of Spangle. About this town are recognizable the same elements in the topography as already outlined—the higher prebasalt hills, the Palouse type of maturely dissected hills, and the lower scablands. The scablands have less relief than either of the other elements, but are much rougher. They are commonly a maze of minor channels and depressions eroded in the basalt.

Cheney lies at the head of the largest tract of scabland on the plateau—a tract which extends from Spokane River to Snake River. It is not uninterruptedly scabland, however. It contains isolated groups of Palouse Hills. One of the largest of these groups lies immediately north of Cheney and has an area of about 13 square miles. Many of them are not a square mile in area. In topography and in soil, these tracts are identical with the Palouse wheat country to the east and southeast; but the gentle, concave lower slopes of maturity, so characteristic of these hills, is absent on the peripheries of the isolated groups. Instead, these outer slopes are much steeper and are generally convex. They meet the roughened plain of the scabland with a definite angle. The bounding slopes clearly are much younger than the valley slopes among the hills.

The hill groups are elongated northeast-southwest, in harmony with the elongation of the channels on the basalt surface and with the scabland tract as a whole. In many of these linear groups there are longitudinal valleys, not of the mature type, but with steep sides and scabland floor. All such valleys pass completely through a hill group, leading from the rocky plain into the rolling hills and out again to the plain.

Another feature of this great scabland tract is the presence of many widely scattered granite boulders. Nowhere (with one exception, to be detailed later) has this foreign debris been found back among or on the slopes of the hill groups. Associated with it, but much less common, are terraces of gravel composed largely of basaltic debris, but with granite and other foreign material distributed through it. Such deposits commonly lie on the southwest sides of rocky shoulders or hills in the channels. They have been opened for railroad ballast and road metal at many places over the whole scabland area.

From a survey of the patches and groups of the Palouse Hills scattered over the scabland plain south of Cheney, it seems clear that they are but remnants of a once continuous cover of the basalt, and that the scablands have resulted from removal of the Palouse Hills by erosion in some unusual way. The basalt of the scablands is the firm and resistant foundation on which the hills stand. The overlying sedimentary deposit is the formation whose etched surface constitutes the hills.

The scabland does not extend north of the Palouse Hills about Cheney and Medical Lake, though it does extend among them in great river channels to their northern limits. Farther north, there is neither scabland nor Palouse Hills. The area is a basalt plain with widely spaced mature valleys and broad, low, flat divides. The whole is thinly covered with glacial drift, some of it a stony till with hummocky morainic topography, some of it washed and stratified glacial sand and gravel. The ice-sheet clearly covered this plain. It, however, did not extend southward into the scabland area, except for a minor lobe between Moran Peak and the Cheney Hills, which reached as far south as Spangle. The association of broad undissected divides with shallow, mature valleys, all in resistant rock (for example, Deep Creek and its tributaries) is anomalous. It is believed to be the result of the glaciation of a tract which possessed a typical Palouse mature topography, developed largely in a silt or ash deposit, but etched in the deeper valleys into the surface of the underlying basalt. The ice removed every trace of the hills in the weaker formation, bringing the whole down to the surface of the basalt; in effect, it cut off the hills well down to their bases without greatly modifying the main valley bottoms.

Vicinity of Lamont.—Twenty miles to the southwest of Cheney the escaping glacial waters had become largely concentrated between Sprague and Lamont. The eroded tract here is nearly 10 miles wide and without a surviving Palouse hill. A sheet of torrential water must have spread completely across the scabland between these two towns. It rapidly removed the weaker material of the Palouse Hills and then scoured out channels in the basalt. By the close of its occupancy it had concentrated in certain channels and eroded them approximately 100 feet below the surface of the basalt. Colville (Sprague) Lake lies in one of these channels.

Between Lamont and Rock Lake, to the east, is a linear tract of Palouse Hills about eight miles wide and traversed by but one valley possessing bare rock in its floor and scattered granite fragments. Separating this tract from the Palouse country of Whitman County is a great river channel, occupied now by Rock Creek and several elongated lakes. Rock Lake is the largest of these and, save one, is the largest and longest lake on the Columbia Plateau of Washington. Rock Lake (see figure 5) is bounded on both sides by sheer cliffs of basalt 200 feet and more in height. There is no damming of consequence in the channel at the lower end of the lake. Rock Lake exists because the ancient river here excavated more deeply in its bed than it did a little farther down stream. Rock Lake is typical of most lake basins of the Columbia Plateau in Washington, in that it is a much elongated true rock-basin in an ancient river channel in a scabland area. The only part played by glacial ice in the formation of these basins is that of supplying the stream. Factors essential for development of these rock-basins made by streams are (1) large volume abruptly introduced, (2) high gradient, and (3) rock which is closely and vertically jointed. The excavation was accomplished by plucking, rather than by grinding.

Vicinity of Kahlotus.—About 25 miles south of the latitude of Rock Lake the scabland is more restricted. So far as now known, all channels but one entered Snake River in the vicinity of the present junction of the Palouse. The one channel which escaped the control of the Palouse system is traceable westward, by way of Washtucna, through Kahlotus, to Esquatzel Coulee at Connell. It is a splendid abandoned channel, in places 250 to 300 feet deep. Throughout its length it has all the characters of the channels of the scabland tract to the east and northeast except that it does not lie in such a tract. It probably was sufficiently deep at the inception of the flood to contain the waters which came its way. A few miles above the junction of Washtucna Coulee, Esquatzel Coulee has none of these characters, but possesses the broad, graded slopes of maturity.

Vicinity of Sprague.—The westernmost channels among the Palouse Hills near Cheney which discharged to the Palouse system enter the broad scabland between Sprague and Fishtrap. The roughness of these channel floors, due to the gashed basalt, is in striking contrast with the smooth flowing contours of the inclosing hills. One needs but little imagination to see again from these hilltops the torrents of glacial waters invading from the north and following the lower valleys southward to join the scabland between Sprague and Lamont. These hills, like those in the Palouse wheat lands, are composed largely of a fine-textured unindurated sediment, probably of lacustrine origin.[7]

It does not seem probable that any water, other than that which occupied Washtucna Coulee, escaped westward from the Palouse drainage during the Spokane epoch. There are two possible routes, however, of such discharge, namely, one by way of Keystone, near the lower end of Colville (Sprague) Lake and Ritzville; the other by way of Ralston. Both enter Lind Coulee at Lind. The altitude at the head of the Ritz-

[7] M. R. Campbell: Guidebook of the Western United States. Part A: The Northern Pacific Route. U. S. Geol. Survey, Bull. 611, 1915, p. 163.

ville route is 53 feet above the surface of Colville Lake in the adjacent scabland, and Ralston is not 100 feet above the floor of the Cow Creek channel. Along both routes are deposits of stream gravel.[8] Yet no scour of the floor by glacial waters, nor steepened valley walls, nor scattered erratic boulders or cobbles were seen.[9] It is possible that these routes were used for but a short time early in the glacial flooding, or it may be that the gravels are older than the Spokane glaciation. It may be, also, that the gravels in channels near Winona and Lacrosse, south of Rock Lake, are of pre-Spokane age.

