Appendix C: Geologic Setting

Introduction

The current study was conducted in the Upper Quinault River Valley (Figure 1) that contains a complexity of geologic and geomorphic features. Previous studies have focused on the structural, bedrock, and glacial geologic aspects (i.e. Brandon and Calderwood, 1990; Tabor and Cady, 1978; Moore, 1965; Harvey, 1959), and the fluvial geomorphology of the Quinault River (O'Connor et. al, 2003). The current study concentrates on (1) a tentative correlation between the Hoh River glacial chronology (Thackray, 1996) and the Quinault River glacial chronology (Moore, 1965); and (2) Quinault Lake's surface elevation during the Late Pleistocene and the lake's subsequent regression during the last 6.5 ka.

The glacial chronology of the Quinault River Valley is very significant because it is responsible for the constructive landform (terminal moraine) that impounds Quinault Lake. The lake, in turn, forms the base level that directly influences the fluvial geomorphology of the Upper Quinault River. As such, a basic understanding of the geologic processes responsible for the Upper Quinault River Valley's geomorphology is necessary so that their impacts to the Upper Quinault River system can be better understood.

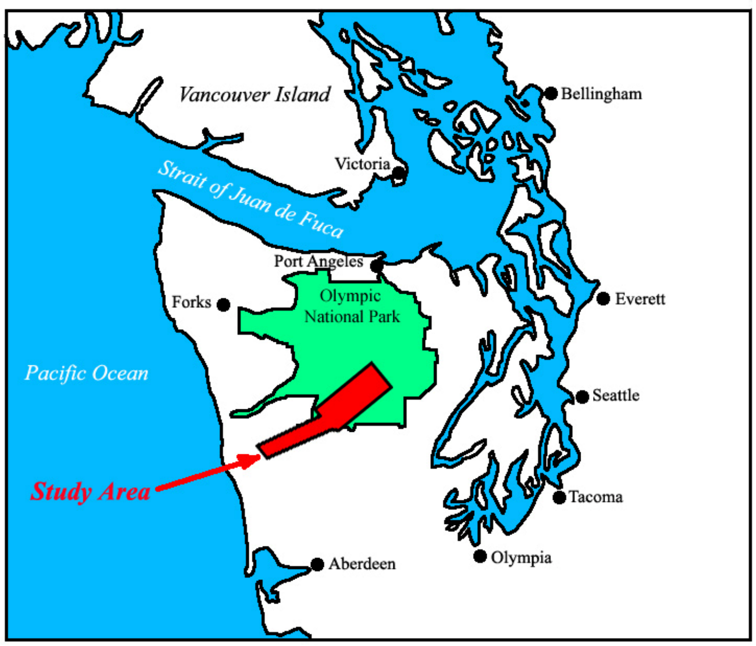

Figure 1. Location map of Upper Quinault River study area on the Olympic Peninsula, Washington.

Structural and Bedrock Geology

The Olympic Peninsula represents a small section of the Cascadia subduction zone’s accretionary complex called the Olympic subduction complex (OSC). Since the Middle Miocene, the OSC has been tectonically uplifting above sea-level forming the Olympic Mountains (Brandon and Calderwood, 1990). Based on geodetic data, the tectonic uplift rates tend to increase eastward from the Pacific coastline toward the Inner Olympics (Savage et al., 1991; Dragert et al., 1991). Contemporaneous with the increase in the rate of uplift, there is a respective increase in the rate of erosion. This suggests that the Olympic Mountains have reached a long-term steady-state condition in which uplift is offset by erosion (Pazzaglia and Brandon, 2001).

There are two primary rock groups within the Olympic Peninsula (Figure 2). The core rocks associated with the accretionary wedge and the peripheral rocks that form an eastward plunging antiform (Tabor and Cady, 1978; Tabor, 1987; Brandon and Calderwood, 1990). Contemporaneous with the uplifting of the antiform, erosion has exposed the accretionary wedge and has created an arcuate (horseshoe shaped) structure comprised of the peripheral rocks (Tabor and Cady, 1978; Brandon and Calderwood, 1990).

