Summer 1983

Net Shore-Drift of Mason County, Washington

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MASTER'S THESIS

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MASTER'S THESIS

Dana G. Blankenship
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NET SHORE-DRIFT OF MASON COUNTY, WASHINGTON

A Thesis

Presented to

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In Partial Fulfillment

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Master of Science

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Dana G. Blankenship

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Dean of Graduate School

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ABSTRACT

Winds from various directions cause waves which transport sediment along the shore. Over a relatively long time interval, sediment is moved in one predominant direction, which is the direction of net shore-drift. Variations in shoreline orientation cause shore drift to occur in discrete, essentially independent, drift cells.

By the specific identification of a number of established geomorphic and sedimentological shore drift indicators, drift cell boundaries can be delineated and the directions of net shore-drift determined. These indicators include changes in bluff morphology, beach width and slope, sediment-size gradation, identifiable sediment, deposition and/or erosion at shore drift obstructions, direction of spit growth and stream diversions, and nearshore bar orientation. Using these shore drift indicators, 136 drift cells have been mapped and described for the Mason County portions of Hood Canal and southern Puget Sound.

Net shore-drift along most of the Mason County shore is generally northward, which reflects the influence of more frequent and stronger winds from southerly directions. Areas of southward net shore-drift occur where fetch from the south is limited. Shore drift in insignificant along parts of the shore where fetch is limited in all directions, where wave energy is diminished by shallow water or man-made barriers, or where cliffs or bluffs extend to deep water.

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INTRODUCTION

The fundamental basis of shore drift is that waves and wave-generated currents transport sediment along the shore. Wave motions, however, are affected by numerous physical parameters which serve to complicate the directional patterns of shore drift. As wind is highly variable with respect to direction, velocity, and duration, so too, waves vary with the wind and are affected by the distance of fetch, offshore bathymetry, obstructions, and other factors. The conveyance of sediment along the shore depends on the sum of the vectors of the forces acting upon the shore; generally, one direction emerges as the direction of predominant transport. As early as 1889, the concept of a direction of net shore-drift was perceived by Cornaglia (1977, p. 12), who wrote:

> "From all this it is deduced that as long as the sea has sufficient force, it moves all or some beach sediments such as sand, gravel, cobbles, etc., and that it moves them now one way and now another way according to its direction. In the end, however, the sediments move principally in the direction from which the sea has its prevalent action . . ."

Although the importance of the process of shore drift to coastal geomorphology has long been recognized, sediment transport has quite often been ignored until after construction along the shore has disrupted the transport pattern. Today, in the age of the environmental impact statement, people are beginning to realize that every physical alteration to the prevailing conditions may upset the balance of some unseen physical interdependency. Although it may seem reasonable that an individual may construct a seawall to protect beachfront property from wave erosion, the rights of neighboring property owners must also be considered. Each artificially designated parcel of beachfront property has a relationship to every other parcel. An understanding of shore drift and general recognition of the dynamic nature of beaches will help define that relationship.

Mason County is the least populated of the five southern Puget Sound counties (U.S. Bureau of the Census, 1980). However, as the population of the entire region increases, more people seek refuge away from the crowded Seattle-Tacoma urban area, creating disproportionate developmental pressures within Mason County. Man-made modifications along the Mason County waterfront consist principally of residential and recreational developments. Heavy industrial shoreline development consists only of a large timber company at Shelton on Oakland Bay, and a log-rafting operation at Jorsted Creek near Eldon on Hood Canal. Additionally, numerous large tidal flat areas are utilized by commercial shellfish operations, whose direct influences upon geomorphic shoreline processes are generally minor. Tideland access restrictions imposed by these concerns, however, decrease the recreational value of neighboring coastal property. Thus, the clam and oyster operations indirectly influence the character of the shoreline by slowing shoreline modification and development.

Because much of the most accessible and aesthetically desirable beachfront property has been developed, construction is spreading to marginal, often less desirable land. The construction of seawalls, groins, and other beach and shore protection structures may profoundly influence beach stability. Therefore, to ensure public and environmental safety, an understanding of the concepts of shore drift and other geomorphic processes which dictate the nature of the shoreline is essential. This report and the accompanying maps will explain how shore drift operates and identify the pattern of net shore-drift of Mason County, Washington.

PHYSICAL SETTING

Geography

Puget Sound is situated within the Puget Lowland in the glacially sculptured northern portion of the Puget-Willamette Trough (Figure 1). The lowland is bordered on the east by the Cascade Mountains and on the west by the Olympic Mountains, the northernmost-extension and topographically highest portion of the Coast Range. South of the Olympics, the Coast Range is present only as low hills which form the divide between Puget Sound drainages and drainage into the Chehalis River basin. The drainage divide marks the approximate limit of advance of the Puget lobe of the Cordilleran ice sheet during the Fraser Glaciation (Easterbrook, 1969). To the north of the Puget Lowland, mountainous Vancouver Island is separated from the Coast Mountains of Canada by the Strait of Georgia. The Strait of Juan de Fuca passes between the Olympic Mountains and Vancouver Island, connecting Puget Sound to the Pacific Ocean.

Three hundred and thirty kilometers of Puget Sound shoreline are located within Mason County (Figure 2). About 35 percent of the total distance is located along Hood Canal in the northern part of the county. The remainder of the shoreline is along several sinuous, irregular, and often narrow inlets and passages of southern Puget Sound.

Coastal topographic relief within the county is greatest around Hood Canal where the bluffs rise steeply to about 150 meters. Within 15 kilometers to the west of Hood Canal, peaks

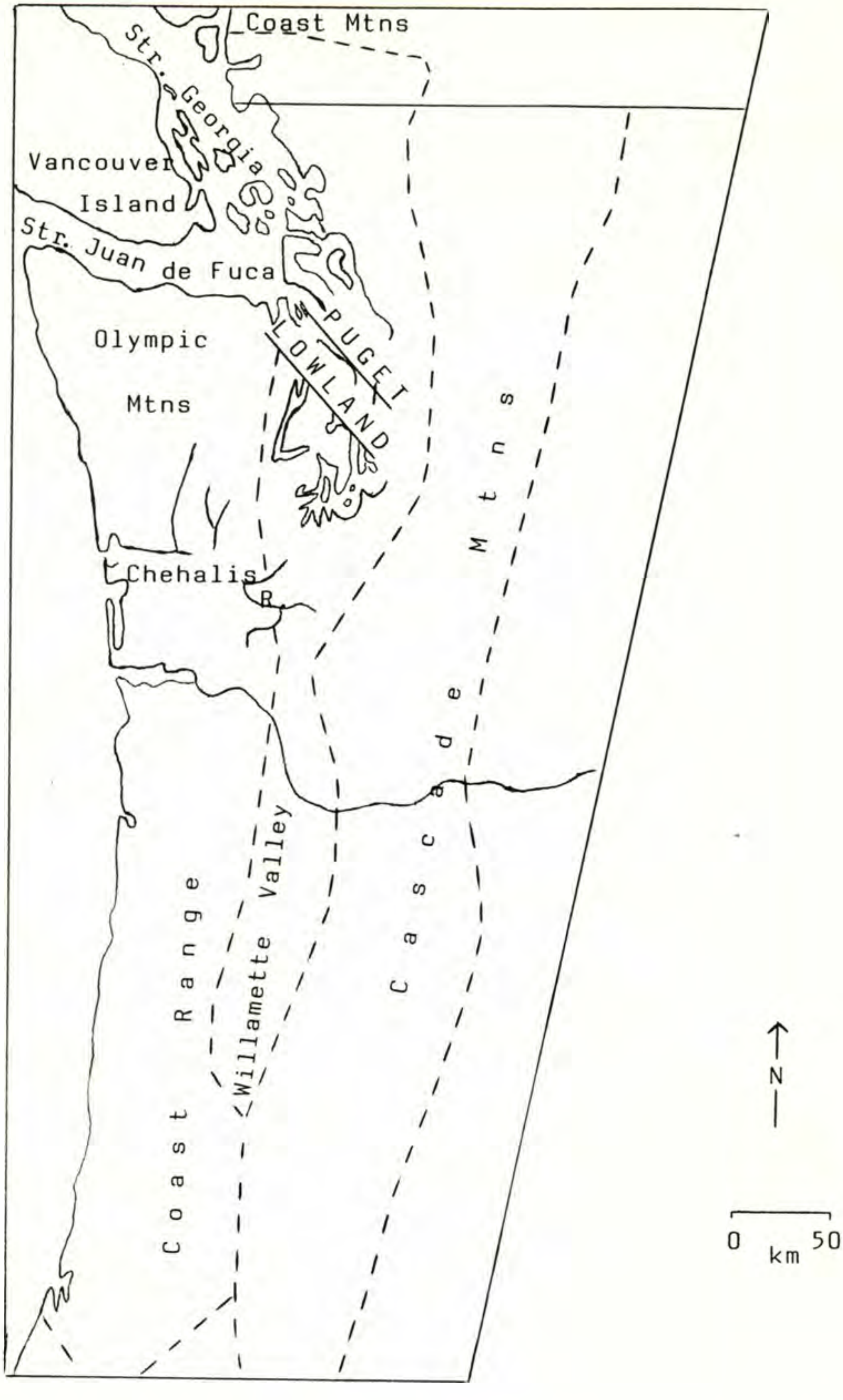

FIGURE 1. Physiographic provinces of western Washington and Oregon (after McKee, 1972).

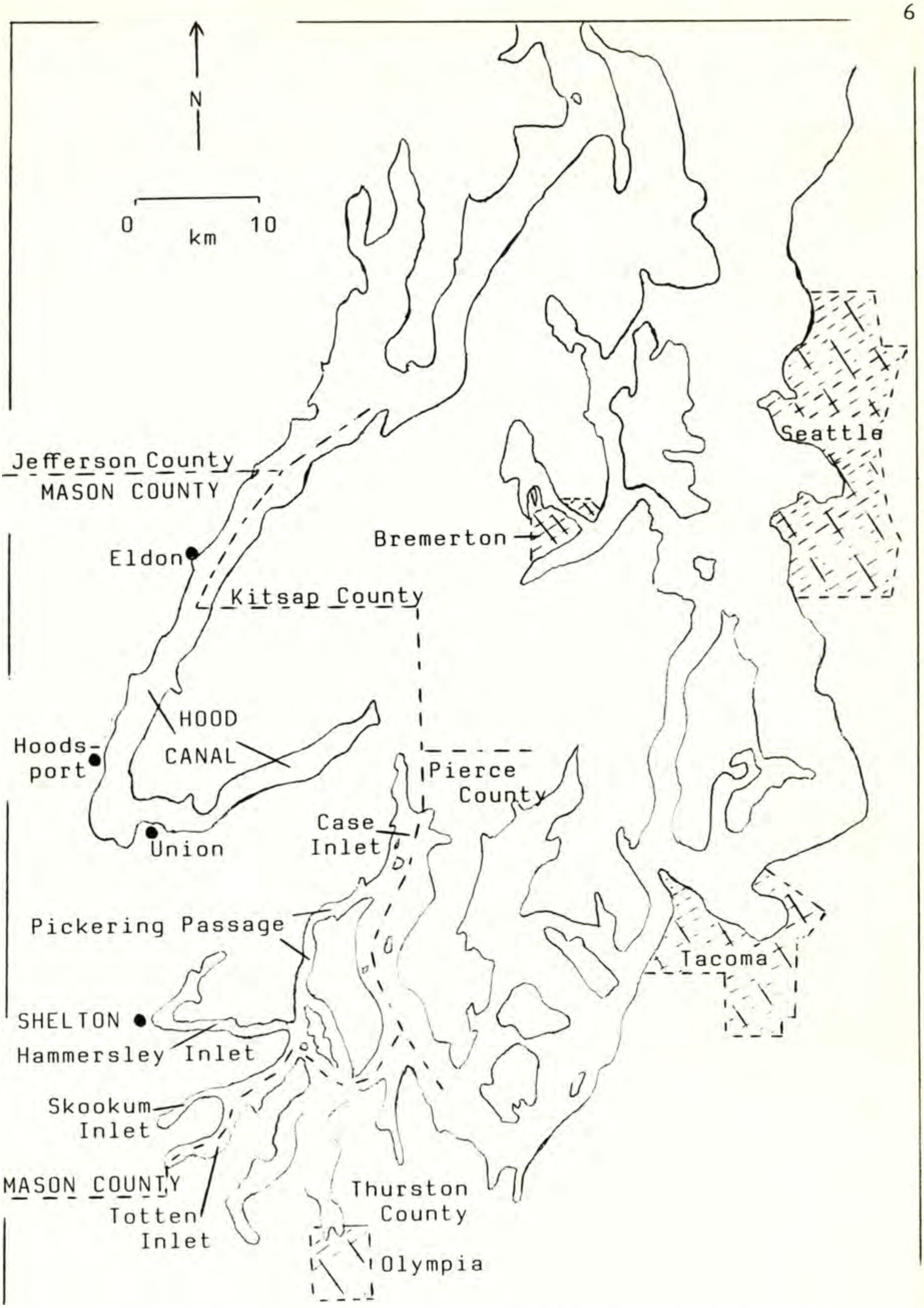

FIGURE 2. The Puget Sound Region (after University of Washington, 1954).

of the Olympic Mountains rise to elevations over 1500 meters. Relief in the southern Puget Sound area of the county is not as great as in the Hood Canal area. In the southern region, bluffs commonly reach 35 to 60 meters elevation.

Wind and Waves

Maritime air masses, originating over the North Pacific Ocean, dominate the weather patterns of the Puget Sound region, creating a marine, west-coast climatic regime. Characteristically, there is a well-defined wet season from October to March, and a less well-defined summer dry season (Pacific Northwest River Basins Commission, 1970).

The Olympic and Cascade Mountains, and the mountains of Vancouver Island to the northwest, have significant moderating influence upon the weather of the region. Cold, continental air masses from the Canadian Arctic are prevented, to a large degree, from reaching Puget Sound by the blocking effect of the Cascades. The Olympics and Vancouver Island restrict air flow from the west and northwest.

Winds, which are of primary importance to shore drift studies, are directed around the mountain ranges. Low-level passages through which air masses can move are the Chehalis River Valley, immediately south of the Olympics; the Strait of Juan de Fuca, immediately north of the Olympics; and the Strait of Georgia, east of Vancouver Island (see Figure 1).

To illustrate how regional physiógraphy affects wind patterns, a wind rose that shows average percentage frequency of occurrence of winds at Olympia Airport from 16 tabulated compass directions is given in Figure 3. The wind rose data are separated to show seasonal variations in wind frequency. The prevalence of winds from the southwest quadrant reflects the ease of passage of maritime air through the Chehalis River Valley. Winds from the northwest and east seldom occur at this station because the Olympic Mountains are situated to the northwest and Cascades to the east. The Puget Lowland stretches to the north and northeast from Olympia and its long direction is reflected in the wind rose by the fairly frequent occurrence of winds from the northeast quadrant. The wind rose indicates north to northeast winds occur more frequently in the spring and summer (April through September) than during fall and winter (October through March). The reverse trend is shown by south to southwest winds. However, southwest winds prevail throughout the year.

In addition to wind direction, wind velocity is also an important factor in the shore drift process. A second wind rose (Figure 4), also using the Olympia Airport data, shows the average velocities of winds from 16 compass directions, again divided seasonally. It shows that the prevailing south to southwest winds are also the strongest winds, and the average velocities are greater in the fall and winter.

Wave energy is primarily expressed by wave height. The height that waves can reach is related to wind velocity, duration of the wind, fetch, and depth. Wave energy increases steadily as wind velocity increases; however, as wind velocity

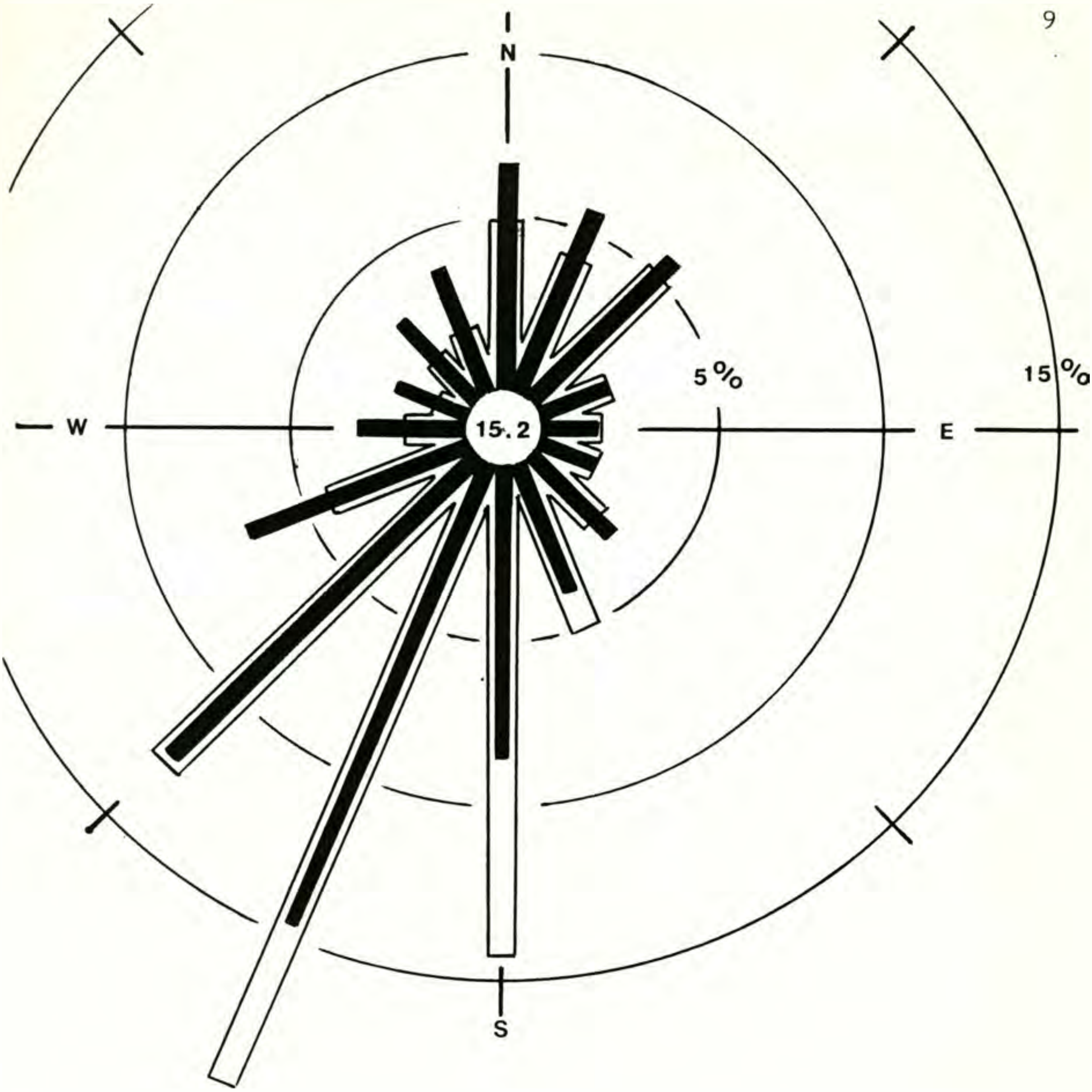

FIGURE 3. Wind rose indicating seasonal average percent-frequency of winds from 16 compass directions for Olympia Airport.

solid, narrow bar = April through September
open, wide bar = October through March
average annual percent calm (winds < 1.6 km/hr) = 15.2%.

(after Pacific Northwest River Basin Commission, 1968).

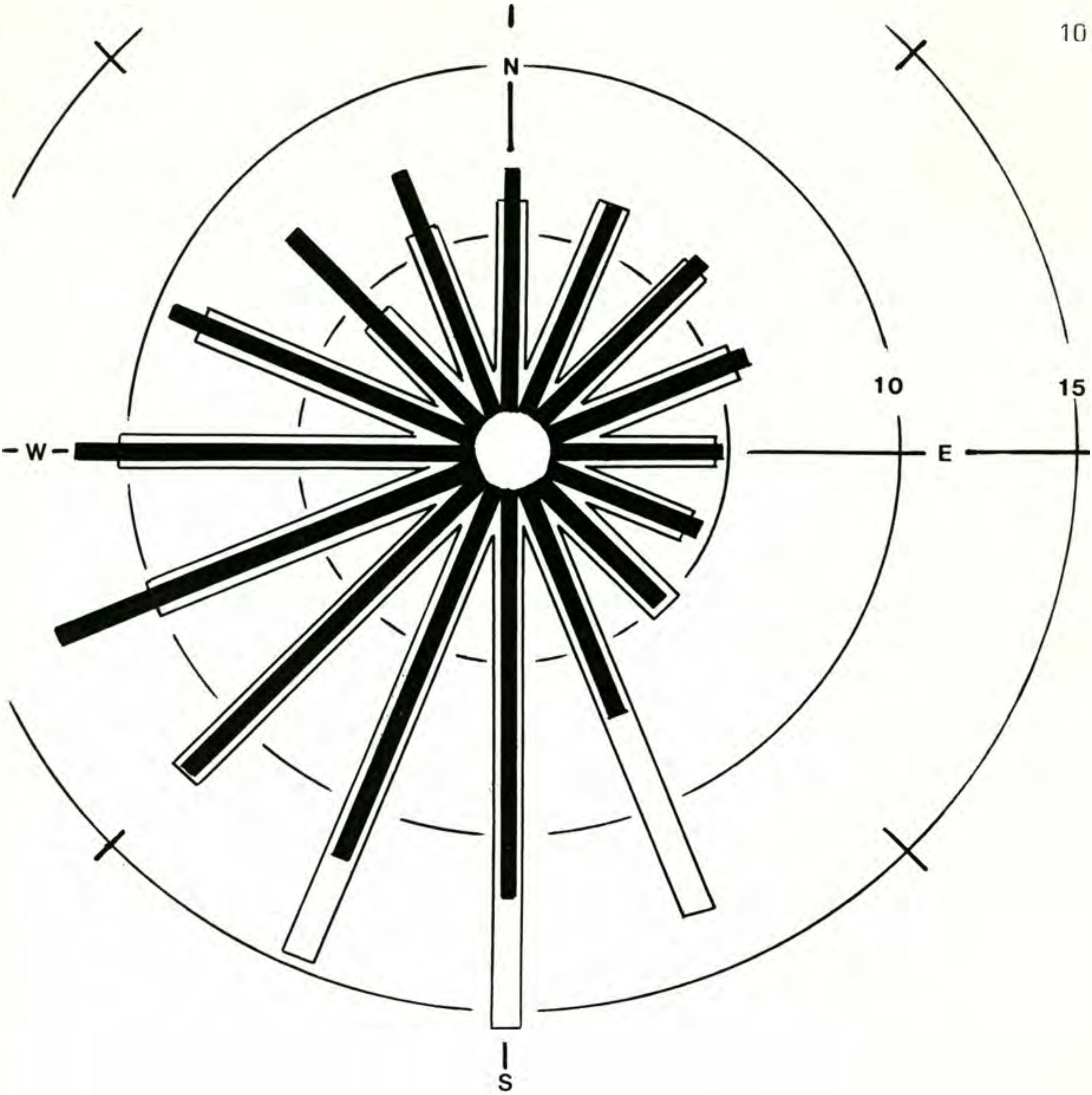

FIGURE 4. Wind rose indicating seasonal average velocities of winds from 16 compass directions for Olympia Airport (in km/hr).

solid, narrow bar = April through September
open, wide bar = October through March

(after Pacific Northwest River Basin Commission, 1968).

increases above about 15 m/s (54 km/hr), wave energy begins to increase very rapidly (Davies, 1980).