The scablands of the Palouse drainage, with channeled basalt, deposits of stratified gravel, and isolated linear groups of Palouse Hills, their marginal slopes steepened notably, bear abundant evidence of a great flood of glacial waters from the north. This flood was born of the Spokane ice-sheet. Its gradient was high, averaging, perhaps, 25 feet to the mile, and it swept more than 400 square miles of the region clean of the weaker material constituting the Palouse Hills. The hills which have disappeared averaged 200 feet in height, and in some places the glacial torrents eroded 100 to 200 feet into the basalt. This flood originated at several places along the ice-front. Great river channels exist among the remaining hills in the flood-swept region. The area overridden by the ice itself has lost every trace of Palouse Hills.[10]

CRAB CREEK DRAINAGE

General statement.—By at least ten different routes, glacial waters from the Spokane ice-sheet west of Cheney and Medical Lake converged to Crab Creek. Another discharge way, still farther west, that of Moses Coulee, found its own way to the Columbia above the entrance of Crab Creek drainage. The glacial streams tributary to Crab Creek, named from east to west, were Rock Creek (Lincoln County), the headwaters

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[8] M. M. Leighton: The road building sands and gravels of Washington. Wash. Geol. Survey, Bull. 22, 1919, pp. 104-105. Leighton clearly recognizes that the Spokane region had been glaciated (p. 246), that numerous glacial drainage courses exist on the plateau (p. 34), and that the scablands are due to erosion of the sedimentary material by escaping glacial waters (p. 279).

[9] Campbell, op. cit., also notes the absence of the granite boulders along the Northern Pacific Railroad, which follows the Ritzville route, west of the lower end of Colville Lake.

[10] Explanation should here be made of certain glacial deposits which are older than the Spokane drift. In an abandoned clay pit near the Cheney Normal School is a very old clayey till first reported by Frank Leverett (Bull. Geol. Soc. Am., vol. 28, 1916, p. 143). It contains striated quartzite boulders and cobbles. One such boulder also has fine chatter-marks on it. Granite is present, but is crumbling or etched to such an extent that no ice-marked surfaces remain. This till also is exposed along roadsides south and east of Granite Lake, and striated erratics have been found back in the mature valleys of this hill group. It seems probable that the old till underlies much of these

of Crab Creek, Coal Creek, Duck Creek, Lake Creek, an unnamed creek west of Lake Creek, Connawai Creek, Wilson Creek, Spring Coulee, and Grand Coulee. The first eight originated from the ice on the northern rim of the plateau between Hellgate and Medical Lake. The other two entered the plateau from the Columbia Valley by one route, upper Grand Coulee, and separated at Coulee City. The location of the edge of the Spokane ice near the head of Grand Coulee is as yet unknown.

The glacial river courses are all youthful canyons in basalt. They are quite unlike the associated drainage lines of comparable length which never received glacial waters and which are typical valleys in maturity. The youthful canyons, however, were not eroded by the streams which occupy them. Despite their size, most of them are but the deepened channels of ice-born rivers, and not true valleys. Like the scablands of the Palouse region, invading, but short-lived, floods traversed the area; but they failed in the main to produce broad, stream-scoured surfaces of bare rock. Where they entered preglacial valleys in basalt they were not able to broaden them much. Extensive scablands have been formed only where the preglacial drainage pattern was eroded in a weak, super-basalt sedimentary deposit.

The limits reached by the Spokane ice-sheet west of Cheney and Medical Lake are not well known, since there is no morainal ridging along the margin. The approximate boundary, as shown on the accompanying map, has been located along the southern limits of a basalt plain with much bare rock and a scattering of glacial debris. South of this margin are unglaciated loess-covered hills of mature aspect and the scoured, and in many places canyon-like, glacial drainage channels. The limits as drawn are, perhaps, too far south in places. The ice is not known to have crossed the Columbia between Hellgate and the head of Grand Coulee. It did cross, however, in Douglas County, farther west, and advanced far enough to discharge its waters into Moses Coulee. The Wis-

hills. The till is covered with several feet of loess at Cheney. The loess is deep on all Palouse Hills of eastern Washington, but does not occur on the scablands or on the glaciated plain to the north. It therefore is older than the Spokane glaciation. Since this Cheney till is beneath the loess and probably underlies the Palouse Hills, it is much older than the mature topography. There is no more suggestion of glacial overriding in the shapes of these hills north of Cheney than there is in the typical Palouse region of Whitman County.

On the other hand, certain large pre-basalt hills west of Medical Lake, rising high above the Palouse Hills of the region, do show a prevailingly steep northern slope and gentle southern slope, as though they had been overriden by glacial ice. If this profile has had such an origin, it must be ascribed to the pre-Spokane, pre-loess glaciation.

The glacial till reported by Pardee (op. cit.) at "scores" of places over large parts of Lincoln, Spokane, and Adams counties, and as far south as Kahlotus, probably is similarly related to the loess which deeply mantles the Palouse Hills of those counties.

consin glaciation of northern Douglas County was more extensive than the Spokane and obliterated all records left by the Spokane ice.

There are scablands in the northern part of some of these spillways, notably between Davenport and Rocklyn and in the vicinity of Telford. The detailed relations of the largest, at and southwest of Telford, are not yet well known; but concentration in preexisting valleys in basalt was completed in most cases within 10 miles or so of the edge of the ice, and rock-walled canyons with elongated lakes in the bottoms are the rule. The altitudes of the heads of these spillways are not the same, and had not the ice been hard against the unglaciated hills south of the basalt plain, marginal drainage would have carried all waters to the lowest of the group.

Gravel deposits and scattered granite boulders and cobbles are well distributed in these coulees. Gravels are chiefly of basalt and appear as fresh as in the scablands of the Palouse drainage. The terrace forms are indefinite, wide-open gullies have dissected them, and they are but remnants, perhaps miles apart, of former probably continuous fillings. This also is comparable to the gravels of the main Palouse channels.

Because of the prominence of cliffs in these canyons of Crab Creek drainage, another feature is well presented—the talus piles which have formed since the glacial streams abandoned their channels. The cliffs are, without exception, composed of the Columbia lava, and, with very few exceptions, the flows are horizontal or but gently inclined and possess columnar jointing. The conditions of origin produced essentially vertical cliffs, and the rock structures and arid climate have maintained vertical faces during all subsequent wasting of the cliff and growth of the talus.

Except in Grand Coulee and Moses Coulee, which carried Wisconsin glacial waters also, these canyons have been occupied by inconsequential streams since the Spokane glacial floods subsided. The present talus, therefore, is a measure of all post-Spokane disintegration in the vertical walls of jointed lava. In the great majority of cases the talus extends from the rock-floor of the canyon three-fourths to four-fifths of the way to the top (see figures 4 and 7). In the lower cliffs it has climbed even nearer the summit, and rarely the cliff has become obliterated by the mounting waste. The talus slopes range between 20 degrees and 30 degrees, with the average probably between 25 degrees and 30 degrees.

Since conditions of origin, of rock structure, and of climate are sufficiently alike in the Crab Creek and Palouse drainage areas, it follows that relative proportion of talus on cliffs of comparable height may be a valuable criterion to establish more firmly the contemporaneity of glacial drainage in the two areas. The cliffs of the Palouse scabland, though less prominent on the whole than those of the Crab Creek canyons, everywhere possess the same average ratios of talus height to depth of channel and the same degree of slope. Further use of this criterion will be made when the Wisconsin glacial drainage channels are examined.