The exhumed core rocks of the accretionary wedge are predominantly sedimentary rocks that are highly deformed, stratigraphically discontinuous, and partially metamorphosed. Conversely, the peripheral rocks of the antiform are predominantly extrusive igneous rocks that are mildly deformed, stratigraphically continuous, and unmetamorphosed (Tabor and Cady, 1978). The core rocks juxtapose the peripheral rocks by the Peripheral Fault. The fault is comprised of the Calawah Fault segment to the north and the Southern Fault Zone (SFZ) to south (Brandon and Calderwood, 1990; Tabor and Cady, 1978). The core rocks enclosed by the Peripheral Fault exhibit metamorphic zonation, with the intensity of metamorphism increasing from west to east, and the metamorphic facies grading from Laumonite (western extent) to Chlorite-Epidote (eastern extent) [Tabor and Cady, 1978].

The Quinault River Valley is bounded by the SFZ along its southern margin between Quinault Lake and Canning Creek. The peripheral rocks of the Crescent Formation outcrop along the south valley wall (hanging wall of the SFZ) from Willaby Creek to Bunch Canyon. The Crescent Formation is predominantly comprised of unmetamorphosed, massive basalt flows and thick-bedded sandstones. The bedrock, within the remainder of the upper valley area including the North and East Forks, is comprised of core rocks mapped as the Western Olympic Lithic Assemblage, Elwha Lithic Assemblage and other undifferentiated sedimentary rocks (Tabor and Cady, 1978).

The core rocks progressively increase in metamorphic grade from Quinault Lake to Anderson Glacier. From the Quinault Lake outlet to the Canning Creek area, the core rocks are of Pumpellyite metamorphic grade and are represented by highly deformed sandstones and shales with minor conglomerates and basalt. Further up the Quinault River drainage, above Canning Creek and including the North and East Fork drainages, the core rocks are represented by highly deformed slates, phyllites, foliated and lineated sandstones, granule conglomerates, and semi-schists of Pumpellyite to Chlorite-Epidote metamorphic grades (Tabor and Cady, 1978).

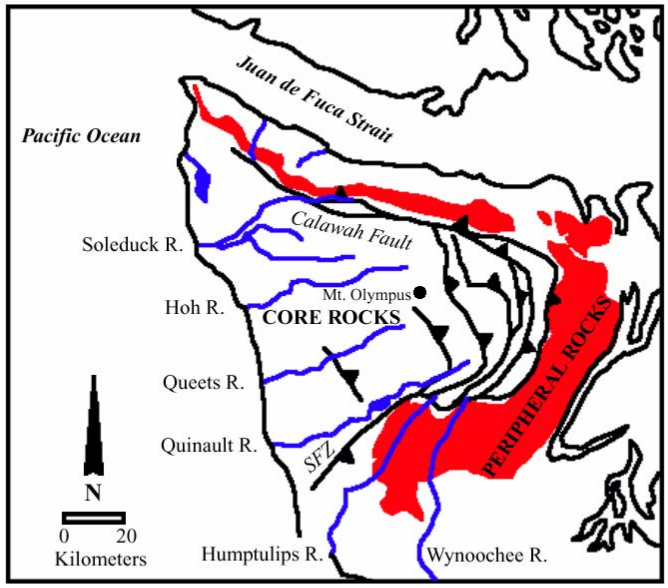

Figure 2. Generalized structure map of the Olympic Peninsula, Washington. Compiled from Tabor (1987) and Johnson et. al. (1999).

Glacial Geology

Valley glaciers have advanced at least six times down the western flanks of the Olympic Mountains in the Hoh and Queets River valleys (Thackray, 1996, 2001). Similarly, six glacial advances have been recorded along the southern flanks of the Olympic Mountains in the Chehalis, Satsop, and Wynoochee River valleys (Carson, 1970). In the Quinault River Valley, Moore (1965) has documented at least two major glacial advances that occurred during the Late Pleistocene, the Humptulips and Chow Chow glaciations respectively. The Humptulips glacier was the most extensive. It advanced to within 4 km of the Pacific Ocean leaving behind broad arcuate moraines.

Following the Humptulips glacial retreat, there was a period when interglacial conditions persisted and a lacustrine environment developed west of present day Quinault Lake. Moore (1965) collected two samples of wood for radiocarbon dating from an organic layer believed to be associated with this interglacial period. The two samples returned radiocarbon ages of greater than 35.0 ka and 32.0 ka, respectively (Moore, 1965). These results provide limiting ages for both the Humptulips and Chow Chow glaciations.

After the interglacial period, ice again advanced to within 12 km of the Pacific Ocean during the Chow Chow glaciation where it constructed broad arcuate moraines (Moore, 1965). As the glacier retreated, it either re-advanced or stagnated constructing the terminal moraine that impounds Quinault Lake. Moore (1965) acknowledged that this re-advance or stillstand could represent a different, distinct glaciation, but could not justify such a division based on his study.

Presently, Quinault Lake forms a base level at an elevation of 57 m above average mean sea-level (amsl). The lake has an average surface area of 1510 hectares and is one of the largest natural lakes on the peninsula. The geologic history of Quinault Lake and its geomorphic influence on the Upper Quinault River were unrecognized until the present study. Based on field observations, new radiocarbon dates, and tentative correlations with the Hoh River glaciations, this study provides insight into the interactions between Quinault Lake and the Chow Chow glacier during the last glacial cycle.

Last Glacial Cycle

In the Quinault River Valley the last glaciation is referred to as the Chow Chow Glaciation (Moore, 1965). Based on glacial stratigraphy and limiting radiocarbon ages obtained by Moore (1965), this study tentatively correlates the Chow Chow Glaciation to the Hoh Oxbow Glaciation studied by Thackray (1996) in the nearby Hoh River Valley. This correlation between the Quinault River and Hoh River glaciers is useful in that it provides a temporal framework of regional glacial-interglacial cycles in which to work. However, further studies are needed to establish chronologic controls for the Quinault River glacier’s advances and retreats.

At its maximum, the Chow Chow ice reached to within 12 km of the Pacific Ocean. This study makes the assumption that this Chow Chow glacial maximum correlates to the Hoh Oxbow I glacial maximum about 29.0 ka. The correlation is based on two radiocarbon dates (32.0 ka and greater than 35.6 ka) obtained by Moore (1965) that limits the maximum age of the glacial advance to less than 32.0 ka.

The Chow Chow glacier probably began its retreat about 29.0 ka and withdrew from the coastal piedmont. At the foot of the Olympic Mountains the glacier re-advanced (or stagnated) building up the terminal moraine that impounds Quinault Lake. This stade is most likely equivalent to Thackray’s (1996) Twin Creeks I re-advance of the Hoh River glacier that occurred about 18.0 ka.

As the Chow Chow glacier resumed its retreat up the Quinault River Valley, the ice melted-back asymmetrically with the north side withdrawing at a more rapid rate than the south side. This asymmetry resulted from hanging valley glaciers coalescing with the main glacier along the southern valley wall (Photograph No. 1 and 2).

Contemporaneous with the valley glacier’s retreat, Quinault Lake began filling behind the terminal moraine. The Late Pleistocene highstand of Quinault Lake was at least elevation 135 m (amsl). This interpretation is based on the elevation of deltaic deposits discovered along Finley Creek (Photograph No. 3 and 4). Determining the aerial extent of the

Photograph No. 1. View of the Upper Quinault River Valley looking southwest toward the Southern Fault Zone (SFZ). Also in the photograph there is a hanging valley visible left of center, the significance of the hanging valley is that the Chow Chow ice must have filled the valley to that elevation.

Photograph No. 2. View of the Upper Quinault River Valley looking northwest at the north valley. Note there are no hanging valleys although most of the tributary drainages were headed by glaciers. Also note the bench along the base of the mountain just above center of photograph. This bench is a depositional feature that can be traced from the terminal moraine that impounds Quinault Lake upstream to the Finley Creek area (valley in the right center of photo).

Photograph No. 3. Delta foreset beds dipping toward the Upper Quinault River Valley exposed along the Finley Creek drainage in Township 24 North, Range 9 West, Section 35, elevation is approximately 134 m (amsl).

Photograph No. 4. View of delta foreset beds looking upstream along the Finley Creek channel (Township 24 North, Range 9 West, Section 35).

glacial lake was beyond the scope of this study, but based on elevation profiling the lake may have extended upstream to the confluence of the North and East Forks of Quinault River.

The limit of the last Chow Chow glacial advance or stagnation in the Upper Quinault River Valley was most likely downstream of the confluence of the North and East Forks of the Quinault River (this study). This stade is believed to be equivalent to Thackray's (1996) Twin Creeks II re-advance of the Hoh glacier about 10.0 ka. During this time, each fork of the Quinault River (North and East) contained a valley glacier and these glaciers coalesced at the confluence. It is likely the ice intercepted Quinault Lake because the glacier's trimline along the south valley wall terminates just downstream of the confluence and there is no evidence of a terminal moraine. Additionally, the outwash plain in the lower section of the Big Creek drainage suggests the North Fork glacier surmounted the bedrock outcrop that separates Big Creek from the North Fork near Irely Lake. However, the glacier advanced only a short distance down the lower section of the Big Creek drainage and its meltwater deposited copious amounts of outwash sediments.

Climatic changes during the Holocene brought about warmer and drier conditions resulting in the North Fork and East Fork glaciers withdrawing up their respective valleys. These valleys are now headed by the small cirque glaciers preserved on Mt. Seattle, Mt. Christie, Mt. Anderson and White Mountain. Contemporaneous with the Holocene retreat of the Quinault River glaciers was the reduction in available meltwater flowing into Quinault Lake. Based on topographic cross-sections of the terminal moraine impounding Quinault Lake, there is an abrupt change from a wide outlet to a narrow outlet (Figures 3 and 4). This change in fluvial geomorphology is interpreted to represent the lake's highstand 10.0 ka at about elevation 110 m (amsl).

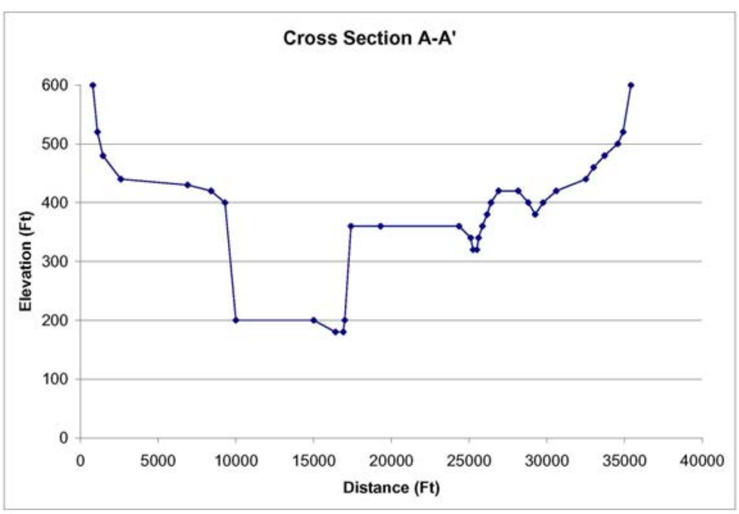

Figure 3. Topographic profile across the crest of the terminal moraine impounding Quinault Lake.

Quinault Lake's Rate of Regression

Quinault Lake forms a base level for the Quinault River. This base level has lowered in elevation through time due to regression of the lake (Figure 4). The lake's regression is controlled by the rate of fluvial incision through the terminal moraine that impounds Quinault Lake. Thus, as the base level is lowered, the river is able to incise into the fluviolacustrine deposits that have filled the valley bottom since the Late Pleistocene.

Organic materials found in numerous lacustrine deposits at varying elevations were radiocarbon dated during this study. The radiocarbon ages provide temporal constraints on Quinault Lake's minimum lake elevations and its approximate aerial extent based on topography. There were three key sample locations analyzed in this study, (1) elevation 61 m (~200 feet) near Pruce Boys Road [Photograph No. 5], (2) elevation 73 m (~240 feet) along the north bank of the Quinault River [Photograph No. 6], and (3) elevation 85 m (~280 feet) in an exposure downstream from the Finley Creek bridge [Photograph No. 7]. The significance of these locations is that they returned radiocarbon ages of 6.5 ka or less implying that the Quinault River valley glaciers would have already retreated and that the glaciers would not have a meaningful impact on the lake's elevation. Figure 4 illustrates Quinault Lake's regression through time and the crest of the terminal moraine that impounds the lake.

Pleistocene-age terrace treads and scarps are well preserved and definable near the confluence of the North and East Forks of the Quinault River. Conversely, Holocene-age terrace treads and scarps are not well preserved and do not appear to be continuous. The interactions between the Quinault River and Quinault Lake since the last glacial cycle have left relatively minor terrace treads that are not continuous on aerial photographs or in the field. Because mapping and correlating these terraces was problematic, this study describes surfaces that are subdivided based on elevation, dissection, and to a lesser degree on vegetation. Within the present floodplain there are three primary surfaces defined as, (1) the upper surface, (2) intermediate surface, and (3) lower surface (Figure 5 and Attachment 1).

The upper surface is elevated about 3 m to 5 m above the normal water surface in the active channel. The surface is infrequently inundated and is dissected predominantly by ephemeral and perennial streams. It is covered with mature ferns, and also large diameter (+1 m) Sitka Spruce, Douglas Fir, and Bigleaf Maple. Large stumps (+1 m) can generally be found in areas where the mature trees have been harvested. Radiocarbon ages collected during this study suggest the fluvial deposits mantling the upper surface are 1.4 to 1.6 ka. Three water wells have been drilled within the limits of the upper surface (Township 23 North, Range 9 West, Section 1). The well logs record about 2 m to 5 m of clayey material with sand and gravel overlying 2 m to 4 m of fine gravel and sand (water well logs can be found on the Washington State Department of Ecology website). This stratigraphy is interpreted to represent lacustrine sediments overlying glacial outwash and/or deltaic sediments.

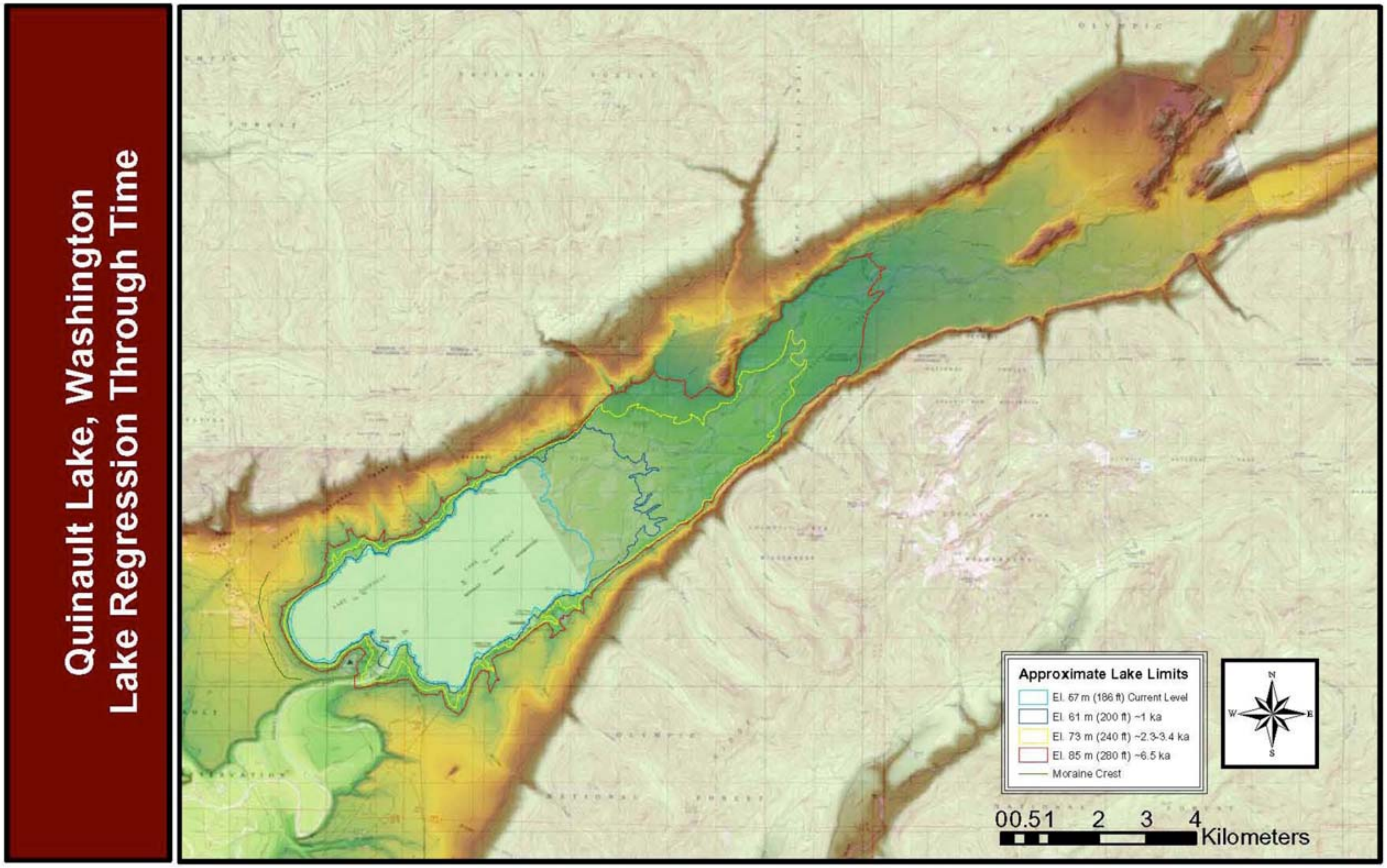

Figure 4. Interpretation of Quinault Lake's rate of regression based on radiocarbon ages and the elevation of where the sample was obtained.

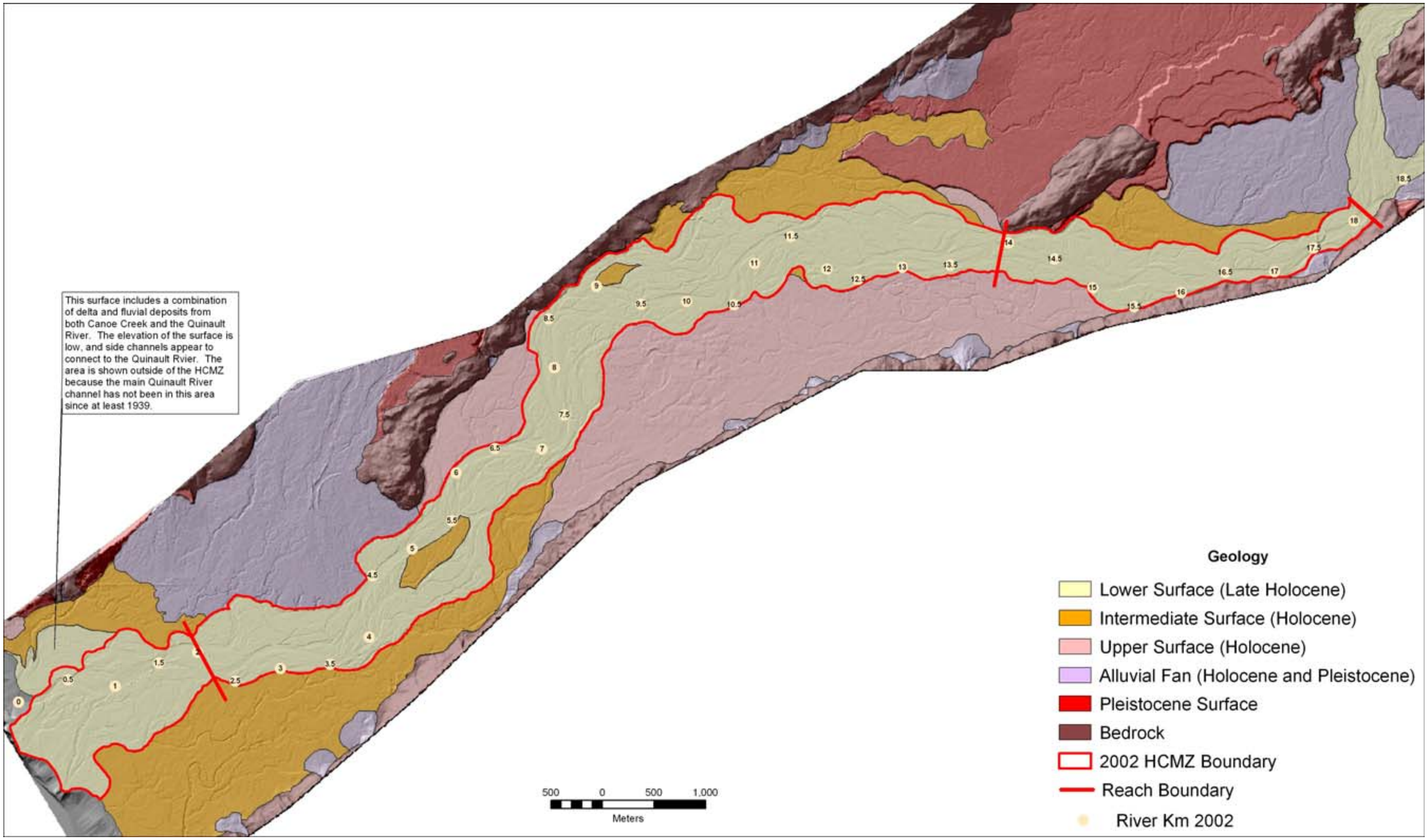

Figure 5. Overview map of geologic surfaces in study area.

Photograph No. 5. Lacustrine sediments exposed along the Quinault River near Pruce Boys Road (Township 23 North, Range 9 West, Section 9, elevation 61m [amsl]). An organic layer within the silt beds returned a radiocarbon age of 1080 ± 40 C14 yr. BP (Sample No. 81904-1-1CO).

Photograph No. 6. Lacustrine sediments containing gravel lenses exposed along the north bank of the Quinault River near the mouth of Finley Creek (Township 23 North, Range 9 West, Section 3, elevation 73 m [amsl]). Bulk samples returned radiocarbon ages of 3250 ± 50 C14 yr. BP, 3720 ± 40 C14 yr. BP, 2480 ± 40 C14 yr. BP, and 3040 ± 40 C14 yr. BP (Sample Nos. 92802-3-1CO, 92802-3-2CO, 92902-1-1CO, and 92902-1-2CO).

Photograph No. 7. Lacustrine sediments containing gravel lenses exposed along the Finley Creek channel (Township 23 North, Range 9 West, Section 3, elevation 85 m [amsl]). Bulk sample returned a radiocarbon age of 5650 ± 50 C14 yr. BP (Sample No. 92902-1-3CO).

The intermediate surface is elevated about 1 m to 2 m above the normal water surface in the active channel. The surface is commonly inundated and is strongly dissected by overflow channels. Vegetation consists primarily of alders and firs up to 30 cm diameter and Sitka Spruce trees up to 50 cm diameter. Radiocarbon ages collected during the current study suggest the fluvial deposits are 0.6 ka to 1.0 ka. Ten water well logs were reviewed from water wells that had been drilled within the limits of the intermediate surface (Township 23 North, Range 9 West, Section 10). The well logs record 1 m to 2 m of "soil" overlying 5 m to 22 m of gravel and sand. One well log also records "lotsa wood" in the gravel and sand. This stratigraphy is interpreted to represent lacustrine and/or floodplain sediments overlying glacial outwash and/or deltaic sediments.

The lower surface generally corresponds to the 2002 Historical Channel Migration Zone (HCMZ). The surface includes the active channel to about 1 m above the active channel. It is frequently inundated on nearly an annual basis and is commonly vegetated with alders, willows, and small conifers. Radiocarbon ages collected during this study suggest the lower surface is less than 0.5 ka.

Discussion

During the last glacial cycle, the Chow Chow glacier reached its maximum extent about 29.0 ka (Moore, 1965). The glacier soon withdrew from the coastal piedmont, but re-advanced or stagnated at the foot of the Olympic Mountains about 18.0 ka where it constructed the terminal moraine that impounds Quinault Lake (based on tentative correlation to the Hoh River glaciations). Deltaic deposits discovered in the Finley Creek drainage suggest the lake reached its highstand during the Late Pleistocene at about elevation 135 m (amsl). The aerial extent of the lake was not determined in this study, but the elevation suggests the lake may have extended at least to the confluence of the East and North Forks of the Quinault River.

Based on elevation cross sections of the terminal moraine that impounds Quinault Lake, this study suggests that about 10.0 ka Quinault Lake's surface was at approximately elevation 110 m (amsl) and has since been lowering at a long-term rate of ~5 mm/yr. The significance of Quinault Lake is that it establishes a base level that has slowly been lowered since the Late Pleistocene. Regression of Quinault Lake also suggests that the intermediate and upper surfaces are comprised of fluviolacustrine sediments overlying deltaic and/or glacial outwash. This interpretation is further supported by subsurface data reported on water well logs.

Conclusions

During the Late Pleistocene, the Quinault glacier (Chow Chow glaciation of Moore, 1965) constructed the terminal moraine that impounds Quinault Lake. Since its impoundment, the lake has formed a base level for the Upper Quinault River. However, the lake has been slowly regressing since the Late Pleistocene due to fluvial incision of the terminal moraine. During its Late Pleistocene highstand, Quinault Lake reached approximately elevation 135 m (amsl) based on deltaic deposits discovered in the Finley Creek drainage. Radiocarbon dating of organic material found in lacustrine deposits at differing elevations and locations show that Quinault Lake has slowly regressed from elevation 85 m to 57 m (amsl) in the last 6,500 years.

Quinault Lake's regression and water well logs suggest that the planar surfaces described in this study as the upper and intermediate surfaces are primarily of lacustrine origin and cored by deltaic and/or glacial outwash deposits. Based on this interpretation, the upper and intermediate surfaces are probably not stream terraces and the lower surface most likely represents the limits of the Historical Channel Migration Zone (HCMZ).

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Attachment 1: Geologic Units Description

The seven surficial geologic units encountered in the study area are designated as follows: (1) lower surface, (2) intermediate surface, (3) upper surface, (4) lacustrine deposits [not mapped], (5) alluvial fan, (6) Pleistocene surface, and (7) bedrock. These units were categorized based on geomorphic expression, age, elevation, material composition, and the process that resulted in their formation. The methodology used to distinguish these units was a combination of field investigation, topographic data (Lidar and USGS quadrangles), and the GIS version of a generalized geologic map based on Tabor and Cady (1978) geologic map (scale 1:125,000) of the Olympic Peninsula. Field investigations focused on distinguishing surfaces based on exposures, observed features, vegetation types (indicating a difference in location and height above Quinault River), and land use.

QUATERNARY GEOLOGIC UNITS

LOWER SURFACE (Holocene) – The lower surface corresponds to the historical channel migration zone (HCMZ) and is comprised of younger alluvium deposited by the Quinault River. The surface is frequently inundated on nearly an annual basis. The unit includes surfaces of several heights and relative ages. Maximum elevation is about 1.0 meter above normal water surface in the active channel. This surface is commonly vegetated with alders, willows and small conifers. The lower surface should be considered unstable and part of the active floodplain.

INTERMEDIATE SURFACE (Holocene) – Composed of fluviolacustrine deposits that are evident as a series of small terrace risers and terrace treads that are elevated about 1.0-2.0 meters above normal water surface in the active channel. This surface is commonly inundated and is strongly dissected by overflow channels. Vegetation consists of alders and firs up to 30 cm in diameter and Sitka Spruce trees up to 60 cm diameter. The intermediate surface should be considered relatively stable on a decadal time scale.

UPPER SURFACE (Holocene) – Composed of fluviolacustrine deposits that form terrace risers that are elevated about 3.0-5.0 meters above the normal water surface in the active channel. This surface is infrequently inundated and is dissected predominantly by ephemeral and perennial streams. The treads are covered with mature ferns, and also large diameter (+1 m) Sitka spruce, Western redcedar, Douglas Fir, and Bigleaf maple. Large stumps can be found where the mature trees have been harvested. The upper surface has been and should remain relatively stable for centuries.

LACUSTRINE DEPOSITS (Pleistocene to Holocene) – The observed lacustrine deposits were not mapped during this project because it was out of the scope of the study. These deposits are directly related to the transgression and regression of Lake Quinault from its impoundment during the Pleistocene to Present. The lakebed deposits are interbedded with or bury the alluvium associated with the intermediate and upper surfaces and are generally bluish grey in outcrop. They are generally comprised of silt and fine sand with lesser amounts of gravel and cobbles. Holocene lakebed deposits have been observed along the Quinault River near Pruce Boys Road, at the Ziegler Creek Bridge, along the North Shore Road, and downstream of the Finley Creek Bridge. Charcoal from the deposits at the site near Pruce Boys Road was dated 1980 ± 40 cal yrs BP, and charcoal from the deposits downstream of Finley Creek Bridge was dated 6500 to 6300 cal yr BP (Appendix L).

The interaction between glacial Lake Quinault and the Quinault valley glacier during the Chow Chow glaciation resulted in the deposition of deltaic deposits observed in the Finley Creek drainage as foreset beds. The significance of the deltaic deposits is that they suggest the minimum glacial Lake Quinault highstand was at about elevation of 135 m (amsl) during the late Pleistocene.

ALLUVIAL FAN (Pleistocene to Holocene) **–** Alluvium that has been deposited by ephemeral and perennial streams that create fan-like features that prograde from the valley walls onto the valley floor. The abundant glacial deposits along the valley walls and floor are re-worked by fluvial processes and transported downstream by sediment laden streams where they generally form conical features. Deposits associated with the alluvial fan consist of interfingering beds of gravel and sand with cobbles.

PLEISTOCENE SURFACE (Pleistocene) **–** Consists of a mixture of clay, silt, sand, gravel, and cobbles with occasional boulders deposited by alpine glaciers during the Chow Chow glaciation. This unit is comprised predominantly of glacial outwash deposits but may include till and moraine deposits. The outwash deposits are generally unconsolidated and composed of silt, sand, and gravel making them very susceptible to erosion. Terrace risers and terrace treads are generally 9.0+ meters above the normal water surface in the active channel. Downstream of the map area, a terminal moraine was constructed by the Chow Chow ice and this moraine presently impounds Lake Quinault.

TERTIARY DEPOSITS

BEDROCK (Paleocene to Miocene) **–** Contains Tabor and Cady's (1978) Core and Peripheral Rocks which are comprised of igneous, sedimentary, and metasedimentary rocks. These rocks are predominantly basalts, sandstones, conglomerates, siltstones, and argillites. They are generally hard and considered to be resistant of fluvial erosion.