THE ORIGIN AND HISTORY OF LAKE WASHINGTON

by

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PREFACE.

Observations on the glacial phenomena of the Puget Sound region have been made from time to time by various observers. The most complete of these and the most masterfully presented is Bulletin 8 of the Washington Geological Survey, entitled "The Glaciation of the Puget Sound Region," by J. Harlen Bretz. It covers the whole subject in detail and will long stand as the standard reference on this subject. Although some of the minor features of the book may prove to be faulty in time as the separate topics and regions are studied more in detail, yet the essential features of the book are sound. It has been drawn upon extensively in this thesis, especially when discussing those general topics for which an examination of the Lake Washington region alone could not give all the information necessary for a complete understanding of the glacial history of the region as applied especially to Lake Washington. I believe that all material in this thesis derived from this work is made clear as such in the text.

Bretz gives a bibliography of the literature on the glaciation of this region. Of this only two articles have been drawn upon in this thesis, and all such information is referred to the proper authority in the text. The articles used are "Drift Phenomena of the Puget Sound Region," by Baily Willis, Buletin of the Geological Society of America, volume IX, and "The Physiographic History of the Puget Sound Basin," by James Kimball, American Geologist, volume XIX.

In conclusion, I wish to especially thank Prof. E. J. Saunders for valuable discussions on a number of the topics treated in the text and also for his advice on some of the relations at Renton which he took the time to visit.

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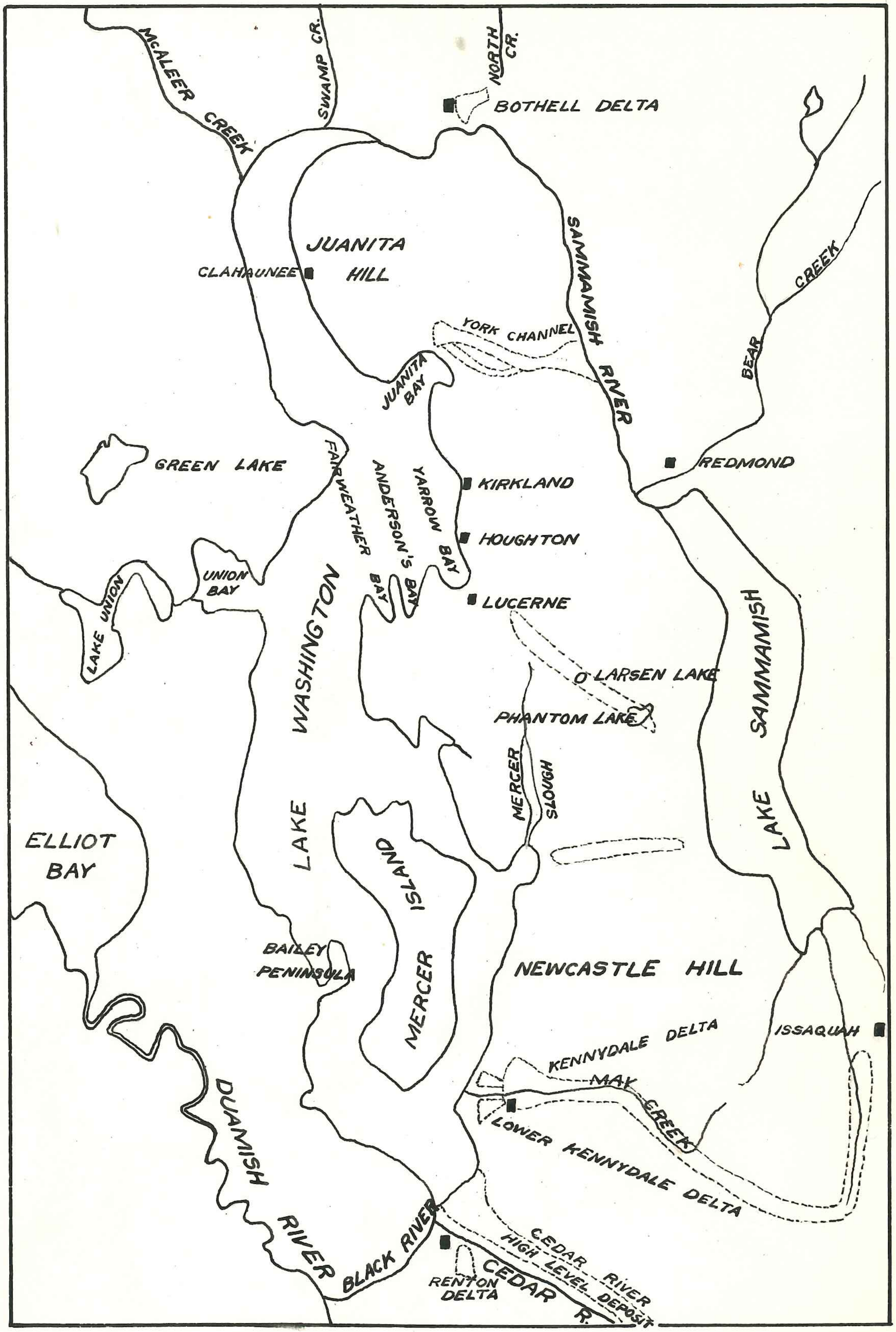

Plate I. Lake Washington Region

OUTLINE OF THE SOUND HISTORY

The history of Lake Washington is so closely connected with the Pleistocene history of Puget Sound that it is desirable to give a brief general history of the glaciation of the region before the phases more directly related to the lake are taken up in detail. The greatest part of this history has been worked out by Bretz in his "Glaciation of the Puget Sound Region", of which the following summary is a brief synopsis.

The Puget Sound trough is the north end of a geosyncline developed during the Eocene and Miocene periods, and lying between the Cascades on the East and the Coast Ranges on the West. It extends south to include the Willamette valley of Oregon, while the Great Valley of California is a continuation of the same general structure. We are concerned with only that part which lies north of the Cowlitz River divide.

The bedrock of Puget Sound Basin consists of great thicknesses of clastic sediments of Eocene, Oligocene, and Miocene age, laid down near shore, and partly under brackish water conditions. Coal and lignite are common in the series. The Pliocene was a period of erosion in the Sound region, during which time the land stood considerably higher relative to the sea than at the present time. Its sediments were deposited far beyond our present shore line.

The Eocene formations of Washington show by their tropical flora and fauna, and possibly also by coal development, that they were laid down under climatic conditions more nearly approximating those of Lower California at the present time. The Lower Miocene period was more nearly temperate in climate, while a great change to boreal conditions took place at the beginning of the Upper Miocene. This climatic oscillation presumably increased thru the Pliocene and finally culminated in the extensive glaciation to which the region was subjected in the Pleistocene.

There are two known advances of the ice in the Pleistocene and possibly more which occurred earlier and of which we have no record as yet, since the last glaciation completely overlapped any preceding ones. The ice came down as a piedmont glacier fed by the snow fields of British Columbia, and not from the Cascades as might be expected, altho glaciers far more extensive than their present day remnants in the mountains pushed down to meet the great Sound Glacier. In places the second master glacier pushed up the channels of these valley glaciers, thrusting them back and leaving the distinctive till of the Northern Ice far up the valleys of these streams.

The first of the two glaciations is referred to as the Admiralty Glaciation, named from its relatively more frequent exposure along the shores of Admiralty Inlet. In general however it is not often exposed and as a consequence it is little known. It left its record in the form of an unstratified sheet of till, consisting of a matrix of gray or blue sandy clay or loam containing numerous rounded pebbles and a few large angular boulders.

Of the average 800 to 1000 feet of Pleistocene sediments of Puget Sound, nine-tenths of them consist of what are known as the Admiralty Sediments. These consist of variable stratified sands and clays containing peat seams, representing the aggradational work of Cascade rivers flowing from the mountains onto the flat floodplains of Puget Sound, and working over the drift deposited behind the slowly retreating Admiralty Glacier front. The Admiralty Sediments are inter-till in position but not interglacial in time.

The Puyallup Interglacial period followed the Admiralty Glaciation. In respect to deposits referable to this period, the results were negative; only the erosion of a drainage system in the Admiralty Sediments and the deep oxidation of these Sediments in places give us any evidence that such a lapse of time existed. From the magnitude of these alterations however, we must conclude that the period was comparatively long.

Following the interglacial period came another advance of the ice from the North in the form of the Vashon Glacier. This is the last glaciation of the region and also the greatest if we assume that the Admiralty was preceded by older periods of glaciation. The history of the Vashon Glaciation has been worked out in surprising detail by Mr. Bretz, for, altho the time interval since its final retreat is greater than the age of historic man, and to be measured in thousands of years, yet the physiographic forms inposed by it upon the region and its numerous types of sediments have been comparatively little touched by erosion.

At its maximum the southern ice front consisted of two lobes with the re-entrant angle between them formed by the Black Hills southwest of Olympia. The front of the east lobe skirted the north and east base of the Black Hills as far south as the neighborhood of Mima and Little Rock, and from there ran east thru Tenino and McIntosh to the north face of the Huckleberry, Bald, and Blue Hills, and on to La Grande. The west lobe extended in a broad curve concave westward thru Summit, Simpson, and Matlock to Lake Cushman.

A terminal moraine was developed along the final front, but it is at present insignificant as a physiographic form, due to its profound modification subsequently by drainage along the ice front. It was obliterated or covered up along much of the front.

That the ice must have lingered at its maximum extent for a long time we know from the enormous amount of gravel outwash which covers the lower lands serving as escapeways for the water at that time. Several broad channels led from the ice front at different places, most of the waters finally becoming confluent and entering the Chehalis Valley southeast of Gate, and in particular along the present site of Mima Prairie. The old outwash plains at the present day exist as sterile treeless prairies thruout the region. The underlying formation of these prairies is a coarse gravel with stream bedding to the south and west.

At the beginning, ice retreat was very slow. Lower escapeways were opened in places and valley trains as extensive as the first ones were developed but adjusted to new outlets. Recessional moraines had a prominent development especially in the region southeast of Lake St. Clair, west of the Nisqually River; at the present time they are a more marked feature of the topography than the terminal moraines, not alone because they were more extensively developed, but because they have not been reworked by running water.

After the ice had melted back over the first few miles, its retreat became accelerated, and no pause, as evidenced by the development of a recessional moraine, was again made until the region of Bellingham in Whatcom County was reached. The intervening area posesses Vashon sediments only in the form of a comparatively thin veneer of till over the surface.

Since it was only at the most southern extension of the glacier that aggradation took place, those valleys of the interglacial drainage lying north of this region were comparatively little affected. With the former southward drainage obstructed by a high drift region on the south, and the northward draining channels filled with ice, the region between the terminal position and the ice front filled with water until a level was reached where the water could overtop the drift hills to the south and reach the Chehalis. The specific channel used was the one along the east front of the Black Hills southwest from Olympia, now occupied in part by Black Lake. The lake draining thru this channel has been given the name Lake Russell by Bretz.

Lake Russell existed until the ice dam finally gave way on clearing the Straits of Juan de Fuca. In its early history it stood at an elevation which at the present time is 160 ft. above tide. This elevation was maintained during the time that the ice front made the greatest part of its retreat in distance. However the rate of retreat decreased sometime after the region of Seattle was laid bare, so that before final disappearance of the lake, it was lowered to 120 feet by the erosion of its outlet channel at Black Lake.

The history of Lake Russel is recorded chiefly in deltas deposited by contemporaneous rivers, but also in one place at least, if identification has been correct, by a beach terrace on the west shore of Lake Washington.

Various lakes tributary to the master lake were formed from time to time, chiefly along the margins of the Sound Basin, wherever the divide between forks of northward draining interglacial rivers, dammed at the junction, occurred above the level of Lake Russell.

One of these more centrally located, known in its earlier stage as Lake Puyallup and later as Lake Tacoma, formed by its outlet the Steilacoom Plains.

Upon the freeing of the Straits from ice, Lake Russell sank to sea level and marine waters came in and occupied those portions of the glacial troughs which lay below sea level. Thus began Puget Sound. The Sound troughs and included with them the Lakes Washington and Sammamish troughs, are due partly to glacial deepening of pre-existing troughs, and partly to the drowning of valleys developed at higher elevations of the region than at present.

The advent of tide waters ends the glacial history of the region.

