INVESTIGATION OF TECTONIC DEFORMATION

IN THE

PUGET LOWLAND, WASHINGTON

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WASHINGTON DIVISION OF GEOLOGY AND EARTH RESOURCES
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ABSTRACT

The main objective of this project is to contribute to the understanding of the late Quaternary tectonic history of the northern Puget Lowland in western Whatcom and Skagit Counties. Evidence is presented showing that uplifted marine terraces and strandlines were formed during late- or post-glacial stands of sea level and are a record of relative changes in sea level. Through the study of their present altitudes, the amount and style of deformation can be determined. However, individual terrace segments most often occur in a north-south direction and have a length of not more than about 2 miles. This distance may not be long enough to identify tectonic deformation on individual terrace segments if broad-scale warping has taken place. Therefore, it is necessary to correlate terraces from different areas in the study region.

The marine terrace and strandline deposits in Whatcom County are all underlain by Everson Glaciomarine Drift, but the deposits' exact age of formation is uncertain. Radiocarbon dating of individual terraces would indicate the time of their formation, but if the time span between formation of terraces is fairly short as preliminary investigation suggests, the age differences between terraces may be less than the limits of precision of radiocarbon dating. In addition, potentially datable materials are relatively scarce in most of the terrace deposits.

Observations made on the soil development of different terraces suggest that the time it took for the terraces to form is not sufficient for distinguishable soils to develop.

Preliminary work has also shown that little can be learned about terrace correlation using ash stratigraphy. Study of the surface textures and cross-sectional morphology of the terraces and strandlines and their spatial relationships to one another may be one means of correlating terraces.

INTRODUCTION

Location

The study area includes the western portions of Whatcom and Skagit Counties in the northern Puget Lowland of Washington. Most of the field work done thus far has been in Whatcom County, although some information has been gathered for a portion of Skagit County.

Purpose and scope

The main objective of this project is to contribute to the understanding of the late Quaternary tectonic history of the northern Puget Lowland in western Whatcom and Skagit Counties. The study of recent tectonism is of particular importance here since this area is expected to embrace a port of entry for Alaska oil, and information is needed for decisions on the siting of oil and gas transmission lines, as well as port facilities and possible refineries. In addition, part of the study area is close to the proposed site of a nuclear power plant in Skagit County. Knowledge of the tectonic history of an area is important to the understanding of crustal stability and meeting required safety standards prior to construction of nuclear reactors.

Uplifted marine terraces, strandlines, and marine-reworked glacial deposits are found in the study area. Marine terraces are narrow strips along the coast that slope gently seaward and are veneered by marine deposits typically consisting of silt, sand, and fine gravel. Strandlines represent former shorelines that are now elevated above the present water level. Marine terraces were horizontal at the time of their wave-action formation, suggesting that any departure from a horizontal datum is due to either isostatic rebound or tectonic deformation, or a

combination of both. The study of the altitudes of correlated marine-terraces should, therefore, provide a means of determining the amount of tilt or uplift involved, as well as the style of deformation.

Fieldwork and Acknowledgments

Fieldwork for this project was conducted from May to September of 1977. For three months I was aided by Bob Siegfried, a geology graduate student from Western Washington University, who also provided me with information he gathered for a portion of Skagit County.

I thank the Washington State Department of Natural Resources Division of Marine Land Management for the use of their 1973 color aerial photographs, which were utilized for a large part of the geologic interpretation during this study. Thanks are also extended to the Department of Geology at Western Washington University for the use of their self-leveling level in most of the profiling, and also to the Soil Conservation Service in Lynden, Washington, for the use of an auger.

Earlier Studies

Marine-terrace deposits in western Whatcom County were identified and mapped by Easterbrook (1962, 1976). Features tentatively identified as marine strandlines or ice-contact fluvial deposits were mapped by Artim and Wunder (1976) on the LaConner 7.5-minute quadrangle in Skagit County.

GEOLOGIC HISTORY

The Vashon Stade of the Fraser Glaciation was "the last major climatic episode during which drift was deposited by continental ice originating in the mountains of the mainland of British Columbia and occupying the lowlands of southwestern British Columbia and northwestern Washington. The stade began with the advance of Cordilleran ice into these lowlands and ended with the beginning of marine and glaciomarine conditions in them" (Armstrong and others, 1965, p. 327).

Around 13,000 years ago, as the Vashon glacier thinned and marine waters inundated the lowland, glaciomarine drift was deposited, marking the beginning of the Everson Interstade.

At its type locality, the Everson Glaciomarine Drift (Easterbrook, 1968, p. 31) consists of the Kulshan Glaciomarine Drift, the Deming Sand, and the Bellingham Glaciomarine Drift.

The Deming Sand, possibly of fluvial origin, separates the older Everson glaciomarine unit, the Kulshan, from the Bellingham, the youngest member of the Everson. If the sand unit represents subaerial conditions, this suggests emergence of the lowland between two periods of submergence. Based on radiocarbon dates and stratigraphic relationships, Easterbrook (1962, 1963) suggests that 300 feet of submergence occurred during Kulshan time, 350 feet of emergence occurred during Deming time, and 500 to 700 feet of submergence took place during Bellingham time. These changes in relative sea level all occurred within approximately 1,000 to 1,500 years following the Vashon glaciation.

Around 11,000 years ago, the beginning of the Sumas Stade marked another period of emergence, occurring not long after deposition of the youngest Everson Glaciomarine Drift. This is evidenced by deposition of Sumas glacial outwash and till directly upon the Everson Glaciomarine Drift (Easterbrook, 1962). A minimum date of 10,000 years before present (B.P.)

for the end of the Sumas Stade is indicated by radiocarbon dates from the base of peat bogs formed in abandoned melt-water channels and kettles developed on Sumas outwash plains (Easterbrook, 1969).

The terraces and strandlines in Whatcom County are all underlain by Everson Glaciomarine Drift, but their exact age of formation is uncertain (only one terrace has been dated). The apparently rapid post-Everson emergence and the lowering of relative sea level around 11,000 years ago supports a late glacial time of origin. However, field relationships do not preclude a Holocene time of origin for at least some of the terraces.

At Birch Bay, a channel, possibly formed by Sumas Stade melt-waters, appears to cut into an uplifted terrace. Radiometrically dated peat deposits from apparently correlative melt-water channels suggest that the terrace is older than 10,000 years.

A date of 11,950±180 years has been obtained from shells collected from a terrace deposit located near Fish Point on Lummi Peninsula (Easterbrook, 1966), but so far this terrace has not been correlated with terraces at Birch Bay.

TECHNICAL DISCUSSION

Field Investigation in Whatcom County

In order to define separate terraces in an area according to their cross-sectional morphology and elevation, and also to aid in correlation between areas, fourteen profiles were run, normal to the trend of the terraces. My field assistant and I began by making a search of available information on the location of bench marks for use as data levels for the profiles. A self-leveling level and tripod, along with a 13-foot fiberglass telescoping rod, were used for the traverses. When necessary, we extended known bench marks to a location nearer to the beginning of our traverse.

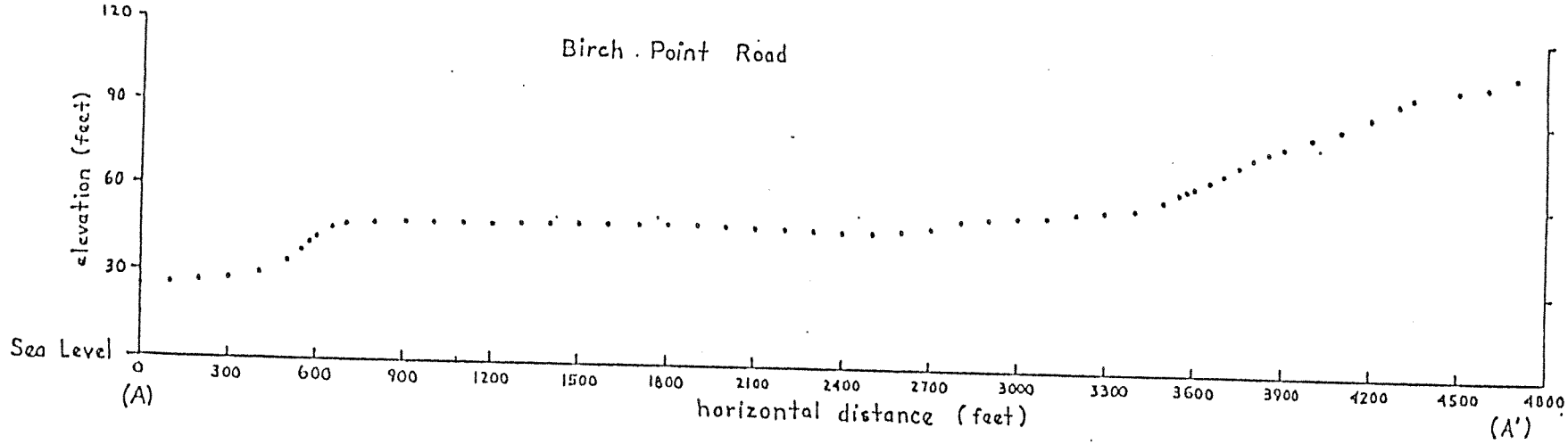
We began by marking off stations at intervals of 50 or 100 feet, depending on the topography, with a tape measure. During the traverse, the rod-person would determine, by noting changes in slope, when intermediate stations were necessary and locate these stations by pacing from known points along the traverse. The instrument-person would signal when turning points were needed.

Intermediate stations were usually chosen for one of two reasons. First, if there was a sudden change in topography, such as a depression or a small ridge, we would take readings from the lowest and highest points, respectively. Secondly, when the terrain had a uniform but steep slope, it was necessary to use a shorter distance between stations in order to be able to read the rod. Wherever possible, the rod-person would locate the rod in nearby fields in order to avoid elevation differences created by the construction of roads. In some areas though, vegetation was too dense for this; thus meaning that the traverse was actually representative of the road profile. However, there were no cases where the difference in elevation was more than a foot or two from the surrounding natural or unmodified topography.

After all the profiles were run, the data were plotted on graph paper, with various vertical exaggerations. Profiles with 10:1 vertical exaggeration are included in this report (figs. 1-6) and their locations are shown on the accompanying map sheets.

