III. Results

A. Physical and Geomorphological Site Descriptions

Twenty-five sites were visited during the reconnaissance survey in August and September 2000. These included six sites on the east side of Cook Inlet, eight sites in the middle of the inlet, including four shoals, and eleven sites on the west side of the inlet (Figure 1-1). These are listed, along with their GPS coordinates (longitude and latitude), in Table 1-1.

1. East Side of Middle and Upper Cook Inlet (6 sites)

a) Clam Gulch

The sampling location at Clam Gulch is approximately 1/2 nautical miles (nm) south of the road access to the beach and approximately 20 nm south of the mouth of the Kenai River (Figure 1-1). The transect extended approximately west across the beach. The predominant features of the beach are a relatively wide (~170 feet) and high (nearly 20 feet), steep (~12% slope) beachface of pebbles and a moderately wide flat (>600 feet) of fine well-sorted sand that extends out to the subtidal zone (Figure 3-1a). The elevation at the upper end of the sand flat is about 1 foot above MLLW. Boulders up to 6 feet in diameter (probably glacial erratics) are scattered sparsely on the beachface and sand flat. A narrow band of cobbles and boulders and a shallow muddy channel are located in the transition zone between the beachface and sand flat.

1) Physical

The sampled sediment at Clam Gulch classifies as fine sand. Median grain size is 0.18 mm. The material is well sorted and the distribution is not skewed by either the fine or coarse fractions (Table 3-1, Figure 3-2). Organic content of the sediment, as represented by TOC and TKN, is low (0.12 and 0.008 percent, respectively (Table 3-1). Materials on below the toe of the beachface were quite uniform.

2) Geomorphological

This site, which is representative of a large segment of the eastern shoreline of Cook Inlet near the town of Kenai, was denoted by Hayes et al. (1976) as a shoreline with: a) near

Table 3-1. Summary of particle grain size, Total Organic Carbon, and Total Kjeldahl Nitrogen parameters for intertidal sediments in middle and upper Cook Inlet in August-September 2000.

Figure 3-1. Beach profiles for sampling locations on the east side of middle and upper Cook Inlet.

Figure 3-2 Particle grain size profiles for sites examined on the east side of middle and upper Cook Inlet.

vertical scarps in bedrock that are generally less than 100 feet high; and b) beaches that are complex mixes of gravel and sand, bordered in places by wide tidal flats and wave-cut platforms in bedrock. This shoreline type makes up 28 percent of the coastline of lower Cook Inlet, only being surpassed in length by embayed *ria* shorelines dominated by mountainous steep valley walls (30 percent). The bedrock in the scarps is mostly flat-lying Tertiary sandstones and shales interlayered with some coal beds. The terrain landward of the scarp is draped with glacial deposits.

Morphology and Hydrodynamics - Two morphological features compose the portion of the station located seaward of the erosional scarp - a depositional high-tide berm and a broad tidal flat. The flat is separated from the beachface by a shallow swale and contains a conspicuous intertidal sand bar. The high-tide berm has a relatively narrow sandy berm top adjacent to the scarp (Figure 3-3a). The beachface portion of the berm has a band of pebbles near the berm crest (Figure 3-3b), an irregular band of sand in the central portion of the beachface, and an accumulation of cobbles near the seaward margin of the beachface (foreground in Figures 3-3a and c). A shallow swale, which contains some muddy sediment, separates the beachface from the broad tidal flat. The relatively steep slope of the beachface (Figure 3-1a) is typical of beaches that contain a significant amount of gravel.

The tidal flat, which in places in this vicinity is 1000 feet wide during low spring tides, is composed of fine-grained sand. A number of low-amplitude intertidal sandbars occur at different positions along the flat. One such bar is located on the transect a few tens of feet seaward of the toe of the beachface (Figure 3-3b). The surfaces of the bars are covered with asymmetrical sand ripples resulting from both wave- and tide-generated currents (Figure 3-3d). This flat is most likely positioned on top of a wave- and ice-cut rock platform in the underlying relatively soft sedimentary rocks. Large boulders scattered over the surface of the flat, as well as on the high-tide berm area, are glacial erratics left behind as the scarp and its overlying glacial sediment overburden have been eroded away during the past few thousand years, causing the scarp to retreat landward.

With tides commonly exceeding 20 feet during spring tides (Table 2-1), the outer parts of the tidal flats are undoubtedly swept by some fairly strong tidal currents during falling and rising tides. However, these currents have little effect on the overall morphology of the profile, which is formed primarily by wave activity that has built the berms, eroded the underlying rock platform (aided no doubt by ice scour), and shaped the intertidal bars. The fetch perpendicular to this shoreline in a northwesterly direction is approximately 30

Figure 3-3. Photographs showing site characteristics at Clam Gulch.

miles. However, wind data collected at the Kenai weather station show that the prevailing and predominant winds at that site blow roughly parallel to the long axis of the lower half of the inlet (northeast-southwest). Southwesterly winds are dominant during the spring and summer and northeasterly winds are dominant during the fall and winter. Wind blows directly out of the northwest along the 30-mile fetch perpendicular to the shoreline less than 5 percent of the time. Northeast winds essentially blow offshore at this site, severely limiting the fetch effect, but open water stretches more than 100 miles to the southwest. Consequently, waves approaching the shoreline from the southwest are probably the waves that have shaped this shore profile. Because these waves would be approaching the shoreline at such a steep angle, this is not an exceptionally high-energy shoreline with regard to wave action. The roundness of the cobbles on the beach, however, indicates that periods of fairly large waves do occasionally occur. Geomorphic evidence (e.g., the orientation of shoreline-attached spits) indicates that longshore sediment transport is overwhelmingly south to north in this area (Hayes et al. 1976).

Sediments - The sediments of the berm show a wide range in grain size, from large cobbles to fine-grained sand. The concentration of cobbles along the toe of the beachface is probably due to a combination of the larger particles rolling to the bottom of the beachface slope during storm activity and the movement of the finer particles up the beachface during berm buildup. Sand is deposited on the tidal flat where wave energy is least. That is, maximum wave action occurs along this profile at high tide, during which time the waves break and wash up the beachface. At low tide, the waves break offshore of the tidal flat.

b) Kalifornsky Beach

The Kalifornsky Beach sampling location is approximately 2.5 nm north of the Kasilof River and the northern access road to the beach; it is approximately 6.5 nm south of the mouth of the Kenai River (Figure 1-1). The transect extended approximately west across the beach. The predominant features of the beach are a relatively wide (~160 feet) and only moderately high (~15 feet), steep (~9% slope) beachface of pebbles and a moderately wide flat of relatively soupy mud or, at creek outwashes, poorly sorted sand. These lower beach features extend out more than 400 feet to the subtidal zone (Figure 3-1b). The elevation at the upper end of the mud flat is ~7 feet above MLLW. Boulders up to 4 feet in diameter are scattered sparsely on the mud flat. A narrow band of cobbles and boulders and a small muddy channel are located in the transition zone between beachface and the mud flat.

1) Physical

The sampled sediment at Kalifornsky Beach classifies as silty fine sand. Median grain size is 0.156 mm. The material is moderately sorted and the distribution is skewed by the quantity of the finer fractions (Table 3-1, Figure 3-2). Organic content of the sediment, as represented by TOC and TKN, is moderate (0.43 and 0.02 percent, respectively (Table

3-1). Materials below the toe of the beachface were varied and so these measurements are not completely representative.

2) Geomorphological

The shoreline at Kalifornsky Beach, located about five miles north of Cape Kasilof, is oriented north-south. This site is similar to the one at Clam Gulch in that the sand-and-gravel high-tide berm is backed by a near-vertical scarp in bedrock (flat-lying Tertiary sandstones and shales) less than 100 feet high and bordered on the seaward side by a wide tidal flat. However, the scarp at this locality shows signs of recent erosion, unlike the vegetated one at Clam Gulch. Boulders of glacial origin are not nearly as abundant at this site as at some of the others on the east side of the inlet, probably because no glacial deposits appear to overlie the sedimentary rocks in the scarp at this locality.

