

SOME MIOCENE AND PLEISTOCENE DRAINAGE CHANGES
IN NORTHERN IDAHO

By

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F O R E W O R D

This paper affords an interesting illustration of a scientific by-product from a purely utilitarian investigation.

The writer, Mr. Alfred L. Anderson, was detailed to study the geologic phases of the road-making materials or of Idaho, and he completed his assigned task in a most satisfactory manner. While traveling on this mission, however, he made incidental but accurate notes of the evidences of physiographic changes in the region. These he later studied with the available topographic maps before him and wrote the report herewith presented in his spare time.

Although primarily a paper of purely scientific interest it is by no means devoid of economic implications. The suggestion of the great amount of available ground-water in the Spokane and Rathdrum valley gravels and of the possible utilization of former river courses are both matters of direct interest to the irrigation engineer.

Furthermore, it is hoped there will be many intelligent laymen who will find much of interest and value in this illuminating discussion of the origin and significance of geographic features with which they are entirely familiar but have never clearly understood.

Francis A. Thomson,
Secretary, Idaho Bureau of Mines
and Geology.

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SOME MIOCENE AND PLEISTOCENE DRAINAGE CHANGES IN NORTHERN IDAHO

by

Alfred L. Anderson

I N T R O D U C T I O N

This paper deals with the changes in drainage that were produced in Northern Idaho, and the immediately adjoining area in Eastern Washington, by flows of basalt in Miocene time and by glacial advances in the Pleistocene. A restoration of the pre-basalt surface features evidences that the whole drainage of the area was southward and westward--that Priest River, Clark Fork, and St. Joe River followed the Spokane Valley until obstruction by the advancing flows of Columbia basalt from the west caused the deposition of the clays and shales of the Latah Formation in eastern Washington and the deflection of these three rivers northward through the Purcell Trench.

Evidence of an early ice advance in Pleistocene time, coming from the north and passing down the Rathdrum and Spokane valleys, is presented and the resultant changes in drainage described. As temporary features of the ice advance, which is believed to be of Spokane age, were Lake Spokane, with outlet through the Mica Spillway, and Greater Lake Coeur d'Alene, a colossal body of impounded water with a maximum depth of about 700 feet and extending several dozens of miles into the mountains. This glacier, which the writer calls the Rathdrum lobe, left an immense thickness of glacial fill and outwash on its retreat and caused the drowned-valley lakes which border Spokane and Rathdrum valleys. At the same time, the writer believes, the St. Joe system was restored to its pre-basalt course through the Spokane Valley and that Spokane Falls and Post Falls are results of this readjustment. The Clark Fork likewise became established in its present course across the state.

Evidence of a much later ice advance from the north, less extensive than the earlier advance and of valley-glacier type, is also presented. This advance is possibly of Wisconsin age and explains the origin of Pend Oreille and Priest lakes.

The writer first describes the present surface features which serve as a base for the interpretation of the older drainage schemes. The changes are, then, described in order beginning with the pre-basalt drainage of Miocene time and the changes therein induced by the basalt. Next, the physiography to the coming of the ice in the Pleistocene, is discussed. The ice lobe is described--its age, its extent, and its course determined, and the impounding and other changes are treated in logical order. And finally, the latest ice advance is described--its character, extent, and position and the resultant surface changes.

The writer is aware that for some parts of the region other drainage interpretations may be possible, yet in the light of the evidence which is presented, the given interpretation is believed to be essentially correct. The final solution of the problem rests on a study of a much larger area, including Montana west of the continental divide and a large part of southwest Canada, covering the region traversed by the Purcell and Rocky Mountain trenches. The writer hopes that this paper will

draw attention to the big field for physiographic and structural studies which are comprised in the area and which have scarcely been touched.

As an aid to mapping the ice advances and the outline of the impounded drainages, the topographic sheets of the U.S. Geological Survey--namely, the Priest Lake, Sandpoint, Rathdrum, Cataldo, Spokane, and Oakesdale sheets were available, the maps in this report are based upon pantagraph reductions of the topographic sheets.

FIELD WORK AND ACKNOWLEDGMENTS

This paper is an outgrowth of a survey for road materials made by the writer during the summer of 1925 under the auspices of the Idaho Bureau of Mines and Geology. About a month was spent in the region between St. Maries, in Benewah County, and the International Boundary. During this time the essential features of the physiography and its development were noted.

The writer, accompanied by Dr. F.B. Laney, Head of the Department of Geology at the University of Idaho, revisited the southern part of the area during the middle of August, 1926, two days being spent in the Rathdrum and Spokane valleys. This visit was made under most adverse weather conditions, but the original observations of the writer were confirmed, and new facts were unearthed. The writer takes great pleasure in acknowledging the aid given by Dr. Laney in the field work and in preparation of this paper.

B I B L I O G R A P H Y

The following publications, in addition to the topographic sheets mentioned, were consulted in connection with this study.

Reference throughout the paper is made to these by parenthetical number followed by specific page reference--thus, (3:pp.16-24) refers to pages 16 and 24 of Bulletin 384 of the U.S. Geological Survey entitled "A Geologic Reconnaissance in Northern Idaho and Northwestern Montana," by Frank C. Calkins.

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P R E S E N T S U R F A C E F E A T U R E S

PURCELL TRENCH

The principal physiographic feature of the region is the long north-south valley or trench which originates in Canada and extends southward into Idaho more than a hundred miles, curving and passing southwestward down the Spokane Valley and becoming obscured where it passes into the Columbia Plateau. This trench extends 200 miles north of the international boundary where it joins the Rocky Mountain trench. A peculiarity of this trench is its generally flat bottom, long in proportion to its width, and its streams divided by low water sheds and flowing in opposite directions, or its intersection by streams which may follow for a distance or may cut directly across. Chamberlin (4:pp.178-9) thinks it probable that this depression, even though its location may have been determined primarily in many places by fault lines, has been brought to its present form by the long continued erosion of great valley glaciers powerful enough to override the divides between the heads of some of the larger streams and to grind them down nearly to general base level. He brings the ice lobe to the south end of Pend Oreille Lake but does not place it in the distinctive category of mountain glaciation. This valley is referred to as the Purcell Trench, and that portion which is in Idaho has been described by Calkins (3:pp.16-20) who states that the continuation of the trench passes down Lake Coeur d'Alene. However, the writer found Coeur d'Alene Lake in a normal stream valley, and if the Purcell Trench extends this far south, it probably curves and passes out the Spokane Valley. Faulting, along the valley side near Rathdrum, suggests evidence for such a course. On the contrary, the trench may end a few miles south of Bonners Ferry, but because of the continuation of old river valleys to the south in direct line with it, the whole will be referred to as the Purcell Trench in this report. Rathdrum and Spokane valleys, of which much will be said, are considered a part of the trench.

The Purcell Trench is from three to five miles wide at the Canadian border and decreases to a narrow valley about a mile wide a few miles south of Bonners Ferry, but widens to ten miles near the town of Sandpoint.

The high Selkirks bound the valley on the west and the Cabinet Range on the east. South of Sandpoint the trench is neither so regular nor so definitely bounded as it is northward. Hills on either side are lower than to the north and are broken by several valleys. Three valleys exist to the south of Sandpoint, each of which merges with Rathdrum Valley still farther south. Hoodoo Valley is probably not a part of the trench system as it lies to the west of the main axis. However, the trench axis does align with Cocolalla Valley, but it is more probable that the trench passes along the Pend Oreille Basin which is much deeper and wider.

Cocolalla Valley is about a mile wide, and the greater part of its floor, which is in solid rock, is higher than either of its parallel neighboring valleys or the trench to the north and to the south. Hoodoo Valley is from three to five miles wide. It is separated from Cocolalla Valley by a narrow ridge, Huckleberry Mountain, about two thousand feet high, which shows evidence of having been over-ridden by a glacier. A roughly circular mountain, Curtis Mountain, of about the same elevation, lies to the west of Hoodoo Valley. Cocolalla Valley is separated from Pend Oreille Valley, in which Lake Pend Oreille now lies, by a ridge lower than the others which shows indications of glacial erosion. This ridge may be called Algoma Mountain.

The three valleys combine near the town of Athol and form the wide flat Rathdrum Valley which is also called Rathdrum Prairie and which is six to ten miles wide. This valley curves westward near Rathdrum, and, on approaching the Idaho-Washington line, it narrows to three miles and is called Spokane Valley. Near Spokane the valley widens and merges into the Columbia Plateau. There is nothing to indicate a boundary between the Rathdrum and Spokane Valleys, for one merges into the other, but an arbitrary boundary may be fixed just east of the town of Post Falls. Parts of the upper Rathdrum Valley have an elevation of 2500 feet, but the slope is gradual to the city of Spokane where the elevation is about 2000 feet along the river above the Falls. Rathdrum Valley makes a gentle elbow curve with Coeur d'Alene Lake near the elbow tip, Spokane River as the south boundary, and the town of Rathdrum on the inside.

The Pend Oreille and Rathdrum valleys are bounded on the east by the Coeur d'Alene Mountains, a continuation of the Cabinets. Rathdrum Valley is bounded on the west by the southern Selkirk range whose highest elevation is Mount Spokane. Spokane Valley cuts across the southern Selkirks which are very low here. Mica Mountain is the highest point south of the valley.

PRESENT DRAINAGES

The Purcell Trench north of Bonners Ferry is occupied by the sluggish meandering Kootenai River which enters Idaho from Montana. The Kootenai flows northwesterly in a narrow youthful valley, determined by a major fault, and enters into the wide trench with a flat marshy bottom a short distance east of Bonners Ferry. There it turns northward and eventually enters the Columbia some distance beyond the Canadian border, first flowing into Lake Kootenai, 18 miles north of the border with outlet 65 miles north of the inlet and at a lake elevation of 1760 feet. The river escapes by a lateral distributary.

No large streams occupy the Purcell Trench between Bonners Ferry and Sandpoint, though the present valley would indicate a large stream. Chamberlin (4:pp.7-8) states that at one time a major stream did occupy the valley. Deep Creek, flowing northward to Bonners Ferry, drains about two-thirds of the trench, and Pack River, flowing south to Pend Oreille Lake, drains the remainder. Both have tributaries which have a barbed relationship, suggesting that the old drainage may have been in opposite directions. The two streams are separated by a low divide of glacial debris at 2,253 feet elevation, and Davis (6:pp.103-4) suggests that a glacier stood for a considerable time near the Elmira divide. Pack River flows directly across the Purcell Trench and makes its way eastward to Lake Pend Oreille through another valley of low gradient cutting off a triangular mass of hills from the Cabinet Range.

Priest River rises in the high mountains near the Canadian border and flows south to the Clark Fork. Its source was probably changed to some extent in its old valley by glaciation, for the valley floor is buried under glacial deposits, but its general direction remains unchanged. Priest Lake lies in its course.