North of Birch Bay, profiles A-A' and B-B' show two main terrace elevations. The lower terrace extends from an elevation of approximately 20 feet above sea level (the beginning of the terrace is not expressed by the graphs) to an elevation of 30 feet. The higher terrace (shown best by profile A-A') lies at an elevation of about 50 to 60 feet. Profiles C-C' and C"-C' show

Figure 1


Birch . Point Road
elevation (feet)
120
90
60
30
Sea Level
0
300
600
900
1200
1500
1800
2100
2400
2700
3000
3300
3600
3900
4200
4500
4800
(A)
(A')
horizontal distance (feet)

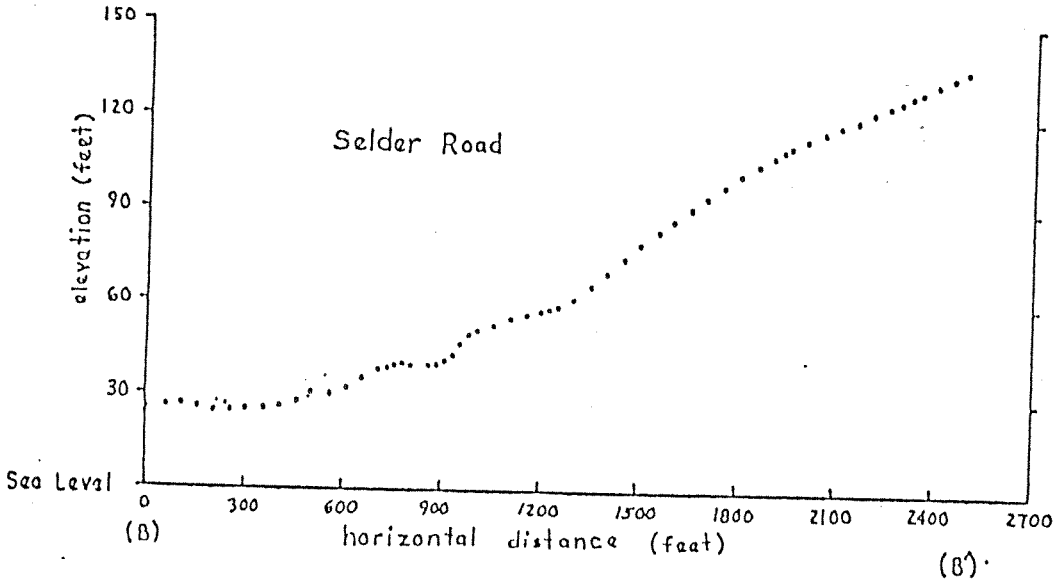
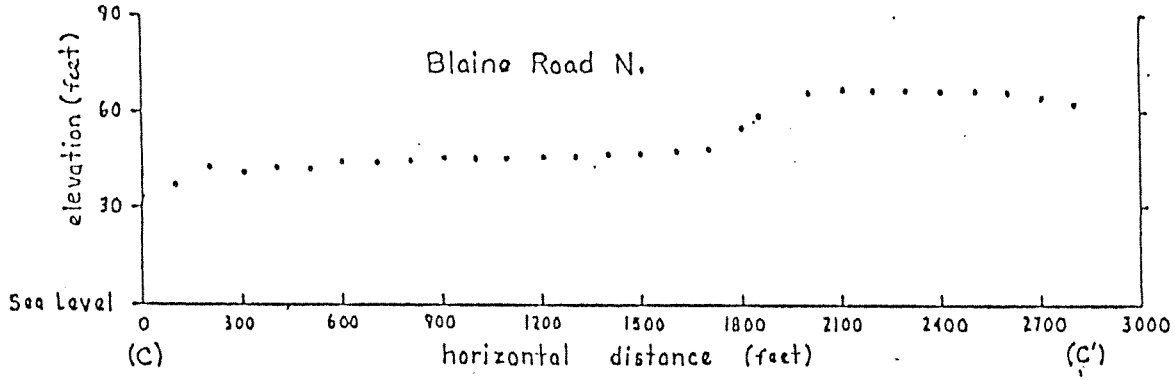

Selder Road
elevation (feet)
150
120
90
60
30
Sea Level
0
300
600
900
1200
1500
1800
2100
2400
2700
(B)
(B')
horizontal distance (feet)

Figure 2


Blaine Road N.
elevation (feet)
90
60
30
Sea Level
0
300
600
900
1200
1500
1800
2100
2400
2700
3000
(C)
horizontal distance (feet)
(C')

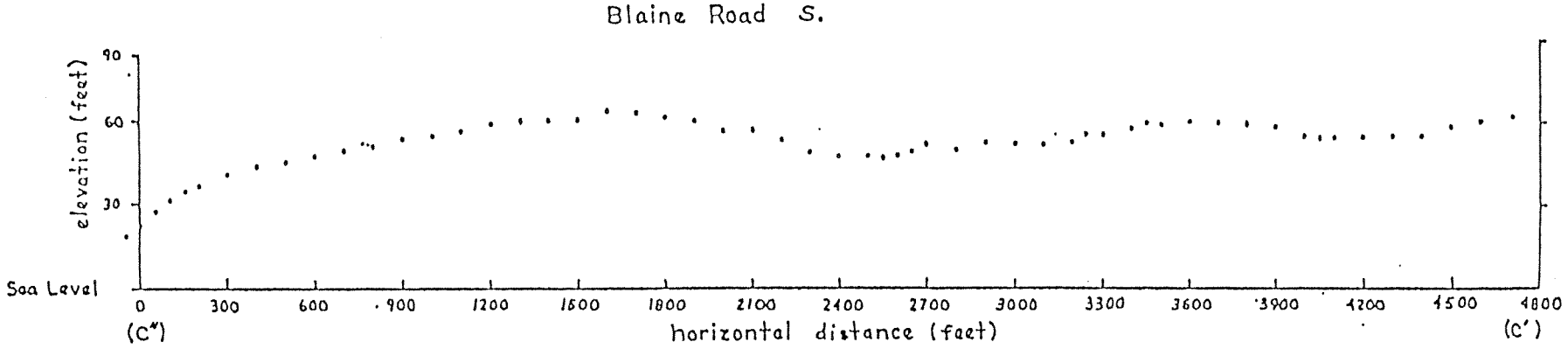
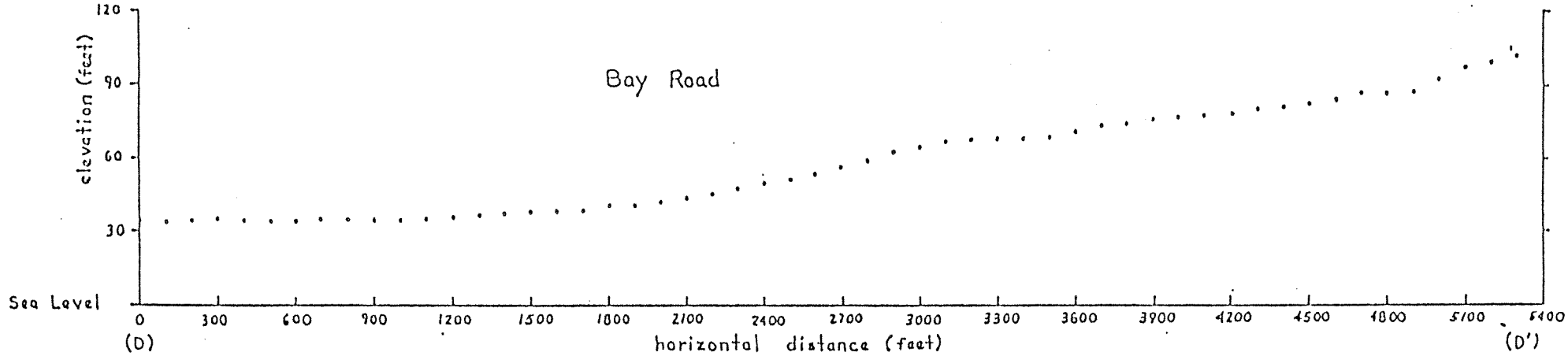

Blaine Road S.
elevation (feet)
90
60
30
Sea Level
0
300
600
900
1200
1500
1800
2100
2400
2700
3000
3300
3600
3900
4200
4500
4800
(C")
horizontal distance (feet)
(C')

Figure 3


Bay Road
elevation (feet)
120
90
60
30
Sea Level
0
300
600
900
1200
1500
1800
2100
2400
2700
3000
3300
3600
3900
4200
4500
4800
5100
5400
(D)
horizontal distance (feet)
(D')

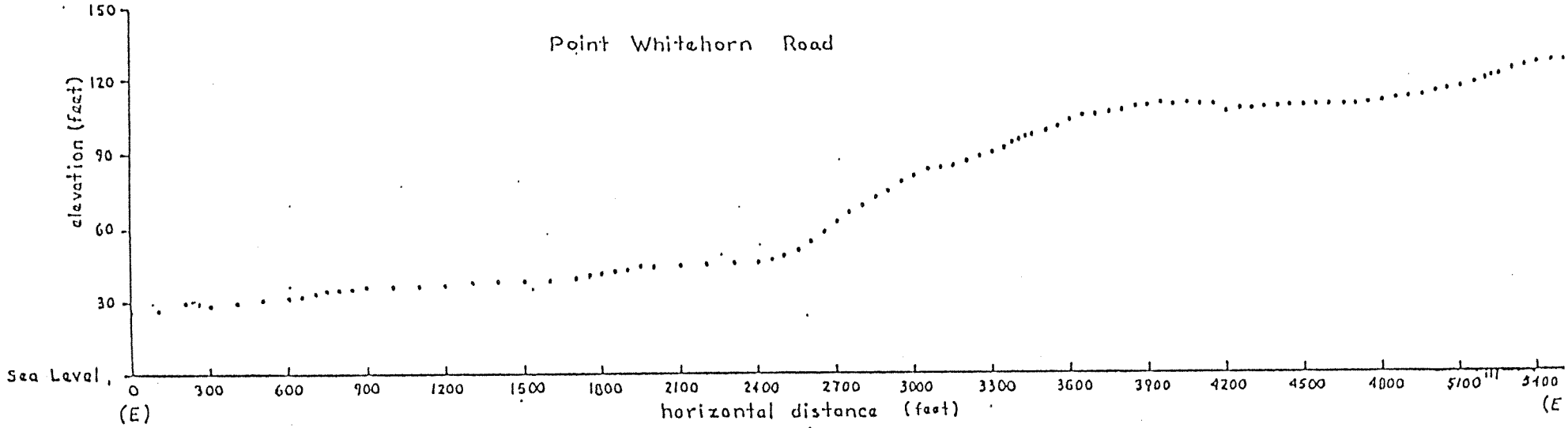
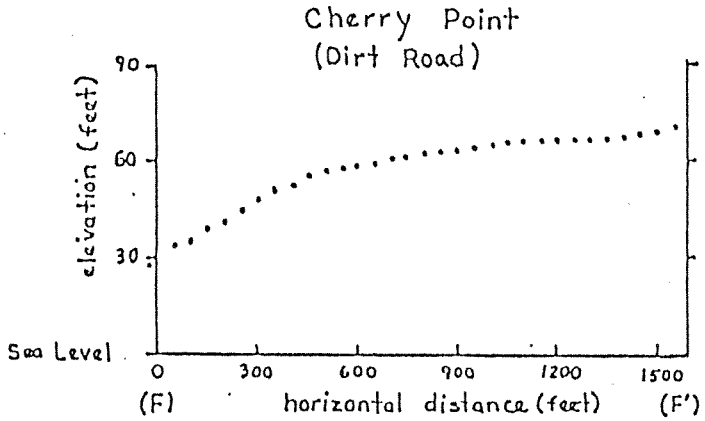
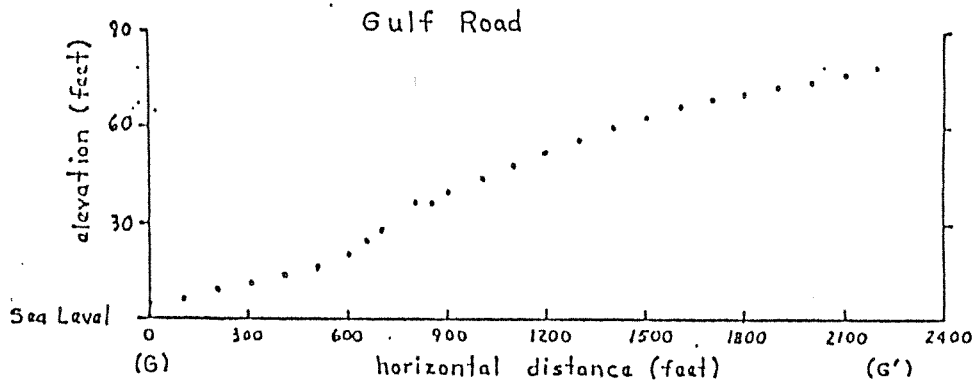