Morphology and Hydrodynamics - Two morphological features, a depositional high-tide berm and a broad tidal flat, compose the portion of the station located seaward of the erosional scarp. The high-tide berm is composed mostly of fine gravel, except for a band of sand located near the high-tide line (Figure 3-4a). A band of pebbles occupies the berm top adjacent to the scarp. The size of the gravel increases down the beachface slope, with abundant cobbles occurring at the toe (Figure 3-4b). The relatively steep slope of the beachface (Figure 3-1b) is typical of beaches that contain a significant amount of gravel. However, the slope decreases abruptly where the base of the beachface joins the near-horizontal surface of the tidal flat (Figure 3-4a).

The tidal flat, which is several hundred feet wide, is composed of mud and muddy sand on the inner half of the flat. The inner portion of the flat has intermittent areas of san over mud in the stream outwashes originating at the bluff. The outer part of the flat appears to be sandy, but it was not included in the survey. As at Clam Gulch, this flat is most likely positioned on top of a wave- and ice-cut rock platform in the underlying, relatively soft sedimentary rocks.

With tides often exceeding 20 feet during spring tides (Table 2-1), the outer part of the tidal flat is probably swept by some fairly strong tidal currents during falling and rising tides, but the stronger flood currents may be deflected offshore somewhat by Cape Kasilof. During flood current a back eddy may be running around the cape, which could account for the presence of mud on the inner part of this flat, whereas the flat at Clam Gulch is more sandy. The strongest ebb-tidal currents tend to occur on the west side of the inlet because of the Coriolis effect (Sharma et al. 1973). Tidal currents have little effect on the overall morphology of this profile, which is formed primarily by waves that have eroded the underlying rock platform (aided no doubt by ice scour) and built the high-tide berm.

The fetch perpendicular to this shoreline in a westerly direction is approximately 21 miles. Because the predominant winds blow from the northeast and southwest directions, the wind blows directly out of the northwest along the 21-mile fetch perpendicular to the shoreline less than 5 percent of the time. Northeast winds essentially blow offshore at this site, severely limiting the fetch effect from that direction, but open water stretches more than 115 miles to the southwest. With such a long fetch, one would normally expect the waves from the southwest to be more effective at this site than they are (based on the occurrence of mud on the tidal flat). Two limiting factors are probably important: 1) the steep angle at which these waves approach the shoreline, though they probably refract around Cape Kasilof to some extent; and 2) the sheltering effect of Cape Kasilof. However, the roundness of the cobbles on the beach indicates that periods of fairly large waves do occasionally occur. Geomorphic evidence such as the orientation of shoreline-attached spits indicates that longshore sediment transport is overwhelmingly south to north in this area (Hayes et al. 1976).

Sediments - The sediments of the berm show a wide range in grain size, from medium-sized cobbles to fine-grained sand. The concentration of cobbles along the toe of the beachface is probably due to a combination of the larger particles rolling to the bottom of the beachface slope during storm activity and the movement of the finer particles up the beachface during berm buildup. Sand and mud is deposited on the tidal flat where wave energy is least. That is, maximum wave action occurs along this profile at high tide, during which time the waves break and wash up the beachface. At low tide, the waves break offshore of and on the outer reaches of the tidal flat. The source of the mud on the tidal flat (Figure 3-4c) is not known. The Kasilof River is a possible source, or the mud could also have come from a number of sources in the inlet and been deposited at this locality because of a back eddy of the flood current around Cape Kasilof.

Figure 3-4. Photographs showing site characteristics at Kalifornsky Beach.

c) Boulder Point

The sampling location at Boulder Point is approximately 5.5.nm northeast of the East Foreland (Figure 1-1). The transect extended approximately north across the beach. The predominant features of the beach are a relatively wide (about 150 feet) and high (~15 feet), steep (~10%) beachface of pebbles and a narrow bar of fine well-sorted sand that extends out into the subtidal zone, which appears to be predominantly cobbles and boulders. Boulders up to 10 feet in diameter (glacial erratics) are common on the beachface, sand bar, and offshore. A narrow band of cobbles and boulders is located in the transition zone between beachface and the sand bar. This site appears to be exposed to strong wave action and currents.

1) Physical

The sampled sediment at Boulder Point classifies as fine to medium sand. Median grain size, at 0.442 mm, was the coarsest observed at the sites examined. The material is moderately sorted and the distribution is skewed by the quantity of the coarser fractions (Table 3-1, Figure 3-2). Organic content of the sediment, as represented by TOC and TKN, is among the lowest observed during this survey (0.013 and 0.006 percent, respectively (Table 3-1). Materials on the beachface and below its toe were relatively heterogeneous and so these measurements are only partially representative.

2) Geomorphological

Boulder Point, located approximately six miles northeast of the East Foreland, is a headland that projects out into the upper inlet because the bedrock or glacial deposits at this locale are more resistant to erosion than the scarp material in neighboring areas. Because of the protrusion of the shoreline, this site is more exposed to wave action than the study sites located either north or south along the east coast of the inlet. As the name implies, large boulders litter the intertidal and shallow subtidal areas. Presumably because of the resistance of the headland to erosion, a broad wave-cut rock platform with a superimposed tidal flat such as occurs south of the East Foreland is not present in this area.

Morphology and Hydrodynamics - Two morphological features that characterize the portion of the station located seaward of the now vegetated erosional scarp are a depositional high-tide berm with a moderately steep beachface and an intertidal sand bar separated from the beachface by a shallow swale. The high-tide berm includes a relatively narrow, sandy berm top adjacent to the scarp. The beachface portion of the berm has a band of pebbles near the berm crest (Figures 3-5a and b). The moderately steep beachface (Figure 3-1c) is composed mostly of pebbles. The relatively steep beachface is typical of beaches that contain a significant amount of gravel. Near the toe of the beachface, the sediment composition is mostly cobbles (Figures 3-5c and d). A shallow swale containing water-saturated sediments that range in size from sand to cobbles separates the beachface from a well-defined intertidal sand bar.

The intertidal sand bar, which is about 300 feet wide in this vicinity (Figure 3-1c), is mostly composed of sand, particularly on the crest, but the sediment on the bar changes abruptly into coarse-grained gravel (cobbles and boulders) near the low-tide line. The surface of the bar contains some wave-modified features that appear to be ebb-oriented sand waves or megaripples, indicating that tidal currents run strongly across the bar. The large boulders scattered over the surface of the entire intertidal zone are glacial erratics left behind as the scarp and its overlying glacial-sediment overburden have been eroded away during the past few thousand years, causing the scarp to retreat slowly landward. The exceptional abundance of boulders at this locality probably reflects a concentration of boulders in the original glacial deposits that overlie the sedimentary rocks that make up the lower part of the scarp. Such a concentration of boulders probably contributes to the slow rate of retreat of the scarp in this locality.

With tides commonly exceeding 25 feet during spring tides (Table 2-1), the outer part of the profile, specifically the intertidal bar, is undoubtedly swept by some fairly strong tidal currents during falling and rising tides. The constriction effect of the headland probably helps to create stronger currents here than elsewhere along the shore. However, the overall morphology of the profile is formed primarily by wave activity, which has built the berm and shaped the intertidal bar.

The fetch perpendicular to this shoreline in a northwesterly direction is approximately 15 miles. Wind blowing directly out of the northwest along the 15-mile fetch perpendicular to the shoreline probably occurs less than 5 percent of the time, assuming that the wind rose at Kenai is applicable (Hayes et al. 1976). The strong northeast winds of the fall and winter months pass over a fetch of 38 miles before reaching this site, the shoreline of which intersects those wind directions at an angle of around 50 degrees. Inasmuch as Boulder Point projects out into the inlet, the waves generated by these winds no doubt intensely rework the sediments. It is probable that the intertidal bar is eroded away during those episodes of storm wave activity. Even during the spring and summer months, when the wind blows mostly out of the southwest, waves may rework the sediments at this site because open water stretches more than 100 miles to the southwest away from East Foreland. Inasmuch as the foreland is only six miles away, waves

Figure 3-5. Photographs showing site characteristics at Boulder Point.

approaching from the southwest that refract around the headland and impinge on the beach at this study site could be significant at times. The roundness of the cobbles on the beach is another clue that periods of fairly large waves do occur with some regularity. Without concrete evidence one way or the other, it is likely that the predominant longshore transport direction at this site is northeast to southwest, owing to the larger size of the waves generated by the northeast winds.