The Clark Fork of Columbia River is one of the major streams in the area and crosses the Purcell Trench. The river rises in Montana, flows in a northwesterly direction for a long distance to the Idaho line, and then crosses Idaho in a westerly direction, entering and leaving the north end of Pend Oreille Lake. It crosses the Purcell Trench almost at right angles. At the Washington line, it again turns to the northwest and enters the Columbia River near the international border. The Clark Fork follows a faulted valley on its entry from Montana. The valley is wide in a rather late stage of maturity. Much gravel of glacial origin skirts the valley side. Soon after leaving Pend Oreille Lake the river flows through a narrow valley which becomes increasingly more rugged, cutting in gneissoid and granite rocks beneath glacial terraces, and at Albany Falls it tumbles over a mass of granitic rocks. Near the Canadian border it enters a canyon famed for its ruggedness and narrowness. Pend Oreille Lake has an elevation 266 feet higher than the Kootenai River at Bonners Ferry, which suggests that at one time the drainage may have been to the north up the Purcell Trench.

Hoodoo Valley is flat-bottomed because of an unknown depth of glacial fill. It contains no streams at the present time, but an immense stranded channel, occupied in part by Hoodoo Lake and swamps, suggests the presence of a former river though not the one that eroded the immense valley. Streams from the mountains disappear in the gravel.

Cocolalla Valley has no large streams. Barbed drainage is present. Cocolalla Creek, starting in a south direction, turns to the north on entering the main wide valley and flows into Cocolalla Lake, a small body of water in a rock basin. It then leaves the main valley to cut across the mountainous ridge on the west.

Pend Oreille Valley is occupied by Pend Oreille Lake, the largest lake in the state, with greatest length north and south, and curved in the shape of a huge questionmark. The lake is 1100 feet deep, and the bottom is about 950 feet above sea level. This is the greatest known depth of the Purcell Trench. The lake is held in on the south by a gravel barrier and terminal moraine. The valley narrows somewhat to the south but widens again east of Athol.

The wide flat Rathdrum Valley owes its present surface to an unknown thickness of glacial fill and outwash which gradually decreases in altitude to the south. It has no streams except the Spokane River which is crowded against the valley side along the south margin. These features are well shown on the Rathdrum and Spokane Topographic sheets. All streams from the mountains are lost in the gravels except the Spokane River which crosses to the north side of the Spokane Valley, a few miles east of the city of Spokane. Wells dug and drilled to more than 450 feet in Rathdrum Valley fail to reach bedrock through the sand-gravel fill.

The lakes in the region, except Pend Oreille, Hoodoo, and a few tiny rock basins in Cocolalla Valley, border the Rathdrum and Spokane Valleys and extend back into the mountains. These lakes are all held by gravel dams and have a surface elevation considerably less than that of the main valley. None have visible outlets except lake Coeur d'Alene, which is drained by Spokane River. Hayden Lake, along the east border of Rathdrum Valley, occupies a position between Athol and Coeur d'Alene city and is enclosed by mountains except on the west, where it fronts the main valley. Spirit Lake and Twin Lakes occur likewise on the west side of Rathdrum Valley, north of the town of Rathdrum. They, also open to the east. Hauser and Newman Lakes occur similarly along the north side of Spokane Valley. Liberty Lake is on the south side of Spokane Valley, opposite Newman. Generally, the two major valleys contain depressions along both sides, much of each valley being higher than its borders.

Coeur d'Alene Lake is in the main valley of St. Joe River, a stream rising in the Bitterroot Mountains along the Montana line and flowing westward to the present south end of the lake where the valley is drowned by the impounded waters. The valley-lake extends northward to the city of Coeur d'Alene, where it enters the Rathdrum valley. The outlet stream is Spokane River which bends abruptly westward and follows the margin of the main valley, tumbling over a resistant mass of gneissoid and granitic rocks at Post Falls, then flowing to the north side of the Spokane Valley at Trent and continue southwest over the gravel fill, finally plunging into the canyon of Latah (Hangman) Creek at Spokane Falls in the city of Spokane. The course is then northwestward to the Columbia River. St. Maries River is an important tributary of the St. Joe system, joining at the town of St. Maries from the southeast. The largest and most important tributary of the St. Joe System is the Coeur d'Alene River with its many tributaries draining westward from the Coeur d'Alene Mountains into the drowned St. Joe Valley near the south end of the lake. This tributary is almost equal to the main river in size, but its position shows that it is a tributary to the St. Joe. Both have built long deltas at their mouths which have greatly decreased the size of the lake. The streams draining into Coeur d'Alene Lake are called the St. Joe drainage system.

Latah Creek plays an important part in the physiographic problem. It rises in Benewah County, Idaho, flows northwestward through the town of Tekoa just over the Washington line, and continues in a straight northwesterly direction through the city of Spokane, where it is joined by the Spokane River. It occupies its old pre-glacial channel and indicates that the pre-Pleistocene drainage was to the northwest. Rock Creek and California Creek are important tributaries from the east. Latah Creek and its tributaries

have cut into the Columbia Plateau, forming narrow canyons which deepen and widen considerably in their lower courses. Latah Creek has been entrenched more than 500 feet in the Plateau at the city of Spokane. Reference should be made to the Spokane and Oakesdale topographic sheets and to the maps accompanying this report.

P R E - B A S A L T S U R F A C E F E A T U R E S

The writer has nothing to offer concerning the origin and development of the physiographic features much before Miocene time, and the problem of possible Cretaceous peneplanation will be left to a later date. Suffice it to say that by middle Miocene time the mountains were established much as at present with deeper valleys and with the same drainage pattern among the smaller streams but not among some of the larger. The original drainage scheme can be interpreted from the tributaries which normally join the major streams at an acute angle. When the angle is obtuse the drainage is referred to as barbed and abnormal. In other words, under normal conditions tributary streams should not flow in a direction contrary to that of the master stream. Since Miocene time, the mountains have been worn down somewhat, but the major valleys are shallower for reasons that will be stated later. The position of the tributary valleys has, however, remained unchanged. But a glance at the topographic sheets of the area will show many of the tributaries discordant with the direction of the present master streams. These changes the writer will endeavor to explain. Some of them were produced by the basalt flows of Miocene time and then changed again by the more recent ice advances of Pleistocene.

A study of the Priest Lake topographic sheet will show that Priest River is in perfect harmony with its tributaries as far as its entry into the Clark Fork. Its direction is south, and was so in pre-basalt time.

Clark Fork River flows northward from Newport, at the Washington line, to Metaline Falls and on to the Columbia (not shown), but a glance at a map giving drainage will show that none of the tributaries are concordant. All enter at a very wide obtuse angle, flowing southwest or southeast in contra-direction to the northward flowing Clark Fork. This suggests that the drainage was normally southward and that a stream of considerable magnitude occupied the valley in pre-basalt time, and probably later, and flowed directly opposite to the present Clark Fork. The Clark Fork valley narrows continuously northward toward Metaline Falls, though in its lower course it is navigable for some distance. Cliffs become prominent a few miles south of Metaline Falls, and, to the north, the river is confined in one place between walls said to be only eighteen feet apart. Thus the river appears to be flowing up-valley, contrary to any normal drainage. This change occurred on the retreat of the ice in Pleistocene time. It will be discussed in greater detail under the problem of changes due to glaciation, but the subject is introduced at this point to show that the former drainage was southward.

Referring again to the Priest Lake sheet, Moyie River drains to the south until it joins Kootenai River. Between Bonners Ferry and Sandpoint the drainage could trend either way, and, indeed, it is believed that the direction of the drainage through the trench has changed more than once. The streams entering the Clark Fork east of Sandpoint appear

normal to the present river. The probability is that this part of the Clark Fork has never been changed though modified to some extent. A study of the Sandpoint sheet shows that the streams which enter the Clark Fork west of the lake outlet are normal, except those north of Sandpoint which flow southeast. Streams flowing into the Hoodoo Valley have a southward direction on each side of the valley. The same is true of Cocolalla Valley, except to the north. The direction of these tributaries strongly suggests that the drainage was south and obviously out from the Rathdrum and Spokane valleys.

The drainage was about as follows. Priest River flowed south as at present, but the stream was much longer formerly, because the Clark Fork did not flow across its valley. The restored stream flowed southeast to the Hoodoo Valley and then south through the valley and out through the Rathdrum and Spokane. In other words, Clark Fork is now flowing across Priest River Valley, beheading it, and leaving the lower course (Hoodoo Valley) unoccupied. A low divide may have existed to the west of the town of Priest River, presumably in the vicinity of Albany Falls, though it is not impossible that the stream which formerly flowed south from the Metoline region joined Priest River--in which case no divide existed. Another low divide had been developed east of Priest River valley, probably just east of the town of Laclede. The position of the tributaries near Laclede favors such a divide. It is not impossible that faulting may have acted in the formation of these low divides by facilitating rapid erosion. The faulting of the region is along east-west to north-west southeast lines, and Clark Fork in its entry from Montana is controlled by such a fault.

The depth of Hoodoo Valley may be cited as additional evidence. This valley is filled with sand and gravel of glacial origin, and wells drilled to 470 feet in its southern part fail to penetrate the fill. This offers further suggestion that the valley was formed by a large stream at an early date and probably cared for the Priest River drainage. The depth of the valley though not known is more than enough to fit the southward projection of upper Priest River valley.

Clark Fork, entering from the east, probably swung to the south and passed down the valley now occupied by Lake Pend Oreille, was joined by Priest River, and continued down the Rathdrum and Spokane valleys. Additional evidence that the drainage of the Clark Fork was to the south through the Pend Oreille, Rathdrum, and Spokane valleys is the fact that Lake Pend Oreille is 1100 feet deep with its bottom at an altitude of 950 feet. Though Davis (6:pp.109-10) states that 1000 feet may be taken as a fair minimum measure for the amount of glacial overdeepening that the pre-glacial valley suffered in its conversion to a glacial trough with the assumption that the lake is 1300 feet deep, it is difficult to believe that ice erosion could remove 1000 feet of metamorphosed rocks when Cocolalla Valley, also in the main paths of the glaciers, shows little evidence of glacial deepening. It is more reasonable to assume that Clark Fork had cut a deep valley southward which has been modified by ice action. However, the writer believes that at the time of the ice advances the Clark Fork was not flowing south, but north up the Purcell Trench, because in Miocene time the Pend Oreille and lower valleys had been filled with seven or eight hundred feet of soft

clays and shales of the Latah Formation and capped with several flows of basalt. This series has been described in the lower Spokane Valley by Pardee and Bryan (9:pp.1-15) where 1500 feet of silts and clays were deposited in front of advancing flows of basalt from the south and west. The estimated elevation of the bottom of the old Spokane Valley is about 500 feet, a depth which provides ample fall for the Clark Fork. A valley of such depth fits the present sides of the three valleys above the level of the lake and the gravel fill. The Coeur d'Alene and St. Joe rivers were then much as at the present and flowed into the Clark Fork in the Rathdrum Valley. There is also strong possibility that they may have flowed westward near the south end of Coeur d'Alene Lake--in continuation of the present direction and alignment of the Coeur d'Alene River, but if any such valley existed it is now masked by basalt.