Wind velocity below 5 m/s (18 km/hr) is considered to have insignificant effects upon geomorphic processes (Davies, 1980). Data for Olympia Airport indicate that winds at or above 5 m/s occur only about 12 percent of the time, winds faster than 8 m/s (29 km/hr) occur less than 2 percent of the time, and winds greater than 15 m/s occur infrequently (Pacific Northwest River Basins Commission, 1968). However, because wave energy increases rapidly as wind velocity increases above 15 m/s, the infrequent, high velocity winds are responsible for a disproportionate amount of the wave energy expended upon the shore.

Fetch is the distance across open water over which the wind is able to directly affect waves. In Mason County, fetch is frequently less than 10 km and is a limiting factor in wave development.

Depth also is a major limiting factor to wave build-up in a few areas of Mason County, such as at the head of bays where tide flats extend a considerable distance out from shore. In some of those areas, there is a combination of shoal water and limited fetch so that wave energy is usually low.

The U.S. Army Coastal Engineering Research Center has developed numerous graphs and equations to estimate potential wave heights (U.S. Army Corps of Engineers, 1977). By extrapolation from the CERC graphs, wave heights for typical southern Puget Sound wind velocities, fetches, wind durations, and depths have been predicted and are shown in Table 1.

Although the wind and wave data are useful for a general overview of shore drift, they cannot be applied directly to the Mason County shoreline. Local wind and wave patterns are affected greatly by coastal topography. The applicability of the wind data, particularly to Hood Canal, is questionable, because Hood Canal is 50 km distant from the Olympia Airport and essentially bounded on all sides by mountains or high bluffs. However, the airport is the nearest wind recording station to the study area.

Geology

Most of the material which forms the bluffs along the shore in Mason County was deposited during the later stages of Pleistocene continental glaciation. Along the west side of Hood Canal, however, cliffs of Eocene basalt and Oligocene sedimentary rocks also occur. Table 2 outlines the geology along the Mason County shore.

Forming resistant outcrops along the northernmost 10 kilometers of the Hood Canal shore in Mason County are volcanic rocks of the Eocene Crescent Formation (Figure 5). The basaltic rocks of this formation comprise much of the Olympic Mountains (Tabor and Cady, 1978). Sandstone and shale of the Lincoln Creek Formation crops out along a short stretch of the shore north of Hoodsport. The Lincoln Creek Formation, which is Oligocene in age, is primarily found to the southwest within the Grays Harbor basin (Beikman and others, 1967).

TABLE 1: Predicted wave heights for typical southern Puget Sound conditions (after U.S. Army Corps of Engineers, 1977).

velocity (m/s)	fetch (km)	duration (hr)	depth (m)	wave height (m)
5.4	10	2	-	0.27
(19.4 km/hr)	"	6	-	0.30
	"	-	7.6	0.27
	25	6	-	0.40
8.9	10	2	-	0.55
(32 km/hr)	"	6	-	0.55
	"	-	7.6	0.52
	"	-	15.2	0.55
	16	6	-	0.70
	25	6	-	0.82
13.4	10	2	-	0.91
(48 km/hr)	"	6	-	0.91
	"	-	7.6	0.79
	"	-	15.2	0.85
	16	6	-	1.13
	25	6	-	1.31
15.6	10	6	-	1.10
(56 km/hr)	16	6	-	1.34
	25	6	-	1.52
17.9	10	2	-	1.25
(64 km/hr)	16	2	-	1.55
	25	2	-	1.83

TABLE 2: Geology of bluff and cliff outcrops along the Mason County shore.

Quaternary	Recent alluvial and organic-rich deposits (primarily deltaic areas).	
	Pleistocene Glacial & Non-glacial sediment	Fraser Glaciation: Vashon recessional outwash Vashon till Vashon advance outwash
		Olympia Non-glacial Kitsap Formation - coarse sand derived from Cascade sources. Skokomish Gravel - derived from Olympics.
		Pre-Olympia Glacial Deposits (Salmon Springs Drift) coarse sand and gravel outwash.
Tertiary	Oligocene:	Lincoln Creek Formation - marine sandstone, siltstone, mudstone.
	Eocene:	Crescent Formation - basalt flows (with pillows, columns, amygdules), mudflow breccias, interbedded fine-grained volcaniclastic sedimentary rocks.

FIGURE 5: View toward the northeast of outcrops of the Crescent Formation, along Hood Canal in northern Mason County.

Bluffs along the remainder of the Mason County shore consist of Pleistocene glacial and non-glacial deposits. Of four glaciations recognized to have advanced southward across the Puget Sound basin, deposits of only two are thought to be exposed in Mason County (Molenaar and Noble, 1970). Deposits of a non-glacial interval are also widespread.

Commonly exposed at the base of bluffs along all the channels in Mason County is drift which has been believed to be of the Salmon Springs glaciation. Recent controversy regarding this material has led to workers more frequently labeling it simply as "pre-Fraser" glacial deposits (Easterbrook and others, 1981; Washington State Department of Ecology, 1980). These deposits vary from unstratified and unsorted gravel to stratified and well-sorted sand. Where openly exposed to wave action, the material is easily eroded and the bluffs are susceptible to landsliding.

The Olympia non-glacial interval is represented in Mason County by coarse sands derived from the Cascades (the Kitsap Formation) and by gravels derived from the Olympics (the Skokomish Gravel). Clay and peat beds are occasionally found within these alluvial deposits (Molenaar and Noble, 1970). The Skokomish Gravel is common in the Hood Canal area, while sand of the Kitsap Formation occurs in a few places along southern Puget Sound. These bluffs, too, are easily eroded by wave action.

Found extensively along Hood Canal and Case Inlet is advance outwash of the Vashon Stade of the Fraser glaciation.

Occasionally, beds of clay that were deposited in ice-dammed lakes are found. Usually these have been progressively covered by coarser material as glacial advance proceeded (Figure 6).

Vashon till is found along most bluffs in Mason County, either high upon the bluffs overlying older material (Figure 7) or sometimes exposed at the base of the bluff (Figure 8). The till, being well-compacted, is less susceptible to subaerial erosion than the underlying, less-consolidated sand and gravel deposits, thus, the former remains for a longer time as vertical, sparsely vegetated escarpments. The outwash and non-glacial alluvial sediments generally support dense vegetation and slowly erode toward a more stable slope, if they are not actively undercut by waves.

Downslope movement, ranging from slow creep to land-sliding, is evident along much of the Mason County coast. The rate and quantity of movement is primarily related to the nature of the bluff material and the amount of wave erosion that occurs at the bases of the bluffs (Figures 9 and 10). In some areas, particularly along the east side of Hood Canal, disruption of the vegetation on the slopes by road grading activities has initiated rapid subaerial erosion.

Vashon recessional outwash is exposed along some areas in Mason County. Although it forms some coastal bluffs, usually it is a relatively thin veneer over till or other deposits.

Most of the sediment forming the generally thin, narrow

FIGURE 6: Clay and peat beds overlain by progressively coarser material are exposed at this bluff along the southeast side of Hartstene Island.

FIGURE 7: Along the eastern shore of Hood Canal, till, exposed several meters up the bluff, overlies less-consolidated outwash material.

FIGURE 8: Non-vegetated, vertical bluff, located at Cape Horn along Hammersley Inlet, is composed of glacial till.

FIGURE 9: A slow rate of bluff erosion along Pickering Passage is indicated by this madrona tree which is still growing despite its precarious horizontal position.

FIGURE 10: Because of wave erosion at the base of the bluff, this man-made structure located on the west side of Hartstene Island is threatened by landsliding of the outwash material.

beaches in the Puget Sound region is supplied by erosion of the bluffs (Keuler, 1983). In Mason County, there are very few streams capable of delivering significant quantities of sediment to the shore, except, however, along the western shore of Hood Canal, where streams flowing rapidly down from the Olympics can provide a considerably larger proportion of beach sediment than is provided by small streams elsewhere in the county.

Beach sediment, in this county, reflects the geology of the adjacent bluffs or cliffs. With a predominance of glacial drift bluffs, the beaches tend to be gravelly. The few sections of sandy beach are usually adjacent to bluffs consisting of Olympia non-glacial sand. Cobbles and boulders are common along the Hood Canal shore where resistant basalt and sandstone crop out.

Tides

There is a fairly common misconception that tidal currents are the main driving force of sediment transport along beaches (Keuler, 1983). Normally, they do not directly affect shore drift, although their effects can be noticeable in constricted areas (Davies, 1980).

The main influence tides have upon shore drift is an indirect limiting effect. That is, tidal fluctuations disperse wave energy across the expanse of the foreshore so that parts of the beach are only intermittently subject to shore drift processes (Davis, 1978). Consequently, bluff erosion, and the resultant supplying of sediment to the beach, may occur only during very high tides or during storms.

Puget Sound has mixed tides, which means that although tidal fluctuations occur semi-diurnally, the two high tides and the two low tides are all of different heights. This diurnal inequality is caused by the declination of the moon and sun relative to the equator (Thurman, 1975). Because the declinations change constantly, the diurnal inequality also changes.

In addition, because of the monthly revolution of the moon around the earth, there are twice-monthly spring and neap tides. The maximum tidal range (spring tide) occurs during the full and new moon phases when the moon is in opposition or conjunction with the sun, relative to the earth. Neap tide, which is the condition of minimum tidal range, occurs at quadrature, when the moon is at right angles to the sun, relative to the earth.

Other variations in the tidal cycle and tidal ranges occur because of the ellipticity of the moon's orbit about the earth, the ellipticity of the earth-moon orbit about the sun, and the angular relationship between the planes of the two orbits (Thurman, 1975).

On a local scale, dimensional variations between adjacent basins can cause large contrasts in tidal ranges. Tide statistics for Mason County are given in Table 3.

TABLE 3: Tide statistics for Shelton (Hammersley Inlet) and Union (Hood Canal) (National Ocean Survey, 1981).

	Shelton	Union
mean lower low water	+0.24m	+0.31m
mean low water	+0.79m	+0.88m
mean tide level	+2.41m	+2.10m
mean high water	+4.02m	+3.32m
mean higher high water	+4.57m	+3.90m
mean range (MHW - MLW)	3.23m	2.41m
spring range (MHHW - MLLW)	4.33m	3.60m

(Datum base: Seattle, MLLW = 0.0m)

PRINCIPLES

Shore Drift

Waves are caused by the transfer of energy from wind to water. As turbulent air moves across the water, it causes surface undulations on the water. Continuing, essentially unidirectional, air flow results in pressure variations on either side of the undulations and wave build-up commences (O'Brien, 1942).

As long as a wave is not affected by the bottom, it travels with negligible loss of energy. However, when the water depth shallows to approximately one-half its wavelength, the wave sustains frictional energy loss to the bottom. The loss of energy causes a decrease of the wave velocity. There is also a decrease in wavelength as the following waves approach more closely before they begin slowing. As the depth continues to decrease toward shore, the height of the wave increases relative to its length; that is, it becomes steeper. When its steepness reaches a ratio of approximately 1:7 (height: wavelength), the wave breaks (Thurman, 1975). The turbulence involved in the breaking of waves creates hydrodynamic forces capable of lifting beach sediment into suspension (Eagleson and Dean, 1977).

For explanatory purposes, the force of wave energy impinging on the shore at an angle can be resolved into two components -- one parallel to the shore and the other perpendicular (Figure 11a). The component parallel to the shore induces a longshore current which can effectively transport

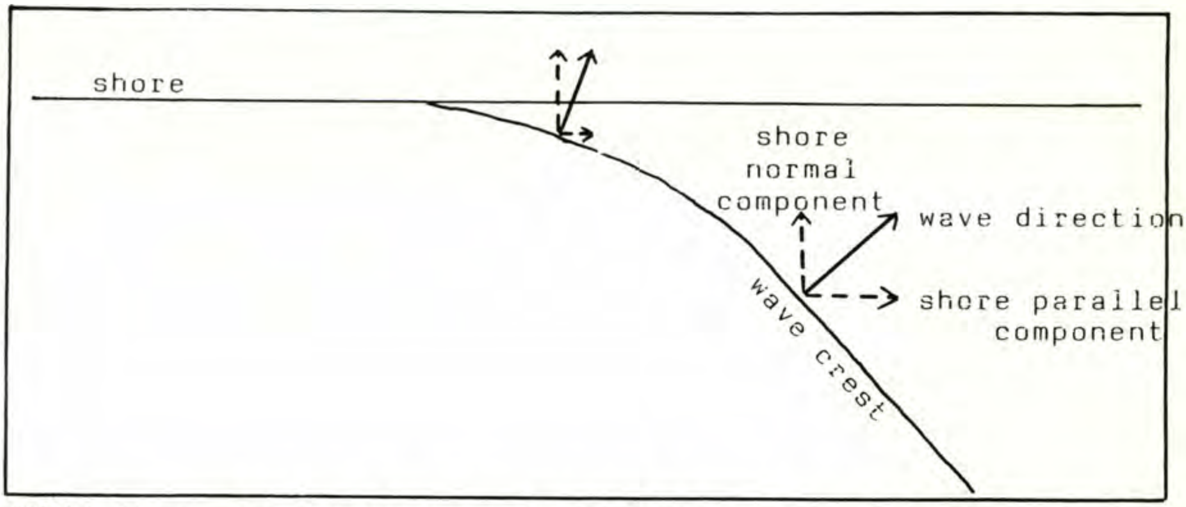

FIGURE 11a: As a wave is refracted toward a normal approach to the shore, its energy decreases; and, proportionally more of its energy is directed toward the shore (after Komar and Inman, 1970).

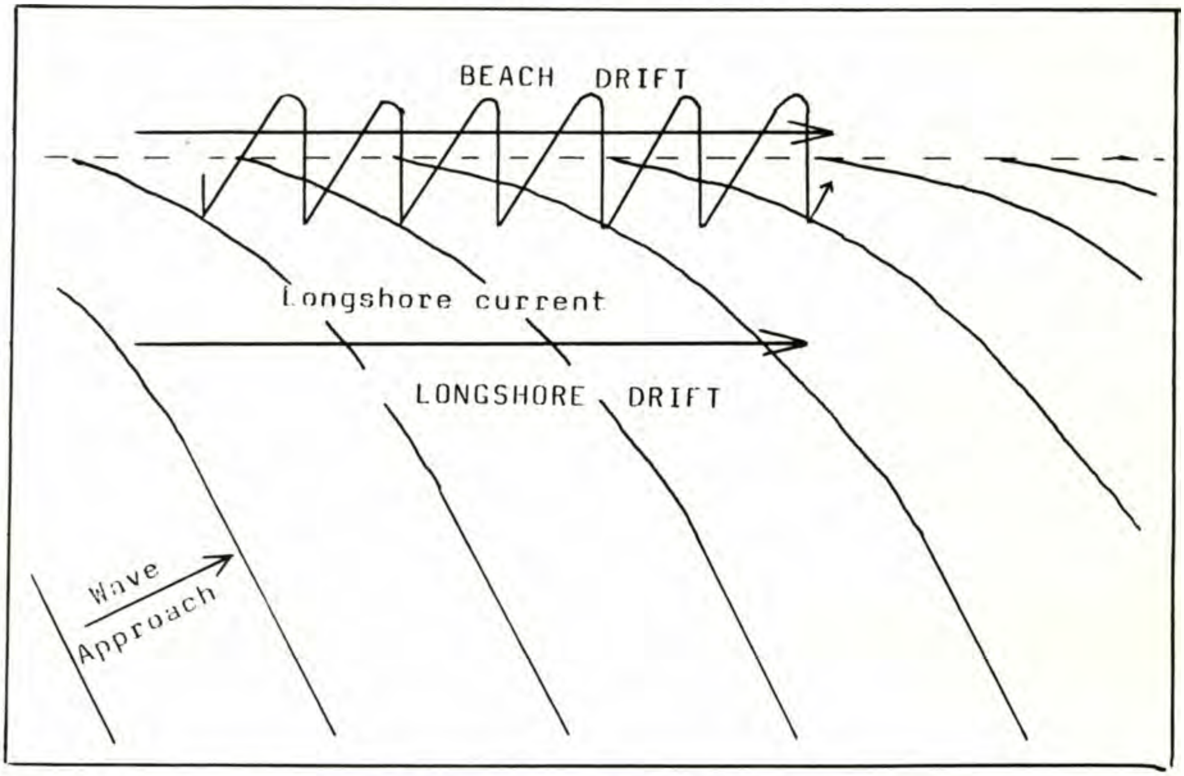

FIGURE 11b: Beach drift, caused by the swash and backwash of waves, and longshore drift, caused by wave-generated currents, combine to comprise shore drift (after Bird, 1969).

suspended sediment along the shore (Komar and Inman, 1970). The transport of sediment along the shore by wave-generated currents is known as longshore drift.

Because waves often approach the shore at an oblique angle, refraction occurs as successive portions of each wave reach shallow water and are affected by the bottom. As wave refraction proceeds, energy is lost due to bottom friction, breaking turbulence, and longshore current generation; however, considerable wave energy may still be expended on the beach. Though the wave crests are refracted toward becoming parallel to the shore, usually the waves reach the shoreline before attaining that orientation, and the water surges up the beach at some angle other than normal to the shore (Johnson, 1956).

The surge of the breaking waves moving up the beach is known as swash, and the ensuing gravitational rush of water moving down the beach face is called backwash (Johnson, 1919). Since swash and backwash generally do not sweep in parallel directions to each other across the beach, there is, for any particular transportable particle of sediment, an irregular, zigzag path along the shore (Figure 11b). The transport of sediment in this fashion is known as beach drift. The combined result of beach drift and longshore drift is known as shore drift (Johnson, 1919).

Obviously, shore drift may occur in either direction along a shore as a result of waves caused by winds from opposing directions. Usually, however, over a long period of time, a greater amount of sediment is transported in one direction, and this is known as the direction of <u>net</u> shore-drift.

For shore drift studies, the distinction must be made between prevailing wave directions and predominant wave directions. Prevailing refers only to the frequency of occurrence, that is, the most frequently occurring wind and wave direction. Predominant, on the other hand, refers to the wind and waves which have the greatest effect on the shore and are, therefore, responsible for the direction of net shore-drift (Jacobsen and Schwartz, 1981).

In Mason County, the two are usually coincident; that is, the prevailing south-southwest winds are usually the predominant influence on net shore-drift. There are several reasons for this phenomenon. First, because the south-southwest winds are the prevailing winds, waves from that direction are acting upon the shore more often than waves from other directions. Secondly, as shown by the velocity wind rose (Figure 4), the strongest winds blow from that direction, also, so that more energy is available for wave generation from the south-southwest, and larger waves may result. Finally, that part of Puget Sound in Mason County is generally aligned in a northeast-southwest orientation, thus winds from those directions have the greatest fetches and, potentially, the greatest influence upon shore drift.

Schou (1952) found that for protected coastal areas the direction of net shore-drift is often determined by the direction of maximum fetch. He found that the prevailing winds may have little or no effect upon a shore because they have little or no fetch across which they can generate waves. On the other hand, less frequent and/or less strong winds with a longer fetch may generate waves with sufficient energy to determine the direction of net shore-drift.

The balance between wind duration, velocity, and fetch is quite evident in Mason County; and, while it should be emphasized that the prevailing wind and wave direction is not necessarily the predominant direction, it is most often that way in Mason County.

Drift Cells

Because the Mason County coastline, like most of that around Puget Sound, is sinuous and irregular with numerous coves, embayments, headlands, and islands, there are frequent variations in fetch directions and distances (Figure 12). As a result, shore drift is naturally compartmentalized, with each compartment being essentially independent of the others. An individual compartment is known as a "drift cell" or "drift sector" (Jacobsen and Schwartz, 1981).

A drift cell is characterized by a direction and distance of net shore-drift. Ideally, a sector extends from a distinct origin, where sediment is supplied, to a point where the cell terminates with sediment deposition. Between the origin and terminus is some distance along which shore drift is the primary geomorphic process (Kidson, 1982).

FIGURE 12: Northward view of Pickering Passage from 300 m altitude. The numerous coves, embayments, and small islands cause net shore-drift to be compartmentalized.

Drift cell origins in Mason County are frequently demarcated by vertical eroding bluffs, which are the primary source of beach sediment (Figure 13). Some drift cells diverge from a common zone of erosion with net shore-drift proceeding away from the zone in both directions along the shore. Divergence zones, as they are called, develop wherever the balance between wind duration, wind velocity, and fetch shifts from causing predominance in one direction to another direction. Most often the cause of divergence is a change in fetch due to a variation in shoreline orientation. However, the location and length of a divergence zone is also governed by wind velocities and durations.

Drift cell terminations are frequently distinctive depositional features such as spits or related accumulation forms. However, drift cells may also end with a beach in front of a headland, beyond which sediment is deposited in deep water (Figure 14). In addition, just as some drift cells diverge, occasionally convergence occurs. Convergence often results in formation of a cuspate beach-form, but other depositional patterns are also found.

The length of beach between a drift cell origin and terminus is a zone of active sediment transport, with net transport directed toward the cell terminus. In Mason County, drift cells vary in length from tens of meters to several kilometers; and, although their boundaries are fundamentally distinct, they are not always absolute, and transport of sediment between cells may occasionally occur.

FIGURE 13: This eroding bluff marks a drift cell origin at Brisco Point, Hartstene Island.

FIGURE 14: This small headland, which extends into deep water, marks the termination of a drift cell along Hood Canal.

The presence of a shore does not assure the occurrence of shore drift. For shore drift to commence, a source of sediment must be available and there must be wave energy to transport the material. Within this report on Mason County, several sections of shore are classified as areas of "no appreciable net shore-drift". Some of these sections are located along outcrops of Tertiary rocks which do not readily erode and which are oriented such that they extend into deep water, preventing sediment bypass. Other sections of "no appreciable net shore-drift" occur in protected coves, along areas where man-made structures baffle wave energy, and at bayheads where marshes and mudflats have developed.

METHODS

Previous Investigations

In a multi-volume compendium covering the coastal zone of the individual Puget Sound counties, the Washington State Department of Ecology compiled data on shore drift, geology, land use, slope stability, flooding, and biology. The shore drift study for the Mason County volume (Washington State Department of Ecology, 1980) was conducted by Norman Associates, a consulting firm located in King County. Their mapping of seasonal shore drift was based on published wind data from various sites around Puget Sound. All of the wind data stations used are at some distance from the shore, and none are within Mason County. Though, as previously mentioned, data from established wind-recording stations may give indications of the regional shore drift pattern, the theoretical prediction of localized wave patterns cannot accurately incorporate the numerous variables which affect net shore-drift.

Ingle (1966) outlined the use of easily identifiable radioactive and fluorescent tracers to identify the direction of sediment movement on beaches. Repeated checking of these materials over a long period of time is necessary to get an idea of the long-term directions of net shore-drift. Along a coast, such as that of Puget Sound, where shore drift is extremely compartmentalized, tracers are not practical on a regional scale, but could be very useful for detailed local studies.

Around Puget Sound, detailed field investigations of geomorphic and sedimentologic shore drift indicators has proven to be the most useful method for mapping net shore-drift directions (Keuler, 1979; Jacobsen, 1980; Chrzastowski, 1982; Harp, 1983; Hatfield, 1983). These methods were utilized for this report, with field work undertaken between March and June, 1982. The field indicators sought were outlined by Jacobsen and Schwartz (1981) and are discussed below.

Shore Drift Indicators

Most of the following shore drift indicators are features of the high-tide beach and/or backshore. Spits and bars, however, are intertidal features, with bars being best developed on the low-tide terrace. In Mason County, the beach profile frequently displays an abrupt break in slope between a relatively steep high-tide beach and a gently sloping low-tide terrace (Figure 15). Usually, the high-tide beach consists of coarser material (coarse sand, granules, pebbles, cobbles), while the low-tide terrace is finer sand and silt. According to Davies (1980), this type of beach morphology is fairly common in areas which have undergone Pleistocene glaciation. Bird (1969) suggested that the development of this type of beach profile is a response of different sizes of sediment to different wave conditions. The break in slope of the beach may develop because of a large tidal range relative to predominant low-wave conditions (Inman and Filloux, 1960).

Several of the following shore drift indicators are quite closely related, and the patterns they display are inter-

FIGURE 15: The break between the high-tide beach and the low-tide terrace is shown in this photo. The view is toward the northwest along the southwestern shore of Hartstene Island.

dependent. Because a single indicator is not necessarily proof of the direction of net shore-drift, as many different indicators as could be found were studied in conjunction. In the few instances where conflicting indicators were found, it was necessary to weigh the value of evidence for each direction, with consideration given to supporting factors such as fetch and topography.

Bluff morphology transition

A relationship between bluff morphology and shore drift was first noted by Keuler (1979) and has been found to be a useful indicator of net shore-drift directions throughout the Puget Sound region. Where waves are actively eroding the shore, such as at drift cell origins, the bluffs are often vertical and non-vegetated. In such places, wave erosion at the base of the bluffs is more rapid than subaerial erosion, and the bluffs do not erode to a lower slope before being undercut by waves. Sediment tends to be conveyed away from these areas relatively rapidly, so the beaches there are commonly narrow, often with just a thin veneer of cobbles covering a wave-cut platform (see Figure 13). The amount of material forming the beach increases in the direction of net shore-drift; and, at some point along the shore, the wedge of beach sediment may become large enough for a berm to develop. As the berm develops in the downdrift direction, it increasingly protects the bluff from wave attack. As the rate of bluff erosion by waves decreases relative to subaerial erosion, there is a corresponding transition from vertical, non-vegetated bluffs to less-steep, more vegetated slopes (Figure 16). Although storm waves may remove the berm, over the long-term, the pattern of bluff transition is relatively persistent.

The transition of bluff morphology does not necessarily occur along all drift sectors; for example, where wave energy is low, bluff erosion and sediment transport may occur at insignificant rates. On the other hand, the transition may occur at any point along a drift cell where wave erosion increases because of a change in shoreline orientation. However, the transition always occurs in the direction of net shore-drift.

Bluff morphology is also influenced by the resistance to erosion of various bluff materials found in this area. For instance, till, being better-compacted that outwash sand and gravel, will remain near-vertical for a longer period than outwash.

<u>Changes in beach width and beach slope</u>

The amount of beach sediment often increases downdrift as the rate at which material is supplied approaches the rate of transport away from the source. The increase may result in significant widening of the beach, which is most noticeable along the upper foreshore, where a berm may develop (Figure 17; see also Figure 13). Berm and backshore development usually only occur near the end of relatively longer drift cells in Mason County. However, they may also form along shorter sectors, where, for instance, there is a sudden influx of material

FIGURE 16: A rapid bluff transition from vertical, non-vegetated escarpment to less-steep, well-vegetated slope occurs northeastward along Stretch Island in the direction of net shore-drift.

FIGURE 17: The berm and backshore developed along the south-western shore of Hartstene Island. This drift cell originated at the wave-cut platform shown in Figure 13.

from easily erodable bluffs.

With the increase in quantity of sediment, which tends to protect the base of the bluff because of the widening of the beach, often there is an associated steepening of the slope of the beach face. Although Bascom (1951) found that beach slope decreased in a downdrift direction in a manner related to a decrease in mean sediment-size, along the Puget Sound shore, there is usually an increase of beach slope in the direction of net shore-drift. This increase is related to the quantity of sediment forming the beach, rather than sediment size. Usually in the Puget Sound area, because there is only a thin sediment accumulation along the shore at the origin of drift cells, the beach attains the slope of the low-angle surface of the wave-cut platform (Keuler, 1979). Seldom does the amount of sediment increase sufficiently downdrift for the slope of the beach face to depend on grain-size parameters. Again, as with bluff morphology, the trends of increasing width and slope may be interrupted at any point along a drift cell.

Gradational variation in sediment size

Closely associated with trends in bluff morphology and beach width and slope is a decrease of mean sediment-size in a downdrift direction (Krumbein, 1944; Bascom, 1951; Keuler, 1979). Because low-energy waves are the most frequent type in Puget Sound, coarser sediment is less often affected by shore drift; consequently, there is a gradual size-sorting in the direction of net shore-drift as finer material is progressively separated (Figure 18). This decrease in size can also be caused

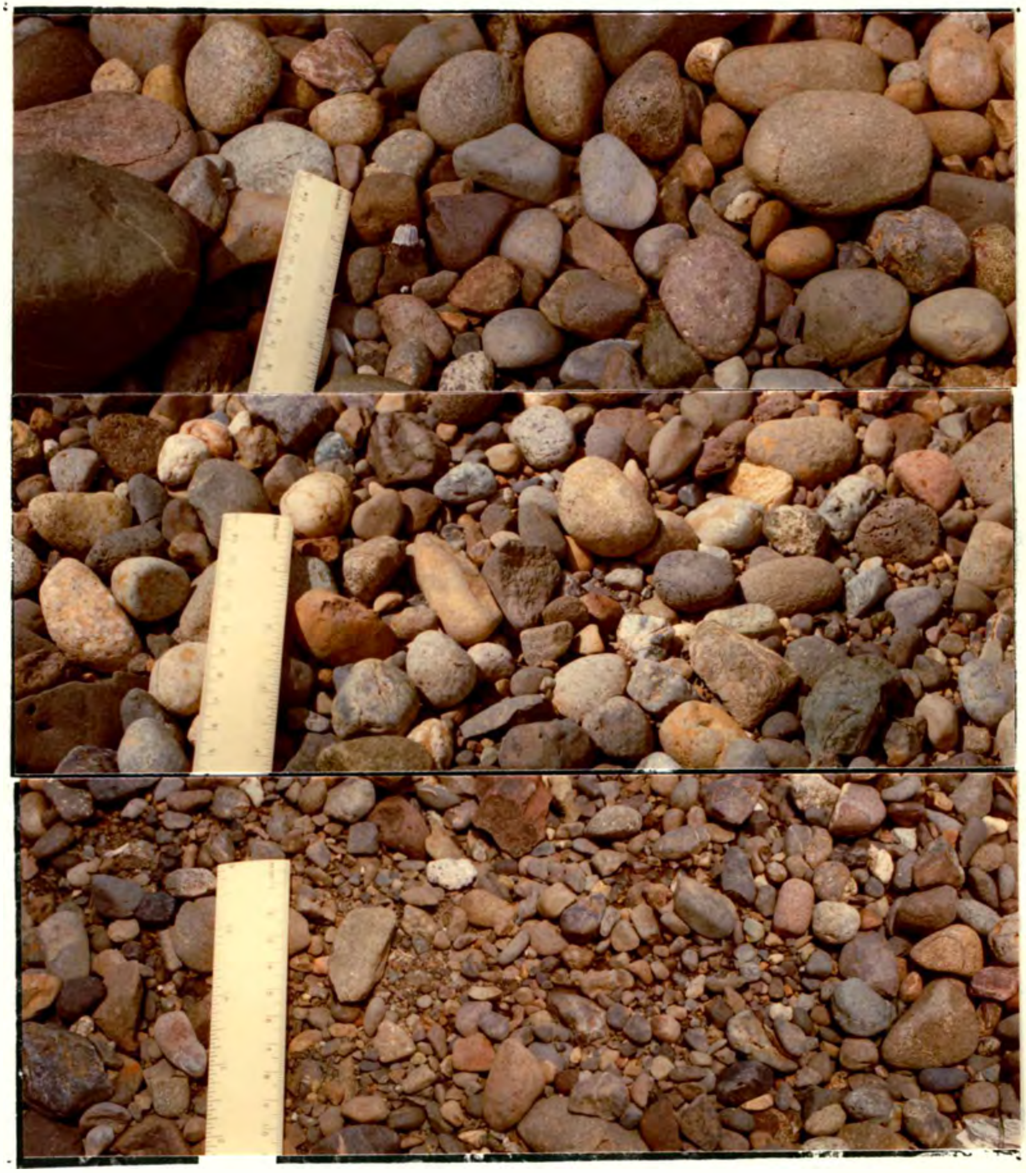

FIGURE 18: Combined photos showing typical decrease of size of sediment in direction of net shore-drift (top to bottom). Photos taken at upper foreshore level near Potlatch along Hood Canal, at approximately 150 m intervals.

by a decrease of wave energy due to shoaling water, such as at the head of a bay, or by refraction around an obstruction, such as a headland (Bird, 1969).

Most of the identified drift cells in Mason County have a downdrift sediment-size gradation, although the trend is sometimes interrupted by rapid influx of bluff material to the beach. As with the previous indicators, sediment-size decreases may occur in sequence along the length of the cell, with interruptions due to shoreline orientation changes and/or influx of sediment supply. Man-made shore development often obliterates the pattern.

Identifiable sediment

Any beach sediment which is clearly identifiable and can be traced along the shore to a point source is a possible indicator of net shore-drift (Jacobsen and Schwartz, 1981). In Mason County, because most of the bluffs consist of unsorted to poorly sorted glacial drift, the beach material tends to be a very nondistinctive gravel. Exceptions occur where sand deposits crop out along bluffs of otherwise poorly sorted outwash material and at one point along Hood Canal where a bed of shale of the Lincoln Creek Formation supplies blade-shaped rock fragments to the beach.

Sediment derived from artificial sources is sometimes traceable along the shore to its point of origin (Figure 19). Many easily identifiable materials, such as brick, asphalt, cement, and even old tires, have been used in the construction of shore protection structures. The destruction of these

FIGURE 19: Fragments of asphalt are found for many meters along the beach in the easterly direction of net shore-drift near Twanoh State Park, Hood Canal. The fragments can be traced to the fill-site at right of photo.

devices by wave-erosion provides beach sediment which is often easily identified, but only occasionally traceable to a point source. Sometimes these materials are used along a considerable distance of shore, preventing a single source identification.

Oyster shell material discarded by commercial shellfish operations is easily transported by shore drift processes. Near a few of these operations, the direction of net shore-drift is clearly indicated by downdrift beaches consisting of oyster shell fragments.

Shore drift obstructions

The pattern of accumulation and erosion at groins, bulkheads, and other obstacles is a good indicator of net shore-drift. Any object which projects across the beach face in a direction more or less normal to the shore will act as an obstruction to shore drift (Johnson, 1919). Sediment accumulates on the updrift side of such objects until the beach either overtops the object or progrades out far enough for drift to bypass the obstacle. Groins are often constructed for the purpose of building up the beach. The updrift end of bulkheads, if they project out across the beach, will accumulate sediment in a similar fashion (Figures 20 and 21). Ramps constructed for boat launching also act as groins. In Mason County, many fallen trees, too large to float in shallow water and with their root systems still attached to land, block shore drift, acting as natural groins (Figures 22 and 23).

Although drift obstructions are convenient indicators of net shore-drift, they have other effects on shore drift pro-

FIGURE 20: Sediment accumulated at the updrift side of a bulkhead built across the upper foreshore, along Hood Canal. Compare with Figure 21, the downdrift side of the same bulkhead.

FIGURE 21: Downdrift side of the bulkhead shown in Figure 20. Compare the beach level to that in Figure 20.

FIGURE 22: Sediment accumulation along updrift side of fallen tree, along northwestern shore of Hartstene Island. Ruler is 30 cm in length. Compare with the downdrift side of the tree in Figure 23.

FIGURE 23: Note algal growth on protected (downdrift) side of log. Compare beach level to updrift side shown in Figure 22.

cesses which are more serious. Erosion often becomes severe on the downdrift side of obstacles because beach sediment, which helps protect the shore, is transported away, while sediment transport into the area has been stopped (Figures 24 and 25).

Bulkheads, if built out upon the foreshore, cause wave energy to be concentrated upon a decreased width of beach, which sometimes results in beach scour. In addition, because bulkheads are sometimes used to prevent bluff erosion, they may prevent the natural supply of beach material; then beach erosion occurs as sediment is transported away and not replaced.

Spits and other accumulation forms

Long-term net shore-drift is often reliably indicated by the direction of growth of spits. Usually composed of sand and gravel, spits are depositional features which diverge from the shore and extend in the direction of predominant sediment transport (Komar, 1976). Provided there is a sufficient amount of sediment being transported, spits are often deposited where wave energy is dissipated, such as where the shoreline orientation curves away from the predominant wave direction (Figure 26), where obstructions such as islands interrupt the wave pattern, or where the water shoals, such as at bayheads (Zenkovich, 1971).

Hooks, or recurved spits, are spits which, at their distal ends, curve back toward the shore. Spits may recurve because of wave refraction around their ends and/or because of the interactions of two or more wave sets from different directions (Evans, 1942). Many of the spits found in Mason County are

FIGURE 24: This large groin at Mike's Resort, on Hood Canal, blocks shore drift and causes sediment accumulation. Downdrift side of groin is shown below in Figure 25.

FIGURE 25: Compare the sediment size and beach level shown in this photo of downdrift side of groin to that of updrift side in Figure 24.

FIGURE 26: Northward growth (toward right) of this spit at Wilson Point, Hartstene Island, occurs because of change in shoreline orientation relative to predominant wave direction. Photo taken from 300 m altitude.

FIGURE 27: This recurved spit is at the mouth of a small cove along Case Inlet.

recurved (Figure 27).

Meistrell (1972) formulated the spit-platform concept by observing spit development in laboratory models. A platform grows in the direction of net shore-drift as sediment is deposited where wave energy is dissipated. According to Meistrell, the depth of water above the platform remains constant and the platform remains below mean low water. Once there is a platform, a spit may develop as an emergent ridge upon the platform and build above the level of wave action. The platform continues to grow as the spit develops. Although the spit-platform is generally considered a singular geomorphic structure, the spit and platform grow in an alternating cycle; that is, when the platform is growing relatively rapidly, spit growth is slow. Inversely, when spit growth is rapid, platform development is slow. However, spit growth always requires preceding platform development.

Meistrell also noted that spit complexes develop as new ridges develop upon a platform on the seaward side of older ridges. In this manner, the older ridges or spits become truncated and isolated as sediment bypasses and is deposited at the distal end of the new, younger spit. The older ridges are largely protected from wave action by the newer ridges and in time become vegetated and soils develop. However, their original configuration is retained and they are excellent evidence of long-term net shore-drift.

Cuspate spits or other cuspate accumulation forms occur where two drift cells converge. Often, depositional growth of a spit leads to the formation of a wave shadow, so that waves from the opposite direction become predominant over a short section of shore, and convergence becomes marked by a cuspate form (Zenkovich, 1959). Often these beach forms are asymmetrical because of considerable variation in wave energy and sediment supply from the opposing directions.

Stream diversion

Stream mouths are commonly diverted in the direction of net shore-drift by spits or spit-like forms (Bird, 1969). A stream channel may act as a physical barrier to shore drift, causing deposition of beach material at the updrift side of the channel. Deposition causes deflection of stream flow toward the downdrift direction, resulting in erosion of the stream bank on the downdrift side of the channel.

The scale of stream diversions in Mason County ranges from a few meters (Figures 28 and 29) to a few hundred meters, with the smaller sizes more usual. Elsewhere around Puget Sound, diversions up to a few kilometers are known (Jacobsen, 1980).

In Mason County, even the smallest intermittent streams show the influence of shore drift. These small streams are incapable of causing significant sediment deposition; however, the flow of these small streams prevents the passage of smaller-size sediment. The sharp contrast in sediment size on either side of the streams is consistent with net shore-drift throughout the county. That is, immediately downdrift of a stream, the sediment is coarser than that on the updrift side. These

FIGURE 28: Diversion of this very small stream occurs along the base of the bluff for a few meters before the stream crosses the shore north of McLane Cove.

FIGURE 29: The small stream at left is diverted in the direction of net shore-drift by spit-like deposition, along Hood Canal.

small-scale features could be obliterated by storm conditions, but they would reappear after some period of calmer conditions.

Chrzastowski (1982) noted that stream deltas are often asymmetrical with accumulation of finer sediment occurring along their updrift margins, while the beach undergoes some degree of erosion at the downdrift margin. This pattern of deposition and erosion at deltas consistently indicates the direction of net shore-drift in Mason County.

Oblique bars

Numerous varieties of wave-formed bars and explanations for bar development are described in the literature (Greenwood, 1982). Bars form under a wide range of conditions of wave energy, tidal range, nearshore slope, and other factors, so care must be used in interpreting the relationship of bars to shore drift.

Bar-type sand waves often occur in a series along Puget Sound beaches. Generally, these bars are aligned parallel to the crests of the predominant waves. According to Sonu (1973), bar-type sand waves can develop if there is a gentle bottom slope, an abundance of beach sediment, and a predominance of lateral wave incidence. These three conditions are met by the bars shown in Figure 30 and by similar series of bars found elsewhere in Mason County. Sonu compares the formation of these bars to the formation of sand-wave trains in open channels. A wave-generated current moving over an erodible bed results in the development of sand waves. These sand waves, or bars, are sensitive to changes in wave direction and may be modified

FIGURE 30: A series of oblique bars along the east coast of Hartstene Island. Net shore-drift is northward, to the right in photo.

in form because of repeated changes of wind direction. If the predominant waves approach shore at a very low angle, rather than being essentially normal to shore as in Figure 30, then the bars may point in the direction of net shore-drift.

Crescent-shaped bars are found occasionally in Mason County. Usually they are attached to shore, spit-like, at their updrift ends and are asymmetric in cross-section with their shoreward, downdrift sides being much steeper than their updrift sides. Small crescentic bars often occur at small coves where the bars are migrating into shoal water (Figure 31). Larger crescentic bars are found at the updrift edge of some deltas in Mason County.

FIGURE 31: Crescentic bars at mouth of a small cove indicate net shore-drift is from the right (south) to left, towards Arcadia.

DESCRIPTION OF THE MASON COUNTY DRIFT CELLS

The Maps

In this report, the Mason County coast is divided into six regions (Figure 32). The divisions are arbitrary and were established for convenience in mapping and discussion. No other significance is implied.

Drift cells are numbered sequentially and follow the order of the maps. That is, drift cells 1 through 13 are drawn on map 1, drift cells 14 through 21 on map 2, and so on.

An explanation of symbols used in mapping net shore-drift is included on each of the six maps (map pocket, inside back cover).

MAP 1: Central Hood Canal

(Drift cells 1 - 13)

Drift cells 1 and 2

Triton Head, composed of basalt of the Crescent Formation, is a headland which projects northeastward from the north-northeast trend of the west side of Hood Canal at the northern boundary of the county. Triton Cove, to the north of the headland, is sheltered from the prevailing southwesterly winds, so that winds from the northeast, with a fetch up to 20 km, are the predominant shore drift influence within the cove.