THE EARLY PLEISTOCENE TOPOGRAPHY OF THE SOUND BASIN

The Tertiary beds of the Sound Basin, including the Upper Miocene, are decidedly folded, faulted, and eroded. Stratigraphically the Pliocene is unrepresented. The Pleistocene sediments on the other hand have been comparatively little disturbed, except locally, where deformation was produced contemporaneous with the ice, or by later slides. Nor has erosion been very aggressive as witness the prevailing of drift plateaus thruout the area. We are forced to conclude therefore that the great changes produced in the Tertiary beds present were primarily the work of the Pliocene and early Pleistocene.

Wherever Tertiary bedrock is exposed in the Sound Basin, it follows that it is a remnant of the early Pleistocene topography, since no subsequent diastrophic movements could have brought it to the surface without at the same time greatly deforming the glacial drift occurring on all sides, and no post-Pleistocene erosion could have carved it into its present form without profoundly eroding the far softer Pleistocene sediments.

Of the character of the pre-glacial topography over which the first ice advanced, very little of it can be constructed except some of the highlands. Present features which are remnants from the early Pleistocene are the San Juan Islands mountain group; the Blue Hills between Hood's Canal and Admiralty Inlet; Newcastle Hill, Issaquah and Squak Mountains south of Lake Sammamish; low bedrock hills south of Seattle connecting the Blue Hills with Newcastle

Hill; and such uplands as the Black Hills, Bald Hills, and Huckleberry Mountains along the southern divide of the Sound Basin.

Of particular significance are the Oligocene and Miocene formations outcropping in a broken line of low hills south of Seattle from Restoration Point thru Mercer Island to Newcastle Hill. This belt is a direct connection between the Blue Hills and the hills south of Lake Sammamish, and represents a cross spur of the Cascades similar to the San Juan Islands. North and south of this area, while the surface of the drift plain is comparatively even, bedrock lies deep beneath the surface. The fresh water well sunk near sea level at the Port of Seattle dock at Bell Street reached bedrock around 450 feet below sea (see appendix) if identifications have been correct. Kimball states that a well sunk on the property of the Bay View Brewing Co. at South Seattle went 500 feet thru drift and below sea level without hitting bedrock. The well recently put down on the golf links of the Country Club north of Seattle apparently reached bedrock around 490 feet below the top of the casing, which, however, is between 450 and 500 feet above sea. South of this zone of Tertiary outcrops, bedrock is apparently as deep as north of it. A well sunk at Delhi and mentioned by Kimball penetrated 400 feet without hitting bedrock. Altho the elevation of this region could not be found, from the text of Kimball's paper it seems to be near sea level.

It is safe to conclude that a divide existed along the line of the Restoration Point uplift in the early Pleistocene. It is conceivable that an antecedent river might have crossed it. Such a river would have had to cut a channel at least 700 feet deep, since the rock hills at the present time run 200 feet in elevation in places. It is hard to pick the present water gap of such a river. Admiralty Inlet and Hood's Canal would both meet the requirements, but these both had their inceptions in drainage channels developed in an aggraded drift plain above the level of the ridge and were subsequently superimposed upon it. Such a coincidence as superposition on top of the old channel would not be likely to occur. Elsewhere along the chain, the separate links are not separated by distances comparable to those required by the mature development of a river of the depth given. But there is no need to assume any such discordant relations since both sides of the divide have a logical outlet, the south side thru the lowlands to the South and out thru the Chehalis Valley, the north side out thru the Straits of Juan de Fuca, which were developed in comparatively soft sediments of a synclinal trough by the Skagit and Frazier Rivers certainly earlier than the first ice.

As for the rest of the preglacial topography, it must have been low since it was completely covered up by the aggraded drift plain deposited coincident with the retreat of the Admiralty Ice. There is no particular reason to suppose that our present day drift hills and ridges posess a bedrock core, for erosion in the drift plain has been controlled by the original configuration of the interglacial drainage and not by bedrock, upon which it was subsequently superposed.

THE ADMIRALTY TILL.

The Admiralty Till is not exposed so far as I am aware anywhere around Lake Washington. Nor is it at all common within the Sound Basin, being generally below tide in the sea cliffs. Outcrops are fairly well scattered along Admiralty Inlet however, from Hartstene Island to the Straits. It is also known to underlie Vashon outwash at Little Rock.

The usual character is very similar to the fresh exposures of Vashon Till, being a blue gray sandy clay, with abundant rounded pebbles. The pebbles are in no way different from those of the Vashon Till. The till, due to its impervious character, is generally unweathered. Willis records the Admiralty Till in places in the Tacoma quadrangle to range up to 50 feet in thickness.

The base of the Admiralty Till was exposed during the Denny Hill regrade in Seattle. It was here described as grading into a dense blue stratified clay in places, both horizontally and vertically, similar to variations from the typical character described by both Russell and Willis, especially by the latter around Tacoma. The thickness was 20 feet. The underlying deposit was a dark gray quicksand. Altho it is probably useless to try to correlate till beds for any distance, attention might be called to the fact that the Bell Street well log shows near the -300 foot level 20 feet of blue clay underlain by 8 feet of quicksand, the latter being the only quicksand recorded in the section. Three feet of brown shale immediately overlies the clay, and this is also its only occurrence in the section. This "brown shale" might very possibly be peat which according to Willis, usually occurs immediately over the Admiralty Till. At least 100 feet of undoubted glacial drift occurs below this general horizon and possibly 50 feet more, or a total of 150 feet.

THE ADMIRALTY SEDIMENTS

The Admiralty Sediments make up by far the largest proportion of the drift of Puget Sound Basin. 500 feet of the Sediments are exposed above tide thruout the center of the Sound geosyncline, but on the borders of the flanking mountains, the surface of the formation rises gradually from 500 feet to around 1000 feet. The depth below sea level must be 500 feet or more in places. The enormous thickness of this modified drift remains one of the chief problems for those who attempt to postulate a mode of origin for these sediments.

They are composed of gravels, sands, and clays with wide and abrupt variations both horizontally and vertically. Peat is a common occurrence, being intercalated with the clays in places up to 8 feet, tho I do not believe that thicknesses greater than a foot are exposed anywhere around Lake Washington.

Cross-bedding and stream-bedding are common in the gravels and sands, while the fine clays are generally horizontally bedded. No sequence of bedding has been observed. So far as noted, the sediments have not been disturbed except locally by slides or by contemporaneous ice thrusts. Broad structural deformations would be hard to detect, due to the impossibility of correlation of horizons from one locality to another, and also by the very uneven nature in which the beds were originally deposited. This applies especially to the coarser variations. However the accordance of plateau summit levels from North to South and the existence of the plateaus still in their aggraded form disfavor the assumption of any differential movement of the land. Altho the altitude of the land has changed several times relative to sea level since the Admiralty Sediments were deposited, such changes have been block movements.

The sands and gravels are generally well separated from clay, the sand often occurring in clean massive beds without distinct bedding. A slight oxidation to a buffy tinge is the rule, but wherever the sediments have been exposed to percolating waters to any considerable extent, especially above or below clay seams, deeper oxidation to a deep yellow color, or in some places to a light orange or brown, has occurred. Unoxidized blue sand is not uncommon however, especially where interbedded with clay, and in my experience, the gravels are not generally altered except on the surface. The gravel is usually small, but in some places cobbles may run up to 3 inches greatest dimension. Granitoid rocks including acid porphyries are perhaps the most characteristic, but basalt is also common as well as quartzites, argillites, etc. At one horizon along the Sound one-half mile north of the locks at Ballard, and 150 feet above water, an ill-defined zone of scattered elongated shale lumps up to one foot long, and lying with their longest axis horizontal, occurs in stratified sand. The shale is cream colored, very soft, and was previously stratified parallel to its present elongation. It is apparently Tertiary, but how it could have gotten into its present position is hard to see. With this exception, no great contrast is shown between the types of rocks occurring in the Admiralty Sediments and those in the much later outwash from the Vashon glacier.

Probably the most characteristic form of the Admiralty Sediments in the region of Seattle is the unoxidized blue clay so commonly exposed in excavations and cliffs around the Sound; certainly it is the most abundant if the shores of Lake Washington can be taken as a criterion. This formation is in evidence wherever favorable exposures occur on the west side of the lake, from Union Bay to McAleer Creek, and is the chief formation underlying the three promontories (Hunt's Point, Yarrow Point, and Fairweather Point) southwest of Kirkland. In addition, much of the present beach, below the superficial shallow beach sands and gravels, is clay, while in certain places, especially noted along the west side of Juanita Hill, along the beach for a mile northwest of Sand Point near Mud Bay, and along much of the shore from Houghton to Lucerne, the beach lacks even this veneer of loose wave rolled material, the surface below water showing water carved clay in situ. Generally the Admiralty clay is blue gray, but near the surface, and especially when exposed at water level or beneath the surface of the water, it is yellow.

Typical sections of the gravelly variation of the Admiralty stratified drift occur in an old gravel pit at the northwest side of Juanita Hill, southwest of the Inglewood golf links, and in a natural slide exposure on the southeast side of Mercer Island. In the former locality, 20 feet of stratified gravel is overlain by 25 feet of clay which in turn posesses a two foot unoxidized gravel seam near its middle. The lower 15 feet of gravel varies in the prevailing size of the pebbles in the different beds from top to bottom, and is unoxidized; the upper five feet of gravel is similar but stained brown. These pebbles range up to three inches in diameter. The base of the section is between 100 and 150 feet above the lake. The Mercer Island section shows 85 feet of stratified sands and gravels, in some places horizontally bedded, at other elevations showing excellent cross-bedding, the whole series being very little oxidized. These sediments are overlain at 275 feet above the lake by 8 feet of Vashon till, the contrast between the two types of drift being quite noticeable.

The well at the Port of Seattle shows gravel to be common in the Admiralty Sediments down to 217 feet below sea level.

The presence of peat is significant (and a problem) in any attempted explanation of the mode of formation of the Admiralty Sediments; the time must necessarily have been long for it to have accumulated in such thicknesses as represented.

Willis and Bretz have both agreed that the Sediments are derived in a large part from the Admiralty Ice. Bretz has offered I believe the most logical explanation of their accumulation. Stratification has been produced by a reworking and redistribution of the debris from the ice by numerous Cascade rivers, which, debouching on the drift surface, spread out over it in meandering courses which were continually being shifted, similar to conditions existing on a flood plain. The waters from the mountains would be augmented by the glacier water which would amount to a considerable percentage of the total water required for such extensive modifications of the drift. Gravels and sands would occur wherever the water current was especially swift as in the main channels or escapeways, while mud and silt would be deposited in the more quiet waters. Stream-bedding and cross-bedding would be common and widely distributed since the main currents in their continual shifting would cover a large part of the area at several successive times, and much that had been stratified at a former time would be truncated and new deposits laid down unconformably. Such relations are generally found to prevail.

Forests and other types of plant growths would have time to grow between invasions of the stream channels, and upon being flooded again, would be left in the form of peat.

The waning of the ice must have been excedingly slow. This is necessarily deduced from the thickness of some of the peat beds, and is borne out by the astonishing thickness of the drift. Of course some of the material present would be contributed by the mountain streams, but nevertheless the sediments show that they were derived in a large part from the regions farther to the North.

Mr. Bretz records the occurence at two localities of marine fossils a few feet above present sea level, both localities being north of the early Pleistocene Restoration Point Uplift. One locality is at the base of Beacon Hill, Seattle, at an unknown distance above the base of the formation; the other locality at Foulweather Bluff at the mouth of Hood's Canal shows the shells only a few feet above Admirality Till. The fauna in both places is well represented and the same as that living in the more boreal parts of the Sound at the present time.

The presence of these shells a few feet above tide water at two widely separated localities shows that one time at least in the formation of the Admiralty Sediments the land must have stood a few feet lower than at the present time. Whether this was the relative positions of land and sea thruout the whole time of glacial retreat, with the applied inference that all the Sediments below sea level are ordinary marine sediments, we have no means of knowing absolutely. Deep borings have been few and the presence of shell beds could easily be overlooked even if the drilling penetrated them. The occurrence of marine fossils is a phase of the history of the Admiralty Sediments on which our knowledge might be much more complete than it is. Circumstances however point to the fact that this known shell horizon marks only a temporary lowering from a higher elevation. We would expect the gravels and sands below this elevation to show foreset bedding to the South if the sediments were deposited in marine waters. This has not been borne out by field observations.