Point Whitehorn Road
elevation (feet)
150
120
90
60
30
Sea Level
0
300
600
900
1200
1500
1800
2100
2400
2700
3000
3300
3600
3900
4200
4500
4800
5100
5400
(E)
horizontal distance (feet)
(E

Figure 4


Cherry Point
(Dirt Road)
elevation (feet)
90
60
30
Sea Level
0
300
600
900
1200
1500
(F)
horizontal distance (feet)
(F')


Gulf Road
elevation (feet)
90
60
30
Sea Level
0
300
600
900
1200
1500
1800
2100
2400
(G)
horizontal distance (feet)
(G')

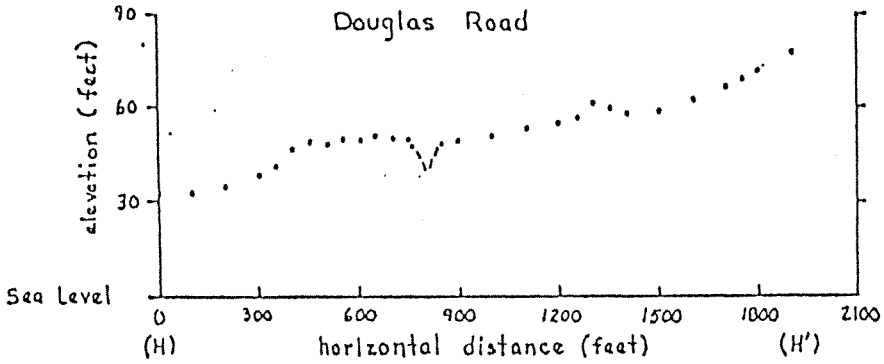
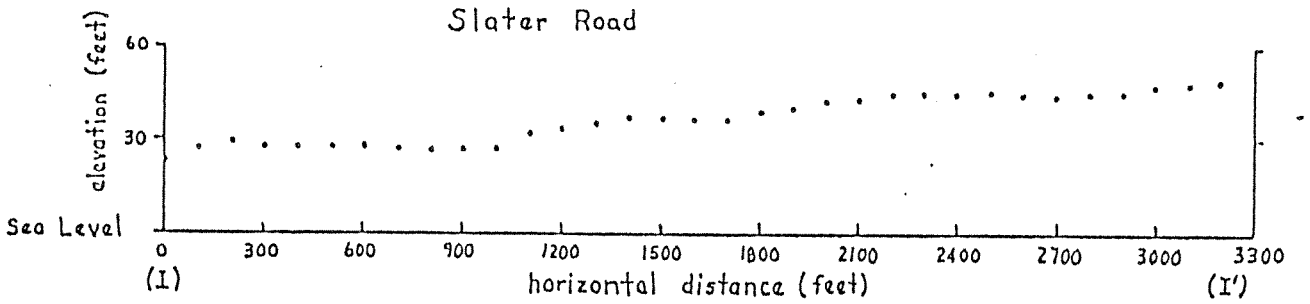

Douglas Road
elevation (feet)
90
60
30
Sea Level
0
300
600
900
1200
1500
1800
2100
(H)
horizontal distance (feet)
(H')

Figure 5


Slater Road
elevation (feet)
60
30
Sea Level
0
300
600
900
1200
1500
1800
2100
2400
2700
3000
3300
(I)
horizontal distance (feet)
(I')

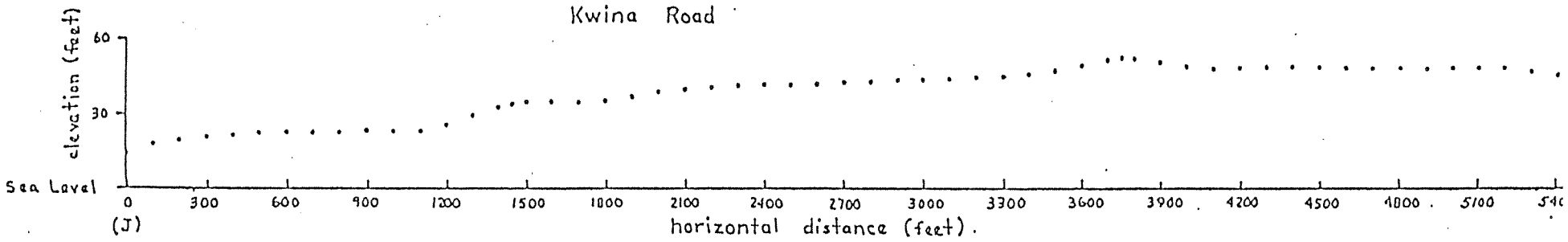
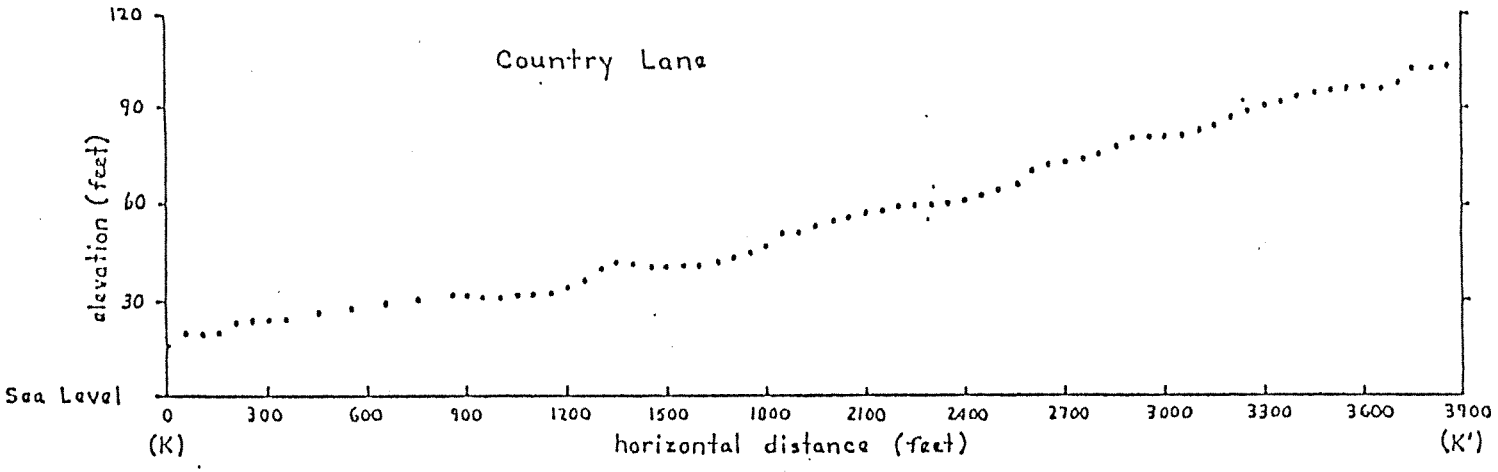
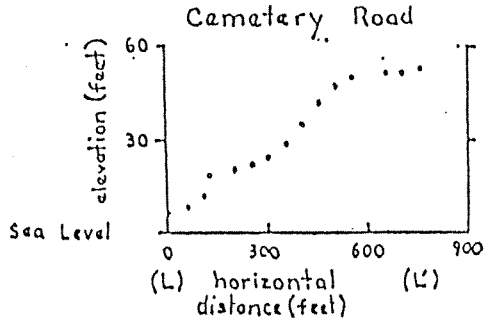
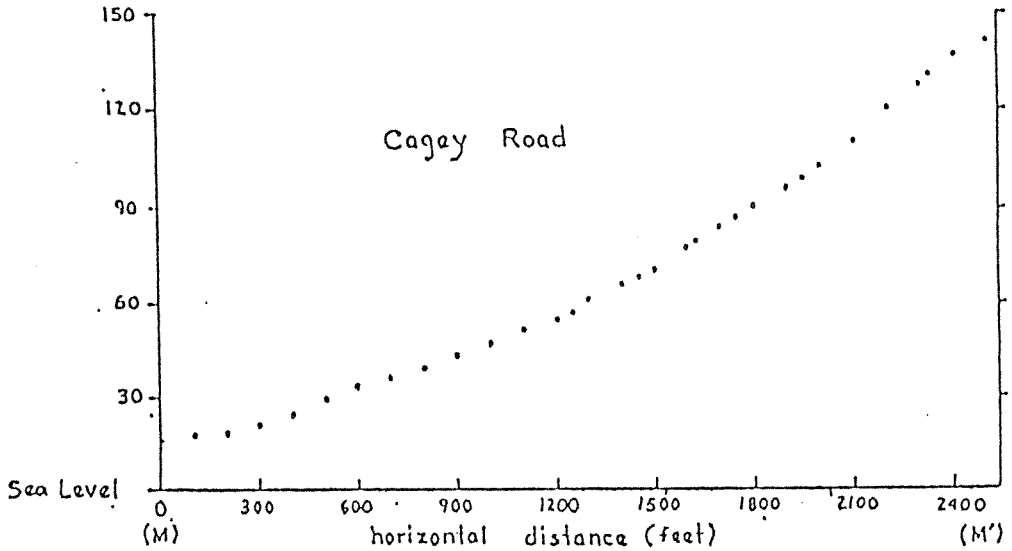

Kwina Road
elevation (feet)
60
30
Sea Level
0
300
600
900
1200
1500
1800
2100
2400
2700
3000
3300
3600
3900
4200
4500
4800
5100
(J)
horizontal distance (feet).