Sediments - The mobile sediments of the berm show a wide range in grain size, from cobbles to sand. The concentration of cobbles along the toe of the beachface is probably due to a combination of the larger particles rolling to the bottom of the beachface slope during storm activity and the movement of the finer particles up the beachface during berm buildup. Sand is deposited on the intertidal bar during periods of relatively low wave activity (such as during this study). The bar is an indication that the beach system was in an accretionary mode when the study was carried out. The abrupt occurrence of the cobbles and boulders at the seaward edge of the intertidal bar is probably a reflection of the fact that waves action is concentrated at that level at low tide.

d) Bishop Beach

The sampling location at Bishop Beach is approximately 10.5 nm northeast of the East Foreland (Figure 1-1). The transect extended approximately north across the beach. The area examined extended approximately 860 feet out onto the flat. The predominant features of the beach are a relatively wide (~160 feet) but fairly low and flat (~11 feet and 7% slope) beachface of pebbles and a wide flat of soupy mud that extends approximately 1000 feet out to the subtidal zone (Figure 3-1d). The surface of this mud flat is marked with drainage channels about 6-10 inches deep. The elevation at the upper end of the mud flat is about 13 feet above MLLW. Boulders are sparse on the beachface and mud flat.

1) Physical

The sampled sediment at Bishop Beach classifies as silty fine sand. Median grain size is 0.17 mm. The material is well sorted and the distribution is not skewed by either the fine or coarse fractions (Table 3-1, Figure 3-2). Organic content of the sediment, as represented by TOC and TKN, is relatively high (0.93 and 0.06 percent, respectively (Table 3-1). Materials below the toe of the beachface were quite uniform and so these measurements are probably representative.

2) Geomorphological

This site is within an arcuate indention of the shoreline that is oriented ENE-WSW. The transect is located a short distance northeast of the mouth of Bishop Creek. Unlike the stations further south along the east side of the inlet, the hinterland in this area is low-lying in the vicinity of the creek mouth, and the high scarp to the southwest of the transect is composed entirely of glacial deposits. Furthermore, a broad tidal flat, at least 0.5 miles wide, is located offshore of the high-tide berm, which is composed of mixed sand and gravel. Large boulders are rare in the intertidal zone, no doubt a function of the composition of the glacial deposits. The subtidal area offshore of the tidal flat continues with a gradual slope. It is approximately a mile from the high-tide line to the –18-feet depth contour.

Morphology and Hydrodynamics – The three morphological features compose the portion of this station located seaward of the erosional scarp are: 1) a depositional high-tide berm, 2) an intermediate mud flat, and 3) a sand flat on the outer margin of the intertidal zone. The high-tide berm has a relatively narrow sandy berm top adjacent to a low scarp less than 10 feet high. The beachface portion of the berm has a mixture of sand and pebbles throughout, except for an accumulation of cobbles near the seaward margin of the beachface (see foreground in Figure 3-6a). The base of the beachface merges abruptly into the mud flat (Figures 3-6a and 3-1d). Because of the high percentage of sand in this particular high-tide berm, the beachface is not as steep as the coarser-grained beachfaces at stations farther south.

The tidal flat closest to the high-tide berm is a mud flat several hundred feet wide (Figures 3-6b and c). Numerous shallow channels (6-12 inches deep) oriented more-or-less perpendicular to the shoreline cut across the mud flat. At low tide, Bishop Creek forms a meandering channel across the flat (Figure 3-6c). The meandering of this channel attests to the low gradient of the flat. The sand flat at the most seaward edge of the intertidal zone contains several low-amplitude intertidal sandbars that appear to have been formed by wave action. However, with tides commonly exceeding 20 feet during spring tides (Table 2-1), the outer part of the tidal flat is undoubtedly swept by strong tidal currents during falling and rising tides. The low-tide outlet of Bishop Creek forms a braided channel across the sand flat, indicating an abrupt increase in slope at the outer margin of the flat.

The overall morphology of the profile is probably the result of a complex interaction of a number of factors, including the initial erosion of the flat, the large tides, and wave action. The fetch perpendicular to this shoreline in a northwesterly direction is

Figure 3-6. Photographs showing site characteristics at Bishop Beach.

Figure 3-6 lists 3 photos but only shows 2. It looks like the real a. is missing and the current a. and b. are actually b. and c.

approximately 17 miles. However, wind data collected at the Kenai weather station show that the wind blows directly out of the northwest along the 17-mile fetch perpendicular to the shoreline less than 5 percent of the time. Southwest winds, the predominant winds in the spring and summer (Hayes et al. 1976), essentially blow offshore at this site. Consequently, waves approaching the shoreline from the northeast, resulting from the predominant northeasterly winds in the fall and winter, are the waves that have shaped the rather small-scale high-tide berm at this site. These waves approach the shoreline at a 45-degree angle, and, furthermore, the waves probably break on the shallow offshore topography most of the time. Therefore, this is a relatively low energy shoreline with regard to wave action. The shape of the high-tide shoreline, a crenulate or fish-hooked-shaped bay with the shank of the hook pointing toward the southwest, as well as other similar geomorphic features in the area, indicate that longshore sediment transport, however small the rate may be, is overwhelmingly northeast to southwest in this area. The westerly orientation of the spit at the mouth of the creek confirms this hypothesis.

Sediments - The sediments of the berm show a wide range in grain size, from small cobbles to sand. The concentration of cobbles along the toe of the beachface is probably due to a combination of the larger particles rolling to the bottom of the beachface slope during storm activity and the movement of the finer particles up the beachface during berm buildup. Sand is deposited on the outer portion of the tidal flat where wave energy is highest and tidal currents are strongest, and at the high-tide area where wave energy is again stronger. Therefore, the mud flat is positioned in a wave-energy shadow between the outer sand flat, where wave energy is focused at low tide, and the high-tide beach, where the waves break during high tide. Water levels are relatively constant for a four-hour period around both high and low tides, and change rapidly in the interim between the two slack tides.

e) Moose Point

The sampling location at Moose Point is approximately 25 nm northeast of the East Foreland (Figure 1-1). The transect extended approximately west across the beach. The predominant features of the beach are a relatively wide (about 155 feet), high (nearly 18 feet) and steep (~11.5%) beachface of pebbles with at least two small berms at mid-tidal heights. Extending west in the lee of the point and parallel to the shoreline is a large bar of scoured fine sand. At the base of the beachface and inshore (south) of the bar is a drainage channel that is filled with very soft, greasy mud. Seaward of the bar is a wide flat of tightly imbricated pebbles, cobbles, and boulders that extends over 500 feet out from the sand bar to the subtidal zone (Figure 3-1e). The elevation at the upper end of the cobble/boulder flat is about 7 feet above MLLW. Boulders up to 8 feet in diameter (probably glacial erratics) are scattered sparsely across the cobble/boulder flat. This site appears to be exposed to strong wave action and currents.

1) Physical

The sampled sediment at Moose Point classifies as silt/clay. Median grain size is 0.053 mm. The material is well sorted and the distribution is not skewed by either the fine or coarse fractions (Table 3-1, Figure 3-2). Organic content of the sediment, as represented by TOC and TKN, is moderate (0.68 and 0.051 percent, respectively (Table 3-1). Materials below the toe of the beachface were highly variable, ranging from fine sloppy mud to boulder/cobble armoring. Therefore, these measurements are not representative.

2) Geomorphological

This site is located on a minor headland that projects about a half-mile seaward of the main trend of the shoreline, which is northeast-southwest. The intertidal zone at this station is very broad and complex. An abundance of large boulders (glacial erratics) is scattered over the entire area. As elsewhere along this coast, the boulders are probably a consequence of gradual shoreline retreat when the sea reached its present level. The flat relief of the intertidal zone continues into the subtidal region. It is around one mile from the high-tide berm to the –18-feet depth contour. A huge tidal sand ridge (Moose Point Shoal) is located about two miles to the north-northeast of the high-tide line at the transect site. This shoal, and the scoured channels associated with it, are responses to the very strong tidal currents that occur in this area.

Morphology and Hydrodynamics – The four morphological features composing the portion of this station located seaward of the high-tide line are: 1) a depositional high-tide berm; 2) a channel at the base of the beachface that contains mud deposits and is connected to a broad sheltered mud flat to the south of the transect; 3) an exposed intertidal sand and gravel flat that contains a low-amplitude tidal sand ridge composed of coarse sand and fine gravel; and 4) a broad gravel flat that is probably an erosional surface carved into underlying glacial deposits. The high-tide berm, which is topped by an accumulation of logs, is composed mostly of pebbles (Figure 3-7a). Two high-tide pebble microberms (less than six feet across) occur near the middle of the beachface. These microberms were formed during brief high-tide slack periods accompanied by modest wave activity. The beachface of this berm is relatively steep and the slope changes abruptly at the base of the gravelly beachface onto a narrow, flat sandy area (Figure 3-1e). A shallow channel, which contains a thick deposit of muddy sediments (Figure 3-7b), separates the beachface from a broad intertidal area to the seaward. South of the channel, the mud zone expands abruptly into a wide mud flat (Figure 3-7a), which has a series of shallow channels across it. These are oriented perpendicular to the general trend of the shoreline.

The tidal flat beyond the muddy channel is composed of mixed sand and gravel for about 200 feet to the edge of a broad, linear sand bar (tidal sand ridge) composed of coarse sand and fine gravel. At the time of the survey, the surface of the bar was covered by large megaripples oriented to the southwest (Figure 3-7c), providing ample evidence of the strong tidal currents that flow across this flat as the tide drops. Strong flood currents probably occur here also, but no current measurements are available for this site. Beyond the sand ridge, a broad flat surface covered with gravel of various sizes extends about 500 feet out to the subtidal zone (Figure 3-7d). This flat is most likely positioned on top of a wave- and ice-cut platform in the underlying glacial deposits. Some exceptionally large boulders are present on this flat.

As noted above, with tides frequently exceeding 30 feet during spring tides, some very strong tidal currents during falling and rising tides undoubtedly sweep the outer parts of the tidal flat. These currents have no doubt played an important role in shaping the tidal flats in this area, but the role of waves is probably also somewhat important during stormy periods. The logs on top of the high-tide berm are evidence that waves occasionally reach considerable size. The fetch perpendicular to this shoreline in a northwesterly direction is approximately 18 miles. However, wind data collected at the Kenai weather station indicate the wind blows directly out of the northwest along this 18-mile fetch perpendicular to the shoreline less than 5 percent of the time (Hayes et al. 1976). With the predominant winds blowing from the southwest in the spring and summer and from the northeast in fall and winter, the shoreline at this site is essentially parallel to the dominant winds. Therefore, waves generated by these winds must be refracted onto this shoreline. The fetch from the study site to the entrance to Knik Arm (to northeast) is 28 miles, and to the narrows between West and East Forelands (to southwest) is 33 miles. These are fairly significant fetch distances, but the orientation of the shoreline diminishes their importance. Moreover, it is protected from waves from the northeast by Moose Point Shoal. Consequently, this area should be considered one with relatively modest wave energy compared to some of the other sites covered in this study.

Sediments - The sediments of the high-tide berm are mostly pebbles. The tidal channel and the flat to the southwest contain thick, gray mud deposits. Most of the flat beyond the muddy channel is a mixture of a wide range of gravel sizes, except on the sand ridge, which is mostly coarse sand mixed with some granules and fine pebbles.

Figure 3-7. Photographs showing site characteristics at Moose Point.

f) Chickaloon Bay

The sampling location at the west end of Chickaloon Bay is approximately 36 nm northeast of the East Foreland (Figure 1-1). The transect extended approximately northeast across the beach. Predominant features of the beach are a relatively narrow (about 70 feet) and low (~8 feet) but steep (~11%) beachface of pebbles and a wide flat of eroded sticky mud that extends out a great distance (>1.5 mile) to the subtidal zone (Figure 3-1f). A narrow band of cobbles and boulders is located in the transition zone between beachface and the sand flat. The elevation at the upper end of the mud flat is about 21 feet above MLLW.

1) Physical

The sampled sediment at Chickaloon Bay classifies as silt/clay. Median grain size is 0.053 mm. The material is well sorted and the distribution is not skewed by either the fine or coarse fractions (Table 3-1, Figure 3-2). Organic content of the sediment, as represented by TOC and TKN, is moderate (0.38 and 0.034 percent, respectively (Table 3-1). Materials below the toe of the beachface were quite uniform. Therefore, these measurements are representative.

2) Geomorphological

This shoreline is located inside the entrance to Turnagain Arm and faces directly northeast. It has a high-tide berm indicative of relatively high wave energy, a morphological anomaly for depositional shorelines in macrotidal settings, flanked on the seaward side by a wide mud flat. As a rule, depositonal macrotidal coasts, such as the coastline of upper Bristol Bay, Alaska, have extensive marshes and mud flats at the high-tide area. Mud flats form there because waves usually break on tidal sand ridges and sand flats located far seaward of the high-tide line. In areas where large volumes of suspended sediments are available, as in Turnagain Arm, mud settles out along the shoreline during slack water periods at high tide, building out the mud flats. The reason for the anomaly at this location is the fact that the land sank around 3 feet during the Good Friday earthquake in March 1964 (Plafker, 1969; see Figure 3-8). With this sinking, the high-tide area was exposed to much greater wave action than before, allowing the high-tide berm to develop to its present size and causing the mud flat to erode. Evidence for the land sinking can be seen in the occurrence of dead trees behind the beach caused by salt-water intrusion into the soils of the sunken forest. Similar dead forests rim the upper margin of Turnagain Arm (e.g., near Portage).

Morphology and Hydrodynamics – The two morphological features composing the portion of the station located seaward of the sunken forest include: 1) a depositional high-tide berm and 2) a broad erosional mud flat. The high-tide berm is composed of a mixture of sand and gravel, with bands of cobbles occurring at the berm crest and at the toe of the beachface (Figures 3-9a-c). The relatively steep slope of the beachface is typical of beaches that contain a significant amount of gravel. The slope decreases abruptly where the base of the beachface joins the near-horizontal surface of the mud flat.

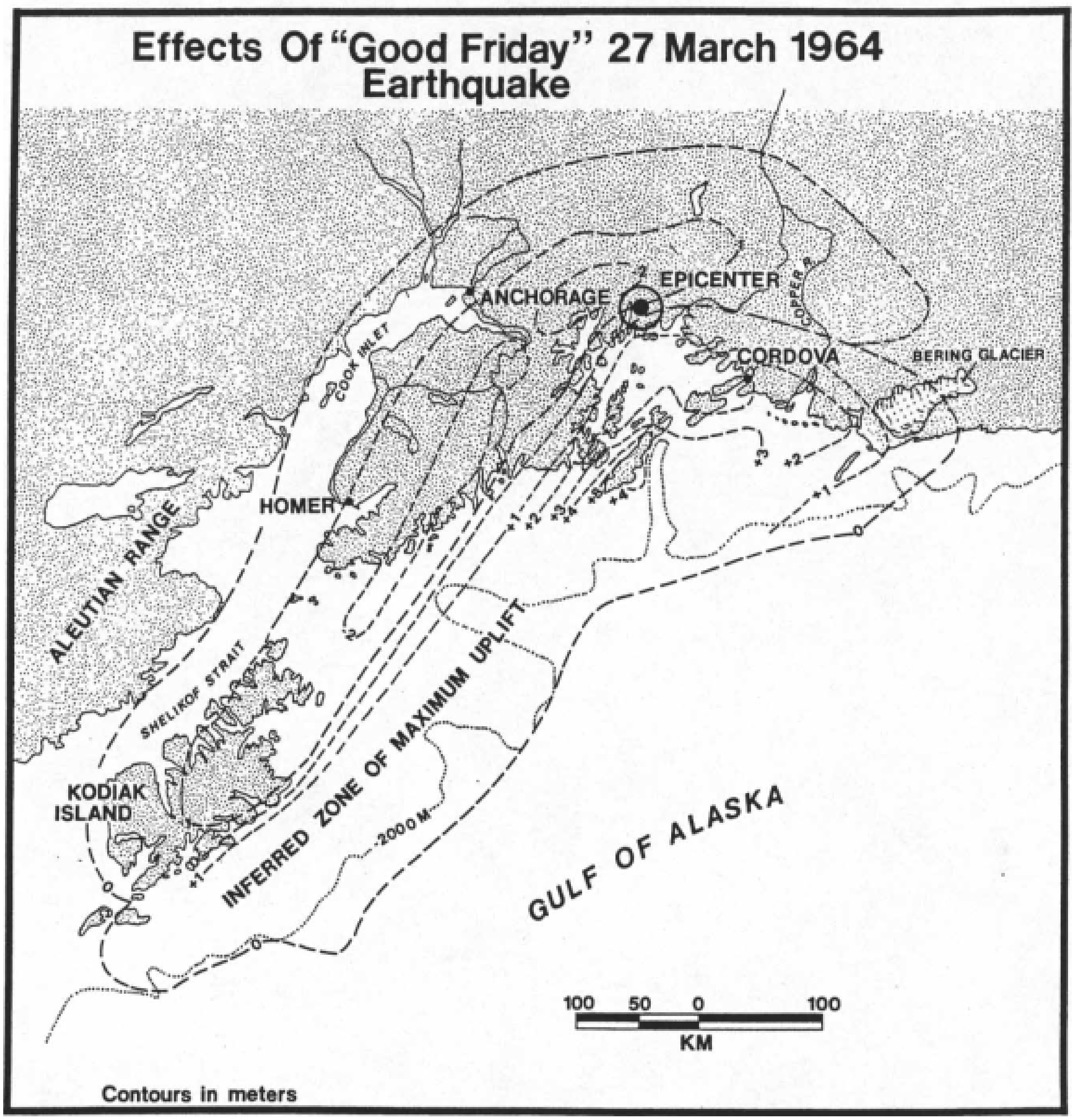
The tidal mud flat, which is at least 1.5 nm wide, is composed of hummocks of mud located between numerous scour pits and eroded channels caused by an increase in wave action since the earthquake. A narrow flat at the base of the beachface coated with gravel has been scoured out of the landward edge of the mud flat by backwash of waves at high tide (Figure 3-9c). According to the ESI maps, the outer part of this intertidal area is a sand flat, but that part of the flat was not included in the survey.

With tides exceeding 30 feet during spring tides (Table 2-1), the outer parts of the mud flat, as well as the tidal sand ridges and channels beyond, are subject to strong tidal currents during falling and rising tides. Turnagain Arm is host to one of the most dynamic phenomena seen on any coastline, a tidal bore that causes a breaking wave to sweep up into the head of the Arm on the rising tide (during spring tides). Thus, the morphology of this station is the result of a combination of tidal flow that has created the flats and the channel systems offshore and storm waves that have shaped the high-tide berm.

The fetch perpendicular to this shoreline in a northeasterly direction is approximately 15 miles, but at low tide the fetch is only about half that distance, because large expanses of tidal flats and tidal sand ridges are exposed at that time. Because the predominant winds blow from the northeast (fall and winter) and southwest (spring and summer) directions, assuming the data at the Kenai weather station are valid for this site, this shoreline is vulnerable to significant waves during the fall and winter. This is particularly true now that the effective fetch has been increased dramatically with the sinking of the land. Southwest winds essentially blow offshore at this site.

With the shoreline facing directly into the dominant wind, one would assume that longshore sediment transport would be minimal at this site. However, some reorientation of the beach berm to a more perpendicular orientation into a northerly direction has occurred (Figure 3-9d). Such a reorientation would be accompanied by some sediment transport to the southeast. Perhaps the occurrence of more open water closer to the mouth of Turnagain Arm has created a more effective fetch from that direction, with the

Figure 3-8. Crustal deformations associated with the great Alaskan earthquake of 1964.



(Modified after Plafker 1969)

Figure 3-9. Photographs showing site characteristics at Chickaloon Bay.

Figure 3-9 lists 4 but only shows 3. It looks like d., the aerial, is missing.

broad tidal flats located directly offshore of the site to the northeast baffling, to some extent, the waves approaching the shoreline from that direction.

Sediments - The sediments of the berm show a wide range in grain size, from medium-sized cobbles to sand. The concentration of cobbles along the toe of the beachface is probably due to a combination of the larger particles rolling to the bottom of the beachface slope during storm activity and the movement of the finer particles up the beachface during berm buildup. Mud was originally deposited on the tidal flat where wave energy was least, but exposure to higher waves is now causing the flat to erode. The source of the mud on the tidal flat is probably the numerous glacial streams that flow into Turnagain Arm.

2. Middle of Middle and Upper Cook Inlet (8 sites)

a) Shoal South of Kalgin Island

We examined the middle shoal of the group of shoals south of Kalgin Island, which is approximately 19 nm northeast of Tuxedni Bay (Figure 1-1). The shoal is composed of moderately fine, well-sorted sand. The surface of the shoal is characterized by strongly developed sand waves. The sand waves are up to 12 inches high in many areas. Drainage channels run outward from the interior of the shoal to the water’s edge in several areas. Generally, the sand was firm enough to support the weight of the investigators. However, some areas of instability were encountered, particularly along some flowing drainage channels and along the water’s edge.

The surficial features of the shoal provide strong indications of the intensity of the currents impinging on the habitat. Further evidence of the intensity of the hydrodynamics is the fact that no animals were observed during an extensive examination of the exposed portion of the shoal.

1) Physical

The sampled sediment at shoal south of Kalgin Island classifies as fine sand. Median grain size is 0.244 mm. The material is moderately sorted and the distribution is slightly skewed by the quantity of the coarser fractions (Table 3-1, Figure 3-10). Organic content of the sediment, as represented by TOC and TKN, is low (0.04 and 0.006 percent, respectively (Table 3-1). Materials on the shoal were quite uniform. Therefore, these measurements are representative.

2) Geomorphological

The portion of this large intertidal shoal, located in the middle of the inlet approximately 22 miles east-northeast of Tuxedni Bay, was approximately 3000 feet in diameter at the time of the survey and has a shape similar to the carapace of a horseshoe crab (Figure 3-11a). It is composed of pure sand.

Morphology and Hydrodynamics - When this site was visited, at low tide on 30 August 2000, the shoal was covered with active bedforms, mostly sand waves, that were formed by the falling tide. With a spring tidal range of about 25 feet on this day in this region (Table 2-1), strong tidal currents run across this shoal on both rising and falling tides. The shape of the shoal indicates that ebbing tidal currents are strongest on the western side of the shoal (note the arcuate channel bending to the south on the west side in Figure 3-11-a) and flood currents are strongest across the top of the shoal (note the arcuate sand lobe building up onto the shoal from the south in Figure 3-11a). It is probable that the sand waves on the shoal (Figure 3-11b) move tens of feet during each tidal cycle, especially during spring tides. The scour pits that move ahead of the migrating bedforms rework the sediments to depths that may reach two feet or more in places. This high instability of the substrate of the shoal no doubt accounts for the lack of observable infauna in the sediment.

This shoal is open to a long fetch (~90 miles)to the southwest, the predominant direction of the wind during spring and summer months, assuming that the wind data from Homer and Kenai (Hayes et al. 1976) are representative of this area. In addition, the fetch to the northeast, the predominant wind direction in fall and winter, is about 27 miles. However, although waves no doubt rework the shoal during major storms, it is the tidal current that shapes and maintains these shoals. As the tide drops, waves rework the tops of the highest of the sand waves.

Sediments - The sediments of the shoal are primarily sand.

b) SE Kalgin Island

The sampling location at the southeast corner of Kalgin Island is approximately 1.25 nm southwest of the southeastern point of the island (Figure 1-1). The transect extended approximately southeast across the beach. The predominant features of the beach are a relatively narrow (~80 feet) and moderately high (~10 feet), steep (~12%) beachface of pebbles, a narrow sand flat and channel of fine well-sorted silty sand (Figure 3-12a), and an extensive bar that extends out at least 3000 feet to the subtidal zone. Boulders up to 6 feet in diameter (probably glacial erratics) are scattered sparsely on the flat. At the outer

Figure 3-10. Particle grain size profiles for sites examined in the middle of middle and upper Cook Inlet.

Figure 3-10. Particle grain size profiles for sites examined in the middle of middle and upper Cook Inlet.

Figure 3-11. Photographs showing site characteristics at shoal south of Kalgin Island.

Figure 3-12. Beach profiles for sampling locations in the middle of middle and upper Cook Inlet.

edge of the bar, at approximately 3.5 feet below MLLW, low cobble/boulder outcrops, probably glacial deposits, emerge from the sand. These outcrops, resistant to scouring, are possibly the structures that allow the bar to exist.

1) Physical

The sampled sediment at the southeastern site on Kalgin Island classifies as silty fine sand. Median grain size is 0.161 mm. The material is moderately sorted and the distribution is slightly skewed by the quantity of the finer fractions (Table 3-1, Figure 3-10). Organic content of the sediment, as represented by TOC and TKN, is low (0.061 and 0.01 percent, respectively (Table 3-1). Materials below the toe of the beachface at this site were somewhat varied. Therefore, these measurements are only partially representative.

2) Geomorphological

This site is located on the south flank of a cuspate spit that makes up the southeast corner of Kalgin Island. The transect is about one and one half miles southwest of the corner. This is apparently a slowly prograding beach system, inasmuch as there is no evidence of erosion landward of the beach and a fairly wide grassy flat area is located landward of the high-tide line. A very large intertidal bar located on the seaward end of the profile also indicates depositional conditions. The island itself is cored with Quaternary materials, presumably related in some way to glacial activity (i.e., either glacial till or glacial outwash). The coarser-grained sediments on the transect probably are derived from erosion of these Quaternary deposits by wave action elsewhere along the shore.

Morphology and Hydrodynamics – The two morphological features that compose the portion of the station located seaward of the grassy flat are: 1) a depositional high-tide berm and 2) a broad tidal flat with superimposed intertidal bars. The beachface is composed of sand at the top of the berm (Figures 3-13a and b) but it also has a band of pebbles near the berm crest (Figure 3-13c), an irregular band of sand in the central portion of the beachface, and an accumulation of relatively pure fine gravel near the seaward margin of the beachface. The relatively steep slope of the beachface (Figure 3-12a) is typical of beaches that contain a significant amount of gravel.

The tidal flat, which is several thousand feet wide during low spring tides in places in this vicinity, is composed primarily of fine-grained sand. A number of low-amplitude intertidal sandbars occur at different positions along the flat. A very large bar is located on the transect about half the way out to the low-tide line. The surfaces of the bars are covered with asymmetrical sand ripples generated by both wave- and tide-generated currents (Figure 3-13d). A large boulder located on a very subtle bar near the middle of the transect is probably a glacial erratic. A very flat, water-saturated surface, which contains abundant small ripples and *Abarenicola* casts, occurs just seaward of the beachface.

With tides approaching 25 feet during spring tides (Table 2-1), the outer parts of the tidal flat are undoubtedly swept by some fairly strong tidal currents during falling and rising tides. However, these currents have little effect on the overall morphology of the profile, which is formed primarily by wave activity that has built the berm and shaped the intertidal bars. The fetch perpendicular to this shoreline in a southeasterly direction is approximately 25 miles, but the predominant winds blow out of the southwest in the summer and spring and northeast during the fall and winter (assuming the wind pattern at the Kenai weather station applies at this site). Northeast winds essentially blow offshore at this site, though waves generated by these winds may refract around the southeast corner of the island at times. Consequently, waves approaching the shoreline from the southwest are probably the waves that have shaped this shore profile, even though these waves would approach this shoreline at an angle of around 45 degrees. Although the fetch is about 105 miles in the southwesterly direction, this shoreline does not appear to be one with exceptionally high wave energy because of the abundance of the intertidal bars and the fine grain size of the sand on the tidal flat. The extensive system of shoals south of Kalgin Island probably affords considerable protection from waves approaching from the southwest but, because the shoals only extend about 6 feet above MLLW, the protection would be reduced during higher tidal stages. The abundant infauna is another clue to the relative stability of the substrate. The roundness of the cobbles on the beach, however, indicates that periods of fairly large waves do occasionally occur. Geomorphic evidence, such as the shape of the cuspate spit, indicates that longshore sediment transport, however mild, is probably northeast to southwest at this site, which is puzzling (Hayes et al. 1976). Complex wave refraction patterns may be involved.

Sediments - The sediments of the berm show a wide range in grain size, from cobbles to fine-grained sand. The concentration of cobbles along the toe of the beachface is probably due to a combination of the larger particles rolling to the bottom of the beachface slope during storm activity and the movement of the finer particles up the beachface during berm buildup. Sand is deposited on the tidal flat where wave energy is least. That is, maximum wave action occurs along this profile at high tide, during which time the waves break and wash up the beachface. At low tide, the waves break offshore of the tidal flat.

Figure 3-13. Photographs showing site characteristics at SE Kalgin Island.

c) Oldmans Bay, Kalgin Island

The sampling location in Oldmans Bay (Kalgin Island) is in the northern corner of the bay, approximately 22 nm northeast of Tuxedni Bay (Figure 1-1). The transect extended approximately southwest across the beach. The predominant features of the beach are a relatively narrow (~85 feet) and moderately high (~8 feet), steep (~10%) beachface of pebble/cobble and a wide flat of firm mud overlying gravel that extends out at least 500 feet to the subtidal zone (Figure 3-12b). The elevation at the upper end of the mud flat is about 12 feet above MLLW. Boulders up to 6 feet in diameter (probably glacial erratics) are common on the beachface and mud flat.

1) Physical

The sampled sediment at the north corner of Oldmans Bay on Kalgin Island classifies as sandy silt/clay. Median grain size is 0.06 mm. The material is poorly sorted and the distribution is moderately skewed by the quantity of the coarser fractions (Table 3-1, Figure 3-10). Organic content of the sediment, as represented by TOC and TKN, is moderate (0.60 and 0.027 percent, respectively (Table 3-1). Materials below the toe of the beachface at this site were somewhat varied. Therefore, these measurements are only partially representative.

2) Geomorphological

This site is located on the north flank of a three-mile-long, arcuate embayment, called Oldmans Bay, on the southwest side of Kalgin Island. The transect is positioned a few hundred feet southeast of a dramatically eroding headland composed of glacial deposits (mostly glacial till). Large boulders are abundant throughout the intertidal zone, no doubt derived from erosion of the glacial till. At the transect, the high scarp behind the beach is presently vegetated, but conspicuous, recently eroded vertical scarps in the till are present a few hundred feet or so to the south (Figure 3-14a). It is approximately 500 feet from the high-tide berm across a very flat intertidal zone to the low-tide line.

Morphology and Hydrodynamics - Three morphological features making up the portion of this station located seaward of the vegetated scarp include: 1) a depositional high-tide berm composed mostly of gravel, 2) an intermediate muddy tidal flat, and 3) a sand flat on the outer half or so of the intertidal zone. The high-tide berm, which contains zones of rather tightly spaced huge boulders eroded from the till, is composed mostly of gravel. The pebbles dominating the berm top are subangular to subround, indicating that they have not been subjected to much rounding by wave action (Figure 3-14b). Perhaps the numerous boulders in that area, most notably a clump just north of the transect, shield the gravel at that level from reworking. On the other hand, the gravel at the lower half of the beachface, composed mostly of cobbles, is very well rounded, indicating considerable reworking by waves (Figure 3-14c). Also, these very well-sorted cobbles appear to have formed a surface armor over that part of the beachface. This part of the beachface is obviously subject to much more wave reworking than the top of the berm, a somewhat curious arrangement as far as gravel beaches are concerned. The concentration of the rounded and well-sorted cobbles along the toe of the beachface is probably also due in part to a combination of the slightly larger particles rolling to the bottom of the beachface slope during storm activity and the movement of the finer particles up the beachface during berm buildup. The steep slope of the beachface (Figure 3-12b) is typical for gravel beaches worldwide.

The base of the beachface merges abruptly into a very flat, gravelly surface coated with a relatively thin mud deposit (Figure 3-14d). That part of the flat also contains numerous huge boulders (glacial erratics), indicating that the underlying gravelly surface upon which the mud is deposited is an eroded surface in the glacial till. The sand flat on the outer half of the intertidal zone contains fewer boulders, but may also be deposited on a wave-cut platform (ice scour may also be a factor in the formation of the platform). With tides exceeding 20 feet during spring tides (Table 2-1), the outer parts of the tidal flat are undoubtedly swept by fairly strong tidal currents during falling and rising tides. The surface of the outer flat was covered with ripples at the time of the survey.

The overall morphology of the profile (Figure 3-14e) is probably the result of a complex interaction of a number of factors, including the initial erosion of the flat, the large tides, and wave action. The fetch perpendicular to this shoreline in a southwesterly direction is only approximately 7 miles (to Harriet Point). The fetch from the headland at the north end of the bay ranges from 13 miles in a northwesterly direction to 20 miles due north. However, wind data collected at the Kenai weather station show that the wind blows directly out of the northwest at this site less than 5 percent of the time, assuming that data from Kenai are relevant to the western shore of Kalgin Island. The headland at the south side of the bay has a fetch of 40 miles in a southwesterly direction (to Augustine Island), the direction from which the predominant winds in the spring and summer blow at Kenai (Hayes et al. 1976). Therefore, one would surmise from these fetch measurements that this shoreline is characterized by relatively low-energy with regard to wave action; however, the geomorphology, notably the eroded scarp, the coarse-grained high-tide berm, and the roundness of the cobbles on the beachface, indicates otherwise. Waves from both the north and southwest have a considerable fetch to the headlands that border

Figure 3-14. Photographs showing site characteristics at Oldmans Bay, Kalgin Island.

Figure 3-14. Photographs showing site characteristics at Oldmans Bay, Kalgin Island.

the embayment, and no doubt refract into the bay with regularity. Also, it is likely that winds from the west and northwest, blowing down off the mountain range and glaciers to the west, are strong from time to time in this locality, though no data are available to support this assumption. In addition, the occasional extra-large storm may be positioned just right at spring high tide to generate exceptionally large waves that expend a significant amount of energy on this shoreline within a short amount of time.

Sediments - The sediments of the berm show a wide range in grain size, from huge boulders to sand. The gravel fragments are predominantly igneous in origin, which indicates that the glaciers that deposited the till on Kalgin Island derived a good part of their gravel load from the rocks that crop out in the mountains to the west (e.g., the Aleutian range batholith, composed largely of quartz diorite, and miscellaneous volcanic rocks, all of Jurassic age). Sand is deposited on the outer portion of the tidal flat where wave energy is highest and tidal currents are strongest, and at the high-tide area where wave energy is again stronger. Therefore, the mud flat is positioned in a subtle wave-energy shadow between the outer sand flat, where wave energy is focused at low tide, and the high-tide beach, where the waves break during high tide. Water levels are relatively constant for a four-hour period around both high and low tides, and change rapidly in the interim between the two slack tides. The sand on the flat was derived from both the erosion of the glacial till scarps and from local streams. The mud could also be derived from those sources, plus the ebb-tidal flow which impinges along this coast due to the Coriolis effect (Sharma et al. 1973), which delivers suspended sediment derived from the upper inlet to this site.

d) Shoal West of Kalgin Island

The largest of the group of shoals west of Kalgin Island, which is approximately 22 nm northeast of Tuxedni Bay (Figure 1-1), was examined quickly. More than 0.5 nm of shoal was exposed on an east-west axis; nearly the entire width was examined. The shoal, which is apparently less than 4.5 feet high, is composed of moderately fine, well-sorted sand. The surface of the shoal is characterized by strongly developed sand waves. The sand waves are up to 12 inches high in many areas. Drainage channels run outward from the interior of the shoal to the water's edge in several areas. Some areas of stability were encountered. However, the sand generally was not sufficiently stable to support the weight of the investigators and so the shoal was not examined extensively. The surficial features of the shoal provide strong indications of the intensity of the currents impinging on the habitat. Further evidence of the intensity of the hydrodynamics is the fact that no animals were observed during an extensive examination of the exposed portion of the shoal.

1) Physical

The sampled sediment at the shoal west of Kalgin Island classifies as fine to medium sand. Median grain size is 0.344 mm. The material is moderately sorted and the distribution is slightly skewed by the quantity of the coarser fractions (Table 3-1, Figure 3-10). Organic content of the sediment, as represented by TOC and TKN, is low (0.034

and 0.005 percent, respectively (Table 3-1). Materials on the exposed portion of the shoal were quite uniform. Therefore, these measurements are representative.

2) Geomorphological

This large intertidal shoal, which is located on the west side of the middle of Kalgin Island in the channel separating the island from the mainland, is lineated in a north-south direction and is several hundred feet long. It is composed of pure sand.

Morphology and Hydrodynamics - When this site was visited, at low tide on 1 September 2000, the shoal was covered with active bedforms, mostly sand waves, that were formed by the falling tide. With a spring tidal range exceeding 20 feet, strong tidal currents run across this shoal both on rising and falling tides. It is probable that the sand waves on the shoal (Figure 3-15) move tens of feet during each tidal cycle, especially during spring tides. The scour pits that move ahead of the migrating bedforms rework the sediments to depths that may reach two feet or more in places. This high instability of the substrate on the shoal no doubt accounts for the lack of infauna in the sediment.

The shoal is open to a long fetch to the southwest, the predominant direction of the wind during spring and summer months, assuming that the wind data from Homer and Kenai (Hayes et al. 1876) are representative of this area. However, although waves no doubt rework the shoal during major storms, it is the tidal current that shapes and maintains these shoals. As the tide drops, waves rework the tops of the highest of the sand waves.

Sediments - The sediments of the shoal are primarily sand.

e) NE Kalgin Island (Light Point)

The sampling location at the northeastern corner of Kalgin Island is within the bight formed by the shoal extending south from Light Point, approximately 26 nm north of Tuxedni Bay (Figure 1-1). The transect extended approximately southeast across the beach. The predominant features of the beach are a relatively narrow (~85 feet) and

Figure 3-15. Photograph showing site characteristics at shoal west of Kalgin Island.

moderately high (~8 feet), steep (~10%) beachface of pebbles and a relatively narrow flat of soft flocculent silt overlying compact clay that is constrained to the east by the shoal (Figure 3-12c). The elevation at the upper end of the mud flat is about 12 feet above MLLW. A narrow band of cobbles and boulders is located in the transition zone between beachface and the sand flat.

1) Physical

The sampled sediment at the northeast corner of Kalgin Island classifies as silty fine sand. Median grain size is 0.08 mm. The material is poorly sorted and the distribution is moderately skewed by the quantity of the coarser fractions (Table 3-1, Figure 3-10). Organic content of the sediment, as represented by TOC and TKN, is moderate (0.25 and 0.013 percent, respectively (Table 3-1). Materials below the toe of the beachface at this site were relatively uniform. Therefore, these measurements are representative.

2) Geomorphological

This site is located on a bight in the lee of a shoal that projects to the southeast away from Light Point on the northeast corner of Kalgin Island. The shoreline at this location is apparently a slowly prograding depositional system, inasmuch as there is no evidence of erosion landward of the beach and a grassy flat area is located landward of the high-tide line, separating the beach from a highly vegetated scarp. A very large intertidal bar located on the middle part of the shoal also indicates depositional conditions. The presence of the vegetated scarp behind the beach indicates that this shoreline was erosional before the shoal began sheltering the backbeach from storm waves. In order to predict when this erosion occurred, one would have to know the relative sea-level history of the area, inasmuch as the erosion did not occur until sea level reached its present position. This happened about 4,500 years ago on shorelines around the world that are tectonically stable. However, with the tectonic instability that characterizes this coast, it is difficult to pinpoint when the sea reached its present level. It is probably safe to say that the erosion of the bluff was taking place several hundred or possibly a few thousand years ago. The island itself is cored with Quaternary materials, presumably related in some way to glacial activity (i.e., either glacial till or glacial outwash). The coarser-grained sediments on the transect probably are derived from erosion of these Quaternary deposits by wave action elsewhere along the shore, probably at Light Point and to the north of it.

Morphology and Hydrodynamics - Four morphological features compose the portion of the station located seaward of the grassy flat- a depositional high-tide berm, a muddy tidal flat located in the lee of a high, very large intertidal bar contained gravelly sediments, and a wide, exposed tidal flat to the southeast (seaward) of the bar. The intertidal bar has a steep slipface that dips landward, which indicates that the bar is migrating landward, though probably at a very slow rate. This bar may be planed off and modified during storms. The flat seaward of the bar contains abundant large boulders (glacial erratics), which indicates that the flat is most likely an erosional surface. The high-tide berm is composed of a mixture of sand and gravel (Figure 3-16a). An accumulation of relatively homogeneous medium-sized cobbles occurs near the seaward margin of the beachface. The relatively steep slope of the beachface (Figure 3-12c) is typical of beaches that contain a significant amount of gravel.

The inner tidal flat, which is several tens of feet wide, is composed primarily of mud and sandy mud. The flat contains an abundant infaunal population with numerous *Abarenicola* casts dotting the surface (Figures 3-16b-d). The unusual occurrence of a mud flat on such an exposed shoreline is attributed to the protection from wave action provided by the wide outer flat and the high intertidal bar.

With tides exceeding 20 feet during spring tides (Table 2-1), the outer parts of the tidal flat are undoubtedly swept by some fairly strong tidal currents during falling and rising tides. However, these currents have little effect on the overall morphology of the profile, which is formed primarily by wave activity that has eroded the outer flat (possibly aided by tidal currents and ice scour), built the berm, and created the large intertidal bar. The fetch perpendicular to this shoreline in a southeasterly direction is approximately 21 miles, but the predominant winds blow out of the southwest in the summer and spring and northeast during the fall and winter (assuming the wind pattern at the Kenai weather station applies at this site). The fetch in a northeasterly direction is over 50 miles, but the transect is sheltered from waves generated by winds from that direction by Light Point and its associated shoal. However, during storms, waves refracting around the point no doubt impact this area. The site is sheltered somewhat from waves approaching from the southwest by Kalgin Island itself; however, waves refracting around the southern end of the island are probably significant at times. The size of the high-tide berm, the presence of large logs on the berm top, and the roundness of the cobbles on the beach all indicate that periods of fairly large waves do occasionally occur at this site. Clearly, waves approaching Light Point from the north have created the intertidal bar, inasmuch as the curving shape of the bar indicates southerly transport of the coarse-grained sediments on the bar. Complex wave refraction patterns may also be involved.

Figure 3-16. Photographs showing site characteristics at NE Kalgin Island.

Sediments - The sediments of the berm show a wide range in grain size, from cobbles to sand. The concentration of cobbles along the toe of the beachface is probably due to a combination of the larger particles rolling to the bottom of the beachface slope during storm activity and the movement of the finer particles up the beachface during berm buildup. Mud is deposited on the tidal flat where wave energy is least in the lee of the intertidal bar. The source of the mud could be any of the numerous streams that empty into the inlet and carried to this location by both flood- and ebb-tidal currents. Maximum wave action occurs along this profile at high tide, during which time the waves break and wash up the beachface. At low tide, the waves break offshore on the tidal flat and intertidal bar.

f) NW Kalgin Island

The sampling location at the northwestern corner of Kalgin Island faces north; it is approximately 27 nm north of Tuxedni Bay (Figure 1-1). The transect extended approximately north across the beach. The predominant features of the beach are a wide (~240 feet) and high (~16 feet) beachface of pebbles and cobble and a narrow flat of fine well-sorted sand, cobbles, and boulders that extends out less than 400 feet to the subtidal zone (Figure 3-12d). Neither structure is well defined but the transition zone is marked with a shallow trough. The sand is a thin layer (thickness averages ~3 inches) over a cobble/boulder bed. The elevation at the upper end of the lower sand flat is about 5 feet above MLLW. Boulders up to 8 feet in diameter are scattered sparsely on the beachface and sand flat.

1) Physical

The sampled sediment at the northwest corner of Kalgin Island classifies as fine to medium sand. Median grain size is 0.40 mm. The material is moderately sorted and the distribution is not appreciably skewed by the quantity of the fine or coarser fractions (Table 3-1, Figure 3-10). Organic content of the sediment, as represented by TOC and TKN, is low (0.059 and 0.007 percent, respectively (Table 3-1). Materials below the toe of the beachface at this site were somewhat varied. Therefore, these measurements are only partially representative.

2) Geomorphological

This site is located on the northwestern corner of Kalgin Island, and the transect is oriented north across the intertidal zone. The shoreline at this site shows little evidence of active erosion of the landward area behind the beach. A vegetated scarp located behind the high-tide berm indicates that erosion did occur at some earlier time since the last glaciation, but probably not for many decades. In order to predict when this erosion occurred, one would have to know the relative sea-level history of the area, inasmuch as the erosion did not occur until sea level reached its present position. This happened about 4,500 years ago on shorelines around the world that are tectonically stable. However, with the tectonic instability that characterizes this coast, it is difficult to pinpoint when the sea reached its present level. The island itself is cored with Quaternary materials, presumably related in some way to glacial activity (i.e., either glacial till or glacial outwash). The coarser-grained sediments on the transect probably are derived from erosion by wave action of these Quaternary deposits, both locally and elsewhere along the shore.

Morphology and Hydrodynamics - Two morphological features compose the portion of the station located seaward of the vegetated scarp - a depositional high-tide berm with a moderately steep beachface and a tidal flat area with a superimposed low-amplitude intertidal bar composed of sand and gravel. The storm high-tide line is marked by the presence of large logs, and the beachface is composed of mixed sand and gravel (Figure 3-17a). A band of sand is located in the central portion of the beachface and an accumulation of pebbles and cobbles occur near the seaward margin of the beachface (Figure 3-17b). A gravel storm berm, such as the ones so common in Prince William Sound, is not present at this locality. The moderately steep slope of the beachface is typical of beaches that contain a significant percentage of gravel (Figure 3-12d).

The inner part of the tidal flat is composed primarily of mixed sand and gravel, with some scattered boulders also being present. These boulders are undoubtedly derived from the erosion of glacial deposits that were part of the island prior to erosion of the shoreline. About one-third of the way across the tidal flat from the beachface, a prominent, low-amplitude intertidal bar composed of sand and gravel is present. A flat, water-saturated zone occurs just landward of the bar. Sand ripples are present across the surface of the bar, indicated that currents are active on the bar during high water (Figure 3-17c). Offshore of the intertidal bar, a flat surface coated with cobbles extends out to the low-tide line. Sand occurs at the low-tide line, and very low-amplitude, relatively small intertidal sandbars occur at other locations on the flat away from the transect. The presence of the boulders at random positions over the surface of the flat indicates that the sediments on the flat most likely overly a wave-cut platform carved into glacial deposits from which the boulders were derived.

With tides exceeding 20 feet during spring tides (Table 2-1), the outer parts of the tidal flat are undoubtedly swept by some fairly strong tidal currents during falling and rising tides. However, these currents probably have little effect on the overall morphology of the profile, which is formed primarily by wave activity, which has built the berm, eroded the underlying platform, and shaped the intertidal bