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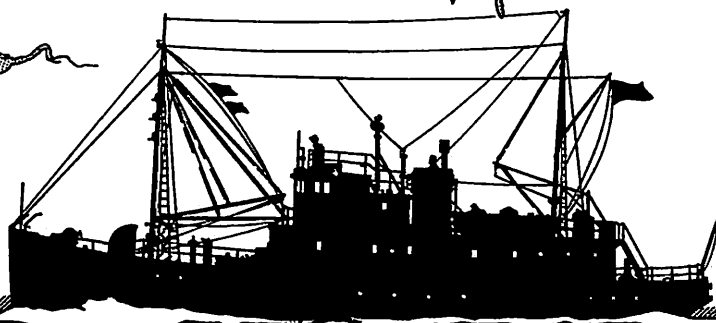
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GRAVITY AND THE PROPERTIES OF SEA WATER, by Ricardo M. Pytkowicz. Limnology and Oceanography, 8(2):286-287, April 1963.

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POSTGLACIAL SEDIMENTS IN UNION BAY, LAKE WASHINGTON, SEATTLE, WASHINGTON, by Dean A. McManus. Northwest Science, 37(2):61-73, May 1963.

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*Postglacial Sediments in Union Bay, Lake Washington  
Seattle, Washington<sup>1</sup>*

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UNION BAY is a shallow embayment of approximately 0.8 square mile of water and marsh located midway along the western shore of Lake Washington, a deep, narrow lake that forms the eastern boundary of the city of Seattle (Figure 1). In January and February of 1961 test borings were made across the bay by the Washington State Highway Commission in preparation for construction of the second Lake Washington Bridge (Evergreen Point Bridge). Core samples and laboratory data from this drilling project were supplied by the Highway Commission to the Department of Oceanography, University of Washington, where the sedimentological studies that form the basis of this paper were carried out.

Although the bottom sediments in part of Lake Washington were briefly described by Wang (1955) and later these descriptions were amplified and the scope of study enlarged by Gould and Budinger (1958), their research did not include the sediments in the shallow embayments. Of the sediments in these embayments, only the peat deposits in the presently emerged lowland of Mercer Slough on the eastern side of the lake have been described in any detail (Rigg, 1958: 69). In this same report Rigg (p. 87) gave a passing description of the peat deposits just north of the present shoreline of Union Bay.

In 1916 Union Bay and Lake Washington were joined with Puget Sound by means of the Lake Washington Ship Canal. As a result of this connection the water level of the fresh water bodies was lowered 9 feet (U.S. Army Corps of Engineers, 1939), and the northern, shallowest part of Union Bay was drained of open water. Because the present shoreline of the bay is controlled by the operations of the canal and locks, the bathymetric chart of the bay (Figure 2) is contoured from the U.S. Coast and Geodetic Survey chart of 1903, rather than from a more recent chart. The water depths and bathymetric configurations shown on the chart, however, are indicative of present conditions in the bay. The location of the sediment profile running from Foster Island to the edge of the bay is also shown in Figure 2.

<sup>1</sup>Contribution No. 281 from the Department of Oceanography, University of Washington.

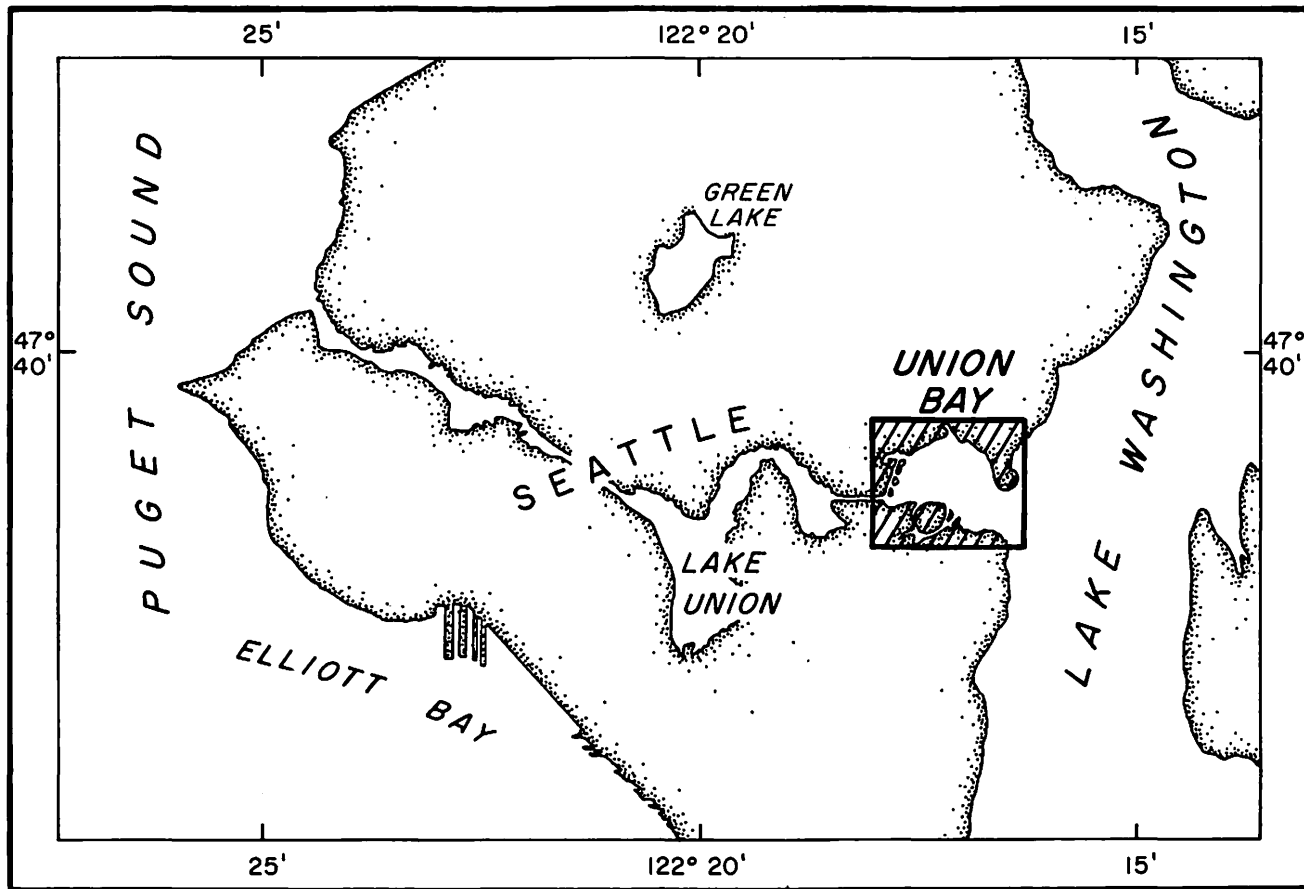


Figure 1. Index map of Seattle area showing location of Union Bay.