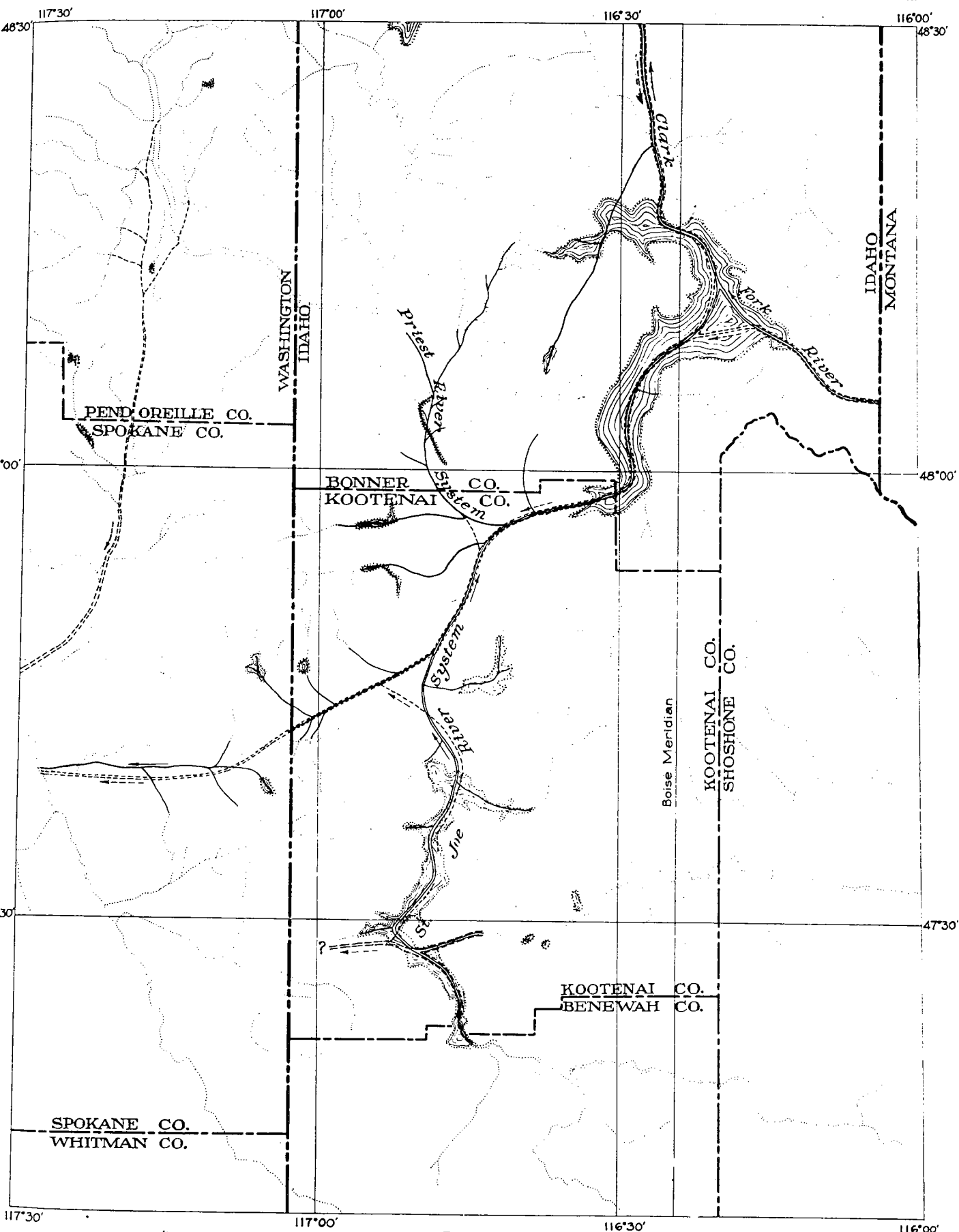
To sum up, it is suggested that in pre-basalt times the major drainage of the area including Priest River, Clark Fork River, and possible Kootenai River, was southward through the Rathdrum and Spokane Valleys, and that it was joined by the St. Joe system in the lower part of the Rathdrum. This accounts for the large Hoodoo Valley and the great depth of Pend Oreille Lake which is held in by a gravel dam on the south. Obviously, a very large river passed out through the Rathdrum and Spokane valleys, normal in every way with the pre-basalt drainage scheme. Other bits of evidence will be introduced which lend support to the given explanation of the pre-basalt drainage.

D R A I N A G E C H A N G E S P R O D U C E D B Y T H E M I O C E N E B A S A L T

The basalt, which has been used as a dividing line in the discussion of the drainage changes, has had a profound influence in disarranging the older systems, particularly some of the major streams, though such streams as were above the upper limit of the flows of course escaped. The lava flows are also useful in interpreting some of the younger changes. A brief discussion of these flows of basalt in Miocene time will follow.

MIOCENE CONDITIONS

The Columbia River basalts are generally well known and have been described in broad terms in many geological and geographical reports. In Miocene time occurred one of the most remarkable volcanic outbursts in the earth's history, when flow upon flow of basalt was poured upon the land from many fissures and spread over more than two hundred thousand square miles. These lavas built up a large plateau known as the Columbia River Plateau. The series of lava flows are more than 4000 feet thick in places near the center of the basin but gradually decrease toward the mountain margins. The flows of lava inundated the mature topography with its own particular drainage and left only the higher hills and ridges as islands. The flows lapped up the mountain sides in eastern Washington and northern Idaho, running back into valleys until an elevation of about 2500 to 2700 feet was reached. The margin of the lava sea is thus like a drowned coast line with mountain spurs projecting like promontories and with estuaries far back the valleys. New drainage systems were necessarily super-imposed upon the lava plateau, and only in the mountain



MAP SHOWING DRAINAGE CHANGES IN
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valleys where the basalt made deep imbayments far into the higher land did the drainage establish itself as before. Even here changes occurred in some places.

That the lava extended into the valleys of the Coeur d'Alene Mountains is clearly shown. Just northeast of Spokane the west base of the rounded hill of old crystalline rocks north of the river valley is seen to be skirted by a horizontal terrace of basalt which connects with the Columbia Plain. This terrace is continued eastward by a line of isolated, level-topped masses of basalt on either side of Spokane Valley. Similar terraces of basalt are seen all about the shore of Coeur d'Alene Lake, up the St. Joe Valley far beyond the town of St. Maries, up the St. Maries River valley to the town of Clarkia, and up the Coeur d'Alene River valley to within a short distance of the town of Cataldo. The height of the surface of the basalt above the lake is about 500 feet, gradually decreasing in elevation up the valleys. A terrace also skirts along the mountains on the west side of Rathdrum Prairie for more than 14 miles north of the town of Coeur d'Alene. No exposures remain north of this point. The basalt entered the Spokane Valley from the west.

The impounded drainage with the deposition of clays and silts caused by the advancing basalt will be discussed under the origin of the Latah Formation.

DRAINAGE CHANGES

It is probable that, as the basalt encroached upon the flanks of the mountains, the streams were crowded aside and made to follow in a general way the lava shores. Thus such streams as Latah Creek were made to flow north-westward. A very low divide in the basalt is south of Latah Creek and parallels the stream canyon in its northward course. This, of course, may have developed in Post-Miocene time by movement. The divide was established in pre-glacial time, for it was crossed by the Spangle ice lobe and caused impounding as described by Bretz (1:pp.583).

The most important drainage change occurred in the Clark Fork-St. Joe systems for the damming caused by the basalt apparently deflected the entire drainage northward through the Purcell Trench. As much as 1500 feet of lake-beds capped by basalt filled the lower Spokane Valley. The obstruction became too high, and the drainage up the Rathdrum Valley was joined by Priest River near Athol, and both continued through the Pend Oreille Valley to the Clark Fork. The entire drainage was up the trench into the Kootenai.

Davis (6:pp.107-8) claims that if the heavy deposit of clays and silts which forms the broad plain for ten miles north of Lake Pend Oreille were absent, the lake would probably at the present time drain northward into the trough, for Kootenai Lake is nearly 300 feet lower than Pend Oreille Lake, and the bottoms of the two are very nearly the same. He states further that it thus becomes all the more probable that the divide of 2250 feet between Bonners Ferry and Pend Oreille Lake (2061) is banked with morainic material of great thickness, otherwise the two lake troughs might be confluent. The writer does not believe that the two lake troughs need necessarily be confluent if the barrier be removed, for a divide with an elevation of as much as 2400 feet would probably have permitted the pre-glacial Clark Fork drainage to pass northward, and normal stream erosion may have

lowered this divide to an elevation of less than 1800 feet before additional reduction by the glacial advances. The narrowness of the valley at that point and the appearance of granite in the valley bottom a short distance to the north indicate that the two lake troughs are probably not confluent.

ORIGIN OF THE LATAH FORMATION

As the basalt encroached upon the flanks of the mountains and formed embayments in the valleys, the grades of the rivers upon entering the lava were lessened, and the streams were forced to drop their sediments into the quiet ponds, shallow swamps, and slowly moving channels. That this actually happened is proved, for lake beds are found bordering the mountains where streams and wells have cut out through capping basalt. In the Spokane region, at least 1500 feet of clays and shales, derived from crystalline rocks in the mountains and from andesitic volcanic ash, are exposed in the valley of Latah Creek for ten miles south of Spokane, along tributaries of Deep Creek and Little Spokane River 20 miles to the north, and in Rathdrum Valley three miles northeast of the town of Coeur d'Alene. Three or four hundred feet of the material are exposed in the canyon of Latah Creek, and the remainder has been penetrated by wells.

The Latah Formation has been described by Pardee and Bryan (9:pp.1-15) who state that during Latah time, lava floods of Columbia basalt advancing from the west were held back from the Spokane area by a ridge, the highest points of which form the hills near Cheney, Marshall, and Medical Lake. The drainage outlet was gradually obstructed by the lava, and sediments accumulated to a maximum depth of 1500 feet. Twice the area was invaded in part by lava before it was overwhelmed by the flows of rimrock basalt which extended far up the valleys in the mountains. After a time interval, measured by the cutting of a valley more than 800 feet deep along Latah Creek through the basalt into the Latah Formation, another series of basalt flows almost filled the valleys. Then the streams cut through the valley basalt to a level below that at present.

The origin of such an immense deposit of lake-bed material exposed in the Spokane vicinity becomes clear when the pre-basalt drainage is known, for Priest River, Clark Fork, and St. Joe River flowed through the Spokane Valley to the west, and with the basalt barrier across its path, deposited the sediments over a wide area, mainly of clay and shale augmented by volcanic ash. The impounding extended far up the Spokane Valley into the Rathdrum and probably beyond the Pend Oreille, how far north it is not possible to state. But a remnant is exposed near Hayden Lake under the protection of overlying basalt. The formation is exposed in many places beneath the basalt which skirts Coeur d'Alene Lake, and the writer has noticed a similar formation southeast of the town of St. Maries beneath the basalt in the present valley side. The younger flows protected the soft beds temporarily, but after the basalt was penetrated by the streams, little time was needed to re-excavate new canyons and valleys.

The filling of Rathdrum and Spokane valleys with soft clays and shales to an elevation of about 2000 feet, and the capping by several flows of basalt which was almost wholly removed by the St. Joe system before the advance of the ice, will explain the great depth of Pend Oreille Lake, for the ice could have but little difficulty in re-excavating the old valley through these soft materials.

P R E - G L A C I A L F E A T U R E S

In Miocene time the courses of some of the major streams were completely changed by the flows of basalt which built up the Columbia Plateau. The impounding and resulting changes have just been described with the drainage now northward through a lower divide in the upper Purcell Trench. Then followed a period of erosion to the coming of the ice in Pleistocene, when marked changes were again produced.