Figure 6


Country Lane
elevation (feet)
120
90
60
30
Sea Level
0
300
600
900
1200
1500
1800
2100
2400
2700
3000
3300
3600
3900
(K)
horizontal distance (feet)
(K')


Cemetery Road
elevation (feet)
60
30
Sea Level
0
300
600
900
(L)
horizontal distance (feet)
(L')


Cagey Road
150
120
90
60
30
Sea Level
0
300
600
900
1200
1500
1800
2100
2400
(M)
horizontal distance (feet)
(M')

comparatively uneven topography. Along this traverse (Blaine Road); there are two small ridges consisting of Bellingham Glaciomarine Drift (Qeb) that protrude through terrace deposits, which help explain the anomalous profiles.

South of Birch Bay, near Point Whitehorn, three separate terraces are delineated. The two lower terraces are difficult to distinguish by topographic expression alone; however, they differ in lithology. Profiles D-D' and E-E' show the different terrace elevations for this area. The lowest terrace extends from an elevation of 20 feet to 35 feet. The intermediate terrace lies at an elevation from 40 feet up to 50 feet. The highest terrace (seen only in profile E-E') begins at an elevation of 105 feet and rises to 115 feet.

Two profiles were run at Cherry Point, where only one terrace was distinguished. Profile F-F' does not show this terrace; the traverse was done mainly to see if any topographic evidence for strandlines could be shown. Profile G-G' shows the terrace, which extends from an elevation of about 15 feet up to 25 feet.

Three traverses were completed on terrace deposits at Lummi Peninsula. Profile M-M' is located where the sands begin to pinch out at the south end of a terrace, and no topographic expression of the terrace can be distinguished. Profiles J-J' and L-L' both show two well-defined terraces. The lower terrace lies at an elevation of 15 to 25 feet. The higher terrace extends from about 40 to 50 feet in elevation.

Three traverses were run on terrace deposits on either side of the Nooksack River valley. Profiles H-H' and I-I' are along the west side of the valley, and profile K-K' is from the east side. All of the profiles show several terrace elevations. However, further work in grain-size analysis (described later in the report) suggested that these deposits were not marine in origin, so no emphasis was placed on distinguishing the different terrace levels.

Terrace and strandline distributions and relationships

General Discussion

The maps accompanying this report represent a combination of geologic and geomorphic evidence for terrace deposits. The methods used to determine the extent of particular terrace deposits were the following: terrace profiling, lithologic descriptions of terrace deposits, and air photo interpretation of the area.

Terrace profiling.-The profiles were helpful in delineating separate terrace levels, as previously demonstrated, especially in areas where there were not major changes in lithology between terraces. However, because they represent only a small portion of the total area covered by terrace deposits, the profiles could not be used as the sole basis for the mapping of terraces. Due to the distance between separate profiles, extrapolation of information gained from one profile was necessary to tie it in with another profile. Continuous profiling along terraces would provide the most valuable information, but since this is not feasible, information from aerial photographs and field observations was used in areas where no profiling was done.

Lithology.-Information regarding the general lithology of the terraces was also used to map individual terraces. Two main map divisions were made on the basis of lithology. These are the map symbols Qts and Qtc, representing terrace sands and gravels, and silt and clay, respectively. Within these divisions however, there exists a certain amount of variation, depending on the locations of the deposits relative to the configuration of the terraces.

Air Photo Interpretation.-1973 color aerial photographs were used in the mapping of terrace deposits and the location of strandlines. The strandlines show up on the photographs as thin, linear deposits that generally parallel former shorelines. Because of their geomorphic expression and lithology, I believe the deposits represent former beaches, now raised above present sea level. The photographs were also helpful in determining lithologic and geomorphic continuity of terraces.

Northern Sheet

North of Birch Bay, two major terraces were mapped-distinguished on the basis of profiles and lithologic differences. The lower terrace (area A on the northern sheet) consists of silt and clay that grades downward into a sandy silt in some areas. The sandy silt contains rounded pebbles and sparse shell fragments. This is underlain by clay and silty clay. The topography is slightly undulating, with a few small depressions that lie behind ridges at elevations of 30 and 40 feet (profile B-B').

The higher terrace (areas B and C) varies slightly in its texture. Area B consists of well-sorted, medium to coarse sands. These grade westward into silty sands and some sandy silt in the sheltered region of area C, the lee of the headland. No primary sedimentary structures or fossils were observed in any of these terrace sands.

Two other terraces were mapped in this area, based on aerial photograph interpretation and lithology. Northeast of Birch Point (area D) is a narrow terrace extending from an elevation of 40 feet to 60 feet. An available exposure (location: NE1/4 NW1/4, sec. 15, T. 40 N., R. 1 W.) shows 1 1/2 feet of sand, underlain by 3 feet of stratified sands and gravel, underlain by another foot of sand that begins to pinch out toward the south. Faint laminations are seen in the bottom sand. Overlying the terrace sands is a shell midden with stratified cultural material (area D on northern sheet).

A terrace to the east of Birch Bay (area E) was identified mainly by its surface texture. This terrace consists of clay and silty clay (Qtc). The front edge of the terrace lies at an elevation of about 20 feet near the southern portion and rises to an elevation of nearly 40 feet at the northern portion. No profiles were run in this area, and field observation does not show any great difference in elevation from the terrace mapped in area B. Because of dense vegetation and lack of exposures, the contact (which was based on surface textures) between this terrace and that in area B is not well documented. The age of this terrace with respect to those in areas A, B and C is unknown.

Covering most of the upland area north of Birch Bay are stratified sand, gravelly sands, and coarse gravels that overlie the Bellingham Glaciomarine Drift (Qbg). The finer sands are fairly well sorted and the gravels are well rounded. These sands and gravels probably represent a lag deposit formed by waves reworking the underlying Bellingham Glaciomarine Drift (Easterbrook, 1962, 1976). Aerial photographs of this area do not show any evidence of former beaches, represented by strandlines.

South of Birch Bay, four different terraces are shown on the map. The three lower terraces (areas F, G and H) are distinguished mainly on the basis of lithologic differences. Elevation changes are subtle, although profile E-E' shows small differences in slope along Point Whitehorn Road. Near Birch Bay State Park two terraces were identified by changes in surface texture. Area G consists of silty clay, while area F is comprised chiefly of sand. The terrace at area G rises in elevation toward the northeast, but was mapped as a single terrace because of its lithologic continuity. There are two shell middens on this terrace, one near its western edge at an elevation of 20 feet, and the other at an elevation of nearly 40 feet where the terrace begins to trend toward the east. A third terrace (area H) lies above the first two, and consists of a well-sorted, fine to medium sand. Faint laminations were observed in some of these terrace sands, but exposures were poor and sedimentary structures relatively scarce.

Adjacent to and above the terrace in area H are a series of strandlines (elevations from 50 to 90 feet), which were mapped from air photos. These strandlines consist of linear accumulations of pebbly sand and gravel separated by areas of finer material. Variation in relief between the ridges of pebbly sand and gravel and the lower areas is never more than about 1

foot. Spacing between ridges is from 100 to 200 feet, and the length of the ridges may be as much as half a mile in some cases. The strandlines cannot be mapped continuously, but there are at least 11 strandlines in this area.

Since pebbly sand and gravel are concentrated in these deposits, they have been shown on the map as a part of Qbg, stratified sands and gravels.

Because of the geomorphic expression and lithology of the strandlines, I believe the strandlines represent beach deposits formed as relative sea level was lowering. Another group of strandlines occurs at elevations ranging from 115 feet to 140 feet.

Stratified sands and gravels (Qbg) cover most of the upland at Point Whitehorn, except where I have mapped a fourth terrace (area I), based on its geomorphic expression and lithology. This terrace can be identified on profile E-E', and consists mainly of fairly well-sorted sand. The Qbg deposits differ from this terrace and consists of coarse sand and gravel with some cobbles and small boulders, underlain by well-sorted medium sand with minor beds of gravel. In one exposure (location: NE1/4 NW1/4, sec. 11, T. 39 N., R. 1 W.), the lower sand showed faint low-angle cross bedding.

Central Sheet

To the southeast of Cherry Point (area J), there is one terrace ranging in elevation from just below 20 feet to about 40 feet. The terrace consists of coarse sand with sparse patches of gravel overlying the sand. A shell midden occurs on the shoreward edge of the western portion of the terrace. Immediately above the terrace is a succession of 7 to 9 strandlines, which lie at elevations from 40 to 80 feet and from 100 to 160 feet. The strandlines (often represented by a brown color on the aerial photographs) consist of pebbly sand and sandy gravel, with accumulations of sandy silt between strandlines.

Along the northern portion of Lummi Peninsula (area K), two separate terraces have been mapped. Lithologically, the terraces are similar, consisting of well-sorted, fine to medium sands. The profiles for this area (J-J' and L-L') distinctly show two different terrace elevations. Easterbrook (1962) described "a terrace 40-60 feet above sea level, underlain by sand and clay which in places contains marine fossils . . . The terrace deposits mark a late or post-glacial stand of sea level when the Lummi Peninsula was an island and much of the Nooksack Valley was inundated by marine water. The terrace is thought to have formed by wave action against the sides of the uplands." (Easterbrook, 1962, p. 87). My field work in this area has not resulted in any exposures that confirm the existence of marine fossils. Stratified sand and gravel (Qbg) mantle the upland area of the peninsula above 100 feet in elevation; no strandlines were visible from aerial photographs.

Linear terraces along both sides of the Nooksack River valley consist of fairly well-sorted, fine to silty sand. Grain-size analysis (referred to in a later section) suggests that these sands are fluvial in origin rather than marine. River terraces have a definite relationship to relative sea level, but further work in this area is out of the scope of this project, so individual terraces have not been delineated on the map.

Southern Sheet

No profiles were run on Lummi Island, but interpretation of aerial photographs and field observations did not show any major terraces on the island. There are, however, numerous strandlines consisting of sandy gravel with rounded pebbles and cobbles underlain by medium to coarse sand in some areas. Some stratification was observed in the sands and gravels. One locality (area L) consisted of black-stained, pebble-sized gravel containing occasional shell fragments. It is not presently known whether this represents a midden or a beach deposit

containing marine fauna. Groups of strandlines vary in number, from 5 to 13 individual strandlines in a group. The strandlines range in elevation from 20 to 200 feet. One possible explanation for the absence of terraces on Lummi Island is that relative sea level was lowering at a different or more continuous rate at Lummi Island than it was in the rest of the study area. There may have been no one stand of sea level that was of a long enough duration to form a well-developed terrace. This could imply some tectonic or isostatic differences between Lummi Island and the rest of the study area.

Archeology of terrace deposits

Cultural deposits, normally in the form of shell middens, occur on many of the terrace surfaces. Interpretations of these deposits by archeologists indicate that the people who occupied the terraces had a maritime lifestyle and were dependent upon the sea and river mouths as travel routes and food sources (Schwartz and Grabert, 1973). Because these people had a close affinity with the sea, archeologists believe that they lived at the uppermost portion of the beach existing during that time, just landward of the berm (Grabert, personal communication). If this relationship is true, careful study of these deposits may have an important bearing on the ages of relative sea level changes in prehistoric times. Radiocarbon dating of charcoal samples from these middens would put a limiting date on the formation of the terraces. However, I do not believe it will be possible to determine how long after terrace formation the people began to occupy them, so study of these deposits will probably have limitations.

Archeological sites at Birch Bay and Cherry Point have been described by Schwartz and Grabert (1973). Other sites in the study area are also known to the archeologists, but have not been excavated.

Several archeological sites are located around Birch Bay (northern sheet). One of the sites, located to the northwest of Birch Bay at an elevation of about 33 feet, contained numerous cobble tools and a few cores overlying thin lenses of weathered shells and a single hearth (Schwartz and Grabert, 1973). A site at an elevation of approximately 98 feet consists of a small shell midden and remnants of a shell-free camp site. Archeologists believe that this site may have been inhabited by people while the site was either an island or a narrow headland.

Other sites in this area are on a series of nested compound recurved spits, extending from the base of the lowest terrace out to the present beach (Schwartz and Grabert, 1973). These sites include deeply buried components that were exposed during marina construction at Birch Bay Village. The sites yielded a few artifacts and cooking hearths, located on extinct beaches that were buried by progradation at the present sea level. Artifacts collected include forms representative of an assemblage which dates from 2350 years B.P. to 1500 years B.P. (Larsen, 1971).

A small shell midden overlies the terrace sands (elevation about 40 feet) in area D, to the northeast of Birch Point. Another shell midden occurs on top of terrace deposits (mainly clay and silty clay) at an elevation of about 40 feet, just to the south of the village of Birch Bay. This midden consists of a thick deposit of shell debris, along with scattered pieces of charcoal and a few artifacts, none of which could be typologically date (Schwartz and Grabert, 1973). Another archeological site occurs at the other end of this terrace, just south of Birch Bay State Park. It lies at an elevation of 20 feet.

The last site mentioned (located at the northern end of profile E-E' on the northern sheet) has not been formerly reported by the archeologists, but I studied material from the site during field work this summer. The midden is at least several meters thick and consists of organic-rich pebbly sand with numerous shells of pelecypods and gastropods (both fragmented and whole), occasional bone fragments, probably stone artifacts, and pieces of charcoal. One

area with a heavy concentration of charcoal also contained what appeared to be fire-cracked rocks. I believe this represents the remnants of a hearth. The total extent of the midden is not known.

The northern edge of the midden is overlain by a pebbly clay containing occasional shell fragments. In one area the pebbly clay and the shell midden interfinger. The origin of the pebbly clay is not known, but because of the range of grain sizes in the material, it is likely that the clay represents some sort of mass-wasting phenomenon. The occurrence of large fragments of shells can be explained by incorporation of them into the pebbly clay from the underlying midden. Both pebbly clay and the pebbly sand samples from the midden were washed and checked for microfossils. None were found in the pebbly clay. The midden material, however, contained several types of microfauna including foraminifers, diatoms, and small gastropods. The forams were identified by Weldon W. Rau, biostratigrapher for the Washington Department of Natural Resources. Included were specimens of Elphidium frigidum, Elphidium bartletti, Buccella frigida and Quinqueloculina cf. Q arctica. There were a few specimens of Elphididella hannai and several species of miliolids. It is not uncommon for microfauna to be found associated with cultural deposits, since shells collected by people living in the area would be brought in clusters, bringing smaller marine organisms that were attached to and eaten by the larger animals (Grabert, personal communication).

It is curious though that the above assemblage of foraminifers represent cold marine, slightly brackish conditions at littoral depths (0-23 meters). Rau reports that the assemblage can be duplicated in Pleistocene and Holocene tide pool and bay deposits of the northeast Pacific, especially from northern Vancouver Island north and westward to the Arctic. The complete lack of warm water elements in the assemblage tends to suggest the possibility that the assemblage represents colder conditions than exist today in Puget Sound; therefore further suggesting that the fauna may be pre-Holocene in age (Rau, personal communication). Although this midden has not yet been dated, no other sites in the study area have been reported as pre-Holocene in age. Radiocarbon dating of this midden may be an important means of confirming a minimum age for the terrace on which it occurs.

Further to the south, at Cherry Point (central sheet), a large shell midden lies on the terrace sands. The midden is about 200 meters in length, roughly parallel to the wave-cut cliff, and is presently about 20 meters wide (Schwartz and Grabert, 1973). A total of more than 1600 artifacts have been cataloged at the Cherry Point site (Schwartz and Grabert, 1973). Above the terrace sands, and below the cultural layer, are sparse patches of pebble and cobble gravel. It is possible that these are remnants of the receding shoreline. A shell-free cultural-depositional layer below the actual shell midden indicates that the people lived back of the beach and discarded their shells on the backshore (Schwartz and Grabert, 1973). C14 dating of four charcoal samples taken from the bottom to the top of the shell midden stratum yielded ages of 2,340, 1,640, 1,300, and 960 years B.P. (all $\pm$ 200 years), respectively (Schwartz and Grabert, 1973).

It is unknown how much time elapsed between development of the terrace through erosion of the Bellingham Glaciomarine Drift and deposition of the sands, and the time at which the people began to occupy the raised terrace. However, assuming that the people who lived at Cherry Point did in fact reside near to the shoreline and that the radiocarbon dates are correct, then relative sea level at Cherry Point must have been higher 2,340 years B.P. than it is today. This conclusion contrasts with Larsen's thesis (1971), in which human occupation on Birch Bay spits suggests that relative sea level has been close to that of today since 4000 years B.P. The apparent inconsistency may be due to incorrect dates and interpretations, or it may be the result of real differences in relative sea level due to tectonism.

Laboratory Work
General Discussion

Determining the origin of the terrace deposits in western Whatcom County was one of the most important parts of this year's project. Poor exposures in most areas did not allow identification of any primary sedimentary structures that may have been present and indicative of the environment of deposition. Marine fossils were scarce in almost all of the deposits. Therefore, evidence for the origin of the deposits was based mainly on lithology, geomorphic expression, and grain-size analysis.

Previous studies

Most of the work I did on grain-size analysis was based upon studies concerning size-frequency distributions for sands of different origins, particularly work done by Friedman (1967) on distinguishing beach from river sands. Friedman takes the differences between the size-frequency distributions of sands from the zone of swash and backwash on beaches and from rivers and relates the distributions to the environmental conditions under which they are deposited.

Friedman's study showed that beach sands are better sorted than river sands, and tend to lack the coarse- and fine-grained tails present in river sands. Occasionally though, some beaches did show coarse-grained fractions. Beaches that exist near the mouths of rivers may have fine-grained tails due to an abundance of fines which exceeds the energy available to disperse them (Friedman, 1967). In these cases, the statistical parameters of their size-frequency distribution overlap those of river sands.

Previous studies have suggested that wave swash has a winnowing effect on fine sand-size and silt particles, creating a relative impoverishment of the finer particles of beach sand populations (Chappell, 1967). Thus, a beach sand can be considered as a lag deposit with the fines removed by waves and currents and the sand remaining as a relict sediment. As previously mentioned, an exception occurs in beach sediment near the mouths of rivers. Such beaches however, are ephemeral in nature, and when the river changes its course, the beach will reach equilibrium and the fine-grained portion will be removed.

There are two main differences between fluvial and longshore beach transport pointed out by Friedman that might explain the most important differences in the statistical measures between the sands from these two environments. (1) The oscillatory water movement in the beach environment has a vertical component which separates the fines from the coarser grained fraction. In fluvial environments on the other hand, flow is unidirectional and the fines are carried along with and parallel to the bedload. Any vertical motions in a stream are associated with irregular eddies in turbulent flow and are not permanent as they are in the beach environment. (2) The separated fine fraction in the beach environment is directed seaward where the fines will settle in deeper water. In a fluvial environment, however, the fines are confined within the channel, except at flood stage, and cannot permanently be removed to deeper water. Along with a continuous supply of fines from upstream, the fine-grained fraction is deposited along with the sand fraction. Aside from these two differences, Friedman also reports that "the competency of a river in its waning stages is much below that of a beach environment" and thus achieves "the low-energy conditions that allow the deposition from suspension of silt and clay."

Procedure

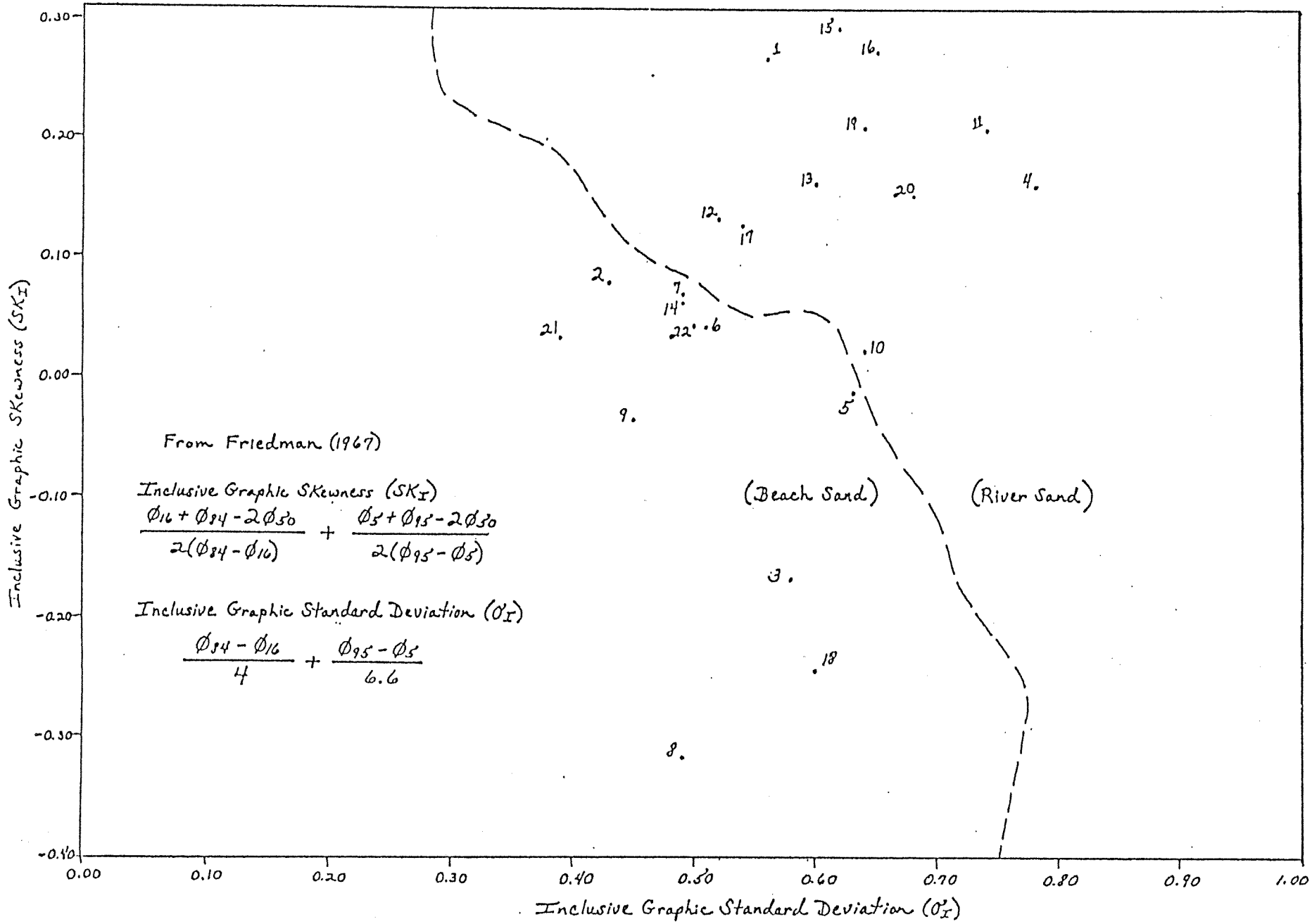
Samples were collected parallel to the bedding whenever possible. However, in many exposures bedding could not be identified, so there was a greater chance of mixing different sediment populations. In the laboratory, grain-size determinations were made by normal sieving methods. We used half-phi sieve intervals (see Folk, 1974, p. 25) and computed the skewness and standard deviation for each sample.