Drift cell 1 originates to the northeast in Jefferson County, and net shore-drift is southwestward into Triton Cove. Along the Mason County portion of this sector, several small groins have slight accumulations of sediment along their north

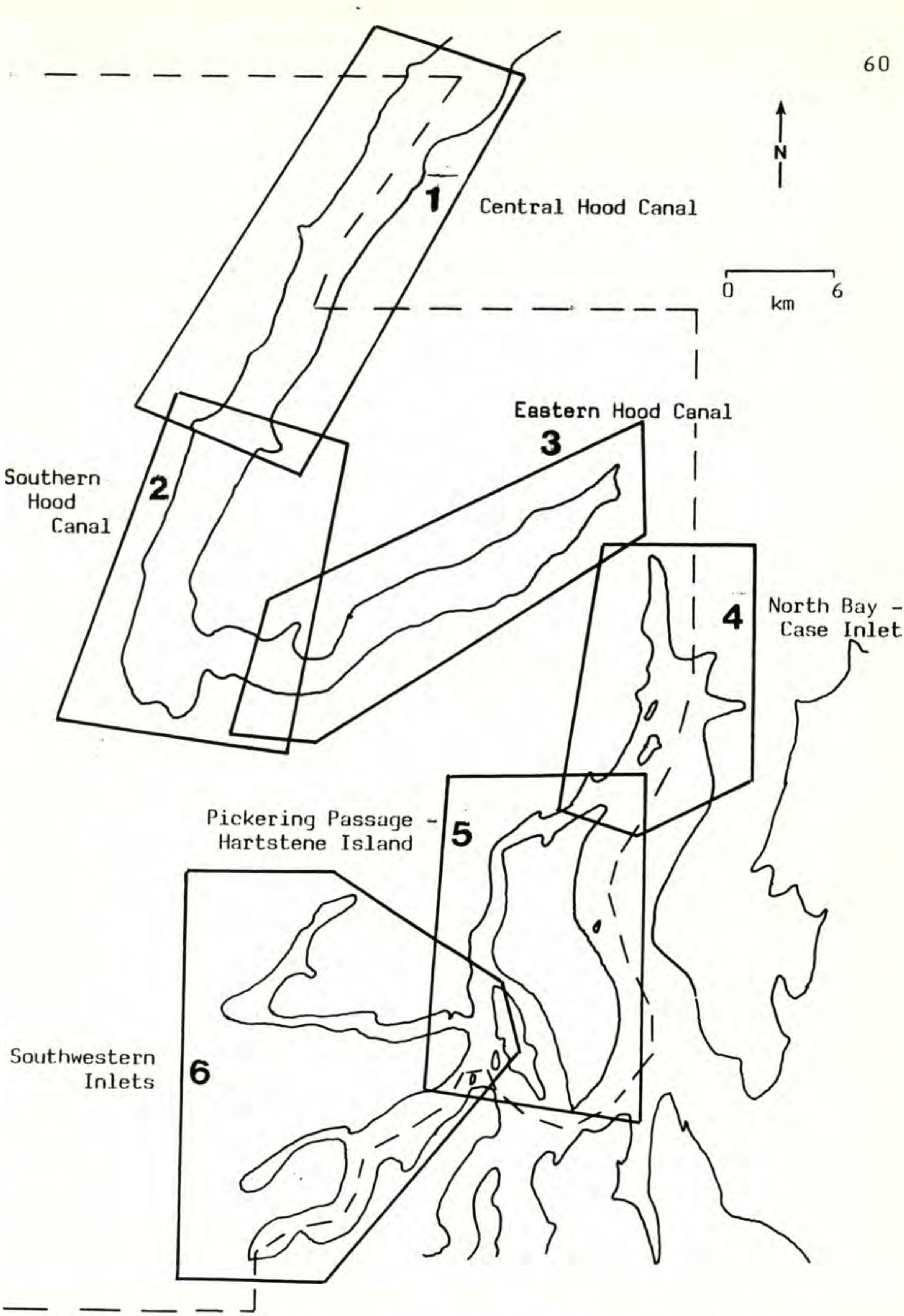

FIGURE 32. Map showing 6 divisions of Mason County coast for drift cell discussion.

sides, and there is erosion along their south footings. The beach is narrow and cobbly, and little easily transportable sediment is available. Nonetheless, the beach widens toward the head of the cove; and although the sediment remains predominantly cobble-size, a larger proportion of finer material is evident at the cell terminus.

Converging with sector 1 from the east-northeast, drift cell 2 displays much the same drift indicators as the first. Slight sediment accumulations, to the east of boat launch rails which cross the shore, indicate that some sediment transport does occur along this cobbly sector. The sector originates a short distance west of an intertidal wave-cut platform located at the northern tip of Triton Head, and the narrow beach widens toward the terminus within the cove.

More resistant exposures of basalt at the outer (eastern) edge of Triton Head project into deep water, thus limiting sediment bypass. Small pockets of pebbly and shelly sediment found between the more resistant outcrops indicate that some transport past the projections does occur, possibly during extreme storm conditions. The shell material is not necessarily proof of significant transport because of the presence of numerous invertebrate fauna, particularly oysters, which inhabit the intertidal surfaces of the rocks at the headland. Because the sediment between the outcrops does not show any directional pattern, this appears to be an area of no appreciable net shore-drift ("nansd" on the map).

<u>Drift cell 3</u>

Drift cell 3 originates about 3 km southwest of Triton Head at the small, pebbly delta of an intermittent stream. Waves generated by prevailing winds with a fetch of approximately 30 km are the predominant shore drift influence and cause northeastwardly net shore-drift. Northeastward from the delta, the sediment decreases in size from large to small pebbles. For about 1 km along this sector, the beach is fronted by riprap and a bulkhead which were built to prevent wave erosion and protect shore development. Small groins projecting from the bulkhead footings have sediment accumulated to the southwest.

Northeastward from the bulkhead, along the central portion of drift cell 3, resistant outcrops of basalt again project across the shore. Unlike the situation at Triton Head, however, these outcrops do not extend into deep water and the intervening pockets of sediment show a pattern of northeastward drift, that is, pebbly material is piled up at the southwest sides of the groin-like outcrops.

At Beacon Point, a small residential/recreational development, a boat ramp extending about 30 m across the upper beach has significantly blocked northeastward shore drift (Figures 33 and 34). The beach to the southwest of the ramp has prograded outward so that an approximately 10 m horizontal offset of the shoreline now exists.

The Beacon Point development obscures the original geomorphic configuration of the Schaerer Creek delta. However,

FIGURE 33: Sediment accumulated updrift (southwest) of boat ramp at Beacon Pt., Hood Canal. Note position of white boat relative to beach and compare with Figure 34.

FIGURE 34: Downdrift (northeast) side of boat ramp at Beacon Pt. Compare with Figure 33, and note driftwood-littered backshore on updrift side.

a depositional pattern, which is typical of most of the deltas along this shore of Hood Canal, is evident. On the updrift margin of the delta (southwest margin in this case), a sizeable accumulation of relatively fine sediment is deposited. Often, a spit-like beach form, or a considerable berm, develops. At the Schaerer Creek area, a berm and driftwood-littered backshore are evident southwest of the boat ramp (Figure 34). On the downdrift margin of the delta, the adjacent beach is somewhat eroded and has a preponderance of cobble-size sediment.

Northeastward from the delta, sediment size again decreases until the terminus of drift cell 3 is reached at the southern flank of Triton Head. Here, a spit has prograded northeasterly so that its distal end nearly reaches the basalt which forms the headland. Drainage from a lagoon enclosed by the spit keeps a small channel open between the basalt and the end of the spit.

Southwest from the origin of drift cell 3, for a distance of about 1 km, the shore is formed by basalt cliffs which extend into deep water, resulting in a zone of no appreciable net shore-drift.

Drift cells 4 and 5

These two short drift cells diverge from the delta of a small stream located about 2.5 km northeast of Cummings Point. Net shore-drift in the 0.5 km long drift cell 4 is north-northeastward and terminates at the southern end of the "nansd" section of basalt cliffs. Sediment size decreases northward from the delta to a large groin at Mike's Resort, near the sector terminus. Pebbly sediment has accumulated south of the groin resulting in a vertical offset of the beach of more than 1 m (see Figures 24 and 25). Erosion to the north of the groin has left cobbles and boulders immediately adjacent the structure, but the sediment decreases to pebble-size northeastward toward the terminus. Immediately north of the groin, the channel of an intermittent stream has been diverted northeastward across the shore.

The approximately 250 m of southward net shore-drift of drift cell 5 is indicated by a decrease in size of the pebbly sediment toward the south and by piling of the sediment along the north side of a basalt outcrop which marks the sector terminus. Similar to Triton Head, this outcrop moderates the prevailing southwest wind influence; thus, northeast winds and waves are predominant along a short stretch of the shore.

For a distance of about 0.7 km southwestward from the terminus of drift cell 5, basalt cliffs prevent appreciable shore drift.

Drift cell 6

Basaltic cliffs to the southwest and northeast essentially confine the northeastward net shore-drift of this sector to the delta of Waketickeh Creek. There is some sediment accumulation southwest of logs. Dredging and artificial channelization of the present stream mouth and other development on the delta have obscured the natural geomorphic configuration. There is topographic suggestion that the stream channel was originally diverted northeastward. That is, a gulley which appears to have been a stream channel is oriented toward the northeast along the edge of the now developed delta area.

There is no appreciable net shore-drift along the cliffs at either end of drift cell 6.

Drift cell 7

At Cummings Point, on the north side of the Hamma Hamma River delta, sediment accumulation south of logs, and a general decrease of sediment size northward, indicate net shore-drift in a northerly direction. Drift originates along the northern side of the delta and terminates approximately 0.7 km to the north, at the southern end of outcrops of the Crescent Formation where sediment is deposited into deep water.

The slightly embayed delta area of the Hamma Hamma River is a prograding marsh and is mapped in this report as an area of no appreciable net shore drift.

Drift cell 8

From a divergence zone 0.5 km north of Ayock Point, net shore-drift in drift cell 8 is northward to the mouth of the Hamma Hamma River, a distance of approximately 3.8 km. The divergence zone is the result of a wave shadow caused by Ayock Point. Much of the bluff along this sector is protected at its base by riprap, which retards wave erosion of the bluff. The pebbly upper foreshore along the divergence zone is narrow, but widens northward. At the same time, the size of the sediment decreases to sand at a prograding beach on the south side of the Jorsted Creek delta. Also indicating northward net shore-drift are sand bars migrating onto the delta from the south and the northward diversion of the mouth of Jorsted Creek.

North of the Jorsted Creek delta, the beach is again narrow and consists of coarse material of pebble and cobble size. Again, the sediment decreases in size and the beach widens in a northerly direction to the Hamma Hamma delta; where, similar to the pattern at Jorsted Creek, there is a prograding sandy beach and numerous sand bars moving onto the delta (Figure 35).

A complex spit, which originally diverted the Hamma Hamma River northward, is visible in the delta area. However, the present river outlet is confined by long quarrystone jetties which truncate the spit and direct the river flow eastward, perpendicular to the shore (Figure 36).

Drift cell 9

From the divergence zone north of Ayock Point, net shore-drift along drift cell 9 is toward the south and southeast and terminates at the tip of Ayock Point, which is a cuspate spit formed by drift convergence. From the narrow beach at the divergence zone, the beach widens to the southeast along the north side of the point. In addition, the slope of the beach face increases toward the point, and the sediment size decreases. There is a slight accumulation of sediment to the northwest of a boat ramp which crosses the beach, also indicating southeastward net shore-drift.

FIGURE 35: Crescentic sand bars are migrating northward onto the Hamma Hamma River Delta.

FIGURE 36: The artificial channel of the Hamma Hamma River truncates the spit which originally diverted the stream northward. Stone jetties in the distance cross the intertidal portion of the delta. View to the east.

Drift cell 10

At the north side of the entrance to Lilliwaup Bay, there is a shore drift divergence zone. Net shore-drift in drift cell 10 is northeastward from this zone and continues for approximately 7 km to the convergence zone at Ayock Point. At the origin, a wave-cut platform is exposed through a thin veneer of cobbles and boulders. Sediment size decreases in a northeasterly direction to a sandy prograding beach located at the south edge of the Eagle Creek delta.

At Eagle Creek, Highway 101, which follows this shore, has been built upon a spit which diverted stream flow northward. Though the area has been altered by development, the remnant of a lagoon on the landward side of the spit was still visible in mid-1982.

Northeast of the Eagle Creek delta, the sediment is very coarse (cobbles), but decreases in size to sand and pebbles at Ayock Point. There are a series of groins and bulkheads along the last kilometer of this sector that have accumulations of sediment to their southwest.

Although Ayock Point maintains a typical cuspate form, sediment deposition by a stream on its south side has formed a delta where a tide flat has developed, while the northern shore descends steeply to a good small-boat anchorage.

The base of the bluff along much of drift cell 10 is protected by riprap to prevent bluff erosion and subsequent destruction of the highway. Consequently, relatively little sediment is supplied to the beach.

Drift cell 11

Net shore-drift in this short sector is northwestward into Lilliwaup Bay. From the boulder-strewn wave-cut platform at the north side of the entrance to the bay, the sediment decreases in size to a gravelly, prograding beach at the footings of the highway bridge at the head of the bay. The bay originally extended farther inland, but highway construction isolated the western portion and now marks the terminus of shore drift into the bay. Riprap protects the base of the bluff along the entire length of this sector.

Drift cell 12

The shore drift pattern of Dewatto Bay on the eastern side of Hood Canal is quite similar to that of Lilliwaup Bay. From a divergence zone at the north side of the bay entrance, net shore-drift of drift cell 12 is southeastward into the bay and terminates at a sandy spit which is prograding southeastward within the bay. Beach sediment, derived from the eroding bluff at the divergence zone, grades in size from pebbles and cobbles at the drift cell origin to sand at the spit terminus.

Drift cell 13

Drift cell 13 begins at the divergence zone between it and sector 12 at the north side of the entrance to Dewatto Bay. Net shore-drift in a northeasterly direction is indicated by sediment accumulation southwest of obstacles (primarily fallen trees, but also a few bulkheads near the origin), and by the northward diversion of several intermittent streams situated at various points along the shore.

The beach along the Mason County portion of this drift cell is narrow and consists primarily of cobble to pebble-size sediment. For most of the length, berms only develop at a few drainage areas where the flow of intermittent streams cause a slowing of sediment transport. A continuous, but narrow, berm has developed near the Mason-Kitsap county boundary, along the last kilometer of this 9 km long sector. Streams along this latter portion show well-developed northeastward diversion (see Figure 29). Northeastward net shore-drift of drift cell 13 continues approximately 1 km beyond the county line to Chinom Point, a cuspate spit in Kitsap County (Schwartz and Taggart, 1982).

Residential development along this section of the Hood Canal shore is extremely limited. Although generally thickly vegetated, the bluffs rise steeply to elevations of 120 to 180 m. Mass wasting of the deposits that form the bluffs normally occurs at a slow rate. Trees along the toe of the bluffs appear to topple at a steady, but slow, rate; so that, along any particular section, dead, barnacle-encrusted, fallen trees are interspersed with precariously leaning, but still growing, trees. However, there are areas where larger-scale mass wasting is evident; particularly where attempts at road building have been made along the upper slopes of the bluff.

Hood Canal is quite deep very near to this shore. Wave-cut platforms, which are frequently exposed through a thin wedge of beach sediment, are not very wide, seemingly indicating that wave erosion of the bluffs is not rapid. Because there are no streams capable of supplying significant amounts of sediment to the beach along this sector, essentially all of the beach material must be derived from the bluff. The sparsity of beach sediment suggests that wave erosion of the bluffs is not rapid. It appears that because this shore is parallel to the predominant wave direction, and because the water shoals very suddenly close to the shore, the waves are only slightly refracted and wave energy is primarily directed along shore, rather than up the beach toward the bluff. This orientation of the shore tends to favor transport of beach material, while not extensively allowing erosion of the bluff to supply more material.

MAP 2: Southern Hood Canal
(Drift cells 14 - 21)

Drift cell 14

Immediately south of Sund Creek, along the western shore of Hood Canal, sandstone of the Lincoln Creek Formation forms a cliff which extends into deep water, resulting is a section of no appreciable net shore-drift.

North-northeastward net shore-drift along drift cell 14 originates at the delta of Sund Creek. Residential development upon the delta has obliterated the original depositional pattern; but groins, extending from the bulkhead which protects the development area, have sediment accumulated to the south. In addition, an intermittent stream, located at the northern edge of the delta, is diverted northeastward across the shore.

North of the delta, more outcrops of Lincoln Creek Formation occur; however, they do not extend into deep water, and therefore do not completely block shore drift. Distinctive blade-shaped fragments of rock can be traced northward from an outcrop of shale which is interbedded with the more resistant sandstone. Northward from the outcrop, the shale fragments become progressively smaller, indicating net shore-drift in that direction.

Approaching Lilliwaup Bay, where drift cell 14 terminates, there are numerous groins and bulkheads with accumulations of sediment along their south sides, indicating net shore-drift toward the north. The shore in this area is protected by riprap and bulkheads, and much of the beach consists of very coarse, cobbly sediment.

<u>Drift cell 15</u>

To the north of Finch Creek, at Hoodsport, sediment accumulations at the south sides of groins and bulkheads indicate northward net shore-drift. Much of the shore along this sector is protected by riprap. Along a nearly 2 km length of this shore, riprap and fill have been placed upon the upper shore for building purposes. Consequently, only a narrow beach is exposed at low tide levels (Figure 37). The beach material consists largely of cobbles and boulders, although pebbles occur frequently at obstacles such as irregularities in the riprap where large blocks of rock project from the base.

Good indicators of northward net shore-drift occur in the

FIGURE 37: Northward view of development upon the upper shore of Hood Canal, north of Hoodsport. Only a very narrow beach is exposed at low tide. Note accumulation of sediment at near (southern) end of development and how the small waves are approaching the shore.

Miller Creek area where sediment has accumulated at the south sides of several groins. About 300 m north of Miller Creek, an outcrop of resistant rock of the Lincoln Creek Formation projects across the shore and marks the terminus of drift cell 15 (see Figure 14). Along this segment of beach, there is a northward decrease of sediment size and an increase in the slope of the beach face.

Although net shore-drift is clearly indicated to be northward from Hoodsport, for a distance of 1.5 km southward from Finch Creek, there are no clear indications of a predominant direction of shore drift. This long section is mapped as a divergence zone in this report, since to the south, beginning at Hill Creek, net shore-drift is clearly southward. Either commercial development in the Hoodsport area has obliterated shore drift indicators, or the long-term balance of fetch (35 km northeast and less than 7 km south), wind velocity, and frequency results in a relatively lengthy zone of divergence. Erosion is not particularly severe anywhere along this zone, although nearly the entire length of shore is fronted by shore-protective riprap. Sediment accumulations occur to either side of groins and bulkheads, thus no pattern is discernible.

Drift cell 16

From the apparent divergence zone in the Hoodsport area, net shore-drift in drift cell 16 is southward to Potlatch, then southwestward to the outlet channel of the Tacoma City Light electrical generation plant. Accumulations of sediment occur to the north of numerous groins at Potlatch, indicating southward net shore-drift. Also at Potlatch, a small, spit-shaped form is prograding southward. About 0.5 km southwest from the rounded point at Potlatch, a row of pilings has interrupted shore drift and caused formation of a sand bar at its base. The outlet channel for the power station has been dredged and blasted through the underlying wave-cut platform and forms the terminus of drift cell 16 (Figure 38).

Drift cell 17

Drift cell 17 originates immediately south of the power station outlet channel. A boat ramp, 100 m south, has blocked southward net shore-drift so that a 15 cm vertical drop of the beach face occurs from the north side of the ramp to the south. South from there, toward Potlatch State Park, sediment accumulations to the north of several groins also indicate southward net shore-drift. Pebble bars at the park are oriented southward. Southward from the park, the sediment size decreases from cobbles and pebbles to pebbles to sand along a 500 m section of beach (see Figure 18). Where the shoreline of Annas Bay curves to the southeast, a small spit diverts a stream in that direction. A second stream, 100 m to the southeast, is similarly diverted. Beyond the second stream, shore drift becomes insignificant along the prograding delta of the Skokomish River.

The present Skokomish River channel is located on the far southeastern side of its floodplain in a manner consistent with the net shore-drift of the area; however, there is no evidence

FIGURE 38: An outlet channel dredged for an electrical generating station at Potlatch marks the terminus of drift cell 16. Note people to right of channel, for scale.

that its position is the result of shore drift.

Drift cell 18

A short sector of southward net shore-drift along the eastern edge of the Skokomish delta is indicated by accumulations of sediment to the north of bulkheads. Shore drift here is minor and probably negated by flood flow of the Skokomish River. In addition, wave energy is low, as tidal mud flats extend about 2 km to the north and west.

Drift cell 19

About 1 km south of the point at Union, sediment accumulations south and erosion north of groins indicate net shore-drift toward the north. Shell material from a commercial oyster operation there extensively covers the beach to the north of the operation. Very little shell material lies on the beach to the south. A crescent-shaped bar, consisting entirely of oyster shell material, was oriented in a manner indicating northward migration of the bar. Although fetch from the west and southwest is only a few kilometers at most, and the water is quite shallow, wave energy is sufficient to move some sediment, especially the very light shell material.

Net shore-drift continues around the point and then to the east of Union. Sediment accumulations occur at the west side of groins, bulkheads, and a boat ramp at Union. Eastward from Union, numerous accumulations to the west of groins and bulkheads continue to indicate net shore-drift toward the east. In addition, the beach widens eastward and sediment size decreases.

Drift cell 19 terminates at a small cove at Alderbrook, 2.5 km east of Union, where it converges with drift from the east.

Drift cell 20

Net shore-drift is eastward along drift cell 20 from a divergence zone at Ayres Point on the northeast shore of the Great Bend of Hood Canal. Indicating net shore-drift to the east, the beach widens, sediment size decreases, and sediment accumulates west of numerous groins, bulkheads, and other obstacles. One kilometer to the east of the point, a prograding sand and pebble beach diverts a small stream eastward. East of the stream, the beach is somewhat eroded, but it again widens farther east. There are numerous groins and bulkheads along the remainder of this sector, and all have accumulations of sediment to the west. Many show erosion to the east, but generally, it is not severe. The 4.5 km long drift cell ends at Tahuya, a large, prograding area at the mouth of the Tahuya River.

Drift cell 21

Net shore-drift along sector 21 diverges at Ayres Point from drift cell 20 and continues northward to Musqueti Point, then northeastward to Dewatto, a total distance of approximately 10 km. The beach at Ayres Point is narrow and there are numerous large boulders upon it. The shore here has an eroded appearance because of the coarse sediment; however, riprap protects the roadway that lies along the shore at this point. The bluff, consisting of coarse outwash gravel, does not now rapidly supply sediment to the beach, because of the road construction. Northward, the beach widens and sediment size decreases. There is considerable development along the shore for a distance of about 2 km northward from Ayres Point. There are many groins and bulkheads with deposition and erosion patterns indicating northward drift along this sector. Rendsland Creek appears to have at one time been naturally diverted northward, but present development has attempted to channelize it toward the southwest. Similar to delta areas on the western shore of Hood Canal, residential development upon the delta has obscured the original geomorphic features. Some sediment appears to become trapped at the cove at Rendsland Creek; but, for the most part, sediment is transported across the wide delta area.

North of Musqueti Point there is much less human development and very few artificial sediment traps. There are occasional bulkheads with accumulations indicating northward net shore-drift. Although this area is directly across Hood Canal from the divergence zone at Hoodsport, the orientation of the shore, with respect to waves and fetch, is sufficiently different so that waves from the north do not dominate shore drift.