Grand Coulee.—Grand Coulee heads in the south wall of Columbia Valley, about 550 feet above the river. At its head it is 1,000 feet deep and about 3 miles wide. In the middle of this valley, 10 miles from the Columbia, stands Steamboat Rock, a basalt mesa with its square mile of summit area at the general altitude of the plateau on either side of the coulee. There are also numerous pre-basalt hills of granite on the floor between Steamboat Rock and the Columbia, formerly buried in the basalt

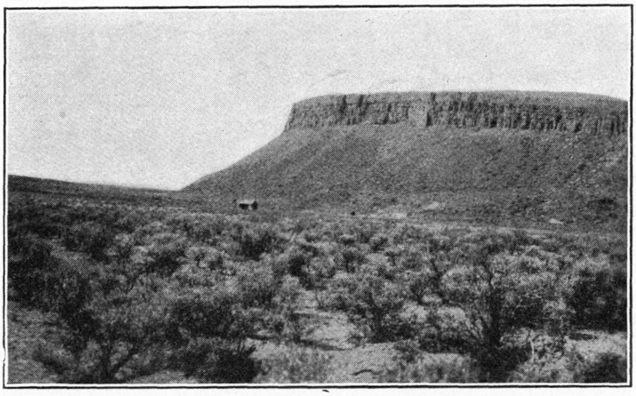

FIGURE 7.—*Post-Spokane Talus in "The Potholes" south of Trinidad*

and later exhumed in the erosion of the coulee. About 13 miles from the head the canyon narrows to about 2 miles and maintains this width and a depth of about 800 feet as far south as Coulee City. Here the canyon form is lost for 4 or 5 miles, the eastern wall descending, because of a monoclinal flexure, until it is not more than 200 feet above the floor of the coulee. In this broadened portion is a great abandoned cataract with a fall of 400 feet. The width of the falls is nearly 3 miles, the full width of the bottom of the coulee; but it was broken into two different parts in its later history through erosion of the floor above the falls. A central portion of the earlier floor, which escaped much of this erosion, became an island on the brink. The western half, Dry Falls or Grand Falls, is the more definite and in itself was a double fall at the close of the history of this great cataract, with a "Goat Island" in the middle. No water now flows over these falls except in times of heavy rain.

Below the falls the coulee again becomes a canyon, both because of the gorge left by retreat of the falls and because the basalt surface rises in that direction. For 15 miles or so this lower coulee is a wild, spectacular feature, its western wall fully 1,000 feet high and its bottom less than a mile in width. For most of this distance the ancient river flowed on the strike of a monoclinal fold the dip of which averages 45 degrees and is to the southeast. The falls took origin where the glacial stream passed from horizontal flows to the tilted structure, about 3 miles below their present location. Grand Coulee debouches in a broad, shallow structural depression, the Quincy basin. Into this same basin discharges Crab Creek, which carried the combined flow of all of the glacial rivers previously listed.

As above outlined, Grand Coulee is a relatively simple affair, with two canyoned portions separated by a shallower part, due to local structural conditions, with a remarkable waterfall in midlength and with a part of its lower course along tilted flows; but the preglacial conditions and the glacial history are not as simple as in the region farther east.

There is no evidence of a preglacial drainage line along the upper canyon between Coulee City and the Columbia. There are but two tributary gorges in the 30 miles of this canyon and these are short and youthful. A mature topography, untouched by glacial ice or water, lies on the plateau to the east, with no drainage lines leading to the coulee. To the west the plateau was glaciated to the edge of the coulee during the Wisconsin epoch, but preglacial topographic features still control and give no suggestion of drainage toward the coulee. Moreover, the altitude of the basalt on the precipitous edge of the canyon is about that of the Columbia River-Crab Creek divide; and on both sides of the coulee, near the head, especially well shown on the unglaciated east side, is a scabland tract (see figure 3), with the mature hills gone and the basalt etched and roughened by a maze of anastomosing minor channels and rock-basins, separated by low buttes and knobs. Elongated meadows, and even lakes, mark some channel courses. No channels are more than 75 feet deep. Glacial erratics of diorite, argillite, slate, schist, and quartzite occur here and there. Especially significant is the talus, which has climbed three-fourths to four-fifths of the total original heights of the channel walls and nowhere is steeper than 20 degrees. On the east side this summit scabland is 3 miles wide, as wide as the floor of the coulee itself, but 1,000 feet higher. The altitude here is about 2,500 feet above tide.

In order that glacial waters should have spilled across this place, the ice-sheet must have blocked the Columbia, both to the west and the east, else lower routes in either direction would have taken the discharge. That it was the Spokane ice-sheet is evident from the amount of breaking down of cliffs since the waters ceased to flow. Searching over the basalt, the wide glacial stream finally selected its central portion, now Grand Coulee, for deeper trenching and withdraw from the margins. Only Steamboat Rock records any of the original anastomosis. To what depth the Spokane waters cut in upper Grand Coulee will be discussed under the subject of Wisconsin glaciation.

Hartline structural valley.—The monoclinal flexure along which much of lower Grand Coulee is eroded swings toward the east about 2 miles north of Coulee City and extends beyond Almira toward Hellgate. Another fold, anticlinal in character, lies nearly parallel with it, about 5 miles to the south. The tract between is structurally and topographically a valley and contains a gravelly plain approximately 40 square miles in area. The floor of the coulee at Coulee City is only 200 feet below this flat, and the entire descent to the town from the flat is across gravel. Wells on the flat penetrate sand and gravel to comparable depths.

The drainage of the Hartline gravel plain is largely southward through Deadmans Draw, a tributary of Spring Coulee, 10 miles east of Grand Coulee. Deadmans Draw is but the deepest and most pronounced of a scabland complex of abandoned channels, basins, cascades, and falls, identical in character with and very similar in proportions to those on the plateau along the east side of the head of Grand Coulee. Talus development is the same. Furthermore, the patchy gravel deposits and stranded erratic boulders tell unequivocally of glacial waters escaping southward across the rim of the structural basin.

East of Deadmans Draw, as far as Wilson Creek, are gently rolling hills with concave lower slopes and deep loessial soils, which have never been touched by invading glacial waters; but between the draw and Grand Coulee to the west, and from Coulee City south to Bacon Station, a distance of 8 miles, is a tract which for wild ruggedness is unsurpassed anywhere among the glacial spillways thus far described. The channels are canyons and the knobs are hills 100 to 300 feet high. Stream gravel covers the interchannel hills. The whole area was overrun by the glacial flood out of the Hartline structural valley. Besides this, at least three of the channel canyons lead *out of* Grand Coulee below the falls, but at about the level of the floor above the falls. It is magnified scabland of the Palouse type. One of these channels leads to Spring Coulee, the others converge to Dry Coulee, a small feature debouching into the Quincy structural basin 5 miles east of the mouth of Grand Coulee.

Some of these are truly distributary canyons. They mark a distributive or braided course of the Spokane glacial flood over a basalt surface which possessed no adequate pre-Spokane valleys. Greater erosion in the tilted basalt on the western margin of this tract finally drew these waters off and down into what has become the lower canyon of Grand Coulee.