During the intervening time, the St. Joe and Coeur d'Alene rivers intrenched through the basalt in their valleys. Near Coeur d'Alene city as much as 600 feet of basalt and lake beds were penetrated. The streams succeeded in eroding most of the basalt from their valleys, and at present only small remnants skirt the valley sides above the lake. Headward more of the basalt remains in the valley sides.

The St. Joe system passed up the Rathdrum Valley and cut through a relatively shallow depth of basalt into the underlying lake beds. The distance the basalt flowed up the Rathdrum Valley and northward is not known. The last trace is seen about three miles south of Athol, and all that remains is the terrace along the east side of Rathdrum Valley in a protecting cover. The basalt probably extended many miles beyond this point, but all traces have been obliterated by the action of the rivers and the ice advances of a more recent date.

It is evident that the St. Joe system cut through to a considerable depth in the Rathdrum Valley. Though Rathdrum Valley is higher than Coeur d'Alene Lake, some of it as much as 370 feet and now prevents any northward drainage, the present surface of the valley is due to glacial fill. Coeur d'Alene Lake has a depth of 155 feet, giving the bottom of the old St. Joe system near Coeur d'Alene city an elevation of about 1975 feet. The present surface of the lake is 2124 feet. Spokane River, which drains the lake and passes along the south margin of Rathdrum Valley and down the Spokane Valley, is very recent in age and flows over the surface of the Pleistocene glacial fill.

The logs of wells in Rathdrum Valley prove conclusively that a wide pre-glacial valley existed from Coeur d'Alene Lake to Pend Oreille Valley and up Hoodoo Valley. Logs of wells in the vicinity of Rathdrum, between Rathdrum and Hayden Lake, near Athol, on the gravel plateau west of Athol, and in the Hoodoo Valley, are all in sand and gravel of glacial origin. Near Athol wells were dug to a depth of 370 feet before water was encountered--this representing the approximate surface of Pend Oreille Lake. The bottom of the well was in gravel. West of Athol about 4 miles a well on a higher gravel terrace was sunk to a depth of 475 feet, all in gravel, and water was again struck corresponding to the surface of Pend Oreille lake. This well did not pass through the gravel. Between Rathdrum and Hayden Lake a well sunk to water showed similar conditions. This is, also, true of wells between Rathdrum and Post Falls and of a well in Hoodoo Valley. In no case was bedrock encountered. Hence, the actual depth of the pre-glacial valley is not established. Some of the wells are said to fluctuate with changes of level of Pend Oreille Lake. Hence, Pend Oreille Lake, whose surface is about 73 feet lower than that of Coeur d'Alene Lake, appears to control the underground drainage of Rathdrum Valley, proving that a deep valley

existed from Coeur d'Alene city northward. Some of these wells are quite close to the valley edge and if the old valley were reconstructed might be a thousand feet or more deeper than at present. How much of this re-excavation was due to the St. Joe drainage, and how much was due to ice erosion, is difficult to say, but the writer is inclined to believe that erosion by Priest River and the St. Joe near Athol had been down to an elevation of 1600 to 1700 feet, and the remainder has been due to ice.

The removal of a valley of basalt could only take place under rigorous stream erosion, and if the pre-glacial streams followed present drainage lines, a flat divide of basalt should exist between Spokane River and Pend Oreille Lake at an elevation of about 2500 feet. It would be impossible for either the glaciers or the present streams to have removed the twenty miles of basalt covering Rathdrum Valley, as no large streams enter the valley from its south edge to the Clark Fork, a distance of about forty miles.

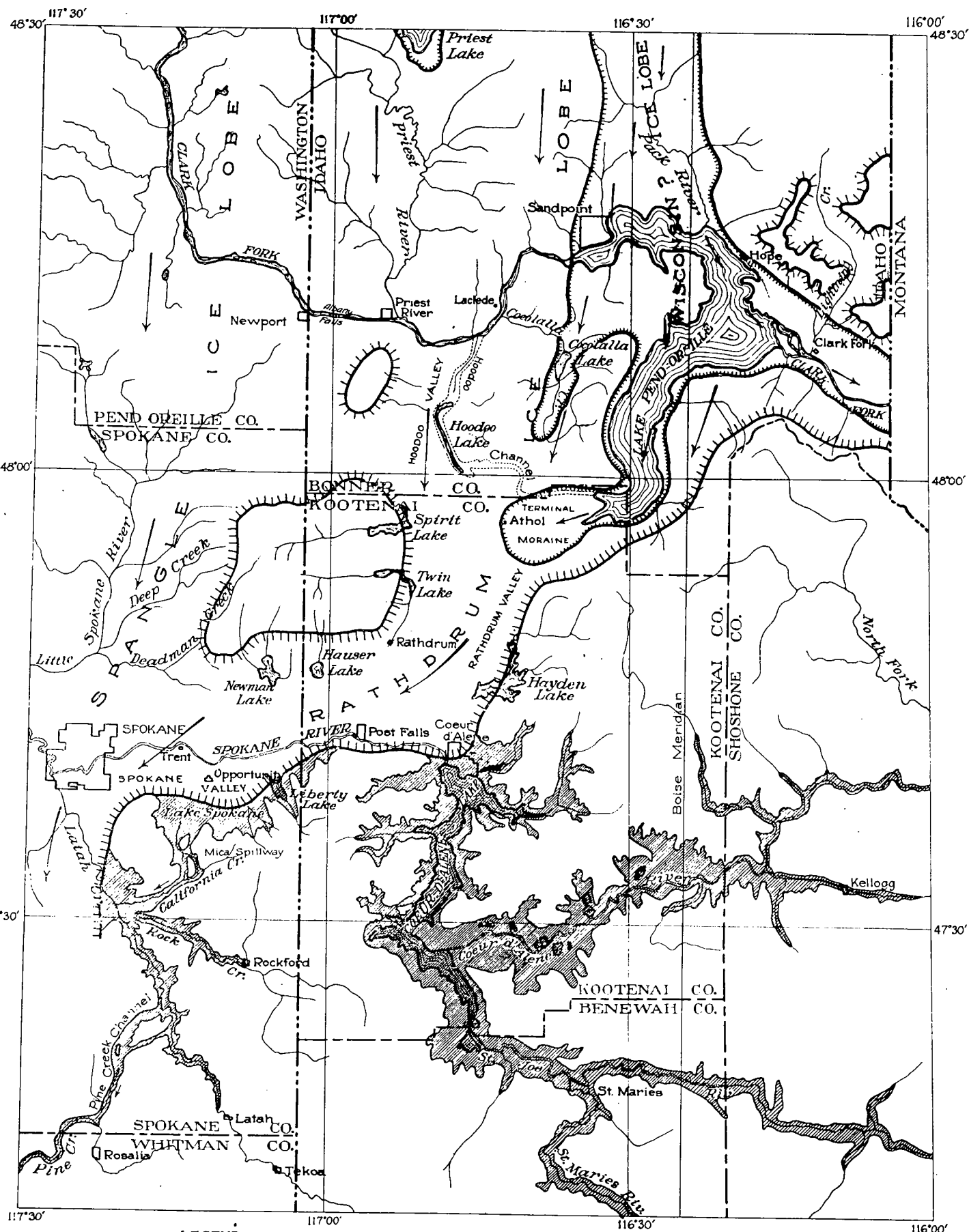
Latah Creek became permanently established during this interval and was not essentially changed in Pleistocene except for impounding and deposition of sands and gravels in its canyon by the ice advance, which, however, was largely flushed out by the stream when the ice retreated. The creek had cut a canyon about 500 feet deep through the second flows of valley basalt before Pleistocene time, flowing in a northwesterly direction from where it crossed the Idaho line near Tekoa, Washington, entrenching itself in the lava plateau, and entering the Columbia to the west and north of Spokane city.

Spokane River as such did not exist in pre-glacial time. A relatively small stream occupied the Spokane Valley representing the drainage of Liberty Creek, Saltese Creek, and others and flowed into Latah Creek. These streams and others flowing eastward into the St. Joe greatly lowered the basalt divide in the Spokane valley which probably existed two or three miles west of Post Falls. The erosion was sufficient to lower the divide to such an extent that with later erosion by the ice, the glacial deposits buried it from sight. The soft beds of the Latah Formation could offer little resistance to the streams and the glaciers after the overlying basalt was removed. The basalt capping near Spokane suggests that the ice erosion was less effective in the lower end of the valley.

The basalt terraces on the valley sides from Post Falls and Hauser west afford evidence that the Post-basalt drainage did not follow its former lines down the Spokane Valley. Though the valley narrows greatly the basalt sides come closer together, and the valley shows much less post-basalt erosion than the Rathdrum Valley. The Spokane vicinity, also, has no deep gravel-filled valley confluent with the Rathdrum for wells encounter basalt and Latah Formation.

P L E I S T O C E N E C O N D I T I O N S

Two advances of the ice are recorded in the region, one an older extensive lobe from the north which joined the Spangle lobe described by Bretz (1:pp.573-649, 1a:pp.646-7), who assigned the ice to Spokane age, and another much younger but less extensive advance assigned to the Wisconsin by the writer. Davis (6:pp.97-111) described the glaciation of the region corresponding to the Wisconsin advance, but he failed to note the much colder and much more extensive Spokane glaciation. He depicts the ice coming down the Purcell Trench from the



MAP OF NORTHERN IDAHO DURING
PLEISTOCENE TIMES

Base from US Geol. Survey and
Forest Service Maps.
Geology by A.L. Anderson, Idaho
Bureau of Mines and Geology

north and terminating just beyond the south end of Pend Oreille Lake, blocking the Clark Fork Valley and causing glacial lake Missoula. The present paper contains the first description of the Spokane ice in northern Idaho. The lobe which followed the Purcell Trench through the Rathdrum and Spokane valleys to its junction with the Spangle Lobe will be designated as the Rathdrum lobe.

The Spokane advance is much older than the Wisconsin ice, yet the streams have made but slight adjustments to the changed conditions, and morainal deposits, striations on polished bedrock, and lakes remain. Bretz (1b:p.342) deduced from the talus slopes in the channeled scablands that the lapse of time since the Spokane glaciation is two and one quarter times as great as that since the Wisconsin glaciation, probably Iowan or early Wisconsin. Of all the lakes in the region only Priest and Pend Oreille were not formed by the Spokane Advance.

The area covered by the Wisconsin ice and that covered by the Spokane ice may be differentiated without much difficulty, for the striations and polished bedrock are remarkably fresh in the wake of the later advance, but the striae and scoring or glacial polishing are more imperfectly preserved, less commonly exposed, and the surface of polished granitic rocks shows slight weathering in the wake of the earlier ice sheet.

THE SPOKANE ADVANCE Spangle Lobe

The Spangle lobe has been described by Bretz (1:pp.573-608), who shows the ice advancing from the north along the west side of the Selkirks, blocking the Spokane Valley a few miles east of Spokane, crossing the valley of Latah Creek, and leaving its terminal moraine on the basaltic plateau near the towns of Spangle and Medical Lake. The ice barred the flow of Latah Creek which produced a ponding far to the south to an elevation of about 2500 feet, with an outlet through the Palouse Hills in the Pine Creek Channel, which was abandoned as soon as the ice dam melted, and the stream resumed its former course.

Rathdrum Lobe

The Rathdrum lobe came from the north, followed the Purcell through the Rathdrum and Spokane valleys to its junction with the Spangle lobe a short distance east of Spokane. No attempt will be made to describe the glaciation in the upper Purcell Trench north of Sandpoint. The writer has observed that all the topography, except some of the highest peaks, bears and evidence of ice erosion. The ice must have had a maximum thickness in places of more than 4500 feet. Daly (5:p.95) has noted that the upper limit of general glaciation was at 7300 feet above sea level at summits occurring in the middle of the Purcell Range on the international border. Kirkham and Ellis (7:PL.VII) also verified this upper limit of Spokane glaciation. In the Lake Darling region north of the town of Clark Fork, the writer has found granite erratics resting on quartzite peaks at elevations of 6000 feet.

The thickness gradually decreased southward, and, on the slope of the Cabinets north of Hope, a town in the valley of the Clark Fork east of Sandpoint, glaciation has been effective up to an elevation of about 3000 feet above Pend Oreille Lake, or 5000 feet above sea level. The striae run nearly north and south. At the mouth of Bull River erratic boulders were noted at a level of 2000 feet above the Clark Fork.

The ice covered the divides between Hoodoo, Cocolalla, and Pend Oreille valleys. The main mass of the ice probably passed down the Pend Oreille Valley and overran the sides of the mountain spur that bounds it on the south to an elevation of more than 3000 feet. Here the spur shows the evidence of great ice erosion, and it was effective in turning the lobe in a westerly direction. The ice in passing down Cocolalla Valley did relatively little deepening, but everywhere bedrock is polished bare. The greatest work was done in the Pend Oreille Valley in the soft clays and shales of the Latah Formation. The ice joined with Spangle lobe to the west of Curtis Mountain, but it was forced to separate by the southern Selkirks, of which Mount Spokane is the highest peak, and continued as a separate lobe down the Rathdrum and Spokane valleys.

From the south end of Pend Oreille Lake to Spokane the thickness of the ice is difficult to estimate because of the deep valley fill of glacial sand, gravel, and boulders. The ice covered, or nearly covered, Lone Mountain, an isolated knob near the valley side north of Rathdrum, and overran the lower foothills and mountain sides north of Hayden Lake. The ice which had been following a south line was deflected by the high mountains to the south of Pend Oreille Lake and turned gradually to the west, following the trend of the valley system.

The ice thinned rapidly to the south and west. It did not enter the Coeur d'Alene Valley, but turning in a westerly direction blocked the mouth of the valley. Some of the ridges between Coeur d'Alene Lake and Hayden Lake appear faceted, but the ice did relatively little work. The ice was several hundred feet thick along the edge of the valley at this point, but most of it was probably stagnant.

The glacier, swinging westward in a wide curve with Rathdrum as an axis, banked up deposits of probable ground moraine which now hem in the Spokane River between Coeur d'Alene city and Post Falls. There is little evidence of glaciation south of the Spokane River between these two towns, for undisturbed loess covers the basalt terrace except at the very edge.

At Post Falls the glacier laid bare granitic rocks, and striations or scorings on the spur above the gravel fill show the ice moving S. 80 degrees W. The ice extended several hundred feet up the valley side at this place. The northern part of the valley from Rathdrum west was glaciated to greater elevations, and polished bedrock is exposed several hundred feet up the sides. The ice was probably six hundred to seven hundred feet thick or more in the center of the valley. The striae on the bedrock a short distance west of Rathdrum show the ice lobe moving in a southwesterly direction.

From Liberty Lake westward the ice extended up the valley sides for short distances in only a few places. Parts of the valley along the south side escaped glaciation. Polished bedrock of granite and pegmatite with glacial striae or scorings on the top compose some low knobs which project 50 feet above the valley fill between the towns of Trent and Opportunity in the Spokane Valley. This shows the ice traveling southwest at an angle of approximately S. 40 degrees W. in direct line with the west face of the low mountainous spur on the south side of the valley facing the plateau. Evidently, the lobe was turned in a more southerly direction on nearing the

Spangle Lobe with which it joins two or three miles to the west. The ice extended up the side of the northwest edge of the spur south of the Spokane Valley, imprisoning the St. Joe drainage so that it found an outlet through the mountains at Mica, first forming glacial Lake Spokane on the south side of the Spokane Valley. The ice probably extended to an elevation greater than 2700 feet on this ridge of the mountain, and the thickness above the plateau upon which it now enters must have been at least 300 feet thick.

The erosive work done by the ice must have been very great--far greater than that accomplished by the later Wisconsin advance. Most of the depth of the Pend Oreille Valley may have been attained at this time. The depth to which the ice eroded in the Rathdrum and Spokane Valleys cannot be definitely determined, but it must have been in excess of 700 or 800 feet below the present gravel fill. The ice was probably successful in removing any terraces of basalt that may have escaped earlier removal in the upper trench by the rivers. The ice would have little difficulty in eroding the soft clays and shales of the Latah Formation in the Rathdrum and upper Spokane valleys, and had no difficulty in wiping out the low pre-glacial divide west of Post Falls, though before reaching Spokane it was forced up on top of the plateau and valley basalts which overlies these soft beds.

The greatest monument of the Rathdrum lobe, however, is the great thickness of gravel deposits which fills the Spokane, Rathdrum, and Hoodoo valleys. This fill where uneroded has nearly everywhere the same surface elevation except in the upper Rathdrum and lower Hoodoo where it is built to a somewhat greater height, a factor which controls the present drainage of the Clark Fork. This deep glacial fill explains the generally flat bottoms of the major valleys which are three to nine miles wide. The plain near Pend Oreille Lake has an altitude of 2400 feet and decreases to 2000 feet towards Spokane, 45 miles to the southwest. The gravel attains the greatest altitude on a terrace, a half mile west of Athol in the upper Rathdrum, and the Hoodoo Valley where the surface is 2500 feet above sea level. This probably represents the height, and the place where the gravel deposits formed a divide, for the surface is lower both to the north and to the south, and explains why the Clark Fork did not continue down the trench after the ice retreated to the north. The Wisconsin ice probably found temporary outlet on the east side of this divide, lowering it about 50 feet in the Athol vicinity, but part of the Wisconsin fluvial drainage is believed to have been northward up Hoodoo Valley. Most of the gravel surface south and over this divide has the appearance of having been formed from immense floods of water which almost filled the valley. Some channels, 10 to 50 feet deep and one quarter to one half mile wide, carrying large boulders yet remain. This depositional feature of the melting ice is well described by Davis (6:p.110), who attributes the fill to floods of water overloaded with debris outwash from glaciers. Morainal material is lacking except possibly between Coeur d'Alene and Post Falls. Deposits near the borders of the valleys are generally composed of stratified sands indicating impounding along the margins. To approach the very edge of the valley and then suddenly to descend many feet into a steep-sided groove behind which the lakes in the region are formed is quite common. This extensive deposit was probably left, for the most part, by the retreat of the Spokane ice and not on the retreat of the Wisconsin.

Temporary Drainage Changes

Some changes in the drainage of the area were temporary in character and changed or disappeared as the ice retreated. The Rathdrum lobe caused much impounding along the south side of Spokane and Rathdrum valleys and some of the valleys to the south contained immense glacial lakes that extended dozens of miles into the mountains, as shown on the map. Some of the valleys still have remnants of these lakes now held in by the gravel fill in the Purcell Trench. Those changes which remain to the present will be spoken of as permanent changes and described later.

Lake Spokane: A lake, in area much less than commonly supposed, existed along the south side of the Spokane Valley. This lake has been called Lake Spokane by Large (8:p.335) and others, who show it as occupying the entire Spokane Valley with Hauser, Newman, and Liberty as remnants. The lake was supposedly held against the Spangle lobe. The writer, however, believes that the lake was confined to a relatively narrow stretch along the south side of Spokane Valley, between the north projecting spur of the Mica mountain mass west of Opportunity about a mile, to Post Falls on the east, and against the south edge of the Rathdrum lobe which did not quite fill the valley. The lake occupied an embayment into the mountains, as shown on the map. An outlet of this lake was found through a low pass in the mountains to the south, which Large called the Mica Spillway. The entire St. Joe drainage was necessarily along the south margin of the ice into Lake Spokane, for no outlet through the mountains, such as lake Spokane had, can be found for the glacially dammed St. Joe Valley. Deposits of stratified sand remain in the bottom of this former lake, showing dips to the south toward the outlet. The water in the lake was more than 500 feet deep. With the removal of the ice dam the lake was drained, and Liberty Lake is all that remains. It is held in by a gravel dam across the mouth of the valley.

Mica Spillway: Prevented by the ice from moving westward, the drainage into Lake Spokane passed through a lower divide near the town of Mica. This divide, with an elevation of a little less than 2500 feet, lies between Mica Peak on the east and Silver Hill on the west, the highest points of the mountains south of the Spokane Valley. Though some of the flood waters escaped through the valley in which the town of Mica is located, most of it followed a somewhat lower pass, about a mile west of Mica, at an elevation of about 2450 feet. These features can be seen on the Spokane sheet. The main channel is about half a mile wide, lying on top of scrubbed basalt. The water washed the Palouse Hills from its path and left as witness basaltic scabland, very slightly channeled with a few basaltic boulders, and a very few granitic and quartzite boulders which had been floated on cakes of ice. Little cutting in the spillway was done, possibly from lack of tools, because Lake Spokane acted as a settling basin, but more probably because the actual current was very slight. The surface of the water probably directly joined the ponded waters along Latah Creek, and only when the barrier across Latah Creek was removed did the waters fall sufficiently to produce an actual spillway from Lake Spokane. Bretz (1a:pp.648-9) remarks that the amount of water passing through the Mica Spillway is not sufficient to care for the natural drainage from the mountains. He supposes that a large part of the St. Joe drainage was sub-glacial through the Spokane Valley. The lake occupied the valley of California Creek and joined with Lake Latah. However, as soon as the water of Latah Lake fell, the waters poured down California Creek, deepening the widening by its plucking action in the jointed columnar basalt.

Pine Creek Channel: Latah Creek was at the same time dammed by the Spangle lobe, and the waters were impounded many miles to the south. An outlet opened through the Pine Creek Channel, shown on the Oakesdale sheet and described by Bretz (1:pp.583-4). The channel is cut through the Palouse Hills a few miles to the east of the town of Rosalia at an elevation of a little less than 2500 feet. The waters flowing from glacial Latah Lake joined the glacial floods a few miles to the west of Rosalia.

As long as the Pine Creek Channel was in operation glacial lakes Spokane and Latah were probably in direct connection, as the Mica Spillway and Pine Creek Channel are at the same elevation, both on the surface flow of Columbia basalt. Therefore, the water passing through the Mica Spillway was probably slow and sluggish in its action and did little actual cutting, but as the ice began its retreat, Latah Creek resumed its normal course to the northwest, cutting a channel through the gravels which had been deposited in its valley. Lake Spokane lasted much longer than Latah Lake and continued to pour its water through the Mica spillway until the ice had retreated to the Spokane Valley and allowed the lake to be drained.