Cougar Spit and the small point 500 m northeastward are looped bars -- spits connected to land at both ends and enclosing marsh areas. Both are at the mouths of intermittent streams. The deltas of these streams provide platforms upon which spit growth occurs. The size of the sediment along these spits decreases slightly northward. Red Bluff is also located at a stream mouth, but the area appears to have been altered by recreational development and there is no spit or looped bar, although sediment has accumulated along the south side of the small point.

The beaches between the small points are narrow and cobbly, similar to those to the north (see drift cell 13). The bordering slopes are similarly steep and well-vegetated. The source of beach material is mainly the bluffs, which are not rapidly eroding. There does appear to be more stream input than to the north, but it is still minor. Fallen trees are often the only sediment traps, always indicating northeasterly net shore-drift with accumulations of sediment on the south sides.

There are very few drift indicators for 3 km northeastward from Red Bluff, except for numerous fallen trees and two very small resistant outcrops that have blocked sediment transported from the south. The bluff is resistant because of the presence of large numbers of well-rounded boulders (up to 1 m diameter) which are slowly eroding from the bluff. As they erode out, they form an effective barrier to further wave erosion, and they temporarily impede shore drift (Figures 39 and 40).

Further evidence of northeastward drift is seen at the cove 1.5 km south of Dewatto, where gravel bars are migrating from the southwest onto the shallow delta within the cove. At low tide, shore drift bypasses this cove and terminates at

FIGURE 39: Boulders, which have eroded from the bluff along the eastern shore of Hood Canal, impede north-easterly net shore drift (note pebbly sediment to right) and protect the base of the bluff from further wave erosion.

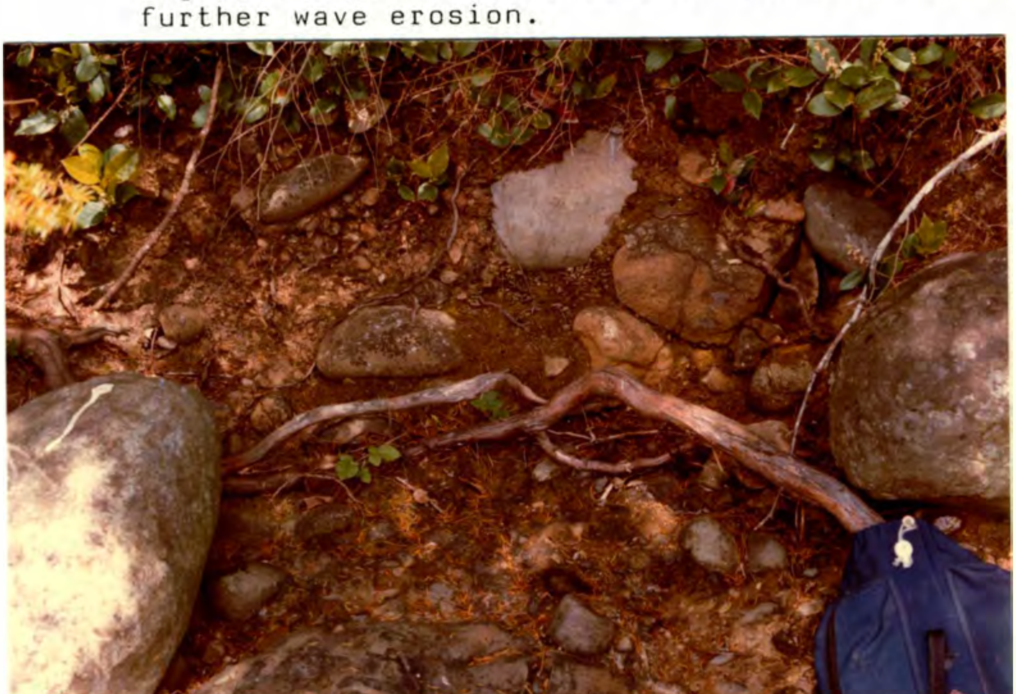

FIGURE 40: Boulders, still embedded in the bluff along the eastern shore of Hood Canal, result in a more-resistant section of bluff which protrudes slightly from the general orientation of the shore. For scale, the photo covers a portion of bluff approximately 80 cm in height.

Dewatto Bay. The southern shore of Dewatto Bay has been extensively altered by development. There is no large depositional feature, such as a spit marking the terminus of the sector, but also no evidence that drift is able to bypass the bay. Possibly the flow of the Dewatto River moves the sediment out to deep water.

MAP 3: Eastern Hood Canal

(Drift cells 22 - 39)

Drift cell 22

Waves from the west are largely prevented from exerting much influence upon the shore within the cove at Alderbrook. The land to the northwest of the cove causes a wave shadow, which results in waves from the east transporting sediment westward along the very short sector 22. A groin with sediment deposited along its east side and a small, westward-prograding spit located at the mouth of the stream at Alderbrook indicate westerly net shore-drift.

Drift cell 23

Beginning at a short divergence zone, where influence of the wave shadow at Alderbrook ceases, net shore-drift of drift cell 23 is eastward for 2.7 km, then northeastward for another 5.4 km to Twanoh State Park, where the sector ends. Virtually the entire length of beach along this shore is fronted by some form of shore defense. Literally hundreds of groins, bulkheads, and boat ramps along this sector have sediment accumulations at their west or southwest sides. Many show varying degrees of erosion to the east (see Figures 20 and 21). Also indicating eastward or northeastward net shore-drift at several areas, such as at Shady Beach, are oblique bars oriented toward the northeast.

Many of the homes along this shore are built upon fill placed on the upper foreshore, usually behind cement bulkheads. As a consequence of this type of development, much of the remaining beach is exposed only during low tides. Within the numerous spaces between bulkheads, a sequence of depositional patterns indicative of net shore-drift is constantly repeated. Usually, there is some degree of erosion at the downdrift (eastern) end of bulkheads (see Figure 21). Downdrift, toward the east, the beach widens, often with a noticeable decrease of sediment size, and the slope of the beach face increases as accumulation occurs at the updrift (western) end of the next bulkhead (see Figure 20). When the beach progrades out as far as the seaward end of the bulkhead, sediment is transported along the front of the bulkhead and "feeds" the next open beach segment (Figure 41). Much of the lower foreshore is completely covered with populations of mussels, and the "trail" of sediment along the front of a bulkhead is sometimes less than 1 m wide. There is also evidence of sediment transport along the shore below the mussel beds, where oblique bars sometimes occur.

Near the western boundary of Twanoh State Park, numerous fragments of asphalt, used as fill for shore protection, are easily traced northeastward along the shore for many meters

FIGURE 41: Waves of pebbly sediment are feeding from the west around a bulkhead, covering coarser material, along the southern shore of Hood Canal. Lines of white shell material marks successive waves. Note black mussels covering the beach just below the level of the bulkhead.

from the fill site (see Figure 19), while only a few fragments are found to the west, indicating northeastward net shore-drift.

At the park, a large boat ramp provides an excellent example of the effects of obstructions to shore drift. The beach to the southwest of the ramp has prograded so that there is up to 2 m of vertical beach offset and 15 m of horizontal offset across the ramp. Beach and shore erosion is severe to the northeast of the ramp, despite the placement of riprap. Shore drift along drift cell 23 is terminated almost completely by this ramp; however, some sediment bypasses the lower end of the ramp. About 100 m northeastward from the ramp, what remains of drift cell 23 converges with shore drift from the east. An early map (U.S. Coast and Geodetic Survey, 1891) shows an eastward-prograding spit forming the point which is now the park.

Drift cell 24

The shore at Twanoh State Park projects northward and causes a wave shadow, which results in waves from the northeast becoming predominant along the eastern shore of the park. Westward net shore-drift commences from a divergence zone located a short distance to the east of the park. Near the origin of sector 24, there are accumulations of beach material along the east side of groins and bulkheads. Toward the park boundary, the size of the sediment generally decreases, and the beach widens. Along the northwest side of the point, the park beach consists of fairly well-sorted, small pebble-size sediment, and, toward the point where the drift cell ends, the slope of the beach face increases.

Drift cell 25

East-northeastward net shore-drift begins at a divergence zone located about 0.5 km to the east of Twanoh State Park. The wave shadow effect of the point at the park ceases along the divergence zone, and waves from the southwest again become predominant, transporting sediment in a northeasterly direction. Erosion is not severe along this zone, and the shore here is largely protected by bulkheads.

Similar to conditions along drift cell 23, there is extensive residential development along the entire 7 km length of shore along sector 25. The intervening beach segments between bulkheads display repetitive indicators of northeastward net shore-drift; that is, the beach generally widens and steepens between bulkheads, with accumulation of sediment occurring at the downdrift ends of the segments. Additionally, oblique bars, oriented northeastward, are numerous along this sector, and several small spits occur. There are two east to northeast-prograding spits located 1.3 km to the northeast of Forest Beach and two are located immediately west of Sunset Beach, where there is a relatively large recurved spit (Figure 42).

Drift cell 26

The Sunset Beach spit protects a section of the shore from the influence of waves from the southwest. Thus, similar to the pattern at Twanoh State Park, there is a short sector of westward net shore-drift caused by less-frequent waves from

FIGURE 42: Northeastward view of a recurved spit at Sunset Beach, Hood Canal. Spit terminates left of center, while an intertidal spit-platform is building from the outer side of the spit and terminates near the red flag at the right of the photo.

the northeast. Indicating net shore-drift toward the west, within the cove formed by the spit, are accumulations of sediment to the east of groins and bulkheads, a decrease of sediment size, and an increase of the beach width.

Drift cell 27

One-half kilometer to the northeast of Sunset Beach, waves generated by southwest winds again become predominant, causing northeastward net shore-drift to diverge from the westward drift of sector 26. Erosion is not severe along the divergence zone as the shore is protected by bulkheads. The sediment tends to be coarse (large pebbles to cobbles) along the zones such as this one.

Three small, northeast-oriented spits are located along the first kilometer of drift cell 27, indicating net shore-drift in that direction. Again, there are numerous discrete segments of beach, situated between bulkheads, with deposition occurring at the downdrift ends of the segments, indicating northeasterly transport of beach material.

Intertidal mud flats that stretch across the width of Hood Canal extend southwestward from Lynch Cove for a distance of 3 km. Wave-energy is dissipated by friction with the shallow bottom; and, northeastward along the shore, shore-drift features become less distinct. Indicating a general progradation of the shore in this area, grasses are encroaching upon the beach, helping to stabilize the sediment (Figure 43); however, there are still a few indications that shore drift is operating. There are slight accumulations of beach sediment

FIGURE 43: Grasses are encroaching upon the beach of Lynch Cove, at the northeast end of Hood Canal where shallow water results in a low energy enviornment.

to the southwest of obstacles; and a large spit, which diverts stream drainage northeastward, marks the terminus of sector 27. The spit is largely vegetated and may be a relict feature from a time when the mud flats were less extensive. It is, nevertheless, an excellent long-term indicator of net shore-drift.

Lynch cove, at the end of Hood Canal, is the location of the delta-front of the Union River. It is not a large river; but, with shore drift and several smaller streams contributing sediment, the delta appears to be prograding fairly rapidly. It is mapped in this report as an area of no appreciable net shore-drift.

Drift cell 28

The net shore-drift of drift cell 28, opposite drift cell 27, along the northern shore of Hood Canal, is also northeastward into Lynch Cove. Originating at a divergence zone located to the east of Sunbeach, the direction of net shore-drift is indicated by numerous oblique bars, several small spits which divert streams northeastward, and sediment accumulations to the west of groins. Wave energy is low because of the shallow tide flats, and there is a general progradation of the entire shore along the northern side of Lynch Cove.

Drift cell 29

The prograding delta of Stimson Creek, along with a compound spit located near the mouth of the creek, causes a wave shadow to the northeast of the delta. Thus, similar to patterns found along the southern shore of Hood Canal, waves from the east and northeast are predominant along the protected area and result in a reversal of net shore-drift.

From a divergence zone northeast of Sunbeach, there is a decrease of sediment size from cobble-size material at the divergence zone to sand-size material along a long, southwest-projecting sand bar located at Sunbeach. Toward the south-west, beyond the sand bar, drift cell 29 converges with net shore-drift from the southwest along the eastern side of the Stimson Creek delta.

Drift cells 30 and 31

The northeastward net shore-drift along drift cell 30 begins immediately east of a residentially developed delta of a small stream located 1.7 km to the northeast of Shoofly Creek. A short divergence zone, which results from the sheltering effect of the small delta, is the origin of the sector. The width of the beach increases and the size of the sediment decreases in a northeasterly direction away from the divergence zone. As on the south shore, numerous man-made structures obstruct shore drift, with sediment deposition occurring to the southwest of the structures. Two small streams, located about 2 km northeast of the sector origin, are diverted northeastward. Also indicating the net shore-drift direction, the terminus of drift cell 30 is at the distal end of the compound recurved spit located near the mouth of Stimson Creek. Slightly vegetated, older growth segments of the spit are now protected by younger segments, developing spit-platforms, and oblique bars, all oriented toward the northeast.

From the narrow, eroded beach at the divergence zone shared with drift cell 30, waves from the east transport beach material westward along sector 31. Only about 100 m in length, the sector terminates in a man-made cove on the eastern side of the developed delta. There is a widening of the beach toward the cove, and a wedge of beach material is prograding into the cove from the east.

Drift cells 32 and 33

Like other prograded areas which project from the northeast-southwest trend of the shore along the eastern arm of Hood Canal, the delta of Shoofly Creek causes a wave shadow which results in a zone of divergence to the northeast of the delta. Eastward of the zone, net shore-drift in an easterly direction along drift cell 32 is indicated by depositional patterns at numerous groins and bulkheads, by increases of the beach width and slope, and by a decrease of the size of the sediment toward the east. Sediment is transported around the developed, prograded area located 1.7 km to the east of Shoofly Creek, and then deposited within a small, man-made cove at the east side of the point.

The man-made cove there, designed to be a small marina, is being filled by sediment transported from both directions along the shore. Unless it is periodically dredged, as it becomes filled with beach material, shore drift from the southwest should be able to bypass the area. This shore drift should be sufficient to mask the seasonal westward shore drift of drift cell 31, resulting in net shore-drift toward the east-northeast without an intervening reversal.

Drift cell 33 diverges from sector 32 with net shore-drift toward the southwest. Near the mouth of Shoofly Creek, drift cell 33 converges with net shore-drift from the southwest. Sediment size decreases from northeast to southwest along the sector, and, in the same direction, there are increases of the beach width and slope.

Drift cell 34

This sector originates about 2.5 km to the southwest of Shoofly Creek. Northeastward net shore-drift is indicated by sediment accumulations southwest of obstacles (boat ramps, groins, and bulkheads), erosion northeast of some obstacles, northeastward increases of beach width and slope, northeastward decrease of sediment size, and several oblique bars oriented toward the northeast. Drift cell 34 terminates at the prograding delta of Shoofly Creek, where the sector converges with drift from the northeast.

Drift cells 35, 36, and 37

The eastern shore of the Sisters Point peninsula is largely protected from the influence of waves from the southwest. Waves generated by northeast winds, with a fetch up to 15 km, are predominant along much of this shore. However, this dominance is not strong, and only a slight projection from the south-southwest trend of the shore allows a drift reversal.

Net shore-drift along drift cell 35 is toward the south-southwest from the divergence zone of drift cell 34. The location of the divergence zone very near the change of shoreline orientation shows that the wave shadow caused by the peninsula does not extend far beyond the shore of the peninsula and does not protect the shore to the northeast from south-westerly influences. Indicating southward drift, accumulations of sediment occur to the north of groins and other obstructions, the size of the sediment decreases southward, and the width and slope of the beach increase. The sector ends at a prograding, lobate beach, where it converges with drift from the south-southwest.

The original cause for the lobate accumulation is uncertain. Usually along Hood Canal, such forms occur at stream mouths where a delta provides a platform for deposition. In this case, there is only a very small intermittent stream. Nevertheless, the slight projection allows waves from the south-southwest to become predominant for a short section (drift cell 36) and converge with sector 35, causing the lobate accumulation. The north-northeast direction of net shore-drift along drift cell 36 is shown by increases of beach slope and width, a decrease of sediment size, and the pattern of deposition at the southwest side of groins and bulkheads and erosion to the northeast.

Drift cell 37 diverges south-southwestward from sector 36 and converges with drift from the west at the westward bend of the shore. Indicators similar to those found in drift cell 35 and 36 show the southward direction of net shore-drift along this sector. Convergence results in a lobate depositional form.

Drift cell 38

Net shore-drift eastward around Sisters Point begins at a divergence zone along the western shore of the peninsula, near Tahuya. Indicators of net shore-drift toward the east are a decrease of sediment size away from the eroded divergence zone, increases of the beach width and slope toward the east, and sediment accumulations west of numerous groins and bulkheads, as well as erosion east of some drift obstructions. Drift cell 38 terminates at the southeast corner of the peninsula where drift converges at a small prograding beach.

Drift cell 39

Northward net shore-drift from the divergence zone on the western shore of the Sisters Point peninsula into the mouth of the Tahuya River is indicated by widening and steepening of the beach northward, decrease of the size of the sediment in that direction, obstruction of drift by groins and bulkheads, and by northward progradation of a spit at the stream mouth, where the sector terminates. Here, too, the shore along the divergence zone is protected by riprap and bulkheads, so that erosion of the bluff is prevented.

MAP 4: North Bay - Case Inlet

(Drift cells 40 - 60)

Drift cell 40

Rocky Point, as its name implies, is a boulder-strewn, wave-cut platform. The low bluff is now protected by a cement bulkhead. Waves from the south-southwest, initiated by winds with up to 15 km fetch, cause a divergence of net shore-drift from the point. Drift cell 40 begins at this divergence zone, with net shore-drift toward the east. Deposition and erosion of beach material to the west and east, respectively, of bulkheads indicate eastward net shore-drift. Additionally, the size of the beach sediment decreases from the point toward the east. Beyond the county line, in Pierce County, net shore-drift continues northeastward into Rocky Bay (Harp, 1983).

Drift cell 41

Northward from the divergence zone at Rocky Point, drift cell 41 stretches for 6 km to the mud flats at the head of North Bay. There is a decrease of sediment size northward from the point, as well as widening of the beach and an increase of the beach-face slope. Widening of the beach is demonstrated by development of a sandy berm, which begins about 1 km to the north of the point.

One of the more unusual examples of a shore drift indicator occurs in the Victor area, where there is a partially destroyed shore defense structure composed of old tires. Several old tires were seen scattered along the beach up to 100 m to the north of the structure site, while there were none seen to the south. In the same area, cobbles with a uniform size and rounded shape could be traced along the beach to the north of a fill-site where a large supply of the cobbles still remained.

Also indicating northerly net shore-drift, two small streams near Victor are diverted northward, and, at the point just north of Victor, a relatively large, complex spit and several spit-shaped oblique bars are oriented toward the north.

Net shore-drift continues northward beyond the spit, although the beach is somewhat eroded immediately north of the spit. The size of the sediment decreases, gradationally, northward. Much of the northern 2 km of North Bay is intertidal mud flats, and, like Lynch Cove on Hood Canal, is characterized by low-energy wave conditions. The area is here classified as an area of no appreciable net shore-drift.

Drift cells 42 and 43

Net shore-drift divergence occurs 0.5 km to the southeast of Sherwood Creek on the western side of North Bay. The northward projection of land (marked "AN" on map) to the southeast of the creek protects the shore between the point and the creek from waves from the south and southeast. As a result, waves from the north, down the length of North Bay, are predominant along part of the shore -- transporting beach material southward into the cove formed by the point.

From the divergence zone, the southward net shore-drift into the cove is mapped as drift cell 43. As the upper foreshore widens southward from the cobble-covered wave-cut platform at the divergence zone, the size of the sediment decreases to fine sand and silt within the cove.

Only a short distance northwest of the point, winds from the southeast impinge on the shore beyond the wave shadow of the point and direct net shore-drift northward. From the wave-cut platform at the divergence zone, drift cell 42 extends northward past the shallow delta of Sherwood Creek. Bulkheads, groins, and boat ramps, located north of the stream, have beach sediment piled along their southern sides, and small-scale erosion is occurring to the north of some of the obstacles. Sediment size also decreases northward. A small spit, located 1.5 km to the north of Allyn, is prograding northward.

Beyond the distal end of the spit, the shoreline curves to the northwest, somewhat protecting the bay to the north. The shore, protected by mud flats, is herein classified as an area of no appreciable net shore-drift.

Drift cell 44

From the area at the mouth of a small cove, located 1 km to the north of the northern end of Reach Island, net shore-drift is northward along drift cell 44. The drainage channel from the cove prevents appreciable sediment bypass from the south, although bypass may occur during extreme storm conditions. Cobbles and pebbles are the predominant beach material at the origin of the sector. Toward the north, there is a gradational decrease of the average size of the sediment. Midway along the sector, there is a sandy, looped bar, which has prograded from the south. Immediately to the north of this beach accumulation, a wave-cut platform is exposed through a thin layer of pebble-size material. Northward, the size of the sediment fines to sand at the sector terminus at the point marked "AN", where there is a recurved spit (see Figure 27). Refraction of waves from the south, and less frequent waves from the north, are causing the recurved distal end of the spit to prograde southwestward into the cove. Increases in the beach width and slope and accumulations of material at groins and bulkheads along this sector also indicate northward net shore-drift.

Drift cells 45 and 46

Much the same as in the pattern of drift cells 42 and 43, Reach Island causes a wave shadow which results in divergence of net shore-drift in the lee of the island. Drift cell 45 is characterized by northerly net shore-drift. From a vertical, wave-eroded bluff at the divergence zone, where the beach sediment is predominantly pebbles and cobbles, northward net shore-drift is indicated by a transition to less steep, more-vegetated slopes and a gradational decrease to sand-size sediment. A sandy spit at the terminus of drift cell 45 (at the point marked "BM") is oriented northwestward across the mouth of the next small cove to the north, about 1 km distance. Deposition to the south of groins along this sector also indicates northerly net shore-drift.

Reach Island prevents waves from the southeast from exerting much influence upon the shore to the northwest of the island; thus, waves from the north are the predominant shore drift influence. Southward along drift cell 46, from the divergence with sector 45, accumulations of sediment occur to the north of groins and a boat ramp; and there is a general decrease in the size of the sediment toward the south into the cove where the sector ends.

Drift cells 47 and 48

The north-northeastward-projecting point of land (marked "CS" on the map) which parallels Reach Island on the west is exposed only to wind and waves from a short (3 km) fetch from the northeast. As a result, net shore-drift is generally southerly along both sides of this point.