There is evidence at the lower end of Grand Coulee that a short pre-Spokane valley was entered a little north of Soap Lake. This lake lies at the mouth of the coulee, where the canyon crosses a low anticline. The syncline between it and the main monocline to the north is low and wide open as a structural valley at the east to the Quincy basin. Some drainage did go through here, but most of it crossed the anticline—a thing which would not have been possible if an antecedent drainage line had not existed at this place.

The original slope on which the glacial waters flowed from the Columbia Valley to the Quincy structural basin was steplike in a general way, a steeper descent existing between the plateau summit to the north and the Hartline basin, and another such on the northern margin of the Quincy basin. These steeper slopes were determined by structure, though they did not conform exactly to it. The monoclinal fold north of the Hartline basin has a maximum dip of 30 degrees. If the slope which the Spokane waters found was only one-third of this, that glacial river, in effectiveness over this stretch, must have been an enormous mountain torrent. The vertically and closely jointed basalt must have been eroded with great rapidity, and, where favorable conditions for sapping were discovered in the channels, falls developed and retreated much more rapidly even than Niagara.

While the talus in the higher abandoned channels reaches up three-fourths to four-fifths of the total original height of the cliffs, that in Grand Coulee itself is only halfway up the cliffs (where the flows are horizontal) and has an almost invariable slope of 35 degrees. It clearly dates from the Wisconsin glaciation, not the Spokane.

Quincy Valley or Basin.—The Quincy structural basin is bounded on the south by the Frenchman Hills anticline, but its drainage escapes southward around the east end of this fold. All glacial drainage routes of the plateau west of Medical Lake, except Moses Coulee, have been traced to it. Enormous quantities of basaltic debris have been swept out of the hundreds of miles of such channels and into this catch-basin. The fill covers 600 square miles and the maximum known thickness is about 400 feet. The lower three-fourths of this fill is clay, silt, and sand, doubtless lacustrine in origin. In this have been found shells of fresh-water boreal mollusks.[11] Only the upper 100 feet, approximately, are

[11] Schwenneson and Meinzer: Ground water in Quincy Valley, Washington. U. S. Geol. Survey, Water Supply Paper 425 E, 1918, p. 143.

river gravels. About the margin of the basin the gravel is thinner and rests directly on the basalt. The aggradational plain now is dissected by stream-cut valleys which lead southward to a group of very irregular channels eroded in basalt around the eastern nose of the Frenchman Hills anticline and thence west to the Columbia between this fold and the parallel Saddle Mountains anticline. Though this drainage line is named Crab Creek, no surface waters from Crab Creek above the Quincy basin now reach it. Dunes of basaltic sand have closed the lower part of these converging valleys and thus formed Moses Lake.

The group of channels around the end of Frenchman Hills anticline will here be termed the Drumheller channels (see figure 8). The altitude of the basalt floor at the head of these channels is 950 feet and the highest altitude over which the water clearly flowed is about 1,200 feet. The group begins as three canyons of nearly equal dimensions, but for most of its length only two dominant canyoned channels exist, one containing a narrow elongated lake, the other containing Crab Creek. The depth of these canyons averages 200 feet. The whole area, however, is scored and gashed by hundreds of similar smaller channels. The two main gorges separate on an accordant level and unite 4 miles downstream, again accordantly, but 100 feet lower than their point of separation.

South of the Frenchman Hills anticline, Crab Creek Valley turns abruptly west and follows the syncline between this fold and Saddle Mountains anticline to Columbia River at Beverly. A capacious, uninterrupted old river course of low gradient exists along this syncline. It is repeatedly referred to in the literature as the lower part of the Grand Coulee route of the diverted Columbia; and certainly the stream which eroded the two dominant channels of the Drumheller plexus took this course; but at an earlier date, before the present Drumheller channels had been eroded, glacial waters also continued directly southward to pass the east end of Saddle Mountain anticline as well. Channeled scabland and stream gravel with granitic material cover 150 square miles of the region south of the end of this fold. As in the Palouse scabland, hills of mature topography and deep soils, developed in a weak sedimentary (presumably the Ellensburg formation) above the basalt, flank the scabland and are isolated in it. Some of the glacial waters entered Esquatzel Coulee and some went by way of Koontz Coulee to the Columbia near Ringgold. Indeed, Esquatzel Coulee below Connell has been eroded in the scabland subsequent to the maximum flooding.

The waters around the tip of the Saddle Mountain anticlinal nose never cut deeper than 900 feet above tide, while the head of the synclinal course just below the Drumheller plexus is eroded in basalt to 700

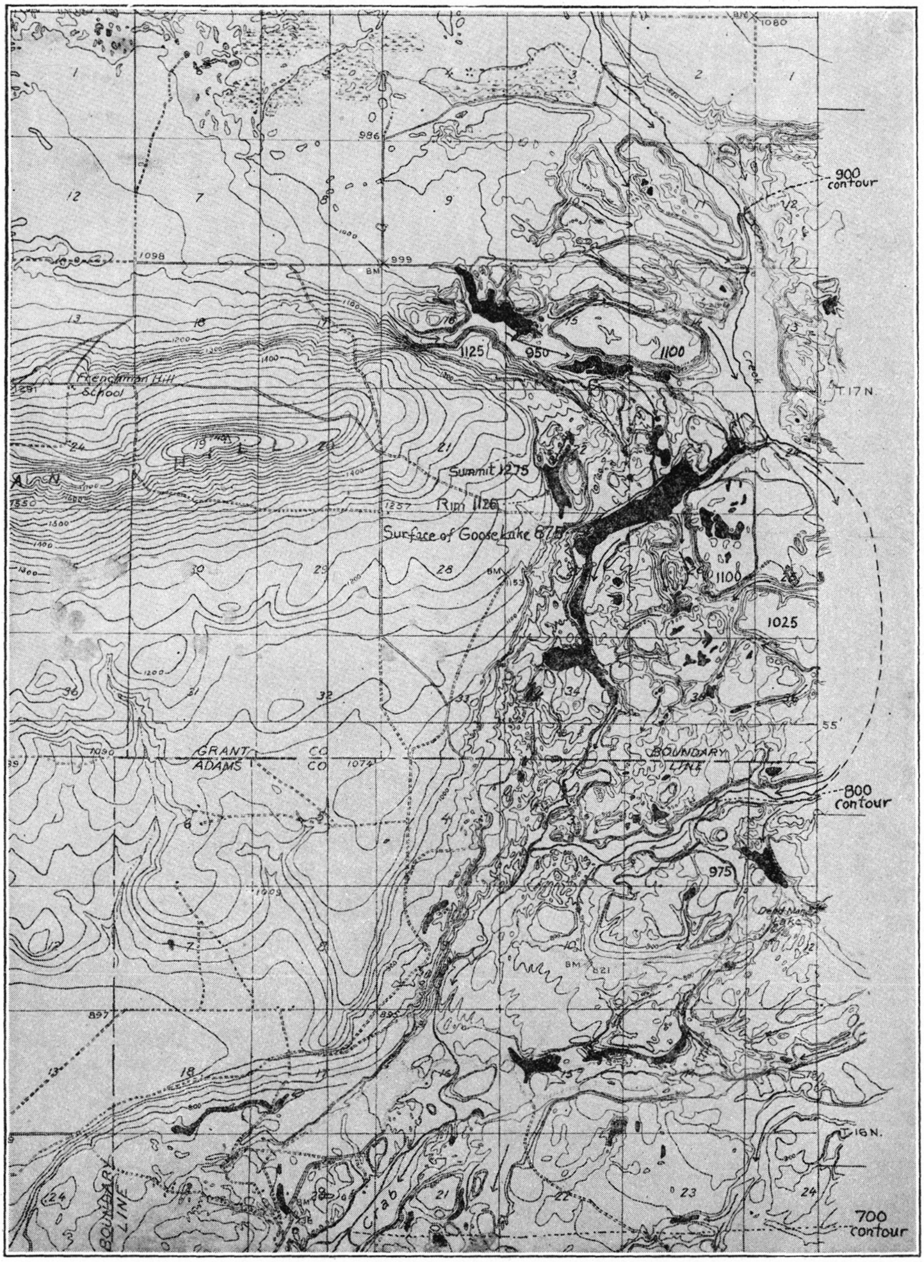

FIGURE 8.—*Part of Drumheller Channels Plexus*

Channels indicated by arrows; rock-basins in black.

feet above tide. Using the criterion of talus accumulation, most of the Drumheller channels and the existing synclinal river valley date from the Wisconsin glaciation, while the spillway around the east end of Saddle Mountain was formed during the Spokane glaciation. Channeled scabland also lies east of the youthful Drumheller channels and at a higher altitude. It apparently belongs to the Spokane spillways.

It appears, therefore, that when Spokane waters escaped southward from the Quincy basin there was no noteworthy valley for lower Crab Creek and, as in the Palouse country, the flood spread out and found its way among the hills of weaker rock. These hills were removed in the Drumheller tract for a width of more than 10 miles. South of Saddle Mountain the width of the scoured tract is equally great. The flood separated into two parts after passing Frenchman Hills anticline, part continuing south to Esquatzel and Koontz coulees and part turning west in the Beverly syncline. The westward course was eroded more deeply than the southward, so that when, in the succeeding Wisconsin diversion, another flood swept through the Drumheller plexus all of it went westward. The striking features of the present plexus, adjusted to the floor of the synclinal route, were then produced.

Two other outlets for the Quincy basin existed during the Spokane epoch. They are at Frenchman Springs and "The Potholes," two great notches in the wall of Columbia Valley on the western margin of the plateau. Each is an abandoned cataract, to which short channels lead across the western rim of the Quincy basin. "The Potholes" is the best example mapped of a receding waterfall over lava flows which is known to the writer (figure 9). The ancient stream spilled over the Columbia cliffs at an altitude of about 1,200 feet above tide and descended at least 400 feet over two great rock terraces, each with a scarp of about 200 feet. In the upper cliff is exposed a very conspicuous flow with exceptionally large, well developed, and uniform columns approaching 75 feet in length. The flow which holds up the edge of the lower rock terrace is more than 100 feet thick and is composed of uniformly small columns from bottom to top.

The amount of recession in the waterfall is quite unequal in the two rock terraces. In the upper the cataract was double from its beginning, the two parts being nearly equal and receding side by side for nearly two miles. This parallel recession left a great blade of rock a mile and a half long, 1,000 feet wide, and 375 feet in maximum height between them. A huge elongated pothole was left by the recession of each member of the twin upper falls, deepest and widest below the falls. There are great gravel bars in these potholes, especially in the downstream portions. The one below the southern fall is 200 feet thick (figure 10).

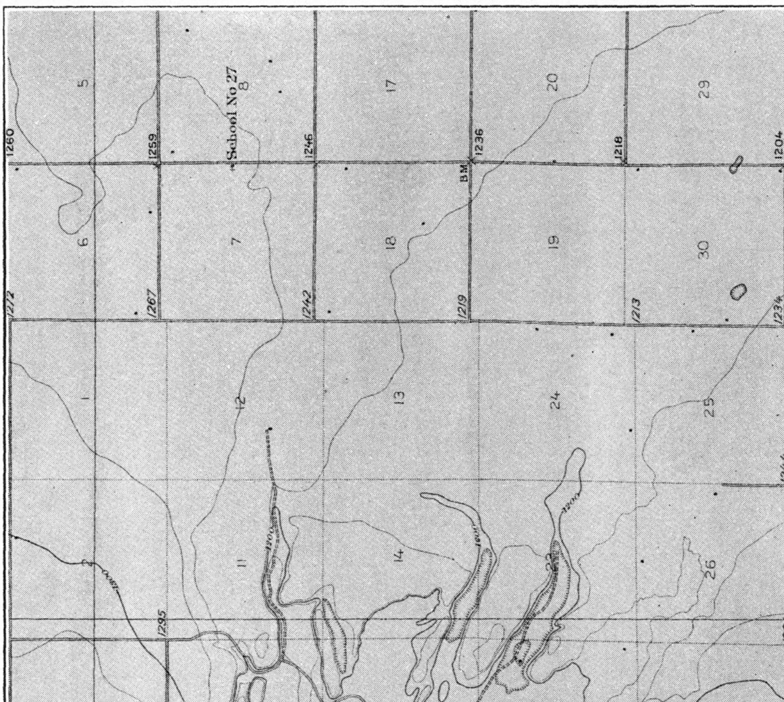

FIGURE 9.—"The Potholes" near Trinidad, Washington

The lava flow which causes the lower rock terrace is much more resistant to plucking and sapping than is the upper terrace. This is shown both in the Columbia Valley and in "The Potholes." The current which emerged from the Potholes themselves spread considerably over this terrace and spilled over its edge in a broad sheet which later became somewhat concentrated in four or five different places, so that minor notching of the edge of the terrace resulted; but none of these notches was cut back more than a quarter of a mile.

Above and east of the upper falls is a scabland tract extending two miles farther east across the low rim of the structural basin and very much diversified by ramifying channels and their separating hills. Rock-basins are common, some of them being 40 feet deep. This channeled tract was an island-studded rapids descending to the brink of "The Potholes" cataract. At the beginning of the cataract this channeled area extended to the original edge of the upper terrace. As the twin falls, narrower than the channel group, receded eastward, some of these channels were left along the edge of the gorge.

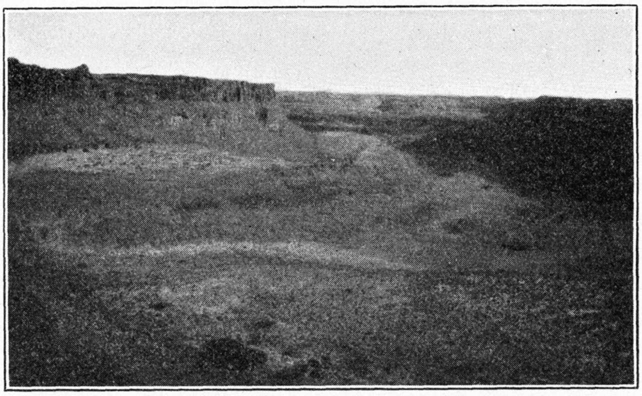

FIGURE 10.—*One of "The Potholes"*

The gravel bar (terrace on left) is 200 feet thick and the cliff back of it is 200 feet high. View is taken looking toward the ancient cataract.

The talus accumulations of "The Potholes" are somewhat irregular in height, because of unusually marked differences among the flows in the cliffs, but the large majority constitute three-fourths or more of the total height of the cliffs (see figure 7). "The Potholes" cataract was formed at the time of the Spokane glaciation by discharge from the Quincy basin. The Columbia Valley here was nearly or quite as deep at that time as it is today. The structural basin was aggraded to the level of this western rim and gravel was carried completely across from

Crab Creek and Grand Coulee. As in the Hartline structural basin, the Spokane floods found the depression only partially filled, but left it brimming over with waste.

The Frenchman Springs cataract, 8 miles south of "The Potholes," functioned at the same time and developed a double fall also, but carried a smaller quantity of water. The northern of the two falls here outran the southern in its recession and at the close of the history of the cataract was carrying all of the discharge.

Why did not Wisconsin waters use the Frenchman Springs and Potholes cataracts? There are two possible answers: (1) Spokane discharge through Drumheller Channels eroded this spillway more than it did the rapids above either of the two cataracts, and (2) post-Spokane but pre-Wisconsin warping depressed the Drumheller tract relative to the channels above the two cataracts enough to cause complete Wisconsin diversion to the southern route; and, of course, it is possible that some combination of both occurred.

MOSES COULEE

This coulee (not to be confused with the valley which contains Moses Lake) ranks second in spectacular proportions only to Grand Coulee. It lies a few miles west of Grand Coulee and leads southwestward directly to the Columbia, 10 miles above "The Potholes." Its length of 40 miles is divisible into three portions, an upper and a lower canyon separated by a broad, shallow tract in a synclinal valley. The upper canyon is eroded in the gentle southward dip slope of this part of the plateau. Its depth averages about 200 feet. Dip of the basalt is greater than descent of coulee floor. The inclosing walls thus become lower until they virtually disappear and the floor of the canyon becomes the floor of the synclinal valley. Here the coulee turns abruptly to the west and follows the axis of the syncline for 6 miles. At Palisades it turns southward again and leaves the syncline to cross a broad uplifted area, or flat-topped anticline, the Badger Mountain fold. The lower canyon across this fold is 900 feet deep.

The lower canyon has been extended upstream by headward erosion about half the length of the synclinal portion. Here it abruptly ends at the foot of a cliff across the coulee. Two great castellated buttresses face down the coulee, with lesser walls connecting them. This notched cliff clearly was a waterfall, and before the deep notching it was comparable in height to Grand Falls at Coulee City.

From this transcoulee cliff to the lower end of the upper canyon is a tract, 5 or 6 miles long and nearly as wide, where the basalt floor of the syncline was widely overrun by a great stream which formed a complex of anastomosing channels with rock-basins and cataracts, leaving isolated knobs and buttes irregularly disposed in a perfect maze (see figure 4). Bare rock or rocky talus covers the area, whereas both canyoned portions have no rock-floor exposed. There is a total descent of 600 feet along this tract. Most of the channels have noteworthy talus accumulations, amounting to three-fourths or four-fifths of the total depths. Only the lower and central channels bear talus comparable to that in Grand Coulee and Drumheller channels. Erratics of granite, quartzites, etcetera, lie here and there, even on the highest of these eroded surfaces.

In the upper canyon, north of the moraine built by the Okanogan lobe during the Wisconsin glaciation, talus is but halfway up the cliffs. Below the moraine some talus piles seem to be of Spokane age, some of Wisconsin, and there is other evidence that Wisconsin waters only partially cleaned away the preexisting cliff waste. In the lower canyon the talus dates back to the Spokane epoch. If there is any record of Wisconsin waters, it is in the gravel fill, more than 200 feet deep, 3 miles from the head of this canyon, and possibly in the existence of a prominent rock terrace, not more than 100 feet above the aggraded floor of the canyon, a few miles south of Palisades. If trenching by Wisconsin waters was performed anywhere in the lower canyon, it was in the production of this terrace.

Moses Coulee, as a drainage line, antedates the Spokane glaciation. Tributary valleys, well developed in the basalt, are recognizable as far north as Mansfield, and the upper canyon itself extends 6 or 8 miles north of the Wisconsin terminal moraine; but the best evidence is in the lower coulee. The cliffs here are deeply notched by wide-open V-shaped tributary valleys. Many notches are two-thirds or more as deep as the main canyon. These notches give the cliffs a striking resemblance to a series of great rounded gables in alignment (figure 11). The slopes of these tributary gorges are graded and covered with sage and grass. Rock ledges in them are rare. They clearly are the relics of a pre-Spokane drainage line, the trunk valley of which was entered and greatly enlarged by the Spokane waters. Both widening and deepening in the basalt occurred and the tributaries were left hanging. They have since attained topographic adjustment by building large alluvial fans out on the canyon floor. Furthermore, Moses Coulee crosses the Badger Mountain fold, as already noted. Like the crossing of the Soap Lake anticline by Grand Coulee, this records an antecedent course determined long before the Spokane glaciation.

Spokane waters could not have entered Moses Coulee if the parent ice-sheet had not pushed across or at least well up on the divide south of the

Columbia. Therefore, though no till or striæ left by the Spokane ice are known on the south side of the Columbia west of Grand Coulee, the operation of both Moses and Grand coulees proves that Cordilleran ice did cross the Columbia, and the Spokane features of Moses Coulee prove that it reached nearly as far south as it did in the later Wisconsin epoch.

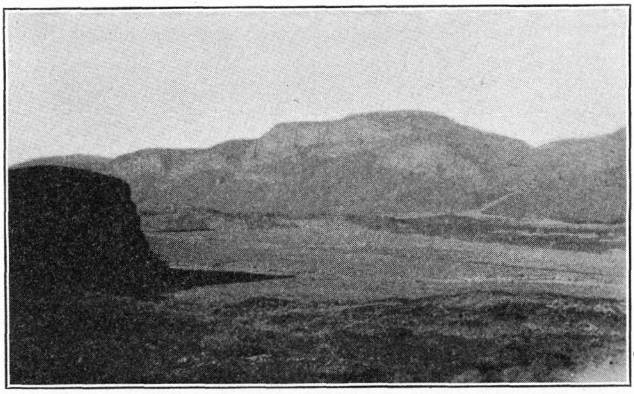

FIGURE 11.—*Cliffs of lower Moses Coulee*

The cliffs are 900 feet high. There are shown the pre-Spokane tributary valleys, the main canyon of Spokane age, and the post-Spokane talus.

The Wisconsin Glaciation

The terminal moraine deposited by the Cordilleran ice-sheet in northeastern Washington during the Wisconsin glaciation has been traced in part by Salisbury and student assistants.[12] The ice reached the Columbia Plateau in two places. One of these was south of the capacious Okanogan River Valley, and the lobe which spread out on the plateau here reached 35 miles beyond the river and was nearly 50 miles wide. The other place was on the lower Spokane River and was of little consequence. The only noteworthy Wisconsin drainage derangement of the entire plateau was the reoccupation of Grand Coulee and lower Crab Creek. Through this route was poured the water from the Cordilleran ice-sheet along the entire front from the Rocky Mountains to the Okanogan lobe. Though the Spokane ice yielded much greater volumes of water, all told, than did the Wisconsin, it was carried by many valleys, no one of which ever contained the quantity which went through Grand Coulee during the later diversion. That flood was greater than the deep-

[12] R. D. Salisbury: Glacial work in the western mountains in 1901. Jour. Geol., vol. 9, 1901, pp. 721-723.