The small drainage from Latah Creek, augmented by the waters passing through the Mica Spillway and down California Creek, flushed a deep narrow valley in the gravel-sand fill left by the glacier in the large older valley of Latah Creek, even cutting into the basalt at the bottom. This clearing from Latah Creek valley of the glacial fill could not have been done by the natural small flow in Latah Creek alone. Most of the flushing had been done before the Spokane River came into being. The water through the Mica Spillway can be regarded as of the greatest importance in restoring the Latah Creek Channel. Terraces of gravel and sand remain on both sides of the valley of Latah Creek, traceable for many miles, even below the junction with Spokane River. These terraces indicate a large volume of water flowing down Latah Creek and show that the floods continued to pour from glacial Lake Spokane through the Mica Spillway into California Creek and Latah Creek after the ice had retreated across the valley of Latah Creek.

Glacial Lake Coeur d'Alene: The largest body of impounded water filled the St. Joe and its tributary valleys, for the Rathdrum lobe blocked the valley near the present outlet of Coeur d'Alene Lake and covered the valley side near Post Falls, effectively impounding the entire drainage from the Coeur d'Alene mountains. The water in the lake stood at an elevation of between 2500 and 2700 feet, for ice-floated erratics have been found almost to the altitude of 2700 feet. Many have been found at the 2500 foot level. The water in the lake was more than 700 feet deep in the lower part of the St. Joe Valley.

The impounded water drowned the St. Joe River valley many miles beyond the town of St. Maries, almost to the Montana line, and flooded the St. Maries Valley, almost to the town of Clarkia. The lake extended up the Coeur d'Alene Valley to a point about midway between Kellogg and Wallace. The lake just escaped having outlets through the mountains in several places. A further rise of about 50 feet would probably have seen a spillway through a pass at Clarkia or over a basaltic divide near Worley to the west of the present lake. Because no spillways can be found, the drainage must necessarily have been along the south edge of the ice in Rathdrum valley into Lake Spokane. A few small banks of clay along the valley side of the Coeur d'Alene river may show the height of the impounded waters.

The writer makes no attempt to calculate the amount of water impounded against the ice barrier, but the volume was enormous and may probably be figured in terms of several cubic miles. The map which accompanies the pamphlet shows the magnitude of the lake.

Permanent Drainage Changes

Those features just described disappeared when the ice melted, or soon after, and were considered merely as temporary changes. The evidence of them remains in the nature of their deposits and their abandoned channels where they had outlets other than at present. But other changes which still remain are considered here as permanent changes and will be so described. These include the lakes which border the Rathdrum and Spokane valleys, held behind gravel dams, and ably described by Davis (6:pp.110-11, 114-5), who, however, believed them to have been formed by the outwash plain which extended to Spokane and formed in front of the Kootenai-Pend Oreille lobe which the writer has put in the Wisconsin. These changes will be briefly described. The Spokane River with its fall at the town of Post Falls, and in the city of Spokane, are also "permanent" changes resulting from the Spokane advance. The establishment of the course of the Clark Fork to the west, beheading Priest River, came as an aftermath upon the retreat of the Rathdrum lobe.

Coeur d'Alene Lake: Though this lake is a remnant of glacial Lake Coeur d'Alene, it needs more detailed description. It ranks second in size of the lakes in the area and is the largest of those formed in Spokane time. It has a length of 24 miles, though 20 miles of delta flats along the St. Joe and a lesser distance along the Coeur d'Alene show that the lake was nearly twice as long at the time of its establishment on the retreat of the Rathdrum lobe. It ranges from one half to two miles wide and has a maximum depth of 155 feet near the north end, and not 400 feet as stated by Davis (6:p.114). Headward, the lake gradually decreases in depth to the delta of the St. Joe.

The lake occupies the lower valley of the St. Joe River and owes its origin to a glacial gravel-sand dam across the mouth of the valley at Coeur d'Alene city. This dam is composed principally of stratified sands, with but little gravel exposed at the surface, and indicates that the deposition was from the sides of the glacier and the glacial rivers into quiet ponded waters. The lake bears every resemblance to a drowned river valley and shows conclusively that it was never occupied by an ice lobe. It shows no glacial striae, polished bedrock, faceted spurs, or erratics, except those floated on ice at the time of the glacial lake. The lake has a very irregular shoreline marked by numerous bays which are well shown on the Rathdrum sheet. Soundings indicate a normal erosional valley bottom. Tributary valleys are drowned, and such bays as Wolf Lodge, Mica, Rockford, etc., project back into the mountains.

Hayden Lake: This lake is much smaller than Coeur d'Alene Lake, but it has a similar origin. The gravel formation of the Rathdrum Valley dammed the mouth of the valley of Hayden Creek. This lake has no visible outlet but drains through the gravel and joins the deep water table of Rathdrum Prairie. The drowning of Hayden Valley has extended headward for more than six miles and widens near its underground outlet to two miles. The lake has numerous bays and promontories and is for the most part a normal erosional valley. Ice passed over the lower part of the course of Hayden Creek but caused little apparent change, though the valley may have been deepened somewhat near its widest part. The barrier is composed of stratified deposits of sand, with a little gravel, and probably represents the load left by the Rathdrum lobe and by its outwash. The level of the lake is 2242 feet and is reached by descending over the edge of the flat fill of Rathdrum Prairie. South of Hayden Lake, natural depressions occur along the margin of Rathdrum Prairie

which contain no water, but which represent protected areas where asker-like forms or bars held back the main fluvial deposits and left these areas only partially filled. Some of the elongated bounded depressions are more than forty feet deep.

Spirit Lake: This lake is also caused by a high gavel dam across the outlet of the valley of Bricket Creek. The glacial deposits did not entirely fill the Rathdrum Valley to the same level and a depression is left along the main valley side. An arm of the lake, however, fills this depression for some distance and parallels the main Rathdrum Valley. The lake is drained by Spirit Creek which flows in a depression northward, but the water soon disappears in the gravels. The lake is four miles long and three quarters of a mile wide. It appears to lie in a normal erosional valley, though part of it may have been overridden by the ice and occupied by ice more or less stagnant. The surface of the lake is 2442 feet and lies about a hundred feet below the surface gravel of Rathdrum Valley.

Twin Lakes: This lake is similar to the others, and particularly to Spirit Lake, because about half of the lake lies outside of the valley of Fish Creek and parallels the Rathdrum Valley. Reference should be made to the Rathdrum sheet where these features are strikingly shown. The fact that part of the lake extends into the mountain valley and the remainder along the main valley has probably given it the name of Twin Lakes. It is sometimes referred to as Fish Lake. This lake is hemmed in by the high Rathdrum Valley fill. The lake is narrow, not over a few hundred yards wide at the most, crescent shaped, and about four miles long. Fish Creek flows into the west tip of the crescent, and Rathdrum Creek flows into the south end. Rathdrum Creek flows northward in a depression from the town of Rathdrum to the lake in another of the marginal depressions. The lake has no visible outlet, but drains through the gravels of Rathdrum Valley. Its surface has an elevation of 2314 feet.

Hauser Lake: This lake is also known as Sucker Lake. It is roughly circular in outline and covers about one square mile. Like the others it is held in by a gravel dam which built up across the tributary valley as the overloaded streams from the ice lobe deposited its sand and gravel. The lake is very shallow and drains through the gravel dam. Ice probably covered this region before the period of deposition, for the bedrock is polished and angularities are reduced.

Newman Lake: Newman like the others has been formed behind a low divide of glacial fill across the lower part of the valley of Newman Creek. It has no outlet, but drains underground into the Spokane Valley. A relatively small rise in the water level would cause the lake to flow over its dam. The lake covers about one and one half square miles and has a surface elevation of 2130 feet.

Liberty Lake: This lake is on the south side of the Spokane Valley and is only a little larger than Hauser Lake. The lake might be considered as a remnant of glacial Lake Spokane, but it owes its existence to a high gravel barrier across the valley of Liberty Creek. The lake is shallow, and, like the other smaller lakes, it drains through the gravels of the main valley which here rises about fifty feet above the lake. The lake has a surface altitude of 2050 feet.

Other depressions which contain no water are present along the south edge of the Spokane Valley, from Liberty Lake to the outskirts of the city of Spokane, similar in most respects to those found along the margins of Rathdrum Valley. The most noted one is the depression into which Saltese Creek drains and which has a marshy bottom. These depressions contain no water because the drainage area is not sufficiently large to maintain an inflow equal to the outflow through the gravel, except in the early spring. These depressions, together with those that hold lakes, appear to have formed behind bars which developed across valleys of protected areas of the main valleys by the heavily loaded floods from the retreating ice.

Spokane River: This name has been given to the St. Joe as it leaves Coeur d'Alene Lake. During the occupancy of the Rathdrum and Spokane valleys by the Rathdrum lobe, the drainage of the St. Joe system was necessarily along the south side of the ice, as no other outlets have been found, and the drainage was from glacial Lake Coeur d'Alene into glacial Lake Spokane, either along the side of the ice and crowded upon the valley side, or was on the ice itself. The water then passed through the Mica Spillway and into Latah Canyon or found, in part, drainage under the ice in the Spokane Valley. As the ice retreated up the Rathdrum Valley, the St. Joe had to continue to flow through the Spokane Valley, because it was blocked from its previous outlet to the north by the ice, and when the ice had entirely disappeared the immense gravel fill to the north, more than 350 feet above the present river, effectively blocked the north outlet.

The Spokane River then continued down the Spokane Valley, hemmed in against the valley margin by a high bank of deposits between Coeur d'Alene Lake and Post Falls.

Post Falls: At the town of Post Falls the river was superimposed on the resistant gneissoid and granitic rocks of a formerly buried spur. Down stream from the spur, the river course is more deeply incised in the gravel and its valley is well open. The river divided into several streams, has cut as many small gorges across the rock spur--with falls at the head of each. The bedrock is highly jointed and the river has cut deeply along a prominent system of joint fractures, and, as the ice retreated, the river was unable to obtain an easier passage through the gravel a half mile to the north. Three channels were cut in the spur and have formed gorges 70 to 80 feet deep with precipitous sides. The gorges extend nearly across the spur, but the adjustment has not been completed and consequently the river plunges into the channels from the top of the resistant spur forming Post Falls.

Spokane Falls: After plunging over Post Falls, the Spokane River followed the lowest depression in the valley fill, which carried it to the north side of the valley at Trent. Then it flowed southwest to Latah Creek. Its channel, to where it tumbles over the basalt in Spokane city, is on the glacial gravels and its present course bears little relation, except in general direction, to the pre-glacial tributary of Latah Creek.

Spokane Falls are the result of blocking of the drainage of the St. Joe system to the north by the ice and gravel fill, and the establishment of a new course down the Spokane Valley. They are caused by the diverted St. Joe tumbling into the canyon of Latah Creek.

Prior to the ice invasion, Latah Creek had cut a wide, deep canyon in the basalt, and a small tributary joined it from the Spokane Valley. Latah canyon was cut more than 800 feet below the rim-rock flows, and the valley was much wider than at present, for today the sides are lined with terraces of gravel. Cutting had extended headward from Spokane almost to the town of Tekoa, more than 40 miles to the southeast. This canyon was obstructed by the glacial deposits during the Spokane advance and retreat, and for a time, as previously explained, the drainage was through the Pine Creek Channel. But as the lobe receded northward of the canyon the waters of Latah Creek resumed their flow in the old valley, and, augmented by the floods which continued to pour through the Mica Spillway into California Creek and then into Latah Canyon, they soon cleared a deep channel through the entire extent of the gravel fill. This new valley has gravel terraces on both sides, for the waters cut deeply and quickly.