Drift cell 47 originates at the point and terminates within the cove on the west side of the projection. Southwesterly net shore-drift along this very short sector is indicated by a decrease of sediment size into the cove.

Drift cell 48 also originates at the point but diverges from sector 47 with southward net shore-drift. The terminus of the sector is at the north side of the Reach Island bridge. From a wave-cut platform at the divergence zone, the size of the sediment decreases southward from cobble-size to sand and pebble-size at the bridge. The quantity of beach material transported in the direction of net shore-drift results in an increase of the beach width and slope. There are slight accumulations of material north of obstacles along this 0.5 km long drift cell; and, at the bridge footings, the sector terminus is at a prograding beach. The bridge footings block shore drift in a manner similar to a groin; however, sediment can be transported past the bridge at a lower level on the shore. The channel is shallow, and the bridge pilings scatter wave energy, resulting in no appreciable net shore-drift within the channel south of the bridge.

Drift cell 49

Waves from the southeast (and to a small degree, from the south) transport sediment northeastward along the eastern shore of Reach Island. Drift cell 49, beginning at the southern end of the island, extends to the northern end of the island. There, refraction of waves from the south moves sediment westward around the point, where waves from the north are later able to move the material southwesterly along the western shore, thereby extending the sector as far as the bridge.

Reach Island is a private residential development, and it is virtually encircled by bulkheads. As each property-owner constructed a bulkhead to protect beachfront property from wave erosion, eventually a nearly continuous wall was established. Since, in this case, the beach sediment was originally derived entirely from the low bluff along the shore, there is now no natural source for rapid beach replenishment. As sediment is transported in the direction of net shore-drift, and no replenishment occurs, the underlying platform will be increasingly exposed to downcutting by wave erosion. The platform is exposed in numerous places along the eastern shore of the island.

The sediment that is present along the upper beach decreases in size from south to north along the eastern shore, and, groins and boat ramps have slight accumulations of sediment to the south. Similarly, along the western shore from the northern tip of the island to the bridge, there are deposits of sediment north of obstacles.

Drift cell 50

A short sector of northward net shore-drift extends from the south end of Reach Island along the western side of the island. Along a short distance there is a decrease in sediment size northward, and slight accumulations occur to the south of obstacles.

About 100 m further northward along the channel, there are no indications of shore drift in this very protected area. A small marina, on the mainland shore of the channel, further prevents shore drift. Therefore, in this report, the inner channel is mapped as an area of no appreciable net shore-drift.

Drift cells 51 and 52

Midway between Stretch and Reach islands, along the mainland shore, net shore-drift diverges. In sector 51, net shore-drift is northward for a very short distance into the Reach Island channel. This part of the shore is exposed only to waves from the east. Easterly winds are very infrequent, and shore drift indicators here are weak, at best. There are slight accumulations of sediment to the south of obstacles, but even these indicators cease immediately south of a small marina located in the channel.

Shore drift indicators along drift cell 52 are more pronounced than those found along sector 51. The channel toward the south is slightly less protected, with a fetch from the northeast of up to 3 km. Waves from that direction have caused sediment to accumulate north of obstacles. Additionally, sediment size decreases southward, and there are increases of the beach width and slope. The footings of the Stretch Island bridge obstruct shore drift, so that there is a prograding beach at the north side of the bridge. Similar to the conditions at the Reach Island bridge, the footings and pilings of this bridge, as well as the shallow depth of the channel, effectively halt shore drift.

Drift cells 53 and 54

At the northwestern corner of Stretch Island, the bluff consists primarily of easily eroded sand. Drift divergence occurs at this point, so sand is transported away from this area in both directions along the shore. Southward net shore-drift characterizes drift cell 53, which terminates at the Stretch Island bridge. The beach widens southward, and there are accumulations of beach material north of groins and bulkheads. Near the bridge, there is a spit-shaped beach prograding southward.

The east-southeasterly net shore-drift along drift cell 54 is indicated by an increase of beach width in that direction and by sediment deposition at the west end of bulkheads. Near the northeastern point of the island, sector 54 converges with net shore-drift from the south.

Drift cell 55

Generally northward net shore-drift along the eastern shore of Stretch Island originates at the southern end of the island and extends to a relatively large spit at the northeastern corner of the island. Winds, with fetches between 5 and 11 km from the southeast and south, generate wave energy that is sufficient to keep the bluffs eroded to near-vertical along much of the length of this sector. Midway along drift cell 55, a berm and backshore are developed at a topographically low area (Figure 44). Vertical bluffs occur along the shore in both directions from the low area; however, toward the north there is a transition to less steep and better vegetated slopes (see Figure 16).

Numerous logs and fallen trees along this shore have accumulations of beach sediment to the south, indicating northerly net shore-drift. In addition, there are a decrease of sediment size northward, increases of the beach width and slope, and northward-migrating oblique bars. The distal end of the spit at the terminus of sector 55 curves westward, more or less parallel to the trend of the shore, and thus shows the influence of both refraction of waves from the southeast and waves directly from the north, where there is a 5 km fetch (Figure 45).

Drift cell 56

From the vertical, eroding bluff and wave-cut platform at the southern tip of Stretch Island, net shore-drift is northward along the western side of the island. The sediment decreases in size as the beach becomes wider and steeper northward. About 250 m from the origin, there is a gravelly spit prograding northward. Although some beach material is transported into the cove behind the spit by wave refraction, it appears that some sediment, expecially finer-sized material, is transported northward, beyond the spit. The relatively

FIGURE 44: A backshore has developed at a topographically low area on the eastern shore of Stretch Island. An eroding, vertical bluff is present immediately north of the low area in the direction of net shore-drift.

FIGURE 45: Recurved spit at the northeast end of Stretch Island. With 5 km fetch from the north, the distal end of the spit is recurved to the left.

shallow depths to the north of the spit result in a low-energy wave environment. Beach material accumulates south of obstacles, and the beach is prograding as material is transported northward into the channel. Sector 56 ends in the narrow and shallowest part of the channel at the Stretch Island bridge.

<u>Drift cells 57 and 58</u>

West of Stretch Island, along the mainland shore, northeasterly net shore-drift of drift cell 57 begins at the mouth of a narrow cove located 1 km southwest of the bridge to the island. From an eroding bluff of glacial till at the origin, the sector extends to the bridge, terminating at a prograding beach. Along the intervening shore, northeastward drift is indicated by a decrease of sediment size, the deposition of sediment southwest of obstacles, and an increase of the quantity of material forming the beach. A pebbly beach ridge has developed along the narrow channel.

The water at the mouth of the small cove at the origin may be shallow enough to allow sediment to be transported past this cove from the south during extreme storms or very low tides. A small spit, prograding northwestward into the cove directly from the eroding bluff, indicates that considerable material is transported into the cove. In this report, drift cell 58 is mapped as extending from the bluff into the cove. In the future, as the cove slowly fills with sediment, net shore-drift can be expected to bypass this cove.

<u>Drift cells 59 and 60</u>

At Stadium, east of McLane Cove, the longest fetches are from the east and southeast; however, more frequent and generally stronger winds from the south-southwest cause net shore-drift to be toward the east-northeast along drift cell 59 and northward into McLane Cove along sector 60. Divergence occurs at the east side of the cove entrance, where there is a wave-cut platform and an eroding bluff. East-northeastward, there is a transition of the bluff morphology to less steep, vegetated conditions and the width of the beach increases. Sediment deposition patterns at obstacles, as well as the gradational decrease in size of the sediment, also indicate net shore-drift toward the east-northeast. Approximately 1.3 km east of McLane Cove, the shore curves toward the north; but net shore-drift continues, and terminates at a long spit that is parallel to the shore. The spit is prograding northward into the small cove located about 1 km southwest of the bridge to Stretch Island. The narrow lagoon enclosed by this spit was dredged for boat moorage, and an entrance channel was excavated across the spit. Despite the emplacement of a quarrystone jetty, the channel is being filled by beach material transported along the spit, and, in mid-1982, the entrance was not navigable during low tide levels.

Net shore-drift along drift cell 60 diverges from drift of sector 59, as material is transported into McLane Cove along the east side of the cove. From the narrow divergence zone, the beach widens and steepens northward into the cove, and sediment size decreases. Shallow water, protected conditions exist within the cove, and shore drift is not a significant geomorphic process within those confines.

MAP 5: Pickering Passage - Hartstene Island
(Drift cells 61 - 103)

Drift cell 61

Along most of Pickering Passage, net shore-drift is in a northerly to northeasterly direction. It is, however, frequently interrupted by small coves (see Figure 12). Such is the case at the northern end of the passage, where three small coves, located 3 km to the southwest of McLane Cove, interrupt sediment transport along the shore. Drift cell 61 originates immediately east of the easternmost cove, along an eroding bluff and cobble-covered, wave-cut platform.

There is a 9 km fetch from the northeast to the origin of this sector. However, since the shore along this sector is essentially parallel to the approach of waves from the northeast, little wave energy is directed toward the shore. Winds from the southwest, with a maximum fetch of only 3.5 km, cause the predominant waves along this shore. Although waves from the southwest also approach this shore at a low angle, there is a greater variation of approaches across the 1 km width of Pickering Passage, and these more frequent waves direct net shore-drift northeastward.

Toward the northeast, from the origin of sector 61, the 35 m high bluffs become more vegetated and less steep, the beach becomes wider and steeper, and the sediment decreases to sand and pebble-size material. Also indicating northeasterly net shore-drift, oblique bars are migrating in that direction, and deposits of beach material occur southwest of logs. The terminus of drift cell 61 is at a prograding beach within the protected confines of McLane Cove.

Drift cells 62, 63, 64, 65, and 66

Net shore-drift, in the area of the three small coves located about 3 km southwest of McLane Cove, is generally northward, into the coves. Wave-cut platforms are exposed along short zones to the east of each of the coves, and net shore-drift diverges from each of these zones.

Diverging from the northeasterly drift of sector 61, net shore-drift of drift cell 62 is north-northwestward into the easternmost cove. There is a lobe of sand prograding, spit-like, along the shore into the cove. From cobble-size on the wave-cut platform at the sector origin, the sediment decreases to sand-size in a very short distance.

Northeastward net shore-drift along drift cell 63 begins at the wave-cut platform located to the east of the central of the three coves. Again, the beach material decreases in size, from cobbles and boulders at the divergence zone to sand and pebbles at the terminus, within the easternmost cove. Sand bars, similar to those shown in Figure 31, are advancing into the cove from the southwest.

Drift cell 64, diverging from sector 63, is nearly identical to drift cell 62. From the cobble-covered, wave-cut platform at the divergence zone, a lobe of sand is prograding northward into the central cove.

From the third divergence zone, east of the westernmost cove, net shore-drift along sector 65 is northeastward, similar to sector 63. The sediment size decreases northeastward from the divergence zone, and the width and slope of the beach increase. Within the central cove, the terminus of drift cell 65 is marked by a small, northeastward-projecting spit, consisting primarily of sand-size sediment.

Drift cell 66, oriented northward into the westernmost cove, is nearly identical to the sectors along the eastern sides of the other two coves (drift cells 62 and 64).

Beaches along Pickering Passage are relatively narrow, as the channel deepens only a short distance offshore. The constricted and sinuous nature of the passage makes it an area of generally low wave energy. Bluff erosion by waves is apparent in some places, and locally appears severe. Overall, wave erosion of the bluff is not a rapid process along Pickering Passage and narrowness of the beaches is maintained.

Most bluff erosion occurs during extreme storm conditions. During these occasional events, waves may be able to transport sediment past many of the coves along the passage. Evidence of bypass would have to be found during, or immediately after, such events, as the more usual low energy conditions result in indicators suggesting that shore drift is interrupted by the coves. However, as the coves are gradually filling with sediment, eventually, shore drift will bypass these areas altogether.

Drift cells 67 and 68

An eroding bluff at Sun Point provides the beach material transported along drift cell 67. Northeasterly net shore-drift occurs along the sector, which terminates within the first small cove located 2 km northeast of Sun Point. Because of the direct approach of waves from the south, where there is a 4.5 km fetch from the Hartstene Island bridge, the bluff at Sun Point is severely eroding. In an effort to halt bluff erosion, bulkheads have been constructed along much of this part of the shore, where new residential development is taking place. The owner of the southwesternmost Sun Point property has covered the entire bluff from his porch to the beach with a layer of concrete as a further step to prevent erosion.

Northeastward from Sun Point, there are sediment accumulations to the southwest of bulkheads and logs, the size of the sediment decreases, the beach widens and steepens, bluff erosion becomes less prevalent, and sand bars (similar to those shown in Figure 31) are migrating from the southwest into the cove at the terminus of sector 67.

Northeastward net shore-drift along drift cell 68 diverges from sector 67 at Sun Point. A lobe-shaped accumulation of sand and pebbles is prograding into the cove from the point.

Drift cells 69 and 70

A zone of eroding beach, located 1.7 km south of Walkers Landing, is the site of divergence of drift cells 69 and 70. The divergence zone occurs as a result of two small, north-northeast-projecting points of land which cause a wave shadow, protecting a short section of shore from waves from the south.

Net shore-drift along drift cell 69 is northward from the divergence zone and terminates within the small cove between Walkers Landing and Sun Point. There is a northward widening of the beach and a corresponding increase in beach-face slope, as well as a decrease of sediment size. Accumulations of beach material occur to the south of logs, groins, and bulkheads along this sector. About 500 m southwest of Walkers Landing, a very small stream is diverted northeastward by a spit-like lobe of sediment.

The wave shadow allows waves from the north-northeast to be predominant along a short section of shore, causing the southward net shore-drift of drift cell 70. There is a widening of the beach and a decrease of sediment size into the cove. As this cove becomes filled with sediment, shore drift from the southwest may eventually bypass the area.

Drift cell 71

At the northernmost of the two small points of land located about 2 km south of Walkers Landing, waves from the south and southeast cause northward net shore-drift along the eastern side of the point. Refraction of waves from the south causes sediment to be transported westward around the point, where waves from the north are then able to transport material into the cove. At the point, there is a wave-cut platform exposed. Within the cove, a small spit is prograding southwestward. The increase of beach width and slope, and decrease of sediment size, occur in a very short distance from the point to the spit. Sediment size decreases from the origin towards the point, also; but material is rapidly moved around the point, leaving coarser material there. Although the cove between the two points is protected, similar to the area northwest of the point, there is no evidence of drift divergence or short reveral of net shore-drift. The northwest corner of Hartstene Island apparently protects this area from significant northeasterly influence, so that a drift cell similar to drift cell 70 has not developed.

Drift cell 72

In the Graham Point area, net shore-drift toward the north along drift cell 72 begins immediately north of the Hartstene Island bridge footings. Prior to 1969, when the bridge was constructed, this sector originated 250 m farther south, at the southwest-projecting point of land. The footings of the bridge extend across the shore into deep water, preventing transport of beach material past the structure.

Immediately north of the bridge, beach erosion is occurring as sediment is transported away from the area without replacement from the south. Consequently, a thin, cobble lag overlying a wave-cut platform is exposed there. Northward, the sediment size decreases, and the increasing quantity of beach material results in increases of the beach width and slope. Accumulations of sediment occur to the south of bulkheads along this sector.

The drift cell terminus, at the small, north-northeast-projecting point located 2.1 km north of the bridge, is the site of a recurved spit. Although this point is oriented like the point located immediately to the north, this point has a much larger supply of sediment. Consequently, the terminus of sector 72 is marked by deposition of a spit, while the point to the north is eroded.

Drift cell 73

Beginning 250 m south of the Hartstene Island bridge, net shore-drift along drift cell 73 is north-northeastward to the bridge. At the southwest-projecting point, a wave-cut platform is exposed through a veneer of cobbles and boulders. Toward the bridge, sediment size decreases to predominantly pebbles at a prograding beach at the south side of the bridge footings, where the sector ends.

Drift cells 74, 75, and 76

Within the embayment south of the Graham Point area, northeastward net shore-drift occurs along the two small points of land which project southwestward into the embayment. Originating at wave-cut platforms at the tip of the points, northeasterly net shore-drift is indicated by decreases of the sediment size along each of these three drift cells. As the points of land are slowly eroded and the coves filled by deposition, straightening of this shore will occur. However, this is a low energy environment with limited fetches in all directions, so shore straightening is not a rapid process.

Drift cells 77 and 78

A zone of net shore-drift divergence occurs along the shore northwest of Island Home. The small island moderates the influence of waves from the southeast, causing a wave shadow which allows waves from the northeast to be predominant in the lee of the island.

Waves from the southeast, where there is about 2 km of fetch, transport sediment generally northward from the divergence zone and around the embayment to the south side of the Graham Point area. Although it is a low energy environment and not a great amount of material appears to be in transport, sediment accumulations occur to the south of groins, and there is a decrease of sediment size toward the north. At higher tide levels, beach material is transported into the cove at the northwest side of the embayment. Generally, transport along sector 77 continues northeastward, where it converges with drift cell 76.

Net shore-drift along drift sector 78, in the lee of Island Home, is indicated by a decrease of sediment size toward the south and by slight accumulations of material to the north of obstacles. Predominant winds from the northeast have only 1.5 km of fetch from the Hartstene Island bridge, and wave energy remains low in the shallow area of the embayment. Although waves from farther northeast may pass through the bridge area without significant moderation, the extension of fetch is not sufficient to allow generation of waves capable of extensive sediment transport or erosion.

Drift cell 79

Drift cell 79 originates 1.2 km to the south of Island Home at the southward-projecting point of land there. There is a 4 km fetch from the south-southeast and waves from that direction transport sediment northward along this drift cell.

From cobbles barely covering a wave-cut platform at the point, the beach material grades to sand at the northern end of Island Home. Also indicating northerly net shore-drift, sediment accumulations occur at the southern ends of bulkheads, and there are varying degrees of beach erosion at the northern ends. An increase in the width of the high tide beach is also evident in the same direction.

At higher tide levels, beach material is washed into the cove to the west of the island via the passage at the southern end of Island Home. However, at most tide levels, this passage is subaerially exposed and sediment is transported past the area. Sediment is transported around the northern end of Island Home by wave refraction. Once the sediment is around the point, less frequent northerly winds cause southward transport into the cove. At the sector terminus, there is a lobate beach accumulation of sandy material prograding toward the south.

Drift cell 80

Diverging from drift cell 79, net shore-drift along drift cell 80 is also northward, but into the cove on the west side of the point. Again, the size of the sediment decreases to sand northward from the cobbly, wave-cut platform. Within the cove, there is a small spit prograding northward.

Drift cells 81 and 82

Within the small embayment located to the north of the Hungerford Point area, there is a zone of net shore-drift divergence. Northward net shore-drift along sector 81 is indicated by deposition of beach sediment at the southern side of several groins, and by a decrease of sediment size from pebbles at the slightly eroded divergence zone to sand and silt within the cove to the north. In the wave shadow of the Hungerford Point area, waves from the northeast transport sediment southward along drift cell 82, with accumulations occurring to the north of groins, and a southward decrease of sediment size. Waves affecting the shore within the embayment are generated by winds with limited fetches in all directions, and shore drift features are accordingly slight in this low-energy situation.

Drift cell 83

From Hungerford Point, at the north side of the entrance to Hammersley Inlet, net shore-drift along drift cell 83 is generally northward along the southern portion of Pickering Passage. Examples of most of the shore drift indicators sought in this study occur along this 1.7 km long drift sector.

At the drift cell origin at the point, the low bluff is kept vertical because of wave erosion by waves approaching from the south. In addition, although fetch from the south is relatively short, the resistant nature of the Vashon till, which forms the bluff at the point, causes subaerial erosion to be slow, and the steepness is maintained. Northward from the point, however, the bluff becomes less steep and more vegetated as wave erosion at the base of the bluff becomes less pronounced. At the sector origin, the slope of the beach is essentially that of the wave-cut platform, as the beach there consists primarily of a thin scattering of cobbles.

Northward, in the direction of net shore-drift, beach material becomes more abundant, and there are corresponding increases of the beach width and slope and a decrease in the size of the material.

About 0.6 km to the north of the beginning of the drift cell, there is a northwesterly prograding spit of sand-size beach sediment. Just beyond this spit, to the northwest along the low-tide terrace, there are several oblique bars, also oriented toward the northwest.

Additionally, sediment has accumulated south of groins and bulkheads along this section of the shore. Although there are substantial vertical offsets of the beach to either side of obstacles, beach erosion to the north is generally negligible, as there is sufficient material passing around the obstacles to prevent erosion.

Refraction of waves from the southeast moves sediment westward into the cove to the north of the Hungerford Point area, where drift cell 83 ends with deposition at the mouth of a small stream.

Drift cell 84

Drift cell 84, a short sector of east-northeasterly net shore-drift, is located on Hartstene Island at the northern end of Peale Passage. The shore along this sector is perpendicular to the direction of the longest fetch (about 7 km from the southeast along the length of Peale Passage). At the point, the low (3 - 5 m) bluff of glacial till is being actively undercut by wave erosion, and a wave-cut platform is visible through a thin veneer of gravelly sediment. Net shore-drift divergence occurs at this eroding point. Indicating east-northeastward net shore-drift from the divergence zone is a decrease of the sediment size along the sector toward its terminus at a small cove, where there is a lobe of sand to pebble-size sediment prograding eastward.

At the cove, sector 84 converges with net shore-drift from the southeast (drift cell 101). It appears possible that sediment transported from the southeast may be able to bypass this small cove, however, there are no preserved indicators to document the occurrence. As the cove becomes filled by sediment deposition and the point further eroded, the resultant straightening of the shore will allow shore drift from the southeast to continue northwestward past this area, eliminating evidence of drift cell 84.

Drift cell 85

Diverging northwestward from drift cell 84, sector 85 extends along the shore for about 2.6 km to the Hartstene Island bridge. The shore at the divergence zone faces a relatively long fetch from the southeast, and sediment eroded from there is transported northwestward, largely protecting the bluff along the first kilometer of the drift sector from wave erosion. Additionally, this section of shore is parallel to the approach of waves from the southeast, so that less wave energy is directed toward the shore and transport is therefore slower than along the divergence zone. As a consequence, there are comparatively gentle, subaerially eroded slopes along this shore. Wave erosion at the toe of the slopes is shown to be gradual by numerous trees which have the seaward sides of their trunks overhanging the beach, while their root systems extend laterally into the bluff. Frequently, these lateral root masses, when extended from the bluff across the beach surface, form obstacles to shore drift as the trees (up to 1 m in diameter) continue to grow, more or less vertically. Along drift cell 85, sediment accumulations to the south of root masses and fallen trees indicate generally northward net shore-drift.