The chronological sequence of periods in the formation of the Admiralty Sediments might be logically interpreted from the existing facts as follows: The Admiralty Ice slowly retreated with its outwash slightly above sea level from its maximum extent to the latitude of Foulweather Bluff. Immediately after it had passed this point, the outwash area whose surface was practically a plain, was submerged for a short time, and the sea entered from the South to the latitude of the ice front. No great time could have elapsed between the clearing of Foulweather Bluff and the submergence, for the fossil bed is directly above the Admiralty Till. After a comparatively short time, the region was re-elevated and our present Admiralty Sediments exposed south of this latitude and above sea level were deposited after the ice had retreated beyond Foulweather Bluff. This is not surprising for all below sea level were deposited during the retreat to that point, which is decidedly still in the Sound Basin. The escapeway of the depositing waters was to the South. The surface of the drift plain lowers slightly to the South from the vicinity of Seattle at least, and Bretz records southward dipping current bedding thruout most of the the Admiralty Sediments.

Admiralty stratified drift occurs in the sea cliffs on the south side of the Straits as far west as Observatory Point, east of Gettysburg. If the Straits cleared of ice at any time before the completion of the drift plateau to the South, they were immediately filled by outwash. A partial change in drainage would occur especially along the West, but such waters would be aggrading rather than degrading, and the Sediments along the Straits might well have been formed by waters flowing to the West. Altho there is no lowering of plateau surfaces in that direction, Bretz records northward dipping current bedding on both Marrowstone and Whidby Islands, apparently near the top of the Admiralty Sediments, since in the former locality these beds are stated to be exposed in a sea cliff underneath Vashon Till. The vertical position is not stated for the beds on Whidby Island. It is at the top of the section that we would naturally expect the sediments of a northward flowing stream to occur, for the underlying beds would be formed while the gradient was yet to the South.

THE PUYALLUP INTERGLACIAL PERIOD.

After the Admiralty Ice had waned to probably a number of disconnected valley glaciers within the mountains of British Columbia, and probably coincident with its retreat, the Sound Basin was elevated far above its present level, probably 1000 feet higher, and glacial aggradation gave way to erosion by streams. The Puyallup Interglacial Epoch thus began which lasted until the region was again invaded by the Northern Ice during the Vashon Period. The interglacial period was far longer than the time that has elapsed since the Vashon Ice withdrew. The drift plateau was dissected by drainage trunk valleys and their tributaries to a degree comparable with that of the present. The Admiralty Sediments were deeply colored in places by long oxidation. Contrasted with this, the deltas, kame terraces, and the veneer of Vashon Till, records of the last ice sheet and very transient features geologically speaking, are in many places untouched by erosion, while only the surface of the Vashon Till is generally iron stained.

Changes in the interglacial features produced by the Vashon Ice were considerable, and our reconstructions of the interglacial drainage are hampered precisely by the uncertainty as to where to draw the line between glacial modifications and pre-existing topography. If the Vashon Ice was potent to deepen some of the Sound Troughs from 400 to 600 feet, might it not have also been able to excavate all of such channels as the Lakes Washington and Sammamish troughs, which are little more than 200 feet deep in the deepest places? Such is at least conceivable. But the problem for anyone who advocated such a simple explanation of the troughs of Puget Sound is to explain why the ice should be so effective in scouring out a deep furrow along certain narrow belts and so ineffective elsewhere. This I believe to be the most important consideration in reconstructing the Puyallup interglacial drainage of Puget Sound so as to correspond as far as possible with the present day troughs. The orientation of certain groups of troughs, especially south of the Narrows, also points to the beginning of the present day arms of the Sound in the form of erosion valleys.

Mr. Bretz has tentatively reconstructed the interglacial drainage of Puget Sound, based on a consideration largely of the Pliocene and early Pleistocene topographic elevations above the drift plain, the original slope of the drift plain, and the orientation, relative depth, width, and length of the present troughs. Only that part of it connected with Lake Washington need be discussed in this paper.

The reconstruction advanced is that Lakes Washington and Sammamish lie in the valley of an interglacial stream that rose at the south end of Lake Sammamish, flowed north to Bothell and from there south along the courses of Lake Washington and White River Valley to Puyallup, uniting with the Admiralty trunk river which flowed north to the Straits along the present day Puyallup Valley and Admiralty Inlet. Thus the waters first flow north for 17 miles, then turn and flow directly opposite for 40 miles. Such a course is wholly at variance with consequent drainage, but checks up with similar anamalous tributaries uniting with the master stream (Admiralty River) from the West. The Duwamish Valley south of Seattle is rejected as the lower course of the Lake Washington River due to the bedrock hills in this region which are so closely spaced as to restrict the valley. Small creeks drained these hills, one flowing north to the Admiralty River and later serving as a locus along which the glacier scoured the lower course of the Duamish Valley, the other creek flowing south to the Lake Washington River.

This thesis was begun with the special intention to try to find a more reasonable drainage pattern for that particular part of the interglacial drainage syatem which is closely connected with Lake Washington, but after considerable time and effort have been spent on the problem, no more reasonable alternative can be advanced, tho I believe that there is rather a little more reason to believe that the drainage was out by way of Lake Union and Salmon Bay. The reasons for final conclusions as drawn are not out of place in a paper which attempts to give the complete detailed history of Lake Washington, especially since it was this interglacial drainage that determined to a large extent the existence of the lake in its present broad configuration.

To begin with, the fundemental premise on which we have to build is that the general lines of Lakes Washington and Sammamish were interglacial stream-eroded valleys, possibly not large, but capable of determining the first lines of glacial advance. The two valleys are roughly parallel, and both are extended several miles farther north of their present connection at Bothell by two broad, rather swampy creeks. These creeks show by their widths and relatively low gradients especially near their junctions with the present day hydrographic basins that they were the main ice channels along which the early tongues of the Vashon glacier advanced from the North. Both Swamp Creek and North Creek are far better developed valleys than the narrow Bothell channel, which is constricted for the three miles between the mouths of the two creeks; in fact part of it is due to post glacial erosion.

From these considerations it might appear that North Creek and Swamp Creek are northward continuations of the interglacial drainage channels of Lakes Sammamish and Washington, and that the water drained the same way in both valleys. The logical direction would be to the North in harmony with the rest of the major interglacial streams. But this hypothesis is untenable as a glance at the Snohomish quadrangle will show.

The divide between Swamp Creek and Puget Sound lies six and one-half miles northwest of the mouth of the creek, and one and one-half miles from the Sound. The elevation is between 350 and 400 feet, which is practically the summit level for the drift plateau in the region. West of the summit, the descent to the Sound is steep and is cut by several ravines which have eroded back at their heads for one and one-half miles at the greatest, usually less than one mile. There is no suggestion of a debris filled channel, either in the summit or in the configuration of the Sound water line.

Similarly, North Creek Valley rises gradually to the North to Silver Lake at the surface of the plateau, with an elevation between 400 and 450 feet. Silver Lake is about nine miles from Bothell and less than two miles from Snohomish Valley on the Northeast. The descent from the top of the plateau to the alluvial flat below is even more regular than in the case described for Swamp Creek. The contours extend practically straight along the escarpment up to and including the 350 foot contour; only the 400 foot contour has a marked departure to the West.

The whole plateau between Puget Sound on the West, Snoqualmie Valley on the East, and north of a line from Bitter Lake north of Seattle to Evans Creek near Redmond, is drained toward the lakes at the center. The drainage divide is everywhere, with two exceptions, within two and one-half miles of the base of the escarpment to the outside, and is generally within two miles of the base. A little creek south of Cathcart has cut back three miles from the Snohomish Valley, while the divide at the north apex of the plateau is probably four miles from the lowlands at Everett. At only one point in this marginal divide is the elevation below 400 feet, and that is for about a mile along the head of the West Fork of Swamp Creek as already described. Several divides occur between 400 and 450. But this is near the average summit level of the plateau, which is generally between 500 and 550 feet, tho in some places it runs above 550 feet, and in two short stretches along the east margin, the hills are between 600 and 650 feet in elevation.

It is impossible that a pre-Vashon valley could have been so completely and evenly filled to the plateau level along the margin of the plateau, even to the marginal escarpment, as to leave no physiographic evidence of its former existence. Furthermore, such an action would be unprecedented in the history of Sound glaciation. No glacier would have filled a valley to 400 feet above sea level in one place, and scoured the same valley out to a depth of 200 feet below sea level 15 miles farther south, especially when the line of advance was in the same general direction as the valley. The conclusion is therefore inevitable that the Lakes Washington and Sammamish valleys did not drain north in the Puyallup Period beyond the vicinity of Bothell. North Creek and Swamp Creek drained south as at present and were strongly enough developed to control the main Vashon ice streams which gouged the two lake troughs to their present depths.

The possibiltiy of the interglacial Sammamish trough having an outlet at the South can be denied at a glance. The present day rock hills are cut ty two mountain streams, both flowing to the North, and with their divides well above the 300 foot contour.

There are only two other channels besides the opening at the south end of Lake Washington that could ever be considered; one is Union Bay and Lake Union west thru the north end of Seattle, and the other is Evans Creek, from Redmond southeast to the Snoqualmie River. Both of these are cross valleys and could very well have been filled up by the glacier crossing them at right angles.

Evans Creek was not visited preliminary to this report, but the topographic map shows it to be a youthful narrow stream deeply cut into the plateau, whose level summit right up to the stream canyon, especially at the Lake Sammamish end of the creek, is incompatible with the idea of a filled channel. The divide at the head of the creek lies at about 160 feet.

With the Lake Union outlet possibility the case is different. The following facts from a study of the topographic and geodetic survey maps led to the field examination of the valley.

Lake Washington curves from its channel near Juanita Bay towards Union Bay, swinging back to its north-south course at the latter point; Yarrow Bay, Anderson's Bay and Fairweather Bay all three open toward the North or Northwest, approximately at right angles to the axis of the main lake channel. Andrews Bay behind

Bailey Peninsula, and Westmore Slough a little farther north-west both open to the North toward Union Bay; the passage at the north-east side of Mercer Island narrows and shallows to a maximum (35 ft.) at Barnabie Point, and the gradient of the bed of this channel is to the North directly into Union Bay. Meydenbauer Bay opens into this channel at right angles, after having coursed parallel with it in its upper region. All of these present day features are due to glacial erosion, but there must have been some pre-Vashon irregularity along these lines to have so caused the ice to gouge them out to their present aspect. Furthermore, altho I have little faith in bathymetric contours being able to give pre-Vashon gradients, nevertheless, the deepest part of Lake Washington, a little more than 200 feet, occurs along Union Bay and for about four miles south of it, while the lake shallows toward each end.

Upon examination of the topographic map of Lake Union and Salmon Bay, there are found to be only about one or two places where the valley is too deep and narrow for an interglacial valley, of the development necessary to have taken care of the Lake Washington drainage, to have existed without haveing been considerably filled by till. One is at Fremont, where the valley is about one-fourth mile wide below the 50 foot contour, and the other is at the west end of Salmon Bay. Even the present development of the valley at Fremont might be sufficient for the drainage of the interglacial Lake Washington trough, for in the first place, placing the outlet here greatly shortens the interglacial creek so that no great valley is required, and in the second place, the development of that part of the valley in which the lake lies was greatly exaggerated by the glacier. That this is so must be evident from the height of the shores of the lake. The outlet at Ballard is constricted only at the extreme western end of Salmon Bay, where a ridge which follows along the edge of the Sound trough has been cut thru. But from the map alone, this ridge could be explained as a till filling into the interglacial valley mouth, the greater thickness of which was due to the greater development of the ice in the trough to which it was marginal.

Upon visiting the valley at Fremont, the south side or Queen Anne Hill was found to be made up of Admiralty Sedments, the lower part of the canal at the south end of the Fremont Bridge is in till, while no formation is exposed on the north side of the valley, or Fremont Hill, except till. Numerous sections up to 30 feet in thickness were noted in cuts chiefly along Fremont Avenue and the region immediately to the West for almost a mile up the hill, but nowhere was the till penetrated in cuts. The north side of the valley would be the side on which a glacier advancing from the North would dump its till. Altho the extent of this filling cannot be determined due to the shallowness of the sections, nevertheless the widespread occurrence of the till and the absence of negative evidence in the form of Admiralty Sediments are points of some value.