Results

The computations done for each sample were plotted on a graph based on Friedman's study (1967). This graph (fig. 7) plots the Inclusive Graphic Skewness measure (SK_I) against the Inclusive Graphic Standard Deviation (σ_I) (Folk and Ward, 1957). Friedman had shown that the beach and river sands of his study fell for the most part into separate groupings which he related to environment. The graph in figure 7 shows the plots of points from samples collected in my field area along with the line Friedman drew, which separated the beach sands from the river sands.

Figure 7 and the list of values in table 1 show that for the most par, all samples from any one particular area were either in the beach-sand category or in the river-sand category. There was not just a random distribution into the two categories of Friedman's graph. Interpretation of these results was used to determine whether or not a particular terrace in the study area is of marine origin. Locations of the samples are given in table 1. Most of the samples that fell into the river-sand category of Friedman are from terrace deposits along either side of the Nooksack river valley. There are however, a few exceptions. To the southwest of Ferndale (between the locations of profiles H-H' and I-I' on the Central Sheet), on one terrace, there are some linear sand ridges which can be seen on the topographic map as well as in aerial photographs. Although most of the sands from terraces in this area fell into the river category of Friedman, samples from these sand ridges fell into his beach category. The significance of this has not yet been determined. In other areas there were also a few exceptions, but for the most part these were explained by poor sample collection (due to lack of visible bedding), and thus a mixing of sand populations. Results were consistent in areas where the sample was properly collected.

Figure 7


0.30
0.20
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-0.40
0.00
0.10
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0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
Inclusive Graphic Skewness (SK_I)
Inclusive Graphic Standard Deviation (σ_I)
From Friedman (1967)
Inclusive Graphic Skewness (SK_I)
$\frac{\phi_{16} + \phi_{84} - 2\phi_{50}}{2(\phi_{84} - \phi_{16})} + \frac{\phi_5 + \phi_{95} - 2\phi_{50}}{2(\phi_{95} - \phi_5)}$
Inclusive Graphic Standard Deviation (σ_I)
$\frac{\phi_{84} - \phi_{16}}{4} + \frac{\phi_{95} - \phi_5}{6.6}$
(Beach Sand)
(River Sand)
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22

Table 1

Sample No.	Location	σ_i	SK_i
1	NW 1/4 SW 1/4, sec.13, T.40N., R.1W.	0.56	0.269
2	NE 1/4 NW 1/4, sec.15, T.40N., R.1W.	0.43	0.081
3	NE 1/4 NW 1/4, sec.11, T.39N., R.1W.	0.58	-0.166
4	NW 1/4 SW 1/4, sec.19, T.40N., R.1E.	0.78	0.163
5	NE 1/4 NE 1/4, sec.19, T.40N., R.1E.	0.63	-0.010
6	NW 1/4 NW 1/4, sec.33, T.40N., R.1E.	0.51	0.043
7	SE 1/4 SW 1/4, sec.06, T.39N., R.1E.	0.49	0.071
8	NW 1/4 NE 1/4, sec.19, T.39N., R.1E.	0.49	-0.318
9	SW 1/4 NW 1/4, sec.36, T.39N., R.1E.	0.45	-0.033
10	SW 1/4 NW 1/4, sec.36, T.39N., R.1E.	0.64	0.024
11	SE 1/4 NE 1/4, sec.35, T.39N., R.1E.	0.74	0.211
12	SE 1/4 NE 1/4, sec.35, T.39N., R.1E.	0.52	0.133
13	NE 1/4 SE 1/4, sec.35, T.39N., R.1E.	0.60	0.164
14	NE 1/4 SE 1/4, sec.35, T.39N., R.1E.	0.49	0.062
15	SW 1/4 SE 1/4, sec.35, T.39N., R.1E.	0.62	0.294
16	SW 1/4 SE 1/4, sec.35, T.39N., R.1E.	0.65	0.276
17	SW 1/4 NE 1/4, sec.25, T.39N., R.1E.	0.54	0.129
18	SE 1/4 SW 1/4, sec.09, T.38N., R.2E.	0.60	-0.243
19	SE 1/4 SE 1/4, sec.08, T.38N., R.2E.	0.64	0.212
20	SE 1/4 SE 1/4, sec.08, T.38N., R.2E.	0.68	0.155
21	NE 1/4 SW 1/4, sec.19, T.38N., R.2E.	0.39	0.033
22	NE 1/4 SW 1/4, sec.19, T.38N., R.2E.	0.50	0.045

Bay View Ridge, Skagit County
Known Stratigraphy and Chronology

Bay View Ridge (fig. 8) consists of sediments deposited during the Fraser Glaciation. A thick unit of Vashon outwash gravels, containing sand lenses, is overlain by Vashon till. Overlying Vashon till is Everson Glaciomarine Drift, ranging from a few feet to about 15 feet in thickness. The Vashon sequence of outwash and till is believed to have been deposited between 18,000 and 13,000 years B.P. (Easterbrook, 1966). Radio-carbon dates from shell, wood, and peat place the date of the Everson Interstade deposits between 13,000 and 11,000 years B.P. (Easterbrook, 1966). No evidence of any sediments derived from the Sumas Stade has yet been found at Bay View Ridge, although Sumas outwash terraces have been mapped a few miles to the northeast, along the Samish River (Easterbrook, 1966).

Preliminary Investigation

Exposures in a borrow pit situated at the northern end of Bay View Ridge (fig. 8) show a stratified sequence (3 to 4 feet) of coarse sand, pebbles, and cobbles. This sequence is separated by a sharp contact from the underlying unit, which consists of medium-grained sand. Thin laminations are evident in the underlying sand and exhibit low-angle crossbedding in places. The thickness of the sand varies from about 1 foot at the north end of the pit to about 8 to 10 feet at the south end. Underlying the sand is a diamicton, possibly glaciomarine drift. The borrow pit spans elevations between 110 and 150 feet above sea level. Strandlines can be seen in the field and on aerial photographs extending laterally toward the pit, until they disappear under forest vegetation.

The sand and gravel units of the borrow pit and other exposures of sand and gravel on Bay View Ridge represent possible marine terraces. Leveling profiles along two roads have been completed by Bob Siegfried, a geology graduate student from Western Washington University. Traverses along Wilson Road and Farm to Market Road indicate a possible correlation between terraces at 90, 110, and 150 feet above sea level.

Grain-size analysis has been completed on sand samples from the previously mentioned borrow pit. Results indicate that most of the laminated sands fall within or near the beach category of Friedman (1967).

Several shallow peat bogs on Bay View Ridge (fig. 8) have been sampled at elevations of 180, 150, and 120 feet above sea level. The 180-foot bog is impounded by a linear sand deposit. A topographic map of the area indicates that the 150-foot bog may also have been impounded by a linear sand deposit, although the area has been plowed since the map was made. All three bogs contain a very fine, yellow volcanic ash layer (possibly Mazama ash, 6600 years, B.P., Wilcox, 1965). Basal peat samples were taken from all three bogs, and have been sent to the U.S. Geological Survey radiocarbon laboratory in Menlo Park to be dated. A sample of the ash was sent to the USGS in order to verify its identification as Mazama ash. Peat from the 150-foot bog will be analyzed for pollen by the USGS. Results from the C^{14} dates, pollen analysis, and ash analysis will all provide information about the minimum age of terrace formation on Bay View Ridge.

Further Study

Bob Siegfried has continued work in the Bay View Ridge area as part of his Master's thesis at Western Washington University. He will determine the origin of the terrace sands by

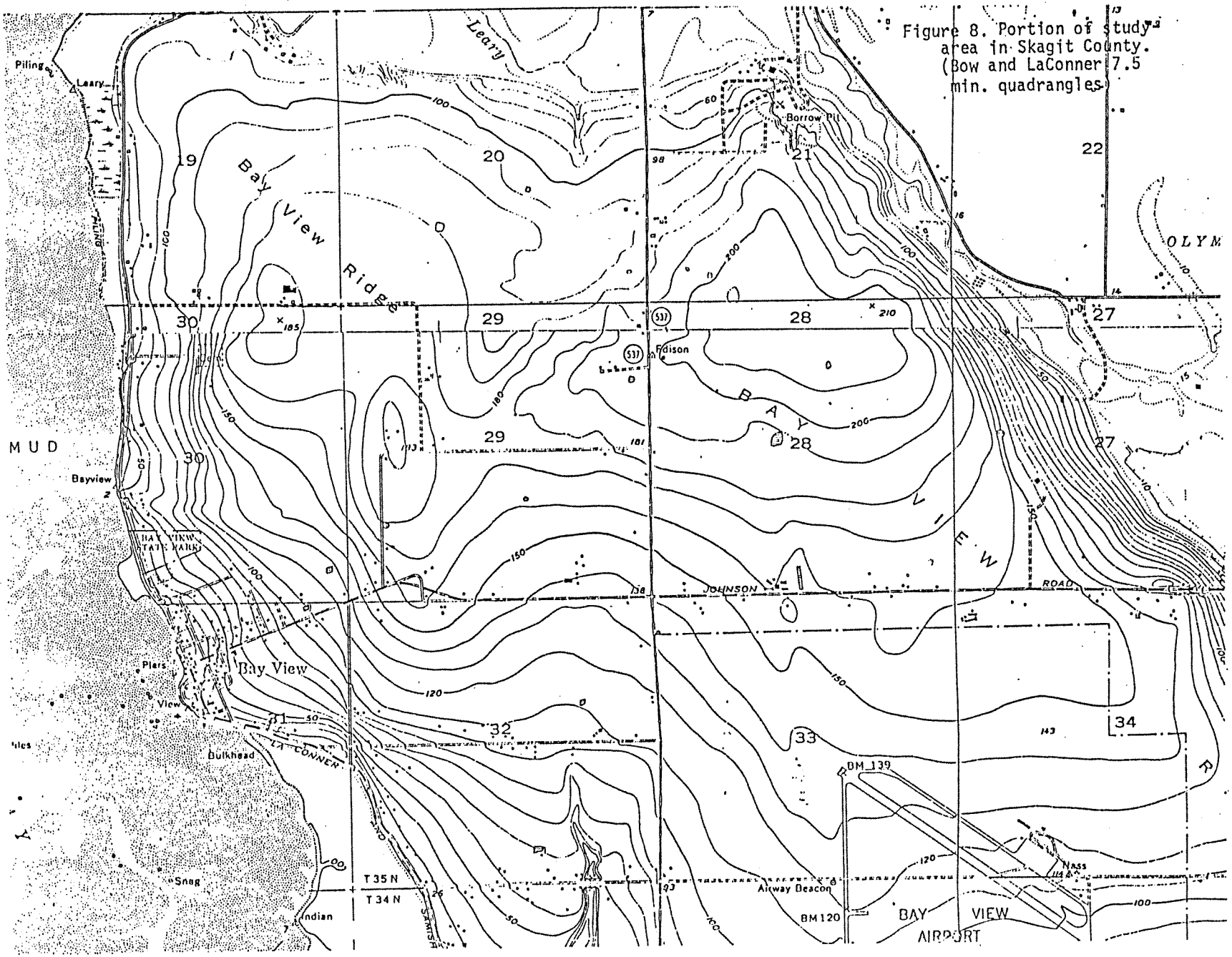


Figure 8. Portion of study area in Skagit County. (Bow and LaConner 7.5 min. quadrangles)