Also along the first kilometer of this sector, there are three small spits, prograding northwestward, which divert the courses of small streams. Northwest of the third spit, about 1 km from the sector origin, the shore becomes exposed to waves from the southwest, past the northern end of Squaxin Island. Waves from the southwest are more direct toward the shore along this area than waves from the southeast, and net shore-drift continues generally northerly. The addition of waves from the southwest does not significantly speed up transport along the sector, and there is no apparent increase of bluff erosion.

Less than 1 km to the south of the Hartstene Island bridge, there is another spit prograding northward across the mouth of a small cove, which indicates northerly net shore-drift. In this area there are a few oblique bars, also oriented northward. The eastern footings of the bridge extend across the shore into deep water. South of the footings, the beach is prograding, marking the terminus of sector 85. Prior to emplacement of the bridge, constructed in 1969, net shore-drift continued northward.

<u>Drift cell 86</u>

Formerly an extension of drift cell 85, drift cell 86 begins immediately to the north of the Hartstene Island bridge. Near the bridge, at the origin of this sector, most of the beach material has been transported northward so that a wave-cut platform is exposed through the gravelly lag deposit. One-half kilometer to the north-northwest, a small spit (about 20 m in length), consisting of sand and pebbles, is prograding eastward into the cove located there. Although accretion is still occurring at the distal end of the spit, the source which originally supplied beach material to this part of the shore has been eliminated by construction of the bridge. As the beach material which remains is slowly transported in the direction of net shore-drift, very little material is replacing it. Wave energy along this zone is low, in part because of the bridge, and also because of the limited distances of fetch. Thus, very little wave energy is available to erode the low bluff and supply more sediment. Also, much of the shore along this sector is protected by a cement bulkhead. Consequently, erosion of the spit can be expected to occur in the future.

<u>Drift cell 87</u>

The cove located to the northeast of the Hartstene Island bridge has a very low-energy environment. Although infrequent waves from the northwest, and refracted waves from the southwest, may transport sediment into the cove along its eastern shore, there are no beach features to indicate shore drift is occurring from the northwest.

Only a short distance to the north of the cove, there are indicators of northward net shore-drift. Along drift cell 87, there are sediment accumulations to the south of a boat ramp, several groins and bulkheads, and numerous fallen trees. Slight erosion occurs to the north of a few bulkheads. Northward, there is a general decrease of sediment size. Several northward-oriented oblique bars occur along the sector, and a few very small intermittent streams are diverted northward. About 0.5 km to the south of the mapped terminus of drift cell 87, there is a small northward-prograding spit.

Fetch from the southwest to the origin of this sector is quite short, and shore drift indicators are not well-developed. Northward, fetch from the south-southwest continually increases and indicators are correspondingly better developed. The bluff is subaerially eroded and well vegetated along most of the sector. Wave erosion at the base of the bluff is not severe, although there is a steady, but slow, undercutting of the trees at the lowest level of the slope.

The terminus of drift cell 87 is mapped in this report as the point along Pickering Passage where the passage begins to bend toward the northeast. As there are no significant depositional features in the area, it appears beach sediment may be moved offshore into deep water.

For a distance of about 1 km along the shore to the northeast of the mapped terminus of sector 87, there is a high-tide platform cut into the glacial till of the bluff. There is extremely little loose beach material upon the platform. However, it is neither a zone of severe erosion, nor an area of rapid sediment transport. The surface of the platform is covered in places by barnacles and seaweed, which would not occur if a significant amount of sediment was moving along the shore. The bluff, although steep, is densely vegetated, and there is thick brush overhanging the platform, indicating insignificant bluff erosion. The foreshore is narrow and relatively steep, and although there is gravelly sediment upon the lower foreshore, there are no shore drift indicators.

The longest fetches to this area are from directions essentially parallel to the shore, and wave energy is apparently directed past this area, rather than toward the shore. In this report, this section of shore is classified as a zone of no appreciable net shore-drift.

Drift cells 88 and 89

At the west side of the entrance to Jarrell Cove, waves from the northeast cause net shore-drift divergence to occur. At the divergence zone, a non-vegetated bluff of till rises vertically from the narrow and somewhat thin beach. Toward the west, in the direction of net shore-drift along drift cell 88, the bluff becomes vegetated and is subaerially eroded to a less steep slope.

Although the beach becomes wider toward the drift cell

88 terminus, this is largely because of an unstable, easily eroded outcrop of outwash sand along the otherwise till bluff. About 1 km to the west of Jarrell Cove, there is a wedge of gravelly sediment prograding from the east into a small cove.

Even though there is a relatively lengthy (10 km) fetch from the northeast to this section of the coast, shore drift indicators are infrequent. There are numerous fallen trees, but no depositional pattern, which would indicate the net shore-drift direction, has developed. Similar to drift cell 87, sector 88 terminates rather indistinctly near the edge of the platform discussed above (see drift cell 87).

A prograding sand and pebble beach, located to the north of a bulkhead just within Jarrell Cove, indicates sediment is transported into the cove from the divergence zone near the cove entrance. The sediment at the divergence zone is predominantly pebbles and cobbles, and the slope of the beach there is low. The slope of the prograding section of beach at the terminus of drift cell 89 is considerably greater. To the south of the bulkhead that causes the progradation, there is a small marina, which protects the shore in the cove from further wave influence.

Drift cell 90

Although there is a fetch of less than 1 km, waves generated by southwest winds transport sediment northeastward out of Jarrell Cove along the eastern side of the cove. At the southwest-oriented point at the origin of drift cell 90, there is a low, eroded bluff; and toward the northeast the bluff becomes much less eroded, although somewhat altered by recreational development. At the outer edge of the cove entrance, there is a 3 km fetch from the west; and in response to the increased fetch, there has developed a vertical, eroded bluff. Wave energy impinging on this part of the shore is greater than wave energy within the cove, so that erosion is renewed along the sector. The width of the beach increases toward the northeast, increasingly protecting the base of the bluff and allowing the bluff to subaerially erode to a more stable slope. Also indicating northeasterly net shore-drift, there is a northeastward decrease in the size of the sediment, and, midway along drift cell 90, a small stream in diverted toward the northeast. Several oblique bars, oriented northeastward, also occur along the sector, and sediment accumulations are found to the southwest of logs (see Figures 22 and 23).

The terminus of drift cell 90 is at Indian Cove, which has been dredged for a marina. Whether or not shore drift originally was able to bypass the cove is not now evident. A lobe of sand and pebbles transported from the southwest is now prograding into the cove.

Drift cell 91

The dredged channel at Indian Cove effectively prevents the occurrence of shore drift past the cove. Beach features at the northeast edge of the cove were modified by dredging; and, in 1982, shore drift features there were inconclusive.

However, within a very short distance northeastward from the cove, there were clear indicators of northeasterly net shore-drift. Sediment accumulations to the southwest of fallen trees, northeasterly widening of the beach, and decreasing sediment size toward the northeast indicate net shore drift in that direction.

The terminus of drift cell 91 is at Dougall Point, where some sediment is transported into deep water, and some is moved by wave refraction around the more northerly part of the point. There, transport along sector 91 converges with drift from the eastern side of Hartstene Island.

Drift cells 92 and 93

Fudge Point, on the northeastern shore of Hartstene Island, causes a wave shadow which results in a zone of net shore-drift divergence along the embayment northwest of the point. Net shore-drift along drift cell 92 is northeasterly away from the zone. Because of the long (up to 25 km) fetches from the southeast, many transport-related beach features are well-developed along this sector. Along Case Inlet, the shore of Hartstene Island is oriented at an oblique angle to the direction of wave approach. This results in considerably more wave energy being expended upon the shore for sediment transport than is available elsewhere in the county.

Along drift cell 92, both the high-tide beach and the low-tide terrace widen considerably in the direction of net shore-drift. Numerous oblique bars, oriented northeastward, occur on the low-tide terrace along this sector. Along the high-tide beach, sediment has accumulated to the southwest of logs, groins, and bulkheads; and, midway along the sector, distinctive cobbles from a fill-site can be traced northeastward, away from the fill-site.

At Dougall Point, a spit, about 300 m in length, curves westward from an initial northeast orientation. The distal end of the spit marks the terminus of drift cell 92. A large, intertidal spit-platform extends seaward from the spit, continuing northeasterly as the spit curves landward. At the distal end of the spit-platform, sediment is transported into deep water.

The bluff along the divergence zone between sectors 92 and 93 is very unstable. Non-glacial, clay-rich beds crop out along the zone, and evidence of mass-wasting is abundant. At one example, the bluff (in 1982) was retreating toward a house still under-construction. The weak bluff material, undercut by wave erosion, was failing in a series of small slump blocks (Figure 46). The erosion characteristic of a divergence zone, coupled with the non-resistant bluff composition, makes the bluff along here unsuitable for typical Puget Sound waterfront construction methods. Toward the northeast, along drift cell 92, the bluff consists of glacial till and outwash and is considerably more stable.

Southeastward from the divergence zone, waves from the northeast, where there is a 10 km fetch, transport sediment along drift cell 93. Beach material is generally fine -- reflecting the bluff composition. Accumulations of sediment

FIGURE 46: Failure of this clay-rich, weakly resistant bluff material results as wave erosion removes material from the base of the bluff. The unstable nature of the bluff has been accentuated by disruption of the upper surface by construction.

occur to the northwest of fallen trees, indicating net shore-drift from that direction. Near Fudge Point, this sector converges with shore drift from the south.

Drift cells 94 and 95

McMicken Island obstructs waves from the southeast causing a wave shadow to the northwest of the island. This results in a divergence zone along the shore of Hartstene Island as waves from the northeast cause a reversal of drift in the lee of the smaller island. Along the divergence zone, the partly vegetated bluff of glacial outwash gravel is kept relatively steep by wave erosion at the base. Northward, in the direction of net shore-drift along drift cell 94, the bluff becomes more densely vegetated, although it remains steep.

As sediment eroded from the bluff is transported northward, both the sandy, low-tide terrace and the coarser, high-tide beach increase in width. The slope of the upper foreshore increases, also, as a berm develops toward the terminus of the sector. Migrating northward on the low-tide terrace are numerous oblique bars. The size of the sediment making up the high-tide beach decreases from coarse gravel along the divergence zone, to predominantly sand and pebbles forming the spit at Fudge Point.

The 500 m long spit marks the terminus of drift cell 94. The spit curves to the west, following the general shore orientation. At its distal end, there is a very small recurve which shows the effect of net shore-drift convergence at this point.

Southward from the divergence zone, waves caused by northeast winds are the predominant shore drift determinant, resulting in the southerly net shore-drift of drift cell 95. Here, too, there are an increase of the beach width and decrease of sediment size in the direction of net shore-drift. Also indicating a southward net transport of beach material, two small streams, near the terminus, are diverted in that direction; and fallen trees have blocked shore drift so that sediment has accumulated on the updrift (northern) side of the trees. The terminus of drift cell 95 is located southwest of McMicken Island where net shore-drift converges from three directions.

Drift cells 96 and 97

With a relatively long (21 km) fetch from the southeast, waves from that direction cause northeastward net shore-drift along the southeastern side of McMicken Island. At the southern point of the small island, a wave-cut platform is partially exposed through a thin layer of cobble and boulder-size lag material. Upon the upper foreshore of the southeastern shore, the size of the sediment decreases to sand and pebbles at the northern point, where some material is further transported into deep water. However, some sediment is moved westward around the point by wave refraction, especially at the upper foreshore level of the beach where a wedge of sand and pebble-size sediment occurs. From this point, waves from the north cause southwestward transport of beach material. Except for the wedge of material forming the small high-tide beach, the most northwestern area of the point, like the southern point, is covered with only a thin veneer of cobbles and boulders. The sediment size decreases in the direction of net shore-drift, now southwestward. As a result of the 180 degree change in direction of net shore-drift, material eroded from the southeastern bluff of the island may be transported a distance of about 1 km, yet be deposited less than 100 m from the origin of the drift cell.

Prograding southwestward from the southwestern tip of McMicken Island is an intertidal bar, which at low tide connects the small island to the larger Hartstene Island, in the manner of a tombolo (Figure 47). This depositional feature, which marks the terminus of drift cell 96, maintains a serpentine shape, showing the complex interactions of waves and shore drift from varying directions.

Extending southwestward from the more southerly point of McMicken Island is a second intertidal feature which somewhat resembles the first (see Figure 47). However, rather than being a depositional feature, this mostly submarine ridge is a wave-eroded extension of the island.

Drift cell 97 is located along the very short southwestern shore of the island. From the southern point, sediment is transported northwestward where it may become incorporated into drift cell 96. The eroded subaqueous ridge considerably dissipates wave energy, and the size of the sediment decreases rapidly in the direction of net shore-drift.

Drift cells 98 and 99

Similar to Fudge Point and McMicken Island, the point of

FIGURE 47: This view of McMicken Island from the east shows two southwestward intertidal-extensions of the island. However, the southernmost (lower) extension is an erosional feature, while the northernmost (upper) extension is depositional.

land near Buffingtons Lagoon causes a wave shadow which results in a reversal of net shore-drift along the shore to the northwest of the point. From the cobbly beach along the divergence zone, the sediment decreases in size toward the northwest along drift cell 98, and southeastward along drift cell 99. Sediment accumulations occur to the southeast of obstacles along sector 98, which terminates at a complex convergence zone located southwest of McMicken Island.

The predominance of waves from the north along drift cell 99 is indicated by two southeast-oriented spits which occur in the Buffingtons Lagoon area. One of the spits is located midway along the sector and the second spit is at the sector terminus, where net shore-drift from the northwest converges with sediment transported northwestward along the southeast shore of Hartstene Island.

Drift cell 100

Brisco Point, the southern end of Hartstene Island, faces into the prevailing and predominant winds. Waves, generated by winds across 4 to 6 km of fetch from the southwest, have caused formation of a wave-cut platform at the point and keep the bluff eroded to near-vertical (see Figure 13). Net shore-drift of drift cell 100 is northeastward along Dana Passage. The shore along this passage is parallel to the approach of waves from the southwest and does not receive the direct force of wave energy that erodes the bluff at Brisco Point. Consequently, the bluff along Dana Passage is generally subaerially eroded to a more gentle slope and supports vegetative growth.

Protection of the base of the bluff is also afforded by the increasing width of the beach in the direction of net shore-drift.

The bluff at Brisco Point and along Dana Passage consists primarily of glacial till. The beach material reflects the bluff composition, although in the downdrift direction there is an increase in the relative proportion of finer sediment comprising the beach. Also indicating northeasterly net shore-drift, there are two northeast-oriented, gravelly spits located about 1 km to the northeast of Brisco Point.

Approximately 2 km to the northeast of Brisco Point, along drift cell 100, deposits of non-glacial sand crop out along the bluff. Although fairly densely vegetated, these deposits are easily eroded by wave action, and there is evidence of frequent landsliding, which results in a considerable influx of sand-size sediment to the beach. A short distance farther northeastward, Dana Passage opens into the southern end of Case Inlet and there is a large increase of fetch from the southeast, which, despite the influx of sandy beach material, results in a very steep bluff. Only near Wilson Point does the beach widen sufficiently to allow subaerial processes to erode the bluff to a significantly less-steep slope.

At Wilson Point, however, the shore orientation curves toward the northwest, thus becoming parallel to the direction of maximum fetch. This change in orientation results in two very noticeable shore drift features. First, a compound intertidal spit has formed at Wilson Point (see Figure 26). Secondly, and partly because of the first, the bluff to the northwest of Wilson Point is subaerially eroded to a much greater degree than the bluff to the south of the point. The change in shore orientation results in a decrease of energy available for sediment transport, and deposition of part of the large amount of sediment being transported along this sector occurs. The prograding spit, in turn, further protects the shore to the northwest from waves from the southeast.

Approaching Wilson Point from the south, widening of the beach, especially the low-tide terrace, is very evident; and numerous oblique bars occur in this area (see Figure 30). Also indicating generally northward net shore-drift, accumulations of sediment occur to the south of obstacles along drift cell 100.

Net shore-drift along this sector continues in a north-northwesterly direction past Wilson Point, although at a slower rate, as the shore becomes essentially parallel to the predominant wave approach direction. Oblique bars oriented north-northwesterly and sediment accumulations to the south-southeast of logs indicate generally northerly net shore-drift; however, these indicators are not as well developed as those to the south of Wilson Point.

The terminus of drift cell 100 is at the distal end of a northwest-prograding spit located at the Buffingtons Lagoon area. The approximately 250 m long spit curves westward, following the shore orientation; and, like the spit at Fudge

Point to the north, shows a growth pattern indicating the long-term direction of net shore-drift.

Drift cell 101

Net shore-drift along drift cell 101 originates at the cobbly wave-cut platform at Brisco Point where drift along this sector diverges from that of drift cell 100. Only 300 m from the origin, along the northwest side of the point, the sediment decreases to primarily pebble-size at a northeast-oriented spit. Drainage from the lagoon enclosed by the spit has transported sediment seaward, resulting in formation of a gravelly delta.

To the north of the spit, the bluff consists of gravelly glacial outwash. With up to 9 km of fetch from the southwest, bluff erosion is relatively severe. Fallen trees, undercut by wave erosion, line the shore nearly continuously for a distance of about 1 km (Figure 48). There, the bluff becomes more stable as the pebbly high-tide beach develops a berm, thus protecting the base of the bluff from wave erosion (Figure 49). However, landsliding is still evident in a few places (see Figure 10).

To the northwest, in the direction of net shore-drift, this pebbly high-tide beach becomes wider and steeper, and a narrow backshore area develops. The deposition of pebble-size sediment forming this beach begins at a position located to the northeast of the southern end of Squaxin Island.

Nowhere else in Mason County is any berm and backshore area as well developed as along this drift cell. The beach consists of fairly well-sorted pebble-size sediment along its

FIGURE 48: Trees, which have fallen because of wave erosion at the base of the bluff, line the beach for about 1km of the shore along southwestern Hartstene Island. Finer sediment is transported northwestward, leaving a coarse lag deposit.

FIGURE 49: The size of the sediment is seen to be much finer here, where high-tide beach deposition has developed a berm, than the size of the sediment toward the origin of this drift cell, as seen in Figure 48.

more than 2 km length (Figure 50). Larger size material is left to the southeast as a lag deposit (see Figure 48). Sand and finer material occurs in the bluff which supplies the material to this beach; and oblique sand bars, migrating northwestward, are found upon the low-tide terrace, which occurs along the southern part of the sector. However, as the pebbly high-tide beach widens in the direction of net shore-drift, the low-tide terrace narrows and ends. As there are no large deposits of sand found to the northwest along Hartstene Island, it appears that sand and smaller size sediment is moved offshore into deep water.

The northern end of the pebble beach is prograding north-northwestward, parallel to the shore (Figure 51). Older growth segments of the beach project as ridges across the marsh area, which occurs between the beach and the protected, subaerially eroded bluff. There are no significant streams along here, but slope wash tends to be ponded behind the beach.

Net shore-drift continues northwestward beyond the end of the pebbly beach. Immediately to the northwest, the beach sediment is primarily large pebbles and cobbles, and the low bluff, not protected by a large beach deposit, becomes more eroded. Sediment size again decreases in the direction of net shore-drift, and sediment accumulations occur to the south-east of obstacles. Also indicating northwesterly net shore-drift along the northern portion of this drift cell, there are several oblique bars and small spits (Figure 52) prograding toward the northwest.

FIGURE 50: Well-sorted pebble-size sediment forms a distinctive 2 km long beach along southwestern Hartstene Island. The ruler is 15 cm in length.

FIGURE 51: Progressively older segments of the prograding pebble beach along southwestern Hartstene Island. View toward the southeast.

FIGURE 52: This small spit is located on Hartstene Island along Peale Passage. It is similar to the prograding end of the pebble beach shown in Figure 51, though on a smaller scale, and it diverts a very small stream. Note erosion of the low bluff beyond the end of the spit.

The terminus of drift cell 101 is here mapped near the northern end of Peale Passage, where there is an abrupt change in shore orientation toward the west-southwest. As discussed above (see drift cell 84), sediment may be transported past this small cove during large storms, but there is no evidence preserved.

Squaxin Island

Most of Squaxin Island is part of the Squaxin Island Indian Reservation and is not covered in this report. Features such as spits, seen from a distance, indicate generally northwestward net shore-drift along the island. However, the numerous coves on the southern half of the island would tend to compartmentalize the shore drift.

Drift cells 102 and 103

Hope Island, the small island located to the west of Squaxin Island, is well-protected from most directions by surrounding lands. There is, however, a 5 km fetch from the southeast through Squaxin Passage, and 2 to 3 km of fetch from the north-northwest along Pickering Passage.

From the most exposed, southeastern shore of the island, net shore-drift diverges toward the west and toward the north. Net shore-drift along drift cell 102 is toward the west and is indicated by a decrease in size of the sediment toward the west, and by widening of the beach in that direction. Along the southwestern shore of the island, drift from the east converges with drift from the north.

Net shore-drift along drift cell 103 begins northward from the southeastern divergence zone, where a wave-cut platform is partially exposed through a thin layer of coarse sediment. Northward, there is a decrease in size of the beach material. At the northern end of the small island, some of the transported material is probably moved into deep water. However, some sediment is moved westward around the point by wave refraction. Similar to the situation at McMicken Island, transport around the point by wave refraction is especially evident on the upper foreshore where a wedge of pebbly gravel material has moved around the point from the east. Below this relatively fine material, on the lower foreshore, large pebbles and cobbles form a thin layer over a partly exposed wave-cut platform. Waves from the north cause net shore-drift toward the southwest along the northwest side of the island. A decrease in the size of the sediment indicates the southwestward net shore-drift. Along the southwestern part of the island, net shore-drift of drift cell 103 converges with that of sector 102. The narrow channel of Squaxin Passage becomes deep, very abruptly, a short distance offshore; and beach material, especially finer sizes of sediment, is easily lost into deep water.