The lower part of the channel below the locks at Ballard is in the Admiralty clays. A cut in the hill on the south side of the locks by the Great Northern Railway shows a thin layer of till overlying Admiralty Sediments. But north of the mouth of Salmon Bay for one-half mile, and directly in line with Salmon Bay at its widest, till only is exposed in the 25 to 30 foot bank above the Great Northern track, which is along the Sound here about 35 feet above tide. A little less than one-half mile from the mouth of the bay and three-fourths of a mile from the locks the till bank above the railroad begins to rise, and in about 300 feet, the base of the till has come up to the level of the track. Still farther north, the bank continues to increase in height, but the till-Admiralty Sediments contact also rises, staying roughly parallel to the top of the section and about 50 feet below it. Thus that part of the basal contact of the till which is below 35 feet in elevation is around one-half mile across, and therefore plenty wide enough for a filled interglacial channel to exist here.

There is one other reason favoring the Lake Union Salmon Bay channel as the interglacial outlet for the Lake Washington trough, and that is the absence of any other way to account for the channel. Lakes Washington and Union are separated by a small till ridge only about one-fourth mile wide and less than 50 feet high, thru which the canal has been cut, yet no drainage has gone thru here since Vashon times. This is the only cross channel from Lake Washington west to the Sound below 350 ft. except Rainier Valley which runs almost parallel to the lake, and has the divide around 200 feet. The ice would hardly have scoured this channel at right angles to its direction of advance, and in fact, Lake Union is good evidence that it tried to get out of the cross-valley and to keep going to the South.

Mercer Slough is headed the wrong way to have emptied thru Union Bay in interglacial times. It is directly in line with the lake channel east of Mercer Island, which evidently drained south thru White River Valley. Mercer Island is apparently part of the interglacial divide between the two creeks. The southermost gap between them was somewhere between Bailey Peninsula and Renton, but the lake bed along this channel shows no evidence of it; it was probably eroded by ice just as was the Narrows of Tacoma, which was also an interglacial divide. Thus Lake Washington according to the hypothesis advanced in this thesis, was genetically connected not with one interglacial drainage line, but with two which flowed in opposite directions.

Whichever outlet we may accept for the Lake Washington interglacial system, the Sammamish Valley drained thru the same outlet. After having reconstructed both valleys, our final problem is to find the point where the two were connected.

The ridge between Lakes Washington and Sammamish has a fairly level profile from the north base of Newcastle Hill to Juanita and is uncut below the 300 foot contour in that distance. At the latter place however, the present day divide is only 147 feet above sea level while at Bothell the only other low place occurs, which ~~is~~ is used by the Lake Sammamish drainage at the present day. Altho the present Bothell Valley has all the appearances of a juvenile valley, especially in the two cuts, one east of the town and the other at Wayne about one-half mile south of town where the valley turns from South to West, yet the depth of the valley is not much more than 100 feet, while above this elevation there is an east-west strip, mainly north of the river, which is everywhere under 200 feet in elevation, and much of it is lower than 150 feet. Thus the trough at Bothell is both wider and lower than that at Juanita, and this, coupled with the fact that the present day drainage goes thru Bothell practically indentifies this as the pre-Vashon connection. The narrowness of the lower part of the channel is due to the filling in of a considerable part of the valley in places on the north side of the present channel by debris from the Vashon Gla-

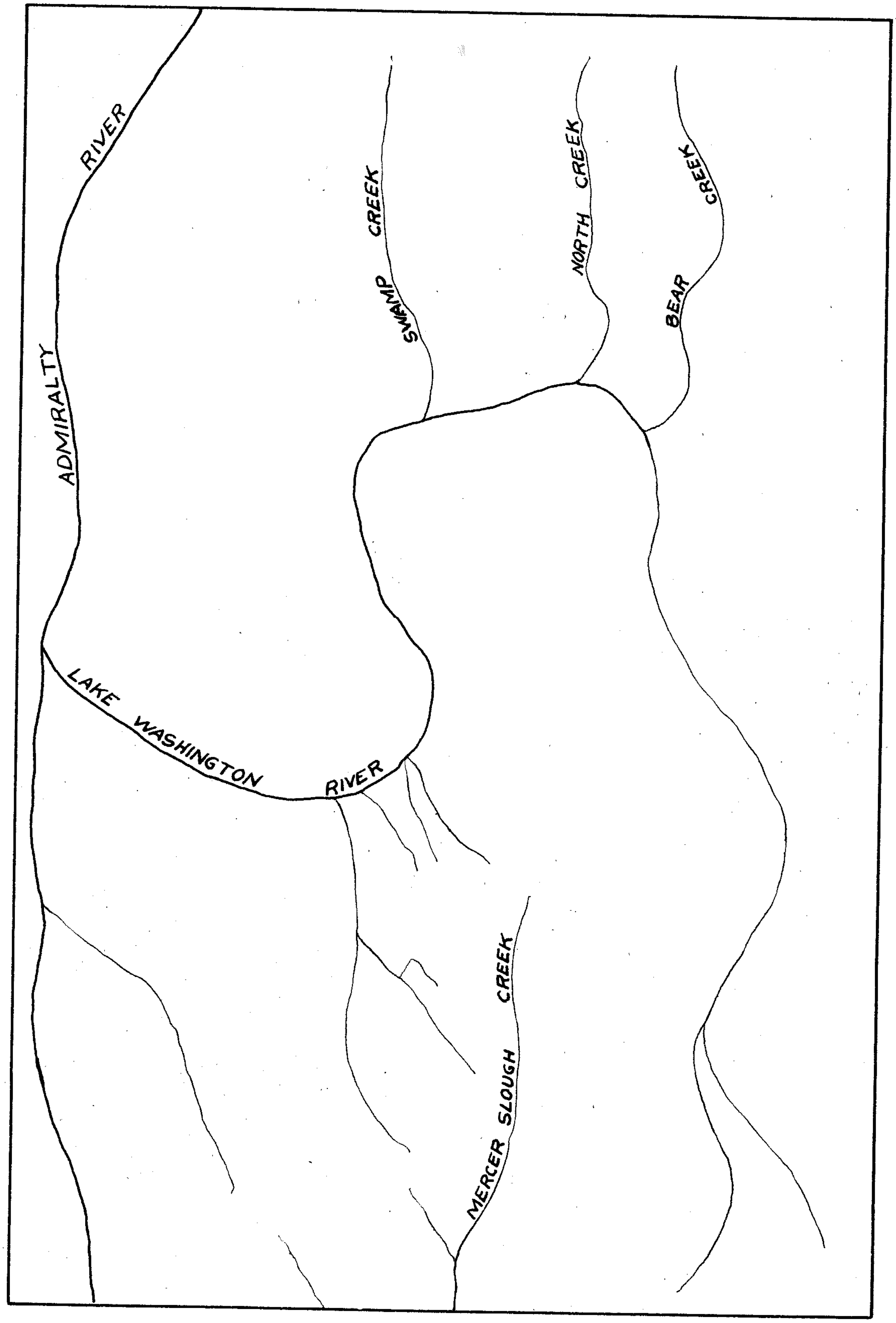

Fig. 1. Lake Washington Interglacial Drainage.

cier, and the erosion thru this till since the glacier left the region.

In conclusion it might be stated that altho I believe Mr. Bretz has fairly well disproved the theory of Willis in regard to the origin of the Admiralty Sediments, namely, that they were built up by lateral deposition from tongues of the Admiralty Ice which occupied the present Sound troughs, and that the troughs themselves are due to lack of deposition on account of occupation by the ice, nevertheless the interglacial drainage of the Lakes Washington and Sammamish troughs as reconstructed are in accord with consequent drainage on a plateau having such an origin. The margins of the plateau would be built up and the sump would be near the center of the resulting drift plateau, with the escape of drainage thru one or two points along the periphery.

THE VASHON ICE.

The Puyallup Interglacial Period was brought to a close by the reinvasion of the Northern Ice, stronger than the preceding and more extensive, tho it did not remain so long.

The Vashon Glacier thruout most of its life in Puget Sound Basin was essentially a piedmont ice sheet, covering all of the territory between the bases of the flanking mountains. But it is highly probable that in the initial invasion, the vanguard was broken up into tongues following the larger interglacial valleys, and that it was not until later that these valleys were filled up so that the ice could overflow onto the tops of the interdrainage plateaus. The early ice modified the erosion topography so as to accentuate the pre-existing inequalities of surface. This tendency, once begun, was continued by the ice in the later piedmont stages; the early channels determined certain axes along which the main masses of the ice were concentrated; the base of the ice in these channels was several hundred feet lower than elsewhere with corresponding greater weight above, so that the scouring action was especially effective in these channels to sink them still deeper. Thus is explained the great depths to which some of the major north-south valleys were scoured, while the divides were, in comparison, little eroded.

Lakes Washington and Sammamish are typical of the present day troughs originating in such a manner. Both lake valleys begin several miles farther north of the present water levels in the latitude of Bothell. (Sammamish originally extended to this latitude, but being shallow, has been filled in as far south as Redmond). The valleys descend with low gradients, especially in the case of Swamp Creek, to the lake surfaces and on to the greatest depths of the lakes without appreciable break at the water lines. Thus Swamp Creek is genetically closer connected with the Lake Washington trough as it exists today than is the valley by way of Bothell. The latter as already stated was not only not used by the ice in its advance, but was filled up in places with till to probably 125 feet above its present floor, due to its cross position with reference to the direction of ice advance.

A number of the minor features in the shore line of Lake Washington, as already mentioned under the discussion of the interglacial drainage, are due to glacial gouging along pre-existing creeks or ravines. Such are Bailey Peninsula, Westmore Slough, Meydenbauer Bay, Fairweather Bay, Anderson's Bay, Yarrow Bay, and Mercer Slough.

VASHON TILL AND ERRATICS.

As the Vashon Ice melted back rapidly across the Sound country, it left nearly everywhere a ground moraine of till. In some places the till grades into or is overlain by stratified outwash sands and gravels which may have intercalated till lenses. Such formations, except in certain well defined channels, mark strictly temporary escapes for glacial waters, used only while the ice was in the immediate vicinity.

Typical till grading into coarse water deposited gravels without any sensible contact is common at several points along the railroad north and south of the trestle at the head of Mercer Slough. The clay pit at Renton shows outwash detritus above till rather more developed than in most places. The thickness at the east end of the pit is around 25 feet, and the whole top of the cliff for the 400 feet exposed is capped by this sand and gravel, in marked contrast with the blue clays below. The structure shows cross-bedding from top to bottom. The lower one-half exposed consists chiefly of sand, unoxidized except at the very base where ground waters issue in the form of springs above the impervious clay. The upper part of the section is predominantly rounded gravel and sand containing numerous clay and till lenses up to 20 feet in length. This outwash deposit is at the edge of the plateau probably 400 feet above sea.

Unmodified Vashon Till is far more generally distributed as the surface formation thruout the Sound Basin than any other form of glacial deposit. In thickness it ranges from 2 to 100 feet or more, but the thickest exposures noted around Lake Washington were only 40 feet, occurring on the west side of Juanita Hill between Juanita Bay and North Point.

A glacial till is derived chiefly from the material held frozen in the glacier, and especially near the base, which is left as a surface veneer upon the melting of the ice. A large part of it is the so called "rock flour", a fine silt due to the mechanical grinding of rock by the ice. Besides the rock flour, the glacier also holds varying amounts of pebbles, cobbles, and boulders which are generally angular and in many cases striated due to abrasion. The melting of the ice is generally so slow that except in certain channels, the water is not strong enough to resort the material. As a result, silt, cobbles and boulders are dumped just as they occur. The most characteristic mark of a till is its lack of stratification.