George Garrey: Glaciation between the Rockies and the Cascades. Master's thesis, in library of Department of Geology, University of Chicago.

ened main channel of the Grand Coulee system could contain and all but one of the distributary canyons again were in operation. The level of the Hartline gravel plain was not reached, however, and Deadmans Draw remained untouched. The evidences for this conclusion are the character of the talus in Deadmans Draw, already outlined, and the gravel deposits in and at the mouth of Dry Coulee. These latter deserve a brief description.

The gravel terraces of Crab Creek Valley above the junction of Dry Coulee, at Adrian, are fragmentary remnants in protected places and in general do not have sharp terrace forms. Most of the valley floor is at the floodplain level; but 3 or 4 miles east of Adrian the floodplain is narrowed almost to obliteration by a great gravel fill whose surface is about 100 feet above the valley bottom. The creek here flows in a narrow inner valley, close to the southern wall of the rock-cut main valley. The surface of the gravel fill rises northward across the width of the main valley and continues up Dry Coulee, which in its lower part is likewise nearly filled. Though there is little difference in amount of weathering between this gravel deposit and the Spokane gravel in Crab Creek Valley east of Dry Coulee, it clearly is much younger in terms of erosion. Its dissection has just begun. It is traceable back up Dry Coulee to the three distributary canyons which lead southward out of the upper walls of Grand Coulee. In all probability it is a deposit made by the Wisconsin floods before the lower canyon of Grand Coulee was deepened sufficiently to take care of the entire discharge.

Lower Grand Coulee therefore appears not to have been much deeper at the beginning of the Wisconsin discharge than the floor of these distributary canyons. Grand Falls probably was formed during this epoch, taking origin at the head of Blue Lake, where the coulee begins its course in the tilted flows of the monoclinal flexure. This cataract has receded about 3 miles to that portion known as Dry Falls, west of Coulee City, and about 5 miles to the less pronounced falls at the head of Deep Lake, about a mile south of Coulee City. They could not have existed farther down the coulee, for there it is eroded on the strike of flows whose dip, on the average, is 45 degrees.[13]

Previous descriptions of the relation of the Okanogan lobe to Grand Coulee state that the ice-sheet deployed eastward only to the edge of the upper canyon; but the granite knobs in Grand Coulee above Steamboat Rock are strongly glaciated down at least to the level of the present

[13] O. E. Meinzer, in "The glacial history of Columbia River in the Big Bend region" (Jour. Wash. Acad. Sciences, vol. 8, 1918, pp. 411-412), argues that the falls have receded for 17 miles, virtually the full length of the lower coulee.

aggraded floor. The northwest sides of these hills are notably smoothed and rounded and some bear striæ. The orientation varies, as would be expected on rugged rock hills overridden by ice, but is not far from northwest-southeast. The southeast sides are steep and jagged. The sheeted structure of the granite apparently has lent itself to plucking by the ice. Furthermore, the summits of the basalt bluffs on the western side of the coulee also are striated in approximately the same directions, and striæ and abundant large granite erratics are reported on the top of Steamboat Rock (figure 12).

The glaciation of these granite hills and the basalt hill south of them occurred at the maximum deployment of the Wisconsin ice on the plateau. It can not be a record of the Spokane glaciation, for these granite

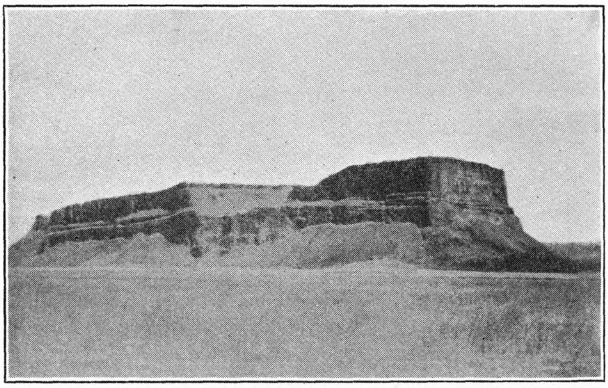

FIGURE 12.—*Steamboat Rock*

Steamboat Rock is in the middle of the Grand Coulee and near the head. The talus is of post-Wisconsin age.

hills then were buried hundreds of feet beneath basalt and have been exhumed by the erosion of both Spokane and Wisconsin glacial drainage. If it be argued that this exhumation occurred during the early stages of the Spokane glaciation, the ice later advancing into the head of Grand Coulee, the answer is that these exposed glaciated surfaces would have been obliterated during the interglacial interval.

What became of the Wisconsin drainage when the Okanogan lobe crowded down into the head of Grand Coulee? Since the Spokane spillways to Palouse River are lower than all others on the plateau except Grand Coulee, and since there was an eastward route open to them in front of the Wisconsin ice, it might be expected that for a short time glacial drainage would be diverted to the Palouse. But reexamination of these spillways has found no signs of such occupation. Furthermore, the granite hills in the coulee close to the eastern wall do not show glacial smoothing, though all others do. This is interpreted to mean that the escaping waters kept a passage open along the eastern edge of the ice, which thus failed to close the coulee completely. All the water at this time flowed on the east side of Steamboat Rock, and perhaps the eastern wall of the canyon here was eroded back to expose the unglaciated granite hills and to make the greater width which the canyon possesses between Steamboat Rock and the Columbia.[14]

A widespread submergence of the lower Columbia Valley is known to have occurred during the Wisconsin glaciation.[15] It is recorded by berg-floated erratic boulders, some of great size, scattered widely in the Columbia Valley below the present altitude of about 1,250 feet above tide. The submergence was due to a lowering of the entire region relative to sealevel. The ponded waters rose sufficiently high to spread over considerable areas of the plateau, and glaciated boulders now are found where glacial ice or glacial streams could not possibly have transported them. Most of these boulders, and all of the large ones, are of granite. They are strikingly abundant in some parts of the Quincy basin, a distribution which points to Grand Coulee as the route by which they reached the basin. After one has seen the dozens of granite knobs in upper Grand Coulee, heavily glaciated on the northwest and apparently much plucked on the southeast, the conviction grows that most of these large granite fragments were quarried in the head of the coulee when the Okanogan lobe was at its maximum deployment. The ground moraine of the Okanogan lobe has but a small percentage of granite boulders compared with basalt boulders, and a still smaller percentage of large granites compared with large basalts. It appears, therefore, that some special condition, such as that outlined above, must have existed to reverse the ratio among the berg-floated boulders.

The upper limit of these erratics earlier reported was 1,283 feet above tide, and in the eastern part of the Quincy basin none have since been found above that altitude; but on Babcock Ridge, near Trinidad, boulders of gneiss, granite, quartzite, schist, slate, and argillite have recently been found as high as 1,350 feet above tide. On the hills northeast of Trinidad a "nest" of twelve granite fragments from an inch to 16 inches in diameter and one quartzite pebble have been found—all within a radius of 15 feet and at an altitude of 1,400 feet above tide. These seem clearly

[14] K. Oestreich ("Die Grande Coulée," Transcontinental Excursion of 1912, American Geographic Society, 1915, pp. 259-274) has suggested, and J. T. Pardee ("Glaciation in the Cordilleran region," Science, vol. 56, December 15, 1922, pp. 686-687) has asserted, that an ice-stream traversed Grand Coulee.