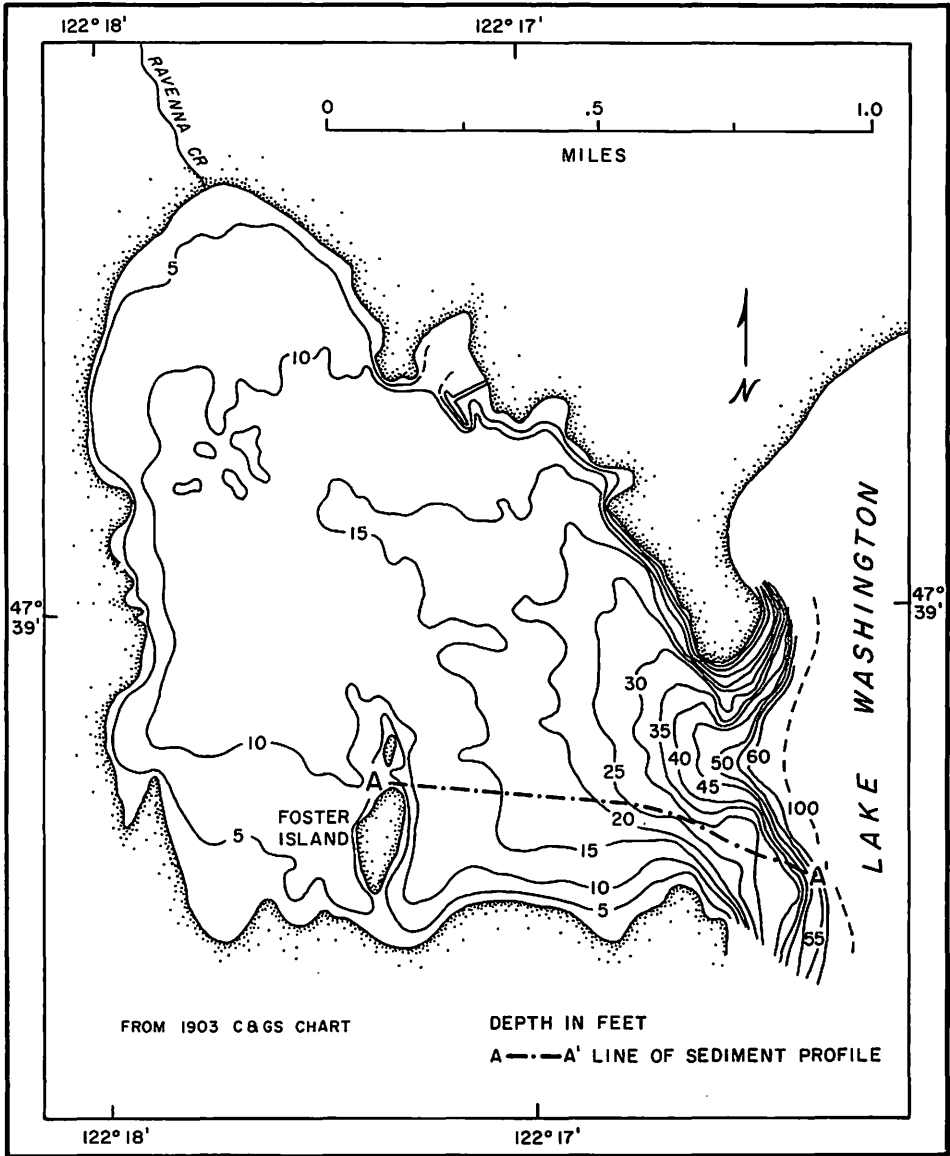


Figure 2. Bathymetric chart of Union Bay. Line AA' is location of sediment profile.

### *Sediment Description*

Several analyses were made of the sediment samples, including standard penetrometer tests at the drilling site, the measurement of various physical properties at the Testing Laboratory of the Department of Highways, Washington State Highway Commission, and the determination of sedimentologic and mineralogic composition at the Department of Oceanography. The analyses performed by the personnel of the Testing Laboratory consisted of the measurement of wet density of the sediment, the cohesion as determined by a compression test, and the water content, expressed in the standard form referred to as a percentage. Actually, this "percentage" is the ratio of sample water weight to sample solids weight, multiplied by 100. Some additional analyses were run at the Testing Laboratory, but the results are not used in this paper. At the Department of Oceanography representative samples were analyzed by sieve and pipette methods, for particle-size distribution. In addition, X-ray diffraction studies in combination with petrographic identification were made of the mineralogic composition.

The postglacial sediments underlying Union Bay evince a diversity of lithologies, ranging from sandy gravel to peat. Yet, one can recognize in the sequence four major sediment units (Figure 3): (1) a friable to consolidated, poorly sorted silty sand at the base of the sequence; (2) a heterogeneous sand, silt, and clay unit; (3) a dense, mottled clay unit; and (4) fibrous and sedimentary peat. The peat terminology used here is that of Rigg (1958: 7).

The sand at the base of the sequence was penetrated only near the eastern margin of the bay and near Foster Island (Figure 3), whereas in the intervening area the borings were terminated in the heterogeneous sand, silt, and clay unit. The sand near Foster Island is gray, friable, poorly sorted, silty, and gravelly, with a median diameter of 0.07 to 0.25 mm. It consists of subangular quartz and subrounded lithic grains, with subordinate grains of orthoclase, olivine, biotite, and muscovite. The gravel and most of the coarsest sand fractions are composed of unweathered lithic grains, principally of igneous and metamorphic origin. In addition to sand- and gravel-size particles, samples from this unit contain as much as 35 per cent silt. The poor sorting is as important a characteristic of this unit as is the sandy texture. Clay-size particles and clay minerals usually form less than 10 per cent of the sample, a condition which is reflected in the low water content of the sediment (14 per cent). In addition, the sediment is very hard, as is shown by the standard penetrometer test performed during the drilling in which 60 to 120 blows produced only 6 inches' penetration.

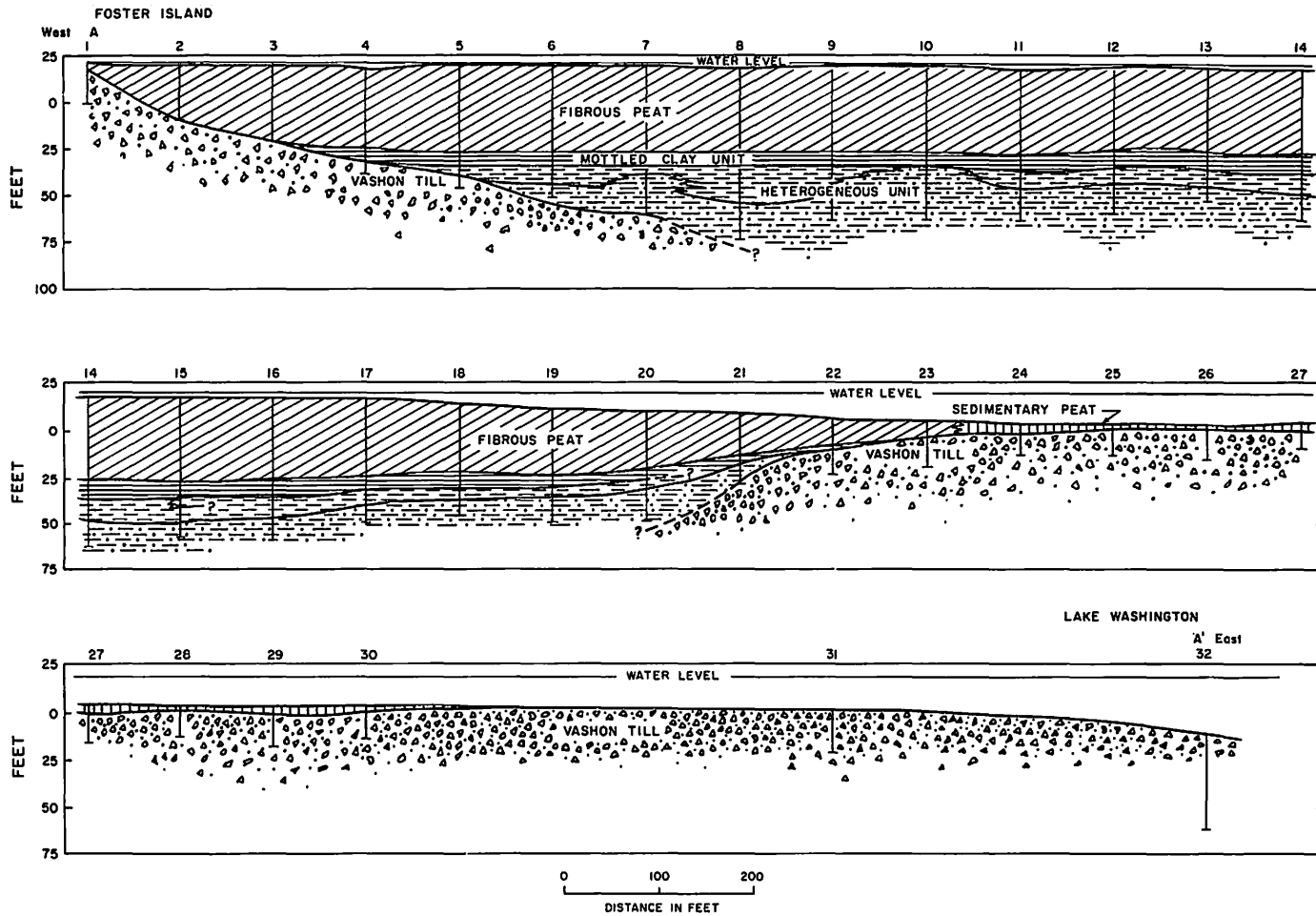


Figure 3. Sediment profile in Union Bay from Foster Island to Lake Washington.

Farther east, where this sand is again encountered in the borings, the upper few feet of the sand appear weathered, especially in cores 22 and 23. Otherwise, the lithology is similar to that near Foster Island although it is not uncommon for the silt content to be less than 15 per cent. As near Foster Island, the median diameter is between 0.08 and 0.26 mm, and the water content remains low, ranging from 2 to 25 per cent with an average of about 10 per cent. Near the outer margin of the bay, however, the percentage is closer to 20, even near the bottom of core 39. The penetrometer tests produced results comparable with those from the sand near Foster Island.

The heterogeneous sand-silt-clay unit overlies the silty sand in the central part of the study area (Figure 3), but to the east and west the unit thins until it pinches out on the flanks of the sand ridges forming the lip of the bay and Foster Island. Variation in lithology characterizes this unit, where small-scale facies changes, reflecting local conditions of deposition, are numerous. These small-scale gradations in lithology, however, are not significant at this preliminary stage of study, nor are the generalized facies relationships which could be shown on the profile given more than provisional import. In general, the unit is composed of a silty to sandy lower part, and an upper clay part containing silty facies.

The lowermost few feet of the unit in the west is a sandy silt, much finer than the subjacent sand, but it is likewise poorly sorted. The median diameter of 0.03 to 0.06 mm is not due to an increase in clay particles, for clay-size material usually forms less than 10 per cent of the sample. Instead, there is an absence of the pebbles and granules of igneous and metamorphic rocks that characterize the underlying unit. Sand-size lithic grains, however, are one of the main components of the friable, poorly sorted sands and silts of this unit. Locally, small disc-like fragments of wood are present. The water content ranges from about 30 to 40 per cent, except along the flank of the outer ridge where the sediment is a poorly sorted, friable, lithic sand composed of subangular to angular lithic grains, principally of igneous rocks, and a few small disc-like fragments of peat. Here the water content is only about 20 per cent.

The sand in this unit occurs not only as distinct, although usually irregular, layers, but also as small lenses in the silt, and in cores 18 and 19 as abundant "floating" quartz sand grains in the light gray clay. As would be expected, the variation within this unit is also revealed in the cohesion, which in compression tests shows values of 3.5 to 5.5 psi. The cohesion thus ranges from material as strong as that of the underlying unit to that which is definitely weaker.

The upper part of the unit is principally a very soft kaolin clay, with minor amounts of chlorite and montmorillonite. Although silty facies are present locally, the orthoclase, biotite, olivine, muscovite, and lithic grains of the silty facies are not numerous in the clayey part of the unit. The clayey texture and composition of this part of the unit permits a greater water content (45 to 60 per cent) than occurs in the silty facies, and as a consequence of these characteristics the cohesion (compression tests) is only 2 to 3.5 psi. This low strength for sediment buried under 55-60 feet of overburden is not unusual when it is remembered that all but 5 or 10 feet of this overburden is fibrous peat which has an extremely high water content, low wet density, and very low cohesion.

Overlapping the heterogeneous unit is the mottled clay unit which varies from a light-gray silty clay to a clayey silt but is everywhere characterized by distinct yellow-brown mottles. These mottles, however, have no textural difference from the surrounding sediment. Except where it thins on the flank of the ridge at the outer edge of the bay, this unit is 8 to 10 feet thick in each core, in contrast to the variable thickness of the underlying unit. In addition to the presence of abundant kaolin and minor chlorite, similar to that of the underlying soft clay, there are common quartz, olivine, orthoclase, biotite, and other silt-size minerals. The water content is only 30 to 40 per cent, somewhat less than that of the underlying clay, but cohesion is greatly increased (5.5 to 12.5 psi). Thus, there is a pronounced decrease in cohesion on passing from the mottled clay unit down into the soft clay of the heterogeneous unit, a condition quite different from the results reported by Richards (1961: 36) and Moore (1961).

The uppermost unit in the section is fibrous peat, except near the outer margin of the bay. There the 45 feet of fibrous peat thins and passes laterally into a 2- to 5-foot unit of sedimentary peat. However, this sedimentary peat, composed of decayed organic matter and diatoms, does not extend completely across the lip of the bay and into Lake Washington. It is absent across the outer one half of the ridge (Figure 3).

Both the sedimentary and fibrous peats have low cohesion and high water content, the sedimentary peat having a water content of 300 to 700 per cent in the terminology described on page 64 and the fibrous peat having greater than 1000 per cent water. Neither of the peat sequences was examined in detail, although an X-ray diffraction study was made of some sedimentary peat samples.

The contacts between the fibrous peat and the underlying mottled clay, and between the sedimentary peat and the underlying sand, are gradational.

The fibrous peat-clay contact shows a complete transition from brown-stained clay with peat fragments into the true peat. At places sedimentary peat occurs between the clay and the fibrous peat. Whether the sedimentary peat-sand contact on the outer ridge indicates a transition or merely the later infilling of the sand interstices by the fine-grained sedimentary peat is uncertain, but as will be discussed later, the latter hypothesis is more acceptable.

In the basal part of the sedimentary peat is a 1-inch layer of volcanic ash which, when dry, is stained light brown at the upper and lower contacts. The ash is also present in the fibrous peat section, usually within 3 feet of the base of the unit. Although some mineral crystals are present, the ash is composed mainly of glass shards.

### *Sedimentary Interpretation*

The variation in texture, composition, and physical properties of these four sediment units reflects the fluctuations of sedimentary environments that developed in the depression of Union Bay after the Vashon glaciation. At some depth below Union Bay there is Tertiary bedrock, but the bay and Lake Washington are relict drainage systems in a pre-Vashon topography somewhat modified by the Vashon ice sheet (Bretz, 1913). According to Stark and Mullineaux (1950: 46) the Union Bay-Lake Union depression was modified by the ice sheet to the extent that 65 feet of Vashon till is present in places on the northern slope of the depression. As would be expected, only a small amount of till is present on the steep southern slope of the depression, the slope which opposed the main ice movement. Stark and Mullineaux (1950: 46) suggested that the depression was floored by Vashon till, and this suggestion appears to be verified by the basal, poorly sorted, gravelly, silty sand described in this paper. Thus the core of Foster Island and the ridge forming the outer lip of the bay were probably formed prior to the development of a glacial meltwater lake in the area.

The close similarity of the mineralogical composition and the texture between the till and the lower part of the heterogeneous unit suggests that the finer sediment of the lower part of the heterogeneous unit merely represents a rearrangement of the underlying material and introduction of similar material from the adjacent areas. Such a sequence passing upward from till to till-derived sediment is very common in glacial lakes (Hough, 1955, 1958).

By the time of deposition of the upper part of the heterogeneous unit depositional conditions had moderated, and the fine materials from the glacial meltwater could be deposited as light-gray clays, with local silty facies. It should be noted, however, that neither the silts of the lower part of this

unit nor the meltwater clay are preserved over the entire study area. Instead, they are present only between Foster Island and the outer ridge.

Although the clay-size particles are probably of meltwater origin, they are not composed solely of rock flour, for most of the particles are clay minerals, mainly kaolin. An analysis of glacial clays in the Seattle area by Subbarao (1953) indicated that kaolin is the most abundant clay mineral in the glacial clays. In the overlying mottled-clay unit, the clay minerals are far less abundant, even though the texture shows little difference. As noted by Taylor (1948: 66), grain-size distributions can be very misleading when fine rock flours and clay are being compared, but the physical properties exhibit marked differences, as is shown by the smaller water content and much greater cohesion of the mottled clay unit.

Although the soft, wetter clay is at a greater depth than the less moist, mottled clay, Shepard and Moore (1960: 143) have noted that the correlation of water content and depth in a core is significant only when the clay content and median diameters are relatively constant. In Union Bay these factors are not constant, and, in fact, the water content appears to be a very sensitive function of the clay mineral content, a correlation reported by Shepard and Moore (1955: 151-9) in sediments of the bays along the coast of Texas. These bays are likewise areas of slow rates of deposition.

The occurrence of the heterogeneous unit and the mottled clay unit only in the depression between Foster Island and the outer ridge and the lacustrine environment of deposition in which many of the sediments in these units were formed suggest that either the units formerly extended across the outer ridge into Lake Washington and have subsequently been removed, or else the site of the lacustrine deposition was areally restricted. There are several objections that can be made to the subsequent removal of the deposits. Yet this hypothesis is in accord with the acceptance of a high stand of lake level at this time. Nevertheless, the lack of postdepositional erosion is suggested by the overlapping shape of the units on the flanks of the island and the ridge, the presence of a thin sequence of sedimentary peat on top of the ridge—although Gould and Budinger (1958) indicate that this peat would be more easily transported into Lake Washington by convection currents than would the meltwater clays—and finally by the presence of weathered till on the ridge. When this weathered till is considered in relation to the stratigraphic distribution of the various units, it is apparent that the ridge was above water during the deposition of the heterogeneous unit and the mottled clay unit.

At the present time the level of this ridge at the line of section in

Figure 3 is about 20 feet below lake level, or approximately the level of mean lower low water in Puget Sound. A connection between the bay and Lake Washington probably existed north of this section in the area of the small canyon cut into the lip of the bay (Figure 2). This canyon appears to be a continuation of the drainage system of Ravenna Creek and the other streams to the north of the bay, but the time of formation of the canyon is difficult to place. According to Stark and Mullineaux (1950: 58) Ravenna Creek is a post-Vashon creek which has cut its deep, narrow gully between Green Lake and Union Bay since the last glaciation. The down cutting could well have continued along the northern side of Union Bay and across the lip of the bay where the canyon was formed.

After the end of deposition of the mottled clay unit, Union Bay, excepting possibly Foster Island, was covered with water, and in much of the area sedimentary peat began to form on the bottom as planktonic and possibly shore plants began to develop. Although sedimentary peat appears in places between the mottled clay and the fibrous peat, it is mainly developed on the outer ridge. This is the first record of diatoms in the sequence and probably corresponds to the blue clay-limnic peat (sedimentary peat) contact in Lake Washington reported by Gould and Budinger (1958). In all younger deposits the diatoms form the principal sedimentary particles. Today they are the dominant plankton group in Lake Washington (Scheffer and Robinson, 1939: 113; Anderson, 1954: 93). In this protected, shallow embayment, however, shore plants could develop, and soon fibrous peat was forming over much of Union Bay.

After only a few inches to a few feet of peat had been deposited, a layer of volcanic ash was laid down. This is the Glacier Peak ash discussed by Rigg and Gould (1957). They obtained a radiocarbon date of 6700 years B.P. for peat underlying the ash in Puget Sound area. This ash, which is very common in the peat sequences of the Pacific Northwest (Rigg, 1958), was also observed near the base of the sedimentary peat in Lake Washington by Gould and Budinger (1958). Thus the 55+ feet of the heterogeneous unit and mottled clay unit of Union Bay must correspond to the 100+ feet of blue clay reported by these workers in Lake Washington, and the 45 feet of fibrous peat or 3 feet of sedimentary peat in Union Bay corresponds to the 5 to 55 feet of sedimentary peat in the lake.

The difference in the thickness of peat above the ash layer is due to several factors: (1) the variation in the Lake Washington sediment is explained by Gould and Budinger (1958) as the result of convection currents of cold water which flow out of the shallow embayments like Union Bay

and redistribute the sediment on the lake bottom; (2) the thin section of sedimentary peat overlying the ash at the lip of the bay has been prevented from increasing in thickness by the current and wave actions at this transition zone between the deep lake and shallow bay. The section of fibrous peat overlying the ash is about three times as thick as the average post-ash thickness of peat in Puget Sound bogs. Rigg and Gould (1957: 361) give a figure of only 14.1 feet as the average for 151 Puget Sound bogs. This discrepancy would imply that the rate of sedimentation of the fibrous peat in Union Bay was about three times the rate in the peat bogs, a relationship that tends to be confirmed by the peat sequence in Mercer Slough on the eastern side of Lake Washington.

Mercer Slough, which is only slightly larger in area than Union Bay, was a narrow arm of Lake Washington before the lake level was lowered. Now it is an almost completely exposed peat area. The peat here is more than 50 feet thick in the center of this slough, which is the largest peat area in King County (Rigg, 1958: 69). The deposit is mainly a combination of sedimentary and fibrous peat according to Rigg (p. 69), and the ash layer is present at a depth of about 45 feet. Dachnowski-Stokes (1930) also reports the ash layer at about 40 feet in his borings in the slough. Thus the peat deposition in the shallow embayments of Lake Washington apparently was about three times as rapid as was the sedimentation in the peat bogs, or about 8 inches/century as compared with 3 inches/century in the bogs.

Even though a radiocarbon date of 11,900 years B.P. is used as a date for the beginning of peat deposition in Puget Sound (Rigg and Gould, 1957: 357), no attempt has been made to determine the rate of peat deposition in Union Bay prior to the ash fall, inasmuch as the hiatus suggested by the weathering of the till and possibly by the mottling of the mottled clay unit cannot be evaluated.

The sediment in Union Bay west of Foster Island is probably similar to that along the north shore where Rigg (1958: 87) reports only a few feet of fibrous peat over sand and gravel.

### *Summary*

The postglacial sediments in Union Bay rest on an unknown thickness of Vashon till which forms the core of Foster Island and the ridge at the outer margin of the bay. This ridge is only partly suggested by the present water depths in the bay. Overlying the till is a sequence of glacial meltwater deposits consisting of two units. The lower one of variable thickness consists of silty sand and silt at the base and soft kaolinitic clay at the top. The upper unit is a uniform 8-foot bed of dense mottled clay. Both units were deposited

only between the island and the outer ridge where the till is weathered. Sedimentary peat began to form in the bay, except on Foster Island, and then fibrous peat was deposited west of the outer ridge. The Glacier Peak eruption (ca. 6700 years B.P.) laid down a layer of ash near the base of the peats. Since then about 40 feet of fibrous peat has been deposited in the bay, a much more rapid rate than elsewhere in Puget Sound, and about 3 feet of sedimentary peat has formed near the outer margin of the bay.

### *Acknowledgements*

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- 2 National Research Council  
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Attn: Committee on Undersea Warfare  
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- 1 Commanding Officer  
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145 Palisades Street  
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Attn: J. D. Pierson
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University of Miami  
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