The Vashon Till is in many ways typical, except that large boulders are relatively uncommon and striated rocks are rare. The matrix consists of a fine sandy clay, generally gray in most of the shallow excavations in which it is exposed, but where exposed in deep excavations, it is generally bluish gray in color. Only the upper two or three feet are ever decidedly oxidized except where peculiar local conditions have prevailed. Pebbles and cobbles up to six inches in diameter are common, the smaller sizes around an inch predominating. The commonest rock type represented is a dense basalt, but granite is only a little less common. Other types of frequent occurrence are quartzite, quartz, argillite, and various feldspar (trachyte) porphyries, and when the uncommon types are considered, there are few rock types that are not represented. These smaller cobbles are almost without exception well rounded, and it is only in the relatively rarer boulders greater than one foot in diameter that angularity prevails. Whereas basalt is dominant among the smaller pebbles, probably three fourths or more of the larger erratics are granite of various types.

The statement that the large boulders are comparatively uncommon might be questioned from the fact that they are so often seen on the surface, but when one considers how rarely they occur in sections, or indeed the chances that they have to occur in sections, the fact is soon evident. Nevertheless they occur more plentifully in some places than in others, one of the most marked localities being the top of Juanita Hill. Large erratics averaging two to three feet in diameter but ranging up to eight feet, are strewn all over the top and southwest side of the hill, which is 550 feet high. The summit is under cultivation, and the line of boulders along both sides of the main road that have been carted off of the fields are favorably located for inspection without the physical exertion that usually has to precede any similar collection of data elsewhere.

The commonest type of rock is granite. Basalt is even less common than usual and I did not find more than one or two typical basalts over the whole hill. Other less common types were well represented however, including conglomerate (boulders up to four feet); blue quartzite; granite porphyry; hard, siliceous, laminated shales; and two or three types of amphibolite. A few boulders were somewhat rounded possibly by spheroidal weathering, but the majority were exceedingly angular.

The beach at Faben Point on the northwest side of Mercer Island has rather more than the normal supply of boulders, and is so marked on the Coast and Geodetic Survey map of Lake Washington. This condition also extends well out from the shore-line under water. The boulders average two to three feet thru, ranging up to six feet, and they are spaced on the average about one every 15 feet. Basalt here makes up one-fourth or more of the rocks represented, while with the exception of one gabbro and one rhyolite, the rest are granites of several types. Since the surface of the ground for several hundred feet back from the beach has a low unbroken slope, the rocks could not have been moved very far vertically from their original position, and must therefore have been dropped on a beach very similar in its lines to the one that now exists.

The case is exactly paralleled by the beach at Mud Bay on Pontiac Point. Cobbles and small boulders are here so thickly strewn as to make walking tedious. Ordinarily such beaches are overlooked by a till bank from which the cobbles were derived, but here the territory back from the beach is flat and swampy. The stones could only have been washed out from a superficial till sheet that once occupied the surface of the ground here.

There are two types of erratics that might be of interest to mention. On the beach about 800 feet north of a mill which is itself a quarter of a mile north of Kirkland there occurs a boulder at the pre-canal water level which shows a contact between a coarse conglomerate and a dense dark rock more nearly resembling an altered basalt than anything else. The rock is nine feet thru and has several eight inch trees growing on top of it.

The other type, a dense, siliceous greenish-gray basaltic rock containing a metallic sulfide (pyrite) has made up the three largest erratics that I have run onto around Lake Washington. Two of them occur about a mile north of Lake Station on the west side of the lake, one of them on the beach and the other 300 feet higher at the top of the bluff. The former is 18 X 15 X 10 feet while the latter is 20 feet across at the exposed base but it is so deeply buried that only the top of it is sticking out. The third boulder is 15 feet in diameter and occurs 115 feet above the lake on the southwest side of Yarrow Bay.

The till exposed in the clay pit at Renton differs somewhat from the typical Vashon. It contains a few soft sandstone and coal pebbles, the latter all being less than one inch in diameter. Numerous basalt boulders up to one foot thru occur (one was three feet thru) and unlike boulders of such size occurring elsewhere and the fewer number of granite cobbles in this same till, they are highly angular. Basalt also predominates among the smaller pebbles, but here they are usually rounded. Some tho not all of the relatively few granite cobbles are so deeply decayed that they crumble. The till matrix is a dark blue clay. The overlying outwash contains rather more granite than basalt.

The local character of this till is evident. The coal and sandstone could have been derived from the Tertiary beds immediately to the North and the basalt from the Tertiary not far off. Or this may be the Osceola Cascade Till of Willis, with which it agrees in a number of ways.

LAKES FORMED DURING THE RETREAT OF THE VASHON ICE

A brief sketch of Lake Russell has been given in the introduction to this thesis. Altho this was the main lake formed during Vashon retreat, the numerous extinct deltas of Puget Sound can not all be so simply referred to just one single water level. Other lakes of which Lakes Puyallup and Tacoma have been mentioned, were formed, especially during the first stages of glacial retreat from a given region. These tributary lakes, as long as they existed, discharged over the lowest divide to the master lake, but all ultimately sank to the controlling water level as soon as the ice had withdrawn any great distance from the vicinity.

The Kennydale Delta.

The first of such lakes lying in the Lake Washington region of which we have found any distinct evidence is recorded by the Kennydale Delta (Plate I). Conditions prevailing in this locality have been described by Bretz; the only thing added in this thesis to his results has been the confirmation of delta origin of the doposit in question.

At a point about three miles back from Lake Washington, the channel of May Creek changes from a narrow steep canyon below to a broad low swampy valley above. The gradient of this valley rises slowly to the East to the col between it and Issaquah Creek, which is at an elevation of about 315 feet. Followed westward and down from the point where May Creek begins its rapid descent to Lake Washington, evidence of this old channel exists part of the way as a terrace above the canyon of May Creek whose gradient corresponds to the present upper valley of the creek. About a mile back from the lake and on both sides of the creek occurs a broad fairly level area which was described as a delta by Bretz. The elevation of the surface is given as 290 feet. From my observations, the surface is not exactly level, but varies possibly around ten feet. Two separate readings at the typical level however gave 290 and 292 feet.

An excellent cut probably 30 or 40 feet deep into the deposit was made along the south side of the canyon by the railroad just before it crosses May Creek ravine. This exposure shows 5 to 15 feet of Vashon Till overlying Admiralty sands and in turn overlain by 5 to 15 feet of clear yellow sand with a slight dip to the West. The contact between the sand and underlying till is somewhat uneven, the elevation in three separate places from East to West along the track being 245, 230, and 220, which are representative. The flexures in the contact line are not sharp, but broad and gentle, probably covering 300 to 400 feet. The true dip of the sands in this section could not be ascertained, due to only one plane section being exposed. In a shallow ten foot cut above and to the East from here however, foreset gravels are exposed with a dip of 30 degrees to 40 degrees to the Northwest, showing the true deltaic origin of the deposit.

Cobbles and boulders are rather rare over the surface of the delta, but a few were noticed up to a foot in diameter.

The level surface formerly extended farther to the Northwest toward Lake Washington, but the upper beds near the outer edge have been eroded.

The extent of this delta and the development of the contemporaneous channel in the upper part of May Creek, which in places is a quarter of a mile wide, shows that a large volume of water emptied thru here at one time in the history of glacial retreat. In all probability, this development can be attributed to Cedar River, which was especially unstable in its courses during that time. The lake into which the delta was built was a local body of water, formed by the withdrawal of the ice from the wall of the trough in the immediate vicinity without opening up an outlet for the water to the South lower than 290 feet.

The Cedar River High Level Deposit.

Cedar River at another and earlier period occupied the line of its present channel three miles south of the May Creek Channel. That it at this time emptied into the same body of water at the same or more probably at a slightly higher elevation, is suggested by the position of the gravels, but if any delta were formed, it cannot be recognized at the present time.

The position of these gravels is shown by Willis on the Tacoma Folio. The surface of the deposit is decidedly irregular over the lower one mile examined, due to the extensive post glacial erosion, and this coupled with the heavily forested condition over most of the area makes the reconstruction of the former level decidedly difficult. There seems to be a fairly uniform level, which is also the highest, best developed near the cemetery on the road which goes east along the first section line road north of Renton. Two elevations carried by steps to this level were 317 and 321 feet. That this is the original level is further evidenced by the following fact: to the Southwest of the cemetery mentioned, the surface in the forest shows a number of pot-holes, some of them more or less rounded (100 feet in diameter) and others elongated (150 X 50 feet), all with a depth between 5 and 10 feet. They could only have been formed at the time the gravels were deposited, and probably by the melting of submerged ice chunks. This is the reason for the belief that this deposit is older than the Kennydale delta, for the ice could never have readvanced without greatly altering the delta.

A person standing near the cemetery with a view of the cleared land north of the section line road can easily follow the high level line of the gravel deposit by noting the contrast between the overlooking low till hills and the lower, more eroded but more gently rounded topography. That this deposit originally extended quite a distance to the North, possibly to the present Issaquah highway, is very likely, since one shallow cut on a road leading north from the hill road showed clear yellow but unstratified sand. The extent in this direction is mapped on the Tacoma folio, but the deposit was not observed to extend so far east along the east west road as there mapped.

Sections along the road which climbs the hill show the deposit to be composed entirely of gravel clear to the surface, but no bedding is evident other than that the gravel was water lain. The separate cobbles range up to eight inches largest dimension, averaging two inches, and are composed largely of granite and volcanic porphyries, but also of some basalts and conglomerates. The surface of the deposit shows its gravelly nature especially around trees where the pebbles have apparently been rooted out. Angular erratics are not common over the surface but a few (about six) were observed, ranging up to three and a half feet largest diameter.

In profile the deposit shows an even straight topped descent from the highest level to an elevation of 270 feet about 1000 feet farther west, where the surface drops off abruptly to the valley bottom. At the foot of the hill and far below these high level deposits, several gravel pits have been opened up by the County. The first is located at the termination of the north wall of Cedar River, while two or three others are scattered along the Lake Washington side of the hill for a distance of about 1000 feet north of this one. Thus all are on the lakeward face of the higher outwash gravels. These pits expose steeply dipping foreset sand and gravel beds clear to the top. The southernmost beds dip slightly north of west at 40 degrees; those in the pit farthest north are more sandy and finely stratified, and dip west at 20 degrees. The strata of these pits are truncated abruptly at the top by erosion surfaces. The top of the pit farthest south has an elevation of 155 or 156 feet (two readings) while the top of the northernmost pit is 135 feet above sea. Till underlies the gravel below 100 feet in the south pit. That these gravel deposits are the remnants of a delta built into Lake Russell by Cedar River has been advanced by Bretz, but they may also be just as well correlated with the high outwash gravels overlooking them.

The Renton Delta.

Another delta deposit (Plate I) on the south wall of Cedar River overlooking the town of Renton cannot evidently be grouped with those lying north of the river. This deposit formerly extended out to the North for a distance of 700 feet from its junction with the plateau slope and in this state was described by Willis. At the present time all of it has been removed for construction work except about 200 feet adjacent to the main land. This remnant shows a steep erosion scarp on the East towards Cedar River, but the opposite side facing Renton is not so steep. The summit line that is left to-day is level and a noticeable feature as one approaches the town along the Seattle highway. Three independent elevations placed on it by myself were 206, 209 and 210 feet. Willis records it as at an elevation of 200 feet.

The section at the back or upper end of the pit which is in a west by northwest plane, shows gravel dipping west at 20 degrees. Overlying the gravel in one place along the west side of the pit is a three foot sand bed.

A large waste pile of well rounded cobbles that were too large to be used has been left in the center of the pit, and a careful examination of 20 of these rocks all picked up adjacent to each other showed the following rock types: 7 basalt, 5 granite, 3 trachyte porphyry, 2 granite porphyry, 1 quartzite, 1 syenite porphyry, and 1 granodiorite porphyry. All that the various porphyries lacked being granite or rhyolite porphyries was the presence of quartz, but none could be found in the macroscopic specimens, although an analysis might give other results. A few sandstone cobbles were noted in the exposed section at the back wall of the pit.

This deposit seems to contain a rather large percentage of coarse material as compared with others around Lake Washington, and it certainly contains a abnormal number of large angular boulders scattered over the floor of the pit. All told there were probably more than 100 blocks over two feet thru and around five that are larger than five feet, largest dimension. Altho most of them are decidedly angular taken as a whole, the sharp edges are somewhat rounded off of many of them, especially of the smaller ones, as if they had been exposed for a short while to running water. A few are decidedly water worn. Most of the large extremely angular blocks are granite, the largest one being around seven feet thru. One garnet schist was noted.