When the ice had receded up the Spokane Valley, Lake Spokane was drained, and Spokane River naturally came into being and flowed into the partially flushed valley of Latah Creek. The river followed as best it could on the gravels which filled the valley of the older tributary, but it found itself placed at one side and hung up on a ridge of basalt. Since then the Spokane River has cut through about half a mile of gravel in the valley of Latah Creek and has further entrenched through about half a mile of basalt.

Little clearing of the valley of Latah Creek was done by the Spokane River, for several terraces of sand and gravel line both sides of the valley. They may be traced unbrokenly from above the mouth of the river at Spokane to long distances below Spokane, which proves further the passage of floodwaters down Latah Creek from the Mica Spillway before the Spokane River was established. Spokane River now cuts directly across these terraces in entering the valley of Latah Creek.

A restoration, by means of basalt outcrops which are exposed above the gravels above the Spokane Falls, of the older tributary valley which cared for the drainage down the Spokane Valley in pre-glacial time shows that this valley was much smaller than that of Latah Creek. Basalt crops out high above the river in the city of Spokane, east of the Falls, less than a half mile on either side. Had Spokane River flowed through the Spokane Valley in pre-glacial time, obviously Latah Creek canyon would have been the smaller of the two.

A study of the map will show that Latah Creek continues in a straight line and that Spokane River enters at right angles, an unusual thing for a larger stream to do had it been superimposed on the surface of the basalt at the same time as Latah Creek. The size of Latah Creek canyon increases progressively down stream, and the entrance of the Spokane appears not to have affected it greatly.

Clark Fork River:* As the ice retreated northward of the Rathdrum and Hoodoo Valleys and up the valley of the Clark Fork, the drainage could not pass up the Purcell Trench, for the valley was blocked by the ice. Nor could the drainage apparently resume to the south through the Rathdrum Valley, because the morainal deposits and outwash, built to an elevation of about 2500 feet above sea level and an unknown depth above the valley

* Clark Fork is better known as Pend Oreille River after it leaves Lake Pend Oreille on its westward course.

bottom, had blocked the river in that direction. But apparently a lower divide existed to the west, and the Clark Fork established itself in that direction through the gravels, crossing the low divide near Laclede, crossing the valley of the Priest River and beheading it, leaving the Hoodoo Valley stranded, and then passing over the low divide west of the town of Priest River with final outlet to the west.

At Newport the Clark Fork probably flowed across the gravel to the southwest and south to the Spokane River and probably not until after the retreat of the Spokane ice, or more likely the retreat of the Wisconsin ice, did it steal a valley to the north. Davis (6:p.107) mentions a singular feature noted here that a head branch of the Little Spokane River rises close to Newport and flows on its southward course through a narrow, rock-walled gorge, with much fresh talus, in part occupied by a long narrow lake. He states further that this had the appearance of being the work of the Clark Fork or of a distributary of that river, temporarily deflected southward during the aggregation of its high terrace. If so, the return of the river to the northeastward course below Newport is probably to be explained by the trenching of the terrace deposits in that direction being easier than to the southward. This place was not visited by the writer. But it seems likely that as the ice receded northward, the upper part of this valley, which normally drained to the south, offered a lower passage than over the gravel terrace and the basalt plateau to the south, and it naturally took this valley for its own. This explains the canyon which it enters to the north near Metaline Falls. It may be more likely that this piracy did not occur until the retreat of the Wisconsin ice.

Large (8a:pp.259-270) also presents evidence to show that the drainage of the Clark Fork from Newport was southward along the valley of the Little Spokane River. But he explains the change in direction of drainage as being due to the tapping of Lake Clark, which he presumed to have occupied the Clark Fork Valley between Newport and Metaline Falls on the close of the Pleistocene. This piracy occurred to the north of Metaline Falls.

Albany Falls: These falls were produced in the adjustment above described. At Albany, between Newport and Priest River, the Clark Fork tumbles over a resistant mass of granitic rocks, having cut nearly through with a hundred foot precipitous gorge below. Conditions are similar to those at Post Falls on the Spokane River, for the river in cutting through the gravel was superimposed on a rock ledge or spur of resistant granitic rock.

THE WISCONSIN ADVANCE

A long interval of time existed between the Spokane ice advance and retreat and the new advance in Wisconsin time. Bretz (1b:p.342) figures the lapse of time since the Spokane glaciation at two and one quarter times as great as the Wisconsin glaciation, and, assuming that the Wisconsin glaciation of the northern part of the Columbia Plateau is late Wisconsin as the strong morainic expressions of its drift sheet suggests, he believes that this ratio would make the Spokane glaciation equivalent to either the Iowan or early Wisconsin, but he states that a definite correlation can be made only when a definite ratio for early and late Wisconsin and post-Wisconsin is obtained in the Mississippi Valley.

The new advance was not extensive and did not pass far southward. The south end of Pend Oreille marks the beginning of its terminal moraine and represents the farthest advance. This advance differed from the earlier in that the ice came from the north in the form of a large valley glacier which did not run far up the present valley sides. Two such valley glaciers descended in this region: one down the Purcell Trench, which Davis (6:p.83) named the Kootenai-Pend Oreille Lobe, and a smaller lobe down the Priest River valley which the writer will call the Priest River lobe. Another lobe probably occupied the Clark Fork valley from the Newport region northward beyond Metaline Falls, but this region was not visited nor was the lobe mapped.

These ice streams caused the formation of Pend Oreille Lake and Priest Lake. Little else remains of the work of this ice except for the quite fresh terminal moraines at the south end of each of the lakes and a few scattered patches of recessional moraine. Pend Oreille Valley shows the most intensive results of glaciation as a consequence of the two advances.

Kootenai-Pend Oreille Lobe

Davis describes this lobe as coming from the north down the Purcell Trench, a distributary going up the Clark Fork valley and another down the Pend Oreille to the south end of the lake and furnishing the vast volume of gravel and sand that forms the outwash plain as far as Spokane. The distributary that flowed up the Clark Fork Valley, he believes caused the impounding in glacial Lake Missoula. The writer agrees with this in part, but believes that the greater part of the Rathdrum and Spokane valley fill formed in Spokane time. The bottom of the valley has strong indication of glaciation which extends several hundred feet up its sides. Glacial striae show an east and west direction along the Clark Fork. Calkins (3:p.31) also noticed the presence of this lobe, for he mentions the indications of glaciation by a deep ice stream in the valley bottom of the Clark Fork from the north of Bull River to Pend Oreille Lake.

Most of the terminal moraine at the south end of the Pend Oreille Lake has a surface altitude less than that of the gravel plain in the upper Rathdrum Valley. The lobe passed down the Cocolalla Valley to near the town of Granite, leaving behind ground and terminal moraine. There is no evidence that Hoodoo Valley was occupied by Wisconsin ice as the gravel fill is undisturbed, except for the Hoodoo Channel, which carried glacial waters from Pend Oreille Lake. The ice did not extend far west of Sandpoint.

Most of the valley of the Clark Fork east to the Montana line has been filled with delta debris and its actual depth during the ice stream is problematical. However, as Pend Oreille Lake has a depth of 1100 feet and as the ice extended up the sides of the present valley several hundred feet it is probably safe to assume that this lobe had a thickness of at least 1400 feet and was capable of doing an immense amount of erosive work.

A drift divide exists between Sandpoint and Bonners Ferry at an altitude of 2253 feet at Elmira and Davis suggests that the glacier stood at this point for a considerable time during its recession and this accounts for the alluvial plain as far south as Sandpoint.

Pend Oreille Lake: The lake is a feature formed definitely in Wisconsin time, For the ice stream advancing down the Pend Oreille Valley cleared out the gravels deposited on the retreat of the Rathdrum lobe and left its

own terminal moraine to the south and west of the Pend Oreille Valley. The southwestern end of the lake is barred by a heavy moraine, and divided by a blunt morainic cusp into two bays, of which the southern one, bordered on its southern side by the ice-scoured wall, is two and one half miles long without a local name, and the northern one mapped as Squaw Bay with the village of Bayview at its end, is a mile and a half long. The Pend Oreille Valley had probably been greatly deepened by the Rathdrum lobe as the ice was confined in the relatively narrow trough, and indeed, most of the deepening may have been done by this earlier lobe, and the Wisconsin advance may have done little more than clear the gravel fill left by the first lobe. The valley controlled the direction of the ice movement of both the Rathdrum lobe and the Pend Oreille Lobe.

Pend Oreille Lake now occupies both the Pend Oreille Valley and the Clark Fork Valley, though the latter has been largely filled by the delta of the Clark Fork River. The lake is shaped like a huge question mark. It is about 42 miles long and averages 4 miles in width, ranging from one mile or less at the ends to six miles near the Clark Fork delta. The lake has a maximum depth of 1100 feet according to soundings made by Edward Sampson of the U.S. Geological Survey*.

The lake has a most regular shoreline, quite unlike that of the drowned valley of Coeur d'Alene Lake. No bays worthy of mention exist. The lake is bounded by faceted spurs with precipitous slopes best seen on the east side of the lake, and is almost free from gravel deposits along the sides, but instead has grooved and polished resistant bedrock which drops abruptly into the lake. The submerged part of the valley drops as abruptly as that above the water and has a typical U shaped bottom. The deep lake, particularly in the south end, confined between steep and for the most part timber covered valley sides presents a beautiful and fascinating picture of utmost grandeur. The dam at the southwest end of the lake has a steep slope toward the water, much of it a hundred feet above the water surface. Then for some distance westward the irregular deposits of the terminal moraine are the dominating features. These rise gradually to a height of 300 feet above the lake level.

The ice probably extended to the gravel terrace just west of Athol and some of the outwash went down the Rathdrum and Spokane Valleys which may explain the semblance of a wide channel in the gravels down the two valleys. But when the glacier had receded a short distance, this flow stopped and the drainage was out the Hoodoo Valley to the north. The gravels which were left by the Rathdrum Lobe were probably pushed ahead or along the glacier front and left in the terminal moraine and distributed as outwash.

The depth of Pend Oreille Lake is interesting, because Cocolalla Valley, also in direct line with the Rathdrum lobe and for the greater part with the Pend Oreille, exhibits no great amount of glacial deepening, though the surface rocks are perhaps no more resistant than the Belt rocks in the sides of the Pend Oreille Valley. It is difficult to explain this discrepancy unless a deep valley existed in the Pend Oreille before the coming of the ice. 800 or 1000 feet of overdeepening, as assumed by Davis, would seem impossible in this case where two parallel valleys show such marked diff-

* Oral Communication

erences and both in line with the ice advances. The much greater depth of Pend Oreille Valley is clear when the pre-glacial and pre-basalt drainage is taken into consideration. The writer has explained earlier how the Clark Fork occupied the Pend Oreille Valley in pre-basalt times, cutting a valley to a depth near that of the present bottom of the lake; and how during Miocene time the drainage was obstructed to the west of the Spokane Valley and caused the deposition of 1500 feet of soft clays and silts at Spokane, and a lesser thickness in the Pend Oreille Valley; how these beds were finally overwhelmed by the basalt flows, though in the meantime the Clark Fork and St. Joe found outlet through a lower divide up the Purcell Trench; and how to the coming of the ice advances the St. Joe was entrenching in these beds, the depth not known, but presumably enough to move out most of the basalt from the upper valley and out its bottom to the elevation of perhaps 1800 feet, with the probable removal of 700 feet of basalt and lake beds leaving then as a maximum amount about 800 feet of lake beds and Belt rocks to be removed by the ice. This, however, seems large, and it is more probable that the river had cut several hundred feet deeper than this before the Spokane advance. This made it relatively easy for the two ice advances to clear out the lake beds and change the valley into a glacial trough of the present depth.