MAP 6: Southwestern Inlets

(Drift cells 104 - 136)

Drift cell 104

The generally westerly net shore-drift along drift cell 104 begins at Hungerford Point at the eastern end of Hammersley

Inlet and extends about 1.5 km to the tip of Cape Horn. Although the fetch to the most exposed part of Hungerford Point is only about 3 km from the south, there is a wave-cut platform carved from the low (10 m) bluff consisting of glacial till. There is a very narrow 7 km fetch from the southeast, passing north of Hope Island and along the south-western shore of Squaxin Island. However, to be effective, waves from that direction would have to be driven by wind with a very limited directional range, and the waves would have to pass by several points of land where moderation by refraction would occur. Thus, wave energy along the sector appears to be limited by the general 2 to 3 km of fetch which otherwise occur. The wave-cut platform at the origin is not very wide, compared to others in the county. The steepness of the bluff appears to be largely the result of the relative resistance of the till to subaerial erosion, rather than rapid erosion by high-energy waves.

There is a gradational decrease of sediment size toward the west, slight accumulations of beach material are deposited to the east of fallen trees, and there is a westward increase of the beach width. All of the above indicate that waves from the southeast quadrant are predominant along this shore. Beach material, transported along drift cell 104, is washed into the channel of Hammersley Inlet at the end of Cape Horn.

Hammersley Inlet has a constricted, largely tidal-dominated channel, and material washed into the channel is redeposited by tidal currents. Periodic dredging maintains the limited navigability of the channel.

Although Cape Horn appears on the map to be a spit, it is far from being a depositional form; rather, it is a narrow point of land rising about 30 m above the water. The southwestern tip of Cape Horn is an active landslide area (see Figure 8).

Drift cell 105

Drift cell 105 is mapped as beginning about 1 km to the west of Cape Cod, with easterly net shore-drift along the southern shore of Hammersley Inlet. Fetch is extremely limited along this sector, which extends between two glacial till headlands. Shore drift here cannot be considered a major geomorphic process, although slight accumulations of sediment to the west of fallen trees indicate some degree of eastward net shore-drift. As at Cape Horn, the glacial till headlands extend into the channel, resulting in areas of no appreciable net shore-drift at either end of the drift cell.

Drift cell 106

From a glacial till headland located about 2 km to the west of Cape Horn, net shore-drift along drift cell 106 is eastward to the tip of Cape Horn, where deposition into the channel of the inlet occurs. The shore along sector 106 is more exposed to waves than that of sector 105, and shore drift indicators are more pronounced. Indicating eastward net shore-drift, sediment accumulations occur to the west of fallen trees, there is an eastward decrease of sediment size and increase of beach width, and, midway along the sector, there is a lobe of sediment prograding from the west into a small cove.

Drift cell 107

Drift cell 107 originates 1 km to the east of the mouth of Mill Creek, at the east side of a headland of glacial till. Sediment accumulations to the west of fallen trees, and widening of the beach toward the east, indicate net shore-drift in an easterly direction. Also, deposition into the tidal-dominated channel at the edge of a till headland marks the terminus of this sector.

Drift cells 108 and 109

A short distance to the east of Libby Point, net shore-drift diverges as a result of a wave shadow caused by the point. Although the area is fairly sheltered and wave energy is low, the bluff, consisting of relatively resistant glacial till, rises near-vertically to about 20 m elevation. Net shore-drift along drift cell 108 is eastward from the divergence zone. The terminus of this sector is just to the west of a till headland, where there is a small cove. Prograding into the cove from the west is a lobe of beach material. At the headland, loose sediment is swept into the channel by strong tidal currents.

The area immediately to the east of Libby Point is sheltered from westerly winds by the point. Less frequent east winds cause waves which transport sediment westward from the divergence zone, resulting in a widening of the beach in that direction. A small stream, which enters the cove there, is slightly diverted toward the southwest. Drift cell 109 ends at Libby Point -- another glacial till headland which extends into the channel of Hammersley Inlet.

Drift cell 110

Drift cell 110 is another short drift cell which extends between headlands of glacial till that are located a short distance to the east of the mouth of Mill Creek. There are only slight indications that shore drift operates along this part of the shore. The beach widens toward the east; and, there are slight deposits of sediment accumulated to the west of fallen trees, indicating easterly net shore-drift.

Drift cell 111

Drift cell 111 begins 0.5 km to the southeast of Skookum Point and ends at the mouth of Mill Creek. There is a south-eastward decrease of sediment size, and a lobe of sediment is prograding across the mouth of the creek from the northwest. Streamflow of Mill Creek blocks shore drift, transporting sediment into the channel of Hammersley Inlet.

In the map view (Plate 6), it appears that spits are prograding across the mouth of Mill Creek -- one from either direction. Although a small wedge of sediment is prograding eastward from the more northerly of these two features, it is insignificant at this map scale. These projections of land, like Cape Horn to the east, are not depositional features. The sharp curve of the mouth of Mill Creek is an incised meander -- cut down into glacial till.

Drift cells 112 and 113

Opposite drift cell 111 on the northern shore of

Hammersley Inlet, net shore-drift along sector 112 is also eastward. The land here, as well as for most of the length of the inlet to the west of Libby and Skookum points, slopes gently to the shore. There is slight erosion along the divergence zone of drift cells 112 and 113, and the beach widens in the directions of net shore-drift -- eastward along drift cell 112, and northward along sector 113. The gravelly beach sediment along both sectors reflects the glacial till source material. Libby Point, extending into the channel of the inlet, marks the terminus of sector 112. Drift cell 113 terminates within a slight cove, located a very short distance to the north of the divergence zone.

Drift cells 114 and 115

Drift cells 114 and 115 diverge from a small, rounded point of land, located approximately 0.5 km to the east of Church Point. Net shore-drift is southeastward along sector 114, into the slight cove where net shore-drift converges. A small stream is slightly diverted southeastward by a lobe of material prograding from the northwest.

From the slightly eroded divergence zone at the point, northwestward net shore-drift occurs along drift cell 115, and terminates at the cove located to the east of Church Point. There is a slight decrease of sediment size into the cove from the southeast, and the terminus is marked by a small prograding beach.

Drift cell 116

Along the southern shore of Hammersley Inlet, beginning to the southwest of Miller Point near the western end of the passage, net shore-drift of drift cell 116 is eastward for a distance of 4.5 km to Skookum Point. Along this sector and indicating easterly net shore-drift, sediment has been deposited to the west of groins, bulkheads, and logs; and several small streams are slightly diverted eastward. Although this portion of Hammersley Inlet has longer distances of fetch than the eastern portion, it is still quite protected. The constricted, tidal-dominated channel and the infrequent westerly and easterly winds are not favorable conditions for wind-derived wave energy to develop to any significant degree. Accordingly, the divergence zone at the beginning of sector 116 is not marked by significant erosion; rather, there is simply an absence of shore drift indicators. At the terminus at Skookum Point, material is transported into the channel of the inlet, where tidal currents control deposition. Skookum Point, like the other points along the inlet, is a glacial till headland, which is swept of loose sediment by tidal currents.

Drift cell 117

Parallel to drift cell 116 along the northern side of Hammersley Inlet, net shore-drift along drift cell 117 also is eastward. Winds from the west and west-southwest cause net shore-drift divergence to occur at Munson Point on the east side of Oakland Bay. The low bluff along the divergence zone, which consists of glacial outwash, has undergone more severe erosion than the shore along the east-west portion of the inlet. Today, however, the bluff is largely protected by bulkheads which were constructed to protect residential development.

As on the south side of the inlet, shore drift indicators along drift cell 117 are generally scarce. Some sediment accumulations occur to the west of groins and bulkheads, and erosion occurs to the east of some obstacles (Figure 53), indicating easterly net shore-drift. The terminus of drift cell 117 is within a small cove to the east of Church Point, where there is a small prograding beach.

Drift cells 118, 119, and 120

Diverging from sector 116 on the south shore of Hammersley Inlet, net shore-drift along drift cell 118 is westward. Eagle Point, projecting northeastward, shelters this part of the shore from westerly influence, thus allowing winds from the east to cause westward sediment transport. Accumulations of sediment to the east of groins and bulkheads, and a westward decrease of the sediment size, indicate net shore-drift in a westerly direction.

Drift cells 119 and 120 diverge from a narrow wave-cut platform at the tip of Eagle Point. Waves from the north appear to be the predominant shore drift influence here, as sediment size decreases both southwestward into the cove south of the point along drift cell 119 and west-southwestward along sector 120 on the north side of the point. Toward Shelton, about 300 m along drift cell 120, pilings and log rafts protect the shore from significant wave energy, and shore drift along this sector is effectively halted.

FIGURE 53: Erosion occurs at the downdrift end of this bulkhead located along Hammersley Inlet. Net shore-drift is from background at left (west) toward viewer.

The waterfront at Shelton, at the southwestern end of Oakland Bay, has been extensively developed by a lumber company. In this report, this portion of the shore is classified as an area of no appreciable net shore-drift.

Drift cell 121

Northeastward from Munson Point, diverging from drift cell 117, net shore-drift along drift cell 121 is indicated by accumulations of sediment to the southwest of groins, bulkheads, and logs; by several oblique bars oriented toward the northeast; and by a northeasterly increase of the beach width. In addition, midway along the sector there is a looped bar which has prograded northeastward; and at Chapman Cove, the drift cell terminus is marked by a northeastward-prograding spit. Southwest winds from across Oakland Bay cause the northeastward net shore-drift. The orientation of this part of the shore, and the fetch from across the bay, result in much more distinctive shore drift indicators than are found along Hammersley Inlet.

Drift cell 122

To the northwest of Chapman Cove there is a zone of net shore-drift divergence. Net shore-drift along drift cell 122 is southeastward from this zone and terminates at Chapman Cove. Waves from the southwest have eroded a wave-cut platform along the divergence zone, and the bluff there, consisting of gravelly glacial outwash, is steep and non-vegetated. Toward the southeast, the bluff becomes less steep and more densely vegetated. Also indicating southeasterly net transport of beach material, the sediment decreases in size from cobbles and pebbles at the divergence zone to pebbles and sand at a southeastward-prograding spit at Chapman Cove. However, these features are somewhat relict in nature. Offshore, a log storage area, consisting of pilings and log rafts, now absorbs much of the wave energy directed toward this shore. Although old fallen trees with their roots still embedded in the bluff indicated erosion of the bluff was once severe, younger vegetation is now taking over the face of the bluff; and grasses are encroaching upon the beach, stabilizing the sediment. Removal of the logs would reactivate the drift cell.

Drift cell 123

Northeasterly net shore-drift along the northwest shore of Oakland Bay begins near Shelton, beyond the limit of the protected, industrialized area. Waves from the south transport material northeastward for a distance of 4.5 km to the mud flats along the south side of Bayshore, at the mouth of Johns Creek.

Sediment accumulations occur to the southwest of groins, bulkheads, and fallen trees; and there is a northeastward decrease in the size of the beach sediment, indicating that net shore-drift is toward the northeast. Additionally, the beach width increases northeastward, and there are several oblique bars oriented in that direction. Near the terminus, a spit is prograding northeastward across the Bayshore mud flats. Johns Creek has deposited levees of gravel for a distance of about 100 m south-soutwestward across the mud flats. Drift cell 123 is mapped here as ending at the mouth of the stream.

Drift cell 124

Bayshore, which projects southeastward across Oakland Bay, has been developed for residential and recreational uses. The peninsula, formed by deltaic deposition of Johns Creek, nearly reaches the opposite shore, but stream drainage and tidal flow keep a narrow channel open. Along the channel, muddy, spit-shaped bars are prograding northeastward along the marshy extreme of the delta, indicating wave energy transports some material around the peninsula. Indicators cease a short distance to the north, and drift cell 124 is mapped as ending there. Marsh and mud flat conditions prevail along the northeast side of Bayshore, and the area is here classified as an area of no appreciable net shore-drift.

Drift cell 125

Net shore-drift along drift cell 125 diverges from sector 122 and is northeastward to the end of Oakland Bay. From the wave-cut platform at the divergence zone, there is a northeastward decrease of sediment size. Also indicating net shore-drift in that direction, sediment has accumulated to the southwest of logs, groins, and bulkheads; and 1 km from the sector origin, there is a small spit prograding northeastward. Drift indicators cease along the shallow mud flats at the upper end of the bay, which is a prograding deltaic area. This portion of the shore is classified as an area of no appreciable net shore-drift.

Interbedded clay deposits crop out along the bluff about 1 km to the southwest of the terminus of sector 125. Consequently, despite low-energy wave conditions, the bluff is unstable, and several small landslides have occurred along the sector.

Drift cell 126

At low tide, about 85 percent of the northeast portion of Oakland Bay is subaerially exposed as mud flats. Despite the low-energy conditions, a few muddy, spit-shaped bars are prograding northeastward along the northwest shore of the bay. Also indicating some amount of northeastward net shore-drift along drift cell 126, there are a few slight accumulations of beach material to the southwest of obstacles. However, shore drift is not an important geomorphic process in this area of Oakland Bay.

Drift cell 127

Drift cell 127 begins near the mouth of Skookum Inlet, several kilometers to the south of Hammersley Inlet. Net shore-drift along this sector originates at a drift divergence zone, where waves from the south cause sediment transport into the mouth of Skookum Inlet (drift cell 128) and northeastward along Totten Inlet (drift cell 127).

Along the initial 2 km of this sector, there are sediment accumulations southwest of drift obstructions, an increase of beach width toward the northeast, a northeastward decrease of sediment size, and oblique bars oriented in a northeasterly direction. All of the above indicate northeastward net shore-drift.

As the shore curves toward the east, the land is more directly exposed to prevailing winds and waves. This exposure is reflected by numerous small landslides which have occurred along this part of the shore. Eastward diversion of small streams occurs along this area, as well as indicators similar to those found along the initial portion of the sector.

To the northeast of Windy Point, the bluff becomes subaerially eroded to a less steep slope, as the shore is again parallel to the prevailing and predominant wave direction. As to the south, beach features indicate northeasterly net shore-drift. Additionally, 0.5 km southwest of Arcadia, there is a northeast-prograding spit. Some beach sediment becomes trapped in the cove there, but generally waves are able to transport sediment past the cove.

Net shore-drift continues northwestward around the point at Arcadia, toward Cape Cod. At the point at Arcadia, there is a large cement wall, designed to prevent foot traffic along the beach. The wall extends from the backshore, across the beach to the lower foreshore. The top of the wall, along its entire length, remains above water at high tide. Because the tidal range in this area is about 4 m, at low tide the seaward end of the structure is a very forbidding 4+ m high. As a result of the wall, an excellent example of a shore drift indicator exists. The beach on the updrift side of the wall has prograded seaward, causing about 2 m of vertical and 30 m of horizontal offset of the beach. Beach material does pass around the lower end of the structure. Drift cell 127 continues to Cape Cod, where sediment is washed into the tidal channel of Hammersley Inlet.

Drift cell 128

As a result of waves from the south and southeast, net shore-drift along the north side of the entrance to Skookum Inlet is west to northwest into Deer Harbor. Sediment size decreases into the harbor from the divergence zone shared with sector 127, and the beach widens, indicating the net shore-drift direction.

To the west of Deer Harbor, for a distance of 3 km, both shores of the narrow channel of Skookum Inlet are areas of no appreciable net shore-drift. This part of the inlet (Figure 54) resembles a river, especially during ebb tide. Tidal currents are the dominant forces affecting the shores, where there are essentially no beaches.

Drift cells 129 and 130

Mud flats extend along the entire upper (southwest) portion of Skookum Inlet, and shore drift is not a major geomorphic process. Nevertheless, there are features indicating that shore drift does occur along the very narrow high-tide beach. Sediment accumulations to the southwest of logs, and small, muddy spits diverting streams northeastward indicate that net shore-drift in a northeasterly direction occurs along both sides of the upper portion of the inlet.

Drift cells 131 and 132

Net shore-drift along sector 131 originates at a diver-

FIGURE 54: Tidal currents dominate the constricted channel of Skookum Inlet. This view toward the east is of a portion of the inlet known locally as "the narrows".

gence zone located midway between Kamilche Point and Big Cove. Northward net shore-drift is indicated by a northward decrease of sediment size, beach material deposited at the south side of obstructions, and an increase of the beach width toward the north. Material is transported to the west around Kamilche Point, and the drift cell ends with deposition into Wildcat Cove.

The rather long divergence zone between sectors 131 and 132 is a result of the balance between relatively frequent waves from the south-southwest, where there is a short fetch of 2 km, and less-frequent and smaller waves from the north-east, where there is a relatively long fetch (7 km).

Southward net shore-drift along drift cell 132 is indicated by a decrease of sediment size, accumulations north of obstacles, and increases of the beach width and slope toward the south. It converges with sector 133 at a small, prograding beach located northeast of Big Cove, where the shore orientation curves from north-south to northeast-southwest.

Drift cells 133 and 134

Because the shore to the northeast of Big Cove faces more directly toward the approach of waves from the south, net shore-drift is northeastward from the area of Big Cove. The beach slope and width increase northeastward, a northeasterly reduction of sediment size occurs, and sediment has accumulated southwest of obstacles, indicating northeasterly net shore-drift along drift cell 133.

South of Big Cove, the shore is oriented north-south, and waves from the northeast are predominant along the shore, causing southward net shore-drift in sector 134. Sediment size decreases southward, the beach becomes wider and steeper toward the south, and accumulations of beach material occur to the north of logs. At Deepwater Point, there is a prograding, lobate beach where net shore-drift from the north (drift cell 134) converges with drift from the west (drift cell 135).

Drift cell 135

Southerly winds, from across shallow Oyster Bay at the southwest end of Totten Inlet, cause northeasterly net shore-drift along drift cell 135, which originates at a divergence zone in the New Kamilche area. Northeastward net shore-drift is indicated by sediment accumulations to the southwest of obstacles and widening of the beach toward the northeast. In addition, about 0.5 km northeast of the origin of the sector, oyster shells, discarded by a commercial shellfish operation, have been reworked into a very small spit, oriented toward the northeast.

Net shore-drift continues eastward to Deepwater Point, as indicated by eastward migrating oblique bars, sediment accumulations west of obstacles, and the eastward diversion of two small streams by small eastward-projecting spits. Near the terminus at Deepwater Point, the beach widens and steepens considerably as material converges at the lobate, prograding beach located there.

Drift cell 136

Although Oyster Bay is very shallow, with tidal mud flats extending out 3.5 km from the head of the bay (Figure 55), there is a small, muddy spit oriented southwestward at the mouth of a small stream, indicating that a short sector of southwestward net shore-drift occurs in the New Kamilche area.

The southwestern end of the bay is characterized by marsh development along the prograding delta of Kennedy Creek. The area at the head of Oyster Bay is classified as an area of no appreciable net shore-drift. The boundary between Mason County and Thurston County is located along the eastern side of the delta.

FIGURE 55: The Oyster Bay mud flats are shown in this view toward the northeast. Note the meander scars of small streams which flow across the flats.

SUMMARY

Beaches and Shore Drift

Beaches are dynamic, multi-faceted systems. To view a beach as a static, three-dimensional geomorphic form can lead to fallacious assumptions which may negate the value of expensive plans for coastal development.

Beaches are possibly best understood when studied in the context of the drift cell concept. By identifying the sources of beach sediment, the direction of transport of the material, and the depositional terminus of the transport system, predictions can be made about the trend of long-term natural change, and how the system will adjust to artificial modifications. The geomorphic and sedimentological indicators, as outlined in this report, can be used to delineate drift cell boundaries and determine the long-term directions of net shore-drift.

With the limits of a drift cell defined, then the factors which propel the system can be examined. Factors which affect wave energy, such as wind velocity, wind direction, wind duration, fetch distance, and water depth, vary continuously from place to place and time to time. Consequently, every drift cell is at its own natural balance, and each may react differently to shore modifications.

Overall Trends

In this report, 136 Mason County drift cells have been identified and mapped. Directions of net shore-drift are largely controlled by a balance between wind velocity and duration, and fetch. Generally, to overcome the predominance of the prevailing southwest winds and waves, there must be a large difference in fetch to cause a reversal of the predominant directions of net shore-drift.

Hood Canal (maps 1, 2, and 3)

Net shore-drift along the western branch of Hood Canal is generally northeastward. There are relatively long fetches from the southwest and northeast, so it is the prevalence and higher velocity of southwest winds which control the general direction of net sediment transport. Short reversals occur where projections of land extend from the western shore of Hood Canal, forming wave shadows by obstructing waves from the southwest. At the southern end of Hood Canal, the long fetch from the northeast causes waves from that direction to become predominant, overcoming the more frequent waves from the southwest, which, because of the short fetch, do not achieve the energy necessary to control the direction of net shore-drift.

Along the eastern arm of Hood Canal, net shore-drift is also generally northeastward, with reversals occurring to the northeast of projections from the shore. These reverse sectors appear to have more recent origins; that is, as small deltas along this shore have prograded, deposition of sediment transported by shore drift has occurred along the updrift margins of the deltas. As this depositional pattern progressed, the shore to the northeast of the deltas was increasingly protected from waves from the southwest. Consequently, the reverse sectors developed as waves from the northeast became predominant within the sheltered zones.

Most of the Mason County portion of the Hood Canal shore is fronted by riprap and bulkheads, which defend roadways and residential developments from wave erosion. It appears probable that severe beach erosion may become a problem in the future because there is little exposed bluff left to supply beach sediment.

Southern Puget Sound (maps 4 and 5)

Waves from the south are generally predominant along the shore at the northern end of Case Inlet. However, many short reversals occur because small islands and northeast-projecting points cause wave shadows, where waves from the north-northeast become predominant.

Along Pickering Passage, to the west of Hartstene Island, fetch is limited by the narrow and sinuous nature of the passage. Generally, southerly winds generate the predominant waves, resulting in net shore-drift toward the north. Again, however, small projections of land result in local reversals.

The shore along the east side of Hartstene Island is generally oriented obliquely to the direction of maximum fetch (southeast), which is the most favorable orientation for transport along the shore. With the favorable orientation, and with the longest distances of fetch in the southern Puget Sound portion of Mason County, shore drift is a more active process along this part of the shore than anywhere else in the county. The four largest spits in the county, and several smaller ones, are located on this side of the island, attesting to the predominance of waves from the southeast upon this area. Reversals occur where waves from the southeast are impeded by projections of the shore at Fudge Point and Buffingtons Lagoon, and by McMicken Island. Net shore-drift along the reversed sectors is primarily because of less-frequent waves from the north; however, it may also be the result of waves from the southeast which have been refracted around the points.

Southwestern Inlets (map 6)

Once again, prevailing southwest winds are the predominant influence of shore drift along these inlets. However, fetches become even more limited than elsewhere in the county, and along some areas, shore drift is not an important process. This is especially evident along Hammersley Inlet and Skookum Inlet, where tidal currents dominate the very constricted waterways. Large tidal mud flats at Oyster Bay, Skookum Inlet, and Oakland Bay also limit wave energy.

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