Of peculiar significance with regard to the position of the ice at the time of formation of the deposit are the numerous clay and till "boulders" occurring in the undisturbed section at the back end of the pit. The till lumps especially have the appearance of having been first formed elsewhere, and later deposited with the gravel in their present position. But due to the unconsolidated nature of the till, it could never have been moved but a very short if any distance before it would have disintegrated under the action of the water. The conclusion more likely to accord with the facts is that the ice was melted in place, leaving the till in roughly the form of the ice block, which apparently must have been more or less rounded, since the till lumps resemble boulders in outline.

Four or five of these lumps of till up to two feet in diameter were noted, consisting of a sandy clay matrix with a few pebbles, generally small, but one or two rounded ones up to three inches largest diameter. The rocks represented were mainly basalt and quartzite, the former largely predominating, but there were a few granite and granodiorite pebbles. The clay lumps resembled till except that they lacked the pebbles. The largest one was about three feet in diameter.

This gravel deposit is around 60 feet in depth as exposed in the section today, and is distinctly underlain by till which, besides the usual complement of basalt and granite pebbles, also carries a few sandstone cobbles.

It is to be interpreted as a Cedar River delta built into a body of water whose surface was around 210 feet above present sea level. This lake, like the one into which the Kennydale delta was built, was held up to the South by the Vashon Ice, but the drop from 290 to 210 feet shows that the ice had begun to withdraw, opening up a new and lower outlet. The ice holding up this body of water might very well have been a tongue in the Duamish Valley, which, having a better feed from the North, lasted longer than the Lake Washington tongue.

The head of this delta has been removed by later erosion of Cedar River, only this remnant protected by the end of the plateau remaining.

Cross Channels North of Newcastle Hill.

There are two glacial drainage channels north of Newcastle Hill from the Lake Sammamish to the Lake Washington trough (Plate I), but if these were ever supplemented by deltas on their west sides, the latter have been eroded. Both channels are described by Bretz and were not visited in the trips preliminary to this report. The southernmost lies just along the north base of Newcastle Hill with its highest elevation at a little above 300 feet. The other, at a slightly lower altitude, lies a mile farther north along the line of Phantom and Larsen Lakes. This second channel ends abruptly on the west side at the top of a steep descent towards the lake, at the foot of which occur unmodified kame deposits which were formed subsequent to glacial discharge thru the overlooking channel. Since these channels are younger than the Kennydale delta and the kames younger than the channels, it follows that ice lingered in the valley at least contemporaneous with the lakes into which the Kennydale and Renton deltas were built, and probably after their disappearance. Mr. Bretz believes that both of these channels emptied into the Kennydale delta lake.

The York Channel.

When next we hear from the Lake Washington trough thru the geological record of deltas and drainage channels, it has become part of Lake Russell.

Southeast of the Juanita school house a gravel pit has been opened up in the southeast side of a small stream which empties into Lake Washington at Juanita Bay. Viewed from the highway at the school house, this gravel deposit shows an uncommonly level summit for a distance around 800 feet north and south, mostly north of the pit, but when examined closer with an aneroid, the level at the back of the pit is found to be about 15 feet lower than the region to the north, south, and front of the pit. The flat above the deposit is swampy and generously strewn with cobbles. Foreset gravels dipping west at 40 degrees are exposed on the northeast wall of the excavation as far back as has been advanced into the deposit, or about 300 feet; at the back of the pit they continue uninterruptedly to the top of the section, but at the front where the surface of the gravel is about 15 feet higher than at the back, the excellent foreset structure occurring in the lower beds dies out somewhere around an elevation of 114, 116, or 117 feet (three readings) above sea level, and the six to nine feet of overlying gravel are rather marked more by a lack of any consistent bedding at all than by either foreset or topset bedding. However in a few places, the suggestion of a flat bedding or even of a low back dip is found. On the opposite or southwest wall of the 35 foot cut, long foreset gravels dipping northwest at 15 degrees are exposed clear to the top. The highest elevation of the top of the deposit on the north side is two feet higher than the highest elevation on the south side of the pit, which is close to the front. This latter point was used as a bench mark with reference to other points in the region. Five independent elevations placed on this point were 107, 107, 107, 100, and 93 feet above Lake Washington, and consequently 121, 121, 121, 114, and 107 feet above sea, taking the elevation of the lake as 14. The two latter elevations, made on the same day, are not as trustworthy as the first three, which were made on two separate days. On the day the last two were taken, the air pressure was varying so rapidly that another important set of elevations taken, as will be pointed out later, are far from satisfactory.

The gravels occurring in the pit are all water rounded and generally small, tho a few range up to a foot in diameter.

Summing up the significant points in regard to this deposit, it is a delta with a surface elevation at the highest points of 121 to 123 feet, and exhibits foreset beds up to around 116 feet. The low place at the back of the pit is due to slight post-glacial erosion by the swampy stream coming in from the Southeast.

The flat above the deposit continues back to the Southeast in the form of a broad, flat, wooded swamp. A duck pond has been made 200 to 300 yards back from the delta. East of a line about a half a mile from the pit, the swamp has been cleared, drained somewhat, and is under cultivation, part of it being pasture. One of the farmers stated that the valley was so flat that they had trouble in keeping it drained sufficiently to serve as a pasture. Its width in this locality is around 600 feet. A broad pond of four or five acres occupies the valley floor about a mile back from the pit. The col occurs between one and three quarters and two miles east by southeast of the delta. Five independent elevations gave it as 41, 8, 25, 24, and 30 feet above the reference point at the pit and consequently 162, 129, 145, 146, and 151 feet above sea. These elevations as already mentioned, are very unsatisfactory. A composite elevation, from an attempt to carry the elevation by steps between intermediate points, gives the elevation as 147 feet above sea which is close to the correct value.

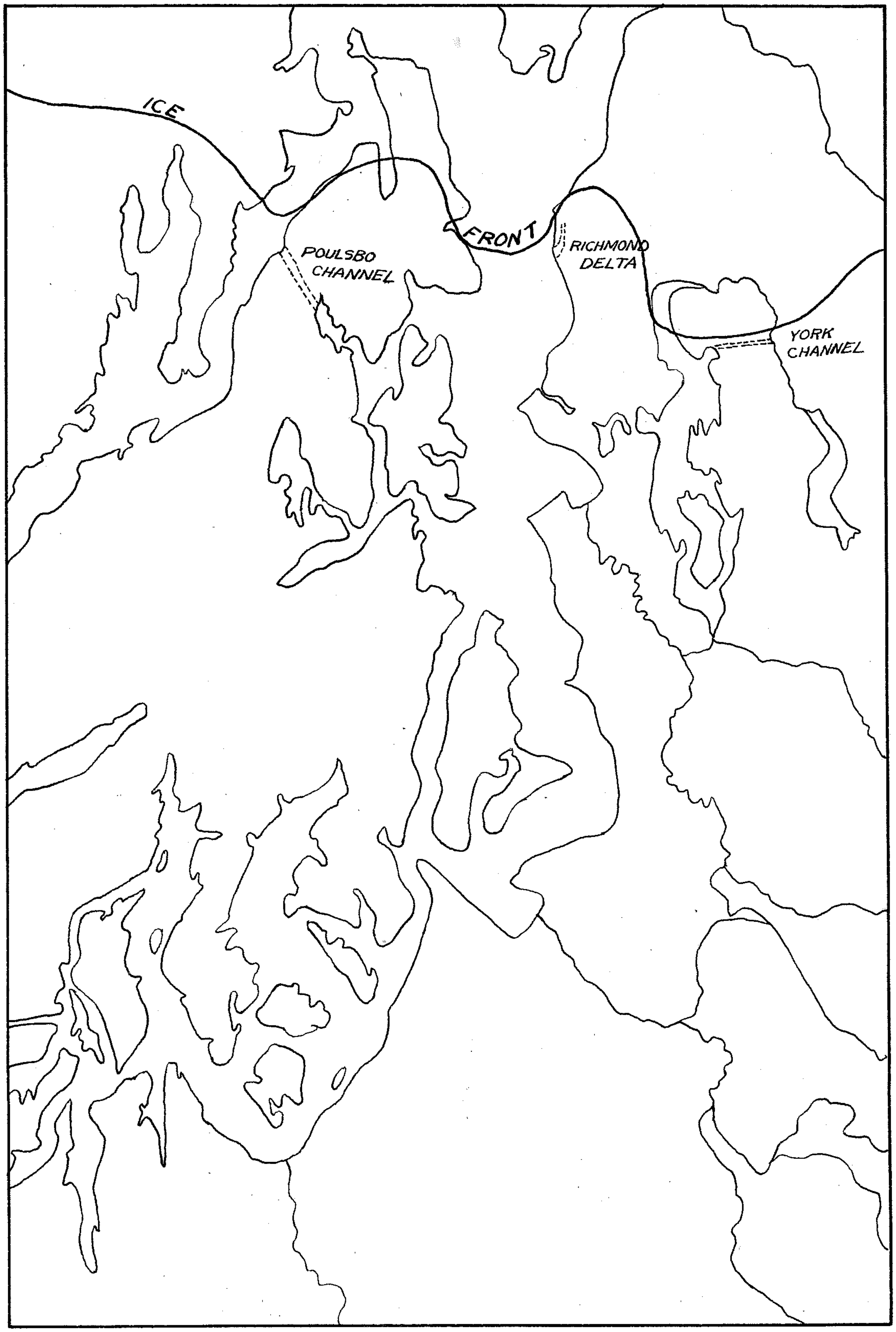

Fig. 2. Upper Lake Russell at Maximum Extent

This then is the drainage channel across the ridge at the time the Juanita delta was formed; it is the York Channel of Bretz (Plate I). It emptied into Lake Russell when the latter stood at its 120 foot level. Since the channel at Bothell is lower than this one, the former must have been blocked by ice at the time that the Juanita delta was formed; consequently Lake Russell had been lowered from 160 to 120 feet before the ice had withdrawn from Bothell. But the delta at Richmond, which is one or two miles north of this lattitude, tho several miles to the west, was built into the 160 foot Lake Russell (see Bretz, p.159). Hence the position of the ice at the time that Lake Russell was lowered, can be rather narrowly defined, the front being north of Richmond but south of Bothell, and probably close to the York channel. (Fig. 2) The ice must have paused at this position for a considerable time, since the outlet of Lake Russell at Black Lake was lowered by erosion of the channel.

The above considerations bring out an interesting point in regard to the shape of the ice front. The Richmond delta was formed with the glacier in contact on the West, and the old channel can be traced for a mile north from the delta. Ice was standing in the Sound trough but not over the land immediately to the East. But over several miles farther east, the ice extended south of Bothell. Apparently the ice, instead of presenting a straight front from east to west, had tongues extending farther south in the troughs than on the uplands. The extent of these tongues is not known, but Mr. Bretz does not believe that the tongue at Richmond was much more than a mile in advance of the ice on the uplands. The tongue in the Lakes Washington and Sammamish region was apparently more pronounced, unless the ice front on the uplands also swung south in