Hoodoo Channel: This is a conspicuous feature on the Sandpoint topographic sheet, and it is represented by the long sinuous Hoodoo Lake with swamps or marshes continuing along both ends, most of the distance from Granite to the Clark Fork near Laclede. Further study of the Rathdrum sheet shows that this lines up with a depression in the north margin of the Rathdrum Valley which joins Pend Oreille Lake. This is an abandoned river channel which connects the southwest tip of Pend Oreille Lake at Squaw Bay with the Clark Fork River, near Laclede west of Sandpoint. The bottom of this abandoned river channel is stranded about 50 feet above the present surface of the lake and is dry, except for the shallow water of the long sinuous Hoodoo Lake and the swamps along its course in the Hoodoo Valley.

From its beginning at Squaw Bay the channel is in the gravel deposits on the north side of Rathdrum Valley and follows closely the edge of the gravel plain, but generally within it. The channel follows westward for six miles and then turns abruptly north two and one half miles, and cuts a fifty foot channel through the resistant granitic rocks at the town of Granite. The channel narrows to almost a hundred yards in crossing the granite ridge. Its previous width in the Rathdrum Valley was from a quarter to half mile wide. It then crosses this granite divide, a low pass in the mountain ridge, and enters the Hoodoo Valley, turning north and cutting a channel in the Rathdrum gravels, along the east side of the valley, more than 50 feet deep and from one fourth to one half mile wide. The channel is not far from bedrock and near the north end of the channel bedrock is exposed. But the channel sides are in gravel, and these sides are steep, symmetrically rounded, dropping off directly from the gravel plain, and indicate that the river was short-lived. Post-glacial erosion has effected the sides very little.

The channel obviously served as an outlet for the waters of Pend Oreille Lake, probably as the Wisconsin ice began its retreat. When the Pend Oreille lobe extended to Athol most of the glacio-fluvial outwash was probably down the Rathdrum and Spokane valleys, but as the front moved back several miles the high glacial divide caused the water to go northward through this channel which in the meantime had probably cared for some of the escaping water on

the north side of the lobe and from the glacier front just north of Granite. The volume of water flowing through this channel was undoubtedly immense, for the erosion of a channel 100 yards wide and at least 50 feet deep in fresh granitic rocks with no great jointing, and for a stream with low gradient, would indicate a volume of water of no small proportions. That the river was short-lived is indicated by the symmetry of the channel sides which in addition show no indication of the lateral erosion of the stream. When the ice had melted from the Pend Oreille Valley, the Clark Fork resumed its present course to the west of Sandpoint, though in the meantime water from the glacier near Sandpoint region passed down the Clark Fork Valley.

What effect the Wisconsin ice had on the valley through which the Clark Fork flows north of Newport is not known, but it is probable that the valley was blocked and the Clark Fork had to pass west and south of Newport until the ice receded from the valley as previously described. Since the northern outlet was established, the Clark Fork has intrenched through the valley train and fill, leaving terraces along both sides of the river more than 100 feet above the present water surface.

Glacial Lake Kootenai: Another lake that had a short life at the end of the Wisconsin glaciation covered the upper part of the Purcell Trench from Elmira to the Canadian border and beyond, though it is likely that the lake once extended even as far south as the gravel divide in the upper part of the Rathdrum Valley. In the vicinity of Bonners Ferry there are exposures of an extensive deposit of fine grained light colored sands and silts which form a high broad terrace on both sides of the trench, which Davis (6:pp.617-46) calls the Creston Terrace. The edge of this terrace is at an altitude of 2200 feet, but the surface is not uniform, the depth being much greater at some places than at others. The Kootenai River flows through these deposits in a wide steep-walled valley. This valley is two to three miles wide and has been partially filled by the delta deposits of the Kootenai River. This delta plain extends from Bonners Ferry to Kootenai Lake, 36 miles to the north. The lake beds cover the older valley bottom to a shallow depth and extend from the Montana line where the deposits are coarse and gravelly, indicating the entrance of Kootenai River into the lake, to the main valley in the Purcell Trench where the deposits of fine silt reach a maximum thickness near Bonners Ferry. The altitude of the deposits decreases northward toward the international border and southward toward Elmira though not greatly. The deposits along the trench are principally fine silts, largely rock powder, and stratified under conditions of generally quiet ponding.

It seems probable that these silts were accumulated in a lake formed in the Purcell Trench during the recession of the ice, held in at the south by the higher divide in the upper Rathdrum Valley fill, or more likely at Elmira, and, on the north, by the retreating glacier front. The decrease in the amount of sedimentation to the north indicates a retreating ice barrier. The lake probably found outlet south through the trench and joined the Clark Fork and flowed westward.

Priest River Lobe

This lobe was much smaller than the Kootenai-Pend Oreille lobe. It started from the mountains in the upper Priest River valley near the Canadian border, and terminated below the south end of Priest Lake which came into existence as the ice melted. The main lobe probably followed the main Priest

River valley and was probably joined by small tributary glaciers along the way. This lobe was not studied in any detail, nor can the thickness be estimated for the depth of the lake was not ascertained, though it is probably not over 500 or 600 feet deep. A terminal moraine remains south of the lake and marks the southern limit of the ice advance. To the south the upper sides of the valley, which are for the most part in granite, are scoured and polished by the earlier Spokane advance.

Priest Lake: The lake has an origin similar to that of Pend Oreille Lake, being held in by the terminal moraine of Priest River lobe which may lie on the gravel fill left by the earlier Rathdrum lobe. From the lake southward Priest River Valley is leveled by the gravel plain which slopes to the south with low gradient and is now terraced by the Priest River in its lower course. The surface elevation of these gravels corresponds to the surface elevation in the Hoodoo, Rathdrum, and other valleys. These, the writer believes to represent fluvio-glacial outwash and valley trains rather than lake sediments, though local ponding has been effective in many places. The thickness of the valley fill at this place is not definitely known, but it is probably not greater than 300 feet, for the river cuts through the gravel in some places.

Priest Lake is divided into an upper and lower part separated by a stretch of polished bedrock over which the joining stream picks its way. The southern lake is the larger. Both lakes are rather irregular in outline. The dimensions can be better obtained from the Priest Lake topographic sheet than by description here.

The outlet of Priest Lake affords an interesting study, for the moraine and outwash were at such a height in the main valley that the lake found a lower outlet by passing up a tributary on the west side and flowing back into its own valley some distance to the south, after cutting over a low divide a short distance from the lake. This peculiarity may be seen on the Priest Lake quadrangle.

C O N C L U S I O N S

These studies have dealt with the pre-basalt, the pre-glacial, and the glacial drainage changes in northern Idaho and eastern Washington. Before the coming of the Miocene basalt flows which have built up the Columbia plateau and formed embayments into the mountain valleys, the drainage was to the southward and westward. The Clark Fork flowed through the Pend Oreille and Spokane valleys to the west. Priest River occupied Hoodoo Valley and joined the Clark Fork near Athol. The St. Joe joined the Clark Fork near Coeur d'Alene though there is a strong possibility that the course was to the west near the south end of Coeur d'Alene Lake--a continuation of the present direction of the Coeur d'Alene River. Earlier basalt flows obstructed this drainage system and caused the deposition of 1500 foot Latah silts and clays in the Spokane Valley before the deposits were overwhelmed and buried beneath later basalt. This disarranged the former drainage system and probably caused a reversal of direction, with the entire system passing north through the Purcell Trench into Canada.

Subsequent erosion removed most of the basalt and Latah formation from the St. Joe and Rathdrum valleys and mere remnants of these now flank the valley sides. In Pleistocene time the region was visited by at least two ice advances from the north; the first being the most extensive and continental-like in character. This covered all but the tops of

the higher mountains in north Idaho and extended to increasingly lower altitudes through the Pend Oreille, Hoodoo, Rathdrum, and Spokane valleys where it joined the Spangle lobe just a few miles east of Spokane. The St. Joe drainage was blocked by the ice, which the writer has designated as the Rathdrum lobe. Glacial Lake Coeur d'Alene which was at least 700 feet deeper than the present lake and extended more than twice as far into the mountains was held back by the ice. The outlet was along the south edge of the ice or on the ice into Lake Spokane, a body of water held in against the south side of Spokane Valley by the lobe. Part of the water leaving the lake was probably subglacial, but some of it used the Mica Spillway through the mountains south of the Spokane Valley and joined Latah Lake which had an outlet through the Pine Creek Channel near Rosalia.

The fluvio-glacial deposits and outwash filled in the Rathdrum, Hoodoo and Spokane Valleys in greater part to unknown depths but in excess of 450 feet, and probably in the upper Rathdrum Valley to nearly 1000 feet. These deposits dammed the mouths of the tributary valleys and by impounding caused Hayden, Coeur d'Alene, Spirit, Twin, Hauser, Newman, and Liberty lakes. Coeur d'Alene Lake alone has a visible outlet. The ice and subsequent gravel fill effectively blocked the drainage of the St. Joe to the north, and the present Spokane River was established. The river was superimposed on a formerly buried spur of resistant gneissoid and granitic rocks at Post Falls, and this mass of rock is responsible for the falls. At Spokane the river tumbles into the canyon of Latah Creek which was established in pre-glacial time, and the falls are the result of the river being suspended on a ridge of basalt.

The Clark Fork River was held from re-entering its pre-basalt course through the Spokane Valley by the glacial fill in the upper Rathdrum Valley, and from its possible former course to the north by the retreating ice. It found a lower divide to the west and later intrenched through about 200 feet of gravels, beheading Hoodoo Valley and isolating it from the former Priest River drainage. It, like the Spokane River, was superimposed on a formerly buried resistant ridge of granite and the falls at Albany resulted.

The second advance of ice occurred in Wisconsin time. This was much less extensive and was more of the valley type. The ice stream followed the Purcell Trench from the north and left its terminal moraine at the south end of Lake Pend Oreille. Part of the outwash from this lobe, called the Pend Oreille lobe, was down the Rathdrum and Spokane valleys adding to that of the earlier advance, but a part was through the Hoodoo Channel and into the Clark Fork River near Laclede. The Hoodoo Channel which connected the south end of Pend Oreille Lake with the Clark Fork was later stranded. The Pend Oreille lobe cleared the gravels left behind by the retreat of the earlier ice, and Pend Oreille Lake remained held in by the gravel dam on the south, and a second gravel divide near Elmira north of Sandpoint. The lake is 1100 feet deep and has a U-shaped bottom. A smaller lobe in the Priest River valley extended to the south end of what is now Priest Lake and on its retreat left Priest Lake behind a gravel dam.

Clark Fork River at this time or less likely on the retreat of the earlier ice sheet, or possibly on the retreat of each, stole the valley of an early southward flowing stream and reversed its direction from Newport to Meteline Falls, though it probably occupied the valley of the Little Spokane until the ice had receded from the upper parts of the valley at Meteline Falls.