three methods: (1) identification of primary sedimentary structures, (2) grain-size analysis, and (3) particle morphology, using the scanning electron microscope. Aerial photograph interpretation, examination of field exposures, and augering will all be methods employed by him in the construction of a surficial geologic and geomorphic map. Further work in the western portion of Skagit County will also be a part of next year's project.

Conclusions

Based on lithologies of deposits, their geomorphic expression, and results from grain-size analysis, the terraces and strandlines in western Whatcom County are interpreted as marine in origin, with the possible exception of terraces adjacent to the Nooksack floodplain. Study of the marine terraces, strandlines, and surficial geology in the area, during this project and by previous workers, demonstrates that relative sea level dropped rapidly, but somewhat stepwise after 11,000 years ago. Because of the interplay between isostatic rebound and eustatic sea level rise, terraces were formed during pauses in the lowering of relative sea level. Today, these terraces represent a consecutive lowering of relative sea level with no evidence of re-submergence of the deposits.

The exact age of formation of the terraces and strandlines is not known. There have been no absolute dates determined for the terraces, except for one radiocarbon date from a shell collected by Easterbrook (1966) from a terrace on Lummi Peninsula. My field work, however, has not confirmed the existence of the fauna reported by Easterbrook, nor any major faunas in other terrace deposits.

There is some field evidence for the approximate age of the terraces in Whatcom County. For instance, east of Birch Bay, a channel dissects one of the major terraces. This channel was probably cut by melt water form Sumas Stade ice. After the ice melted, peat formed in the abandoned outwash channels. Dated peat deposits from apparently correlative channels east of the study area suggest that the terrace, as well as higher terraces and strandlines, is older than 10,000 years.

Other evidence for the ages of terrace formation comes from archeological sites that occur on many of the terraces. There is a limitation in the use of radiocarbon dates derived from archeological sites. There is no way to know the exact length of time between terrace formation and terrace occupation by prehistoric cultures. However, if it is true that these people lived near the beach, as archeologists believe, then it follows that former sea levels can be specified by near-shore human occupation sites, and by dating of the sites, place an age for relative sea level in separate areas.

At Cherry Point, charcoal in the bottom of a shell midden stratum was dated, indicating an age of 2,340 $\pm$ 200 years B.P. (Schwartz and Grabert, 1973). Since the people living at that time were closely tied to the sea for their lifestyle and subsistence, archeologists are confident that sea level was very close to where their shells were discarded. If the radiocarbon dates from Cherry Point are correct, then relative sea level was probably 20 to 30 feet higher 2,340 years ago than it is today. This statement contrasts with the situation at Birch Bay.

Terraces at Birch Bay were probably dissected close to 10,000 years ago (by Sumas Stade melt waters). The ancient melt-water channels do not show evidence of having been submerged below sea level. Therefore, sea level was probably as low or lower than today after dissection of the terraces. By 4,000 years ago, sea level was near the present level at Birch Bay (Larsen, 1971). Because of the discrepancies between dated relative sea level stands at Cherry Point and Birch Bay, there is a suggestion of tectonic uplift at Cherry Point during the late Holocene.

Many of the archeological sites found on terraces have not been radiometrically dated. The sites that have been dated are fairly young. However, at one terrace site in Birch Bay, the

microfaunal assemblage in the midden indicates colder conditions than exist today in Puget Sound. This suggests a pre-Holocene age for the cultural material. If this is the case, the site would be the oldest known in the Birch Bay area. It will be important to have this site dated in order to support the evidence from the microfauna.

No major terraces were mapped on Lummi Island. The strandlines on the island begin at a lower elevation and continue to a higher elevation than those in other parts of the study area. This suggests one of three possibilities: (1) the terraces never formed because of more rapid lowering of relative sea level, (2) the terraces never formed because coastal environments on Lummi Island were different from other areas, and (3) the terraces formed, but are now submerged below present sea level. Possibilities (1) and (3) suggest a difference in relative sea level movement between Lummi Island and the rest of the study area. Whether this is due to tectonism is not presently known.

SELECTED REFERENCES

Armstrong, J.E.; Crandell, D.R.; Easterbrook, D.J.; Noble, J.B., 1965, Late Pleistocene stratigraphy and chronology in southwestern British Columbia and northwestern Washington: Geological Society of America Bulletin, v. 76, no. 3, p. 321-330.

Artim, E.R.; Wunder, J.M., 1976, Preliminary geologic map of the La Conner quadrangle in Skagit County, Washington: Department of Natural Resources, Division of Geology and Earth Resources, Open-File Map 76-1.

Chappell, J., 1967, Recognizing fossil strand lines from grain-size analysis, Journal of Sedimentary Petrology, v. 37, no. 1, p. 157-165.

Easterbrook, D.J., 1962, Pleistocene geology of the northern part of the Puget Lowland, Washington: University of Washington, Ph.D. thesis, 160 p.

Easterbrook, D.J., 1963, Late Pleistocene glacial events and relative sea level changes in the northern Puget Lowland, Washington: Geological Society of America Bulletin, v. 74, no. 12, p. 1465-1484.

Easterbrook, D.J., 1966, Glaciomarine environments and Fraser glaciation in northwest Washington: Guidebook 1st Annual Field Conference, Pacific Coast Section, Friends of the Pleistocene, Department of Geology, Western Washington State College, Bellingham, Washington, 52 p.

Easterbrook, D.J., 1968, Pleistocene stratigraphy of Island County: Washington Department of Water Resources Water Supply Bulletin No. 25, part 1, 33 p.

Easterbrook, D.J., 1969, Pleistocene chronology of the Puget Lowland and San Juan Islands, Washington: Geological Society of America Bulletin, v. 80, no. 11, p. 2273-2286.

Easterbrook, D.J., 1976, Geologic map of western Whatcom County, Washington: U.S. Geological Survey Miscellaneous Investigations Series, Map I-854-B.

Folk, R.L., 1974, Petrology of sedimentary rocks: Hemphill Publishing Co., Austin, Texas, p. 25.

Folk, R.L.; Ward, W.C., 1957, Brazos River bar: a study in the significance of grain size parameters: Journal of Sedimentary Petrology, v. 27, p. 3-26.

Friedman, G.M., 1967, Dynamic processes and statistical parameters compared for size frequency distribution of beach and river sands: Journal of Sedimentary Petrology, v. 37, no. 2, p. 327-354.

Larsen, C.E., 1971, An investigation into the relationships of change in relative sea level to social change in the prehistory of Birch Bay, Washington: Western Washington State College M.A. Thesis, 89 p.

Othberg, K.L., 1977, Washington coastal zone atlas, v. 1; Whatcom County: Washington Department of Ecology, 9 pages plus maps.

Schwartz, M.L.; Grabert, G.F., 1973, Coastal processes and prehistoric maritime cultures. In Coates, D.R., ed., Coastal geomorphology, State University of New York, Publications in Geomorphology, p. 303-320.

Wilcox, R.E., 1965, Volcanic ash chronology: In Quaternary of the United States, VII INQUA Congress, Princeton Press, p. 809.

State of Washington Department of Natural Resources Division of Geology and Earth Resources Open File Report No. O.F. 77-6

Geologic and Geomorphic Map of Terraces and Associated Surficial Geology of Western Whatcom County, Washington.

PAMELA PALMER
1977

Geologic Explanation

Holocene

af Qa Qb Qos Qp

af, artificial fill

Qa, alluvium (sand, silt and clay)

Qb, beach deposits (sand and gravel)

Qos, saturated, organic-bearing sand, silt and clay

Qp, peat

Quaternary

Pleistocene

Qso Qsc Qts Qtc 1/

Qso, Sumas outwash sand and gravel

Qsc, Sumas silt and clay

Qts, terrace deposits, sand and gravel

Qtc, terrace deposits, silt and clay

Qbg

stratified sand and gravel mantling Bellingham Glaciomarine Drift

Qe

Everson Glaciomarine Drift, undifferentiated

Qeb

Bellingham Glaciomarine Drift (upper member of Everson)

Qu 2/

Tertiary and pre-Tertiary

b

Undifferentiated Tertiary and pre-Tertiary bedrock

1/ Age equivalency of these units uncertain.

2/ Qu, Pleistocene sediments, undifferentiated.

——— — — Contact, dashed where approximately located.

---------- Inferred contact.

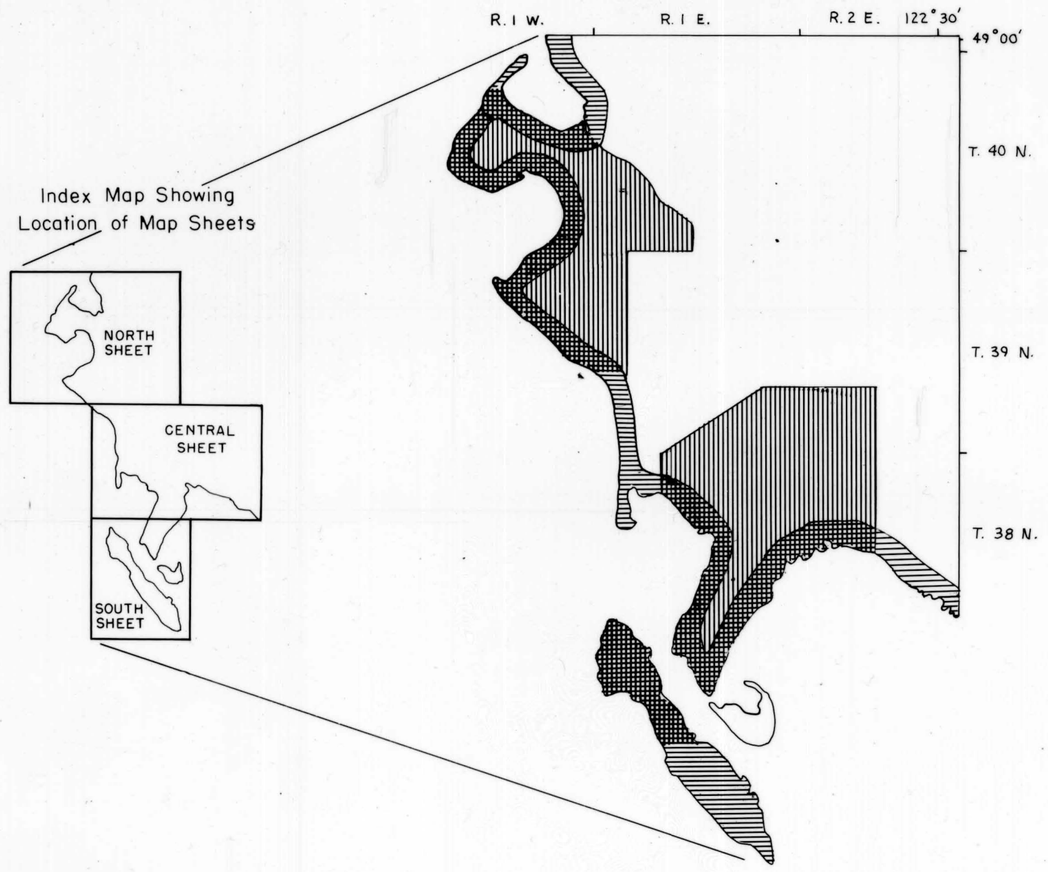
—·—·—·— Strandline; thin, linear sand deposit.

A ——— A' Location of leveling profiles on terraces.

▲ Location of archeological sites discussed in text.

Ⓐ Areas of discussion in text.

Geologic Map Index



These maps accompany the report entitled "Investigation of Tectonic Deformation in the Puget Lowland, Washington."

Research sponsored by the U.S. Geological Survey, Department of the Interior, under U.S.G.S. Grant No. 14-08-0001-G-366.

☐ The entire area was mapped by Easterbrook (1976)

▤ Othberg (1977)

▥ This report

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

LUMMI ISLAND QUADRANGLE
WASHINGTON
7.5 MINUTE SERIES (TOPOGRAPHIC)
NW/4 ANACORTES 15' QUADRANGLE

Base Map U.S.G.S. Lummi Island Quadrangle
SOUTHERN SHEET

SCALE 1:24 000

1 MILE
7000 FEET
1 KILOMETRE

CONTOUR INTERVAL 20 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929
DEPTH CURVES AND SOUNDINGS IN FEET— DATUM IS MEAN LOWER LOW WATER
SHORELINE SHOWN REPRESENTS THE APPROXIMATE LINE OF MEAN HIGH WATER
THE MEAN RANGE OF TIDE IS APPROXIMATELY 4 FEET

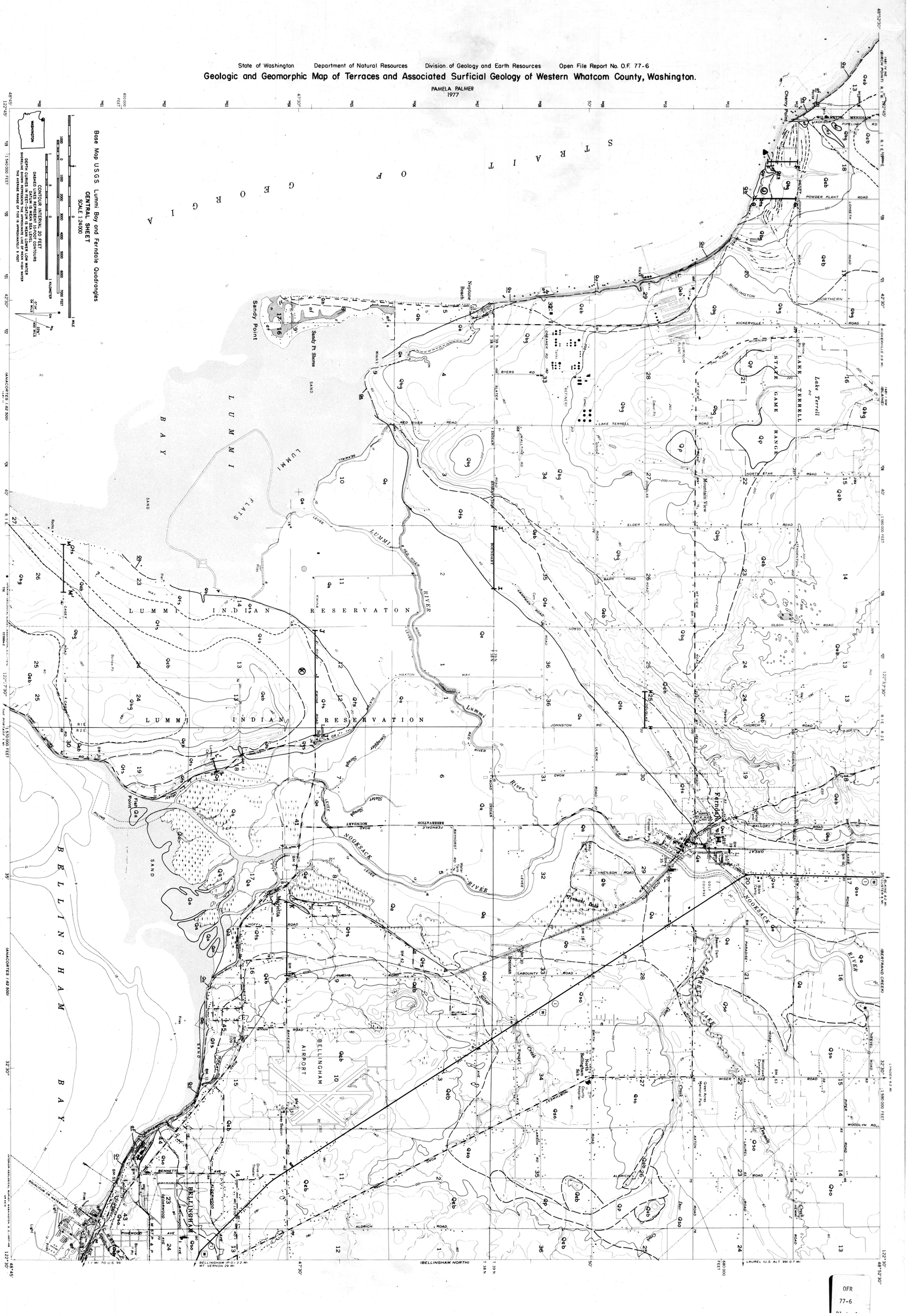
0°14' 4 MILS 22° 391 MILS

WASHINGTON

State of Washington Department of Natural Resources Division of Geology and Earth Resources Open File Report No. O.F. 77-6

Geologic and Geomorphic Map of Terraces and Associated Surficial Geology of Western Whatcom County, Washington.

PAMELA PALMER
1977



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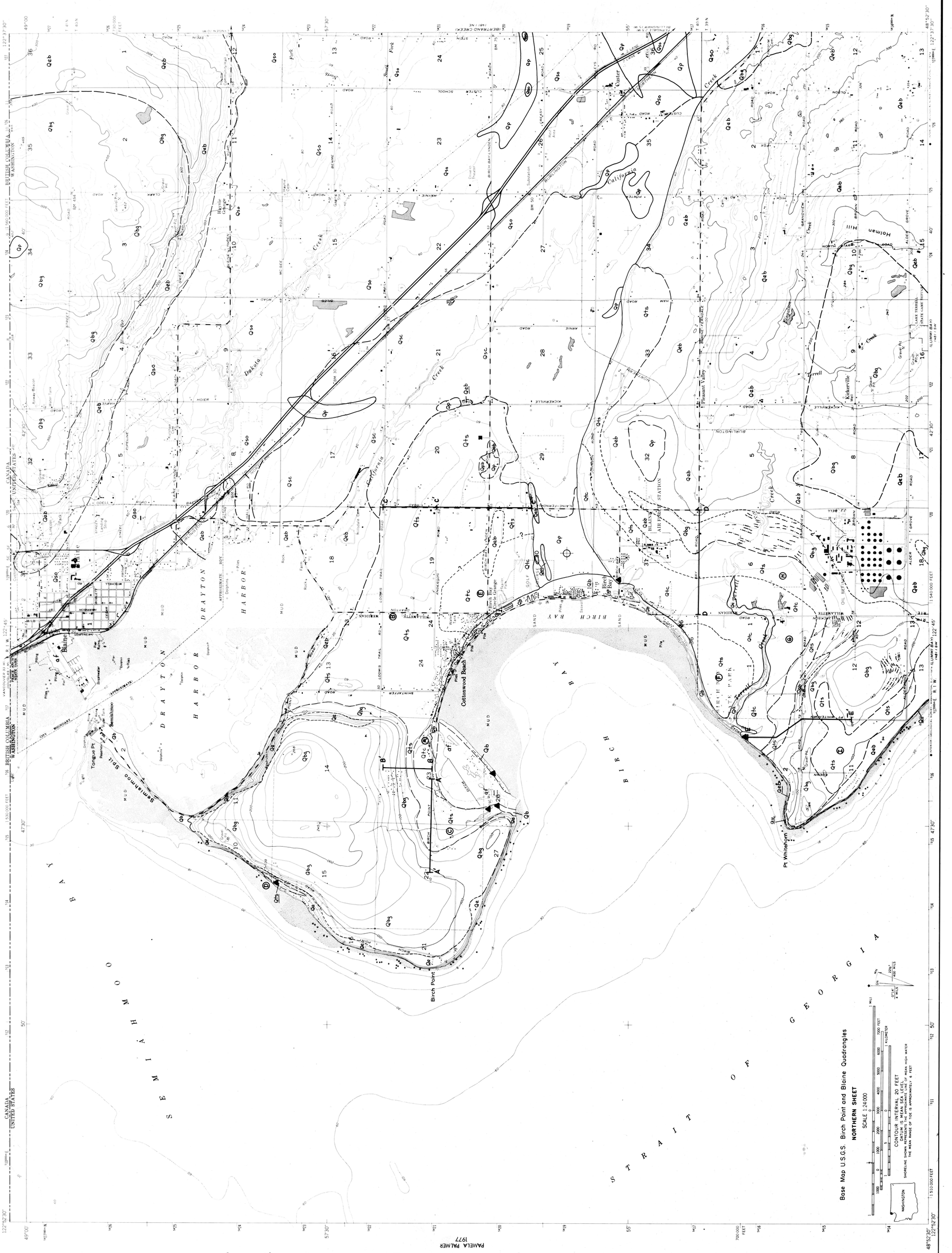

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