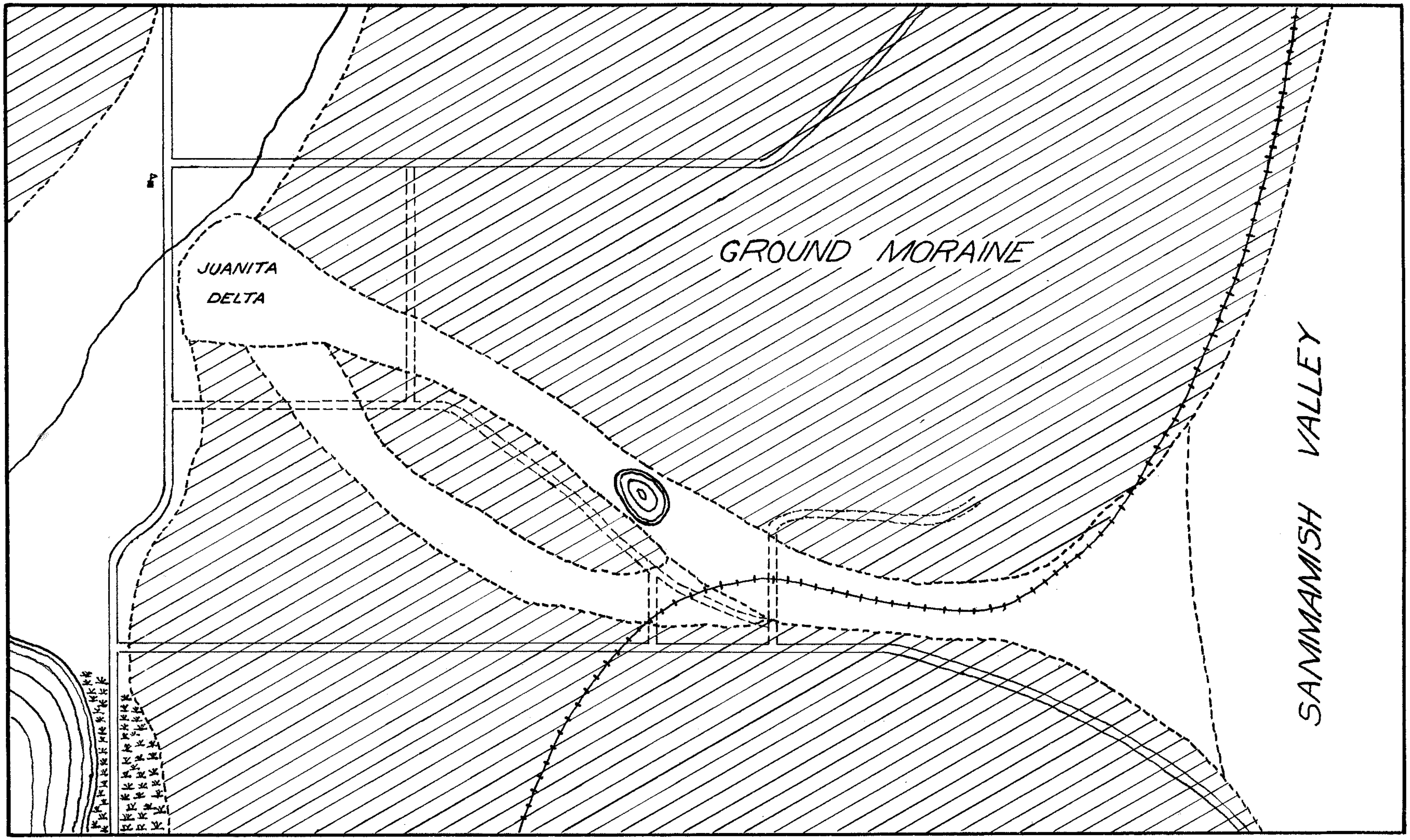

Fig. 3. York Channel and Juanita Delta

that direction. A tongued front after all is more to be expected, since the ice was waning rapidly, and was sure to melt back faster where it was not so thick than in the troughs where, added to the greater depth of the ice, better feeder connections to the North helped to keep the ice present for a longer time.

The York channel as described is not the only one that was ever used in the immediate vicinity. Another old valley lying less than a quarter of a mile south of the main channel occurs as a shunt on the main one (Fig. 3). This old bed is 3800 feet long and joins the main channel about a quarter of a mile above the Juanita delta, and again 3800 feet farther east. This old channel is around 700 feet wide at its greatest development. It is flat, swampy, and has a very rocky bottom in places. The gravel averages between two inches and four inches in size, but rounded and semi-rounded boulders up to two feet occur. The elevation is somewhere around 156 feet at the upper end (elevation not satisfactory) and only five feet lower at the lower end, where it drains by a short, shallow, steep branch to the main swamp below. The two channels are separated by a high sharp crested ridge. Horizontally bedded gravels are exposed in a shallow road cut at an elevation of around 146 feet along the upper junction of the two channels which is not so steep as the lower one. This old higher level channel was used while the ice was present immediately north of the dividing hill, which may be in the nature of a moraine deposit. It is rather low, if the elevations on it are correct, to have drained into 160 foot Lake Russell, but it may represent a stage in the lowering of that lake; in fact that the ice paused long enough within the one-fourth mile between the two channels for the upper one to be formed shows that the ice front was practically stationary at that time. No delta corresponding to the higher level was noticed, tho the wooded nature of the west end and the lack of exposures could easily conceal such a form if it existed.

The Bothell Channel and Delta.

The last but by no means least interesting records of the Vashon Ice that occur in the Lake Washington trough are found at Bothell.

Just east of the town and in the north bank of the Sammamish River, a gravel pit has been opened up, and is being developed at the present time. Gravels dipping south by southwest at 40 degrees were exposed in the back or working face of the pit at the time that it was visited. Underlying the gravel, tho not sharply distinguished from it, sand is exposed clear down to the highway at the base of the hill. No consistent dips are shown in the sand sections, varying from horizontal to first steeply in one direction and then in the other, but this is largely due to irregularities in the section, the true dip not being apparent. The texture of the beds, especially in the intermediate positions, varies greatly both horizontally and vertically, the sand changing to both fine pebbly sands and gravel on the one hand, and to a few seams of clay on the other. The gravels range up to possibly a foot, being coarser at the top. In one or two places at the top of the section till lenses occur, probably up to three feet thick.

The surface of the deposit east of the pit shows a level terrace for about 500 feet, the highest part of which, along its junction with the overlooking till hill to the East, is 118, 117, or 113 feet in elevation (3 independent readings), the general level running to three or four feet lower. Shallow sections along the high-

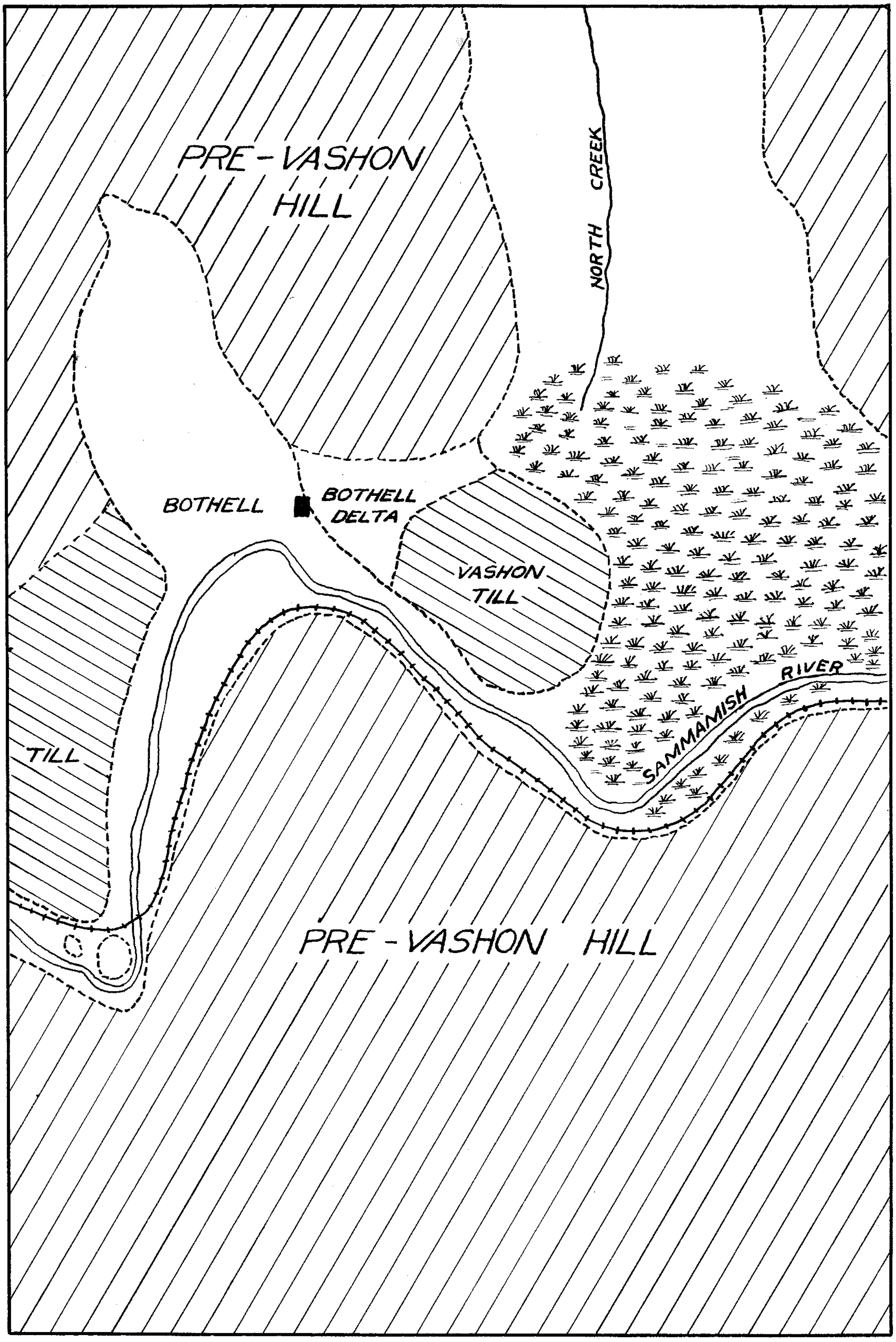

Fig. 4 The Bothell Region

way at the base of the hill shows gravel to extend as far east as the overlying terrace, beyond which it gives way to till, which is exposed along the highway at the point of the hill extending southeast from Bothwell. The terrace formerly extended about one-fourth of a mile northeast from the pit to a position overlooking North Creek Valley, but a small stream, or more properly gully, which formerly drained out at the pit, has removed it everywhere except where described. The town is built on the eroded surface of these gravels. This terrace is the remains of an old delta built into lower Lake Russell (Plate I).

The till hills which lie southeast of the old delta extend out from the main Admiralty drift ridge to the North, and lie almost directly in the path of North Creek. The highest elevation is around 175 feet. The Sammmamish River has cut a narrow post-glacial channel between these hills and the much higher hill to the South, which is made up of Admiralty Sediments. Fig. 4 is a sketch map of the Bothwell region.

With these facts in mind, the next point is to interpret them. When the Vashon Ice rode over the interglacial valley at Bothell, the latter was partly filled with till in various places. One place was east of Bothell, and another was near the station of Wayne farther south, but apparently the region right at and just to the west of Bothell was not filled to such a great extent. After the retreat of the Vashon Ice, the drainage from the glacier down North Creek was thru a channel northeast of Bothell and several hundred feet north of the present channel. A considerable delta was built into lower Lake Russell. After some time, the ice made a local re-advance far enough south to block the former drainage channel. The increasing coarseness of the beds in the gravel pit from bottom to top, together with the till lenses at the top both point to an advancing ice. It was this advance which threw the outlet of glacial Lake Sammamish over to the South along the base of the Admiralty drift hill, into its present position. The new channel was cut low enough that when the ice finally retreated, the waters failed to go back to their old course. Upon the final lowering of Lake Russell, the new channel was rapidly cut down to somewhere near its present position; hence its narrow post-glacial appearance.

That a continuation of the gravels of the Bothell delta for some distance up North Creek once existed is suggested by the occurrence of gravels in a shallow road cut on the west side of the creek at an elevation of 72 feet about a quarter of a mile north of the delta. The delta terrace as it exists today has been saved from erosion due to the small amount of water which has to drain across it.

The Kennydale Delta into Lower Lake Russell.

At the mouth of May Creek, and overlooking the low mudflat into the lake, is a flat-topped sandy deposit which, altho no sections are exposed, can confidentially be referred to as a delta. It is plainly developed on both sides of the creek. The south terrace is roughly in the form of a right triangle, being 400 feet long parallel to the creek, and the same length parallel to the lake. The north terrace is probably 800 feet long paralled to the creek and not so wide; unlike the south side, it has been somewhat eroded along its north edge along the base of the slope which rises in that direction. Four elevations placed on the south side at its youngest (farthest west) edge gave it as 96, 96, 100, and 105 feet above the lake, or adding 14 feet, between 110 and 119 feet above sea. It is underlain at 50 feet in elevation by till. The north side by a single aneroid comparison, was found to be only one foot lower than the south side, measured in a corresponding place, and probably five feet higher when measured at its oldest, basal (farthest east) end.

Altho these elevations average slightly low for lower Lake Russell, the highest one is just about right. Having become fully aware by experience of the fickleness of an aneroid, I am inclined to believe that another series of elevations might have given a higher average. Final conclusions either way cannot be drawn too closely in advance of more accurate measuring devices.