[15] J. H. Bretz: The late Pleistocene submergence in the Columbia Valley of Oregon and Washington. Jour. Geol., vol. 27, 1919, pp. 489-506.

to have been carried here in floating ice. Either the upper limit of the submergence was greater over the plateau than has been thought or there has been post-Wisconsin upwarping in the vicinity of Trinidad. The latter seems the more probable.

Pardee has described a deposit of silt with sand and gravel, the Nespelem formation,[16] in the Columbia Valley above Grand Coulee. This he believes to be of Wisconsin age and to have been caused by a lowering of the region such that the upper surface of the deposit (1,700 feet above tide) records the sealevel of that time. What is taken to be a part of this formation lies on the floor of Grand Coulee about Steamboat Rock and the granite hills. Its upper surface here is about 1,650 feet above tide and *it is seasonally banded.* From its position, it obviously was deposited after the margin of the Okanogan lobe and the diverted glacial Columbia had abandoned Grand Coulee. It therefore was deposited after the berg-borne debris had been carried through the coulee. None of this silt has been recognized in the Quincy Valley or in the Columbia Valley below the Okanogan lobe. It may be a record of the submergence, as are the berg-carried erratics. It also may be related to the ponding of the Columbia by the Okanogan lobe, or by the large Wisconsin Valley train from the Okanogan Valley, which Pardee describes and which was formed during the retreat of the Cordilleran ice-sheet.

Most of the fill of the Quincy structural basin, as shown by well records, is clay and silt. The Pleistocene boreal mollusks reported from the upper part of the clay[17] suggest that it was deposited while a glacial climate prevailed, but probably not when the glacial waters were being discharged across the northern rim of the plateau, for the gravels overlying the clays were then carried into the basin.

There appears to be one great summit plane of the gravels, now dissected into four parts. The altitude of the northern part of each terrace is about 1,250 feet above tide. The surface (restored) slopes toward the Frenchman Springs and Potholes cataracts on the western margin of the basin and toward the Drumheller plexus on the southern margin. A continuous grade exists westward into the bottoms of the eroded channels at the head of the cataracts, but to the south the gravel terrace is 150 feet above the floor of Crab Creek Valley immediately adjacent and as high as the basalt buttes among the channel heads.

This gravel fill probably dates back to the Spokane epoch, though some of it may have been aggraded during the early part of the Wisconsin

[16] J. T. Pardee: Geology and mineral deposits of the Colville Indian reservation, Washington. U. S. Geol. Survey, Bull. 677, 1918, pp. 28-29 and 47-50.

[17] Schwenneson and Meinzer: Ground water in Quincy Valley, Washington. U. S. Geol. Survey, Water Supply Paper 425 E, 1918, pp. 143-144.

diversion, as that at Adrian, where Crab Creek was completely blocked by Wisconsin gravel. The basin fill is not dissected, however, as are Spokane gravel terraces in the upper Crab Creek drainage. This may be because it does not lie in a narrow valley and because it is very porous, absorbing all rainfall and allowing no surface streams to form. The dissection takes the form of three large meridional channels converging to the Drumheller plexus. Two of these lead from the mouth of Grand Coulee; the third and easternmost leads from upper Crab Creek near the mouth of Dry Coulee. It seems probable that, though some interglacial trenching by Crab Creek occurred, these channels were eroded largely by the diverted Columbia during the Wisconsin epoch, the erosion being rendered possible because of the contemporaneous deepening of the two main Drumheller channels. The western channel is broad but much shallower than the other two. Its proportions indicate that it is the channel of a large stream, not the valley of a small one, and its shallowness indicates that it was abandoned early in the Wisconsin dissection of the fill.

The mouth of Grand Coulee is an undrained depression containing Soap Lake. It is dammed by the gravel deposits in Quincy Valley. All drainage of the lower canyon of Grand Coulee comes to it, upper Crab Creek flows to it (when it flows at all), and the neighboring gravel plain, through an arc of 180 degrees, from east through south to west, slopes back toward it. The slope in this arc is gentle and clearly constructional. Whether this back slope is wholly of Wisconsin age or dates in part from the Spokane epoch, it seems clear that it is a graded subfluvial slope, adjusted to the traction load and the velocity of a current emerging from Grand Coulee. The velocity here was greatest within the rock walls of Soap Lake and decreased rapidly as the waters spread out in the Quincy basin. The depth of that glacial stream can not be measured, however, by the difference in altitude of lake floor and gravel rim. During the later stages of Wisconsin discharge, as the Drumheller channels were gashed more deeply and the three channels eroded across Quincy basin fill, notches appeared in the rim of the gravel barrier and the constricted portion containing Soap Lake probably was then deepened.

In all gravels in glacial spillways across the Columbia plateau, basalt is by far the most important constituent. Only a small fraction of 1 per cent is of other material. It therefore is not to be considered as glacial outwash in the ordinary sense, for it has not come from the Cordilleran glacial drift. It represents basalt eroded by the high-gradient glacial streams in producing scablands and canyoned coulees.

Thus a brief episode in the latter half of the Pleistocene (the maximum of the Spokane glaciation) introduced conditions under which the scablands, much more than a thousand square miles of the plateau, and more than a tenth of the total area of the plateau (as the term is used in this paper) have been denuded of overlying sedimentary deposits by running water. But, despite the enormous amount of erosion by escaping glacial waters in both Spokane and Wisconsin epochs, no permanent derangement of drainage lines, save that of the Palouse from Hooper to Snake River, resulted. The Palouse formerly flowed to Esquatzel Coulee by way of Washtucna Coulee. Its course to Snake River was shortened 50 miles by this diversion, probably during the Spokane epoch.

The Wisconsin history of Drumheller channels and Moses Coulee has been outlined in the description of these features under "Spokane Glaciation." It remains to note that the small amount of erosion in the synclinal plexus of Moses Coulee and the small valley train built by drainage from the tip of the Okanogan lobe suggest that this lobe may have evaporated in considerable part. This suggestion of large evaporation may also explain the relatively small amount of Wisconsin water which came from the Cordilleran ice east of the Okanogan lobe.

Discussion

Dr. M. M. Leighton: The speaker is to be congratulated on the character of the work he has done in eastern Washington. A few years ago I had the opportunity to see some of the features which he describes, and the case for at least two glaciations is perfectly clear and, as he suggests, there may have been three. In support of this, I may say that in a gravel pit in the southwestern part of Spokane I found balls of apparently old glacial till in what seemed to be gravel of Spokane age.

Mr. Oscar E. Meinzer: I was especially interested in this excellent paper, because of my own brief field work a few years ago in this region. The glacial features of the region are on a grand scale and very striking. I understand that in the Spokane Stage the lake in Quincy Valley discharged directly into the gorge of the Columbia and also through the outlet east of Frenchman Hills, and that the latter was over lava rock. How is the deep trenching of the plain in Quincy Valley during the Wisconsin Stage accounted for?

Author's reply to Mr. Meinzer: Only the upper or gravelly part of the Quincy Valley fill is surely of Spokane age. Wisconsin waters added but little to this deposit. They eroded it instead, because of downcutting in the basalt at the Drumheller Channels at this time. All the remarkable features of that tract are in basalt and were produced largely by Wisconsin waters.

Brief remarks were also made by Mr. Leverett, with reply by the author.