General Discussion on Delta Elevations.

In concluding the discussion of the lower Lake Russell deltas found around Lake Washington, it might be stated that all three studied (Juanita, Bothell, and Kennydale) have pointed to a slightly lower elevation of that body of water than the figure given by Bretz (120 feet). Were its elevation to be determined by these three deltas alone, which agree quite well among themselves, it would be nearer 115 feet than 120 feet above mean tide. The bench mark used for all elevations given, with two exceptions, is Lake Washinton, at 14 feet above mean tide (U. S. Engineers); a U.S.G.S. bench mark at Renton was used in that locality, and a Northern Pacific Railroad elevation was used at Bothell.

Lake Russell Terraces.

Mr. Bretz found no terraces anywhere in the Sound region that could be correlated with Lake Russell. At one place however, on the west side of Lake Washington, beginning about a quarter of a mile north of Lake and extending north for a distance of a quarter of a mile, disconnected remnants of a terrace occur along the "bluff" at the level of upper Lake Russell. This terrace, as measured at the back side at the base of the overlooking slope, is 160 feet at the southernmost point noted, 159 feet on the next remnant 500 feet farther north, and 165 feet 800 feet still farther north. The last elevation was taken possibly three quarters of an hour later than were the first two, and was checked on the lake as soon after as it was possible to get down thru the brush, but the aneroid was dropping at the time (16 feet between checks) and it is possible that some of this drop may have taken place during the descent, throwing the elevation a little high.

The terrace runs between 150 and 200 feet wide, and was around ten feet lower along its lakeward edge than at the back side where the elevations were noted. It is not especially rocky, but had formerly been covered with a forest so that rocks might have been covered up. Erosion has removed much of it and the little gullies tend to develop first along the back side of the terrace, leaving the outer side to extend out, separated from the main slope, tho nowhere were connections completely severed.

The uniformity in level of this terrace over a quarter of a mile, and the correspondence of its level to that of upper lake Russell make it probable that it is a lake terrace, and not a slide or kame terrace.

LAKE WASHINGTON SINCE THE DRAINAGE OF LAKE RUSSELL.

Mr. Bretz has concluded, chiefly from observation in Island and Whatcom Counties, that at the time of lowering of Lake Russell the region was from 30 to 50 feet lower than at present. It is certain that the region has risen between 40 and 50 feet since that time; terraces with marine shells occur above Vashon Till at several elevations about the Sound up to 40 feet, the most prominent of which is the lowest at an elevation of about 20 feet, showing plainly at numerous places around the Sound, as at Alki Point Restoration Point. Such terraces plainly record an elevation of the region by the amounts shown in the elevations of the terraces, and since marine waters entered the Sound.

But Mr. Bretz does not believe that the case has been so simple as just a mere emergence; from the occurrence of marine shells believed to be in situ, and obscure wave cut terraces as high as 280 feet above present sea level, he concludes that the region was submerged after the disappearance of Lake Russell and has risen 280 feet since then.

Whether this hypothesis is accepted or not, the bearing which it has on the history of Lake Washington is slight. Before it was lowered to its present level, Lake Washington was 22 feet above sea level. Consequently 22 feet can be taken as a dead-line, a submergence beyond which the lake would exist only as another arm the Sound. But in all probability it so existed even subsequent to the final emergence to the present level, and has been raised since by the damming of its outlet by the Cedar-White River delta.

Willis, in his work on the Tacoma folio, showed that the deltas and alluvial cone gradients of the various rivers which enter the White River trough and drain out to the Sound at Seattle and Tacoma, are perfectly adjusted to the present water levels. There are no traces of forms referable to other sea levels. Hence we conclude that the present alluvial development of Duamish Valley has been attained entirely since the final emergence. The White River trough contained Sound waters just after the last uplift and has since been filled in to the North and South. The positions of the deltas in Seattle and Tacoma harbors today show how far this filling has progressed.

The time during which the land stood 20 feet lower than at the present time must have been brief in comparison to the time that has elapsed since, for otherwise the heavily aggrading glacial streams would certainly have built considerable alluvial fans, remnants of which should exist above the present graded streams.

Cedar River, aided by the advancing alluvium from the South, very soon cut off that portion of the Sound lying to the North, and the building up of this delta and flood plain has slowly raised the outlet of the lake formed to 22 feet, the level of Lake Washington before the canal was put in. Coincident with the raising of the outlet, its waters were converted from salt to fresh-water.

A line of evidence tending to confirm this view is the occurrence of the base and roots of old trees at present water level, and consequently 8 feet below the former water level, in Juanita Bay, where they could not possibly have been placed by a slide. Three of them were observed together, representing trees probably three feet in diameter. They were decidedly wave worn, so much so that nothing was left above the roots. The region back from the beach at this point is flat and it is at least 500 feet to the North before a hill is reached. The bay is shallow and sandy so that the roots were well anchored in the sand. The depth of this loose beach sand would have an important bearing on whether the trees are in place or not. The Coast and Geodetic Survey map has the center of the bay with a depth of 10 feet marked "hard," so that the present sandy beach is probably just a veneer. Trees along the lake shore drowned by rising water should be a common occurrence, and it is possible that some of the root stubs at other places along the lake shore, in particular some of those along the west side of Juanita Hill and in Yarrow Bay, may have had such a history, rather than submergence by a slide.

THE SUBMERGED FORESTS OF LAKE WASHINGTON.

An interesting feature in connection with Lakes Washington and Sammamish which has attracted considerable interest is the submerged forests. They were mentioned by Kimball in 1898, and were attributed to landslides. Such is the only explanation that can be offered, though it is difficult to believe in one of the places. There three areas in Lake Washington, one on the west side of Mercer Island, one on the southeast side of this island, and a third on the west side of Juanita Hill at Clahaunee. Since these forests were for the most part concealed from view but extended practically to the surface, they were a considerable menace to navigation, especially after the lowering of the lake. Two or three boats were sunk which had formerly passed over this same area without the slightest mishap. Consequently those snags which extended to within 20 feet of the surface of the lake west of Mercer Island, to within 15 feet of the surface southeast of Mercer Island, and to within 30 feet of the surface at Clahaunee, were dredged out in the winters of 1916, 1917 and 1918 under the direction of the U. S. Engineers. Captain F. A. Siegel of the snag boat Swinomish was directly in charge of this work, and it was from him that the following facts were learned in regard to these forests.

All told, (as I recall from memory, tho Captain Siegel has the exact number) there were around 290 snags removed, every one being fir. They stood just as thick as trees in a forest. The largest snag, 9 feet in diameter, was taken out at Rhodes Landing southeast of Mercer Island. The longest one taken out entire was 121.5 feet long, 5½ feet in diameter at the base, and of considerable size (2½ feet) where broken off at the surface of the lake. It occurred at Clahaunee and was in 120 feet of water, the greatest depth at which the trees stood. There were probably longer ones handled, for many had to be shot off with dynamite far below the surface to get them out of the way.

All were rotted off at the surface of the water. Under the water they had been eaten in by decay and wood boring animals for four to five inches on all sides, only the hard knots projecting out due to their greater resistance. All limbs had long been gone. At the base however, they were buried in eight to ten feet of mud; everything, even to the bark, was preserved. Silicification had gone far enough to make them exceedingly hard to saw, and several teeth were broken out of different saws. The wood was so completely watersoaked and heavy that it more nearly resembled rock in its specific gravity. The earlier snags were piled along the beach, but when it was found out that they sank so readily, the rest were taken out and dropped in deep water. A few even were used as achors for buoys. Several chips were dried out for 5 or 6 months when they went to the opposite extreme, and rode the water like a duck. In a few hours, however, they took up the water again and sank. Captain Siegel said that these dried chips were very much like a piece of pumice.

The trees at Clahaunee and on the west side of Mercer Island stood practically straight up, but those on the southeast side of the island were tipped to the Northwest anywhere from 0 to 45 degrees. The southeast end of the island is high and steep a piece back from the shore, but this bluff does not come down close to the water. Evidences of a slide are clearer here than any place else, but it has not been very recent. The trees extend out to a depth of 100 feet.

At Clahaunee on the other hand, it is almost inconceivable that the forest could have been put into its present position by a slide. Trees extend out a quarter of a mile from the shore to a depth of 120 feet. The slope of the lake bed both beyond here and back to the shore is practically an unbroken gradual slope. The trees were not observed in water shallower than 50 to 60 feet. (This holds good for the other two localities also.) The lake bank shows no noticeable evidence of a slide of such a great extent. How the trees could have gotten into their present position on a flat bottomed lake and still have remained upright is almost a mystery. Captain Siegel states that according to an old Indian legend, this used to be a happy hunting ground, but owing to the fact that some kind of a dam got in below, the waters came in and drowned it.

On the west side of Mercer Island, slide evidences are about intermediate between these two extremes. I am informed by Mr. Warren Marple, a student who lives on this side of the island, that small slides only 200 to 300 feet across are continually occurring, and that many of the trees on the hill are leaning out of the position in which they originally grew due to movements of the surface, but that there is no evidence of a slide, of any recent time at any rate, that was as big as the one attested by the submerged forest.

The areas and depths of these forests are quite acurately delineated on the Coast and Geodetic Survey map of Lake Washington.

RECENT ALTERATIONS IN THE LAKE

The Lake Washington Canal was cut thru between Lakes Union and Washington in 1916, and the lake was lowered about 8 ft. Cedar River formerly flowed into Black River close to the lake, and the chief bulk of its water flowed either into the lake or out thru Black River according to the season. When the canal was made, the outlet of the lake was placed at the canal, and the course of Cedar River was changed so that its whole discharge was into the Lake. Black river was changed as a result from a respectable river to a very small creek in the nature of a slough, and its course is rapidly being overrun by willows.

The former Lake Washington beach extends around the lake as a terrace and has not yet been overgrown by vegetation, although alders and willows are getting such a start in some places as to make traveling rather exasperating.

One effect of the canal has been to more nearly stabalize the level of the lake. Whereas it formerly fluctuated over several feet according to the season, it now stays close to the same level, about 14 feet above mean tide.

The locks at Ballard are so operated that a considerable quantity of salt water is let into the fresh water canal every time a boat goes thru. It was thot at the time the locks were designed that this marine water would not diffuse to a great enough extent to ever effect the lakes to any appreciable extent. Considerable interest has consequently been directed toward this matter, and chemical tests for salinity have frequently been made of the water in different parts of the fresh system. These tests have shown that the salt is spreading rather faster than was anticipated. The latest analysis, made by Dr. T. G. Thompson of the Chemistry Department of the University of Washington, shows that as yet no trace of salt has diffused east of the Latona Bridge. Consequently Lake Washington is up to the present unpoluted. But at the rate at which traces of salt are spreading at present, it cannot long remain so, unless better arrangments for the disposal of marine waters are made at the canal.

APPENDIX.

Log of the Bell Street Well.

Fine Blue Clay, Silt, Sand,	21 feet.
Blue Clay,	31 feet.
Gravel,	7 feet.
Black Sticky Gumbo,	3 feet.
Yellow Clay,	9 feet.
Blue Sand,	39 feet.
Clean Gravel, Water,	6 feet.
Unrecorded,	26 feet.
Gravel,	3 feet.
Blue Sand,	28 feet.
Gravel,	44 feet.
Fine Blue Sand,	6 feet.
Red Clay,	2 feet.
Pack Sand and Gravel,	18 feet.
Fine Blue Sand,	28 feet.
Blue Clay,	2 feet.
Brown Shale,	2 feet.
Blue Clay,	20 feet.
Quick Sand,	8 feet.
Blue Clay,	10 feet.
Sand, Water,	4 feet.
Blue Clay,	19 feet.

Fine Blue Sand, Water,	2 feet.
Blue Clay,	11 feet.
Brown Clay,	2 feet.
Blue Clay,	36 feet.
Brown Clay,	4 feet.
Gravel and Hardpan,	31 feet.
Gravel and Good Water,	32 feet.
Hardpan,	8 feet.
Fine Blue Sand,	232 feet.
Thin layers of Blue Clay, Sand, Shale, Brown Clay,	32 feet.
Water Bearing Coarse Sand, Fine Gravel,	6 feet.
Total depth of Well,	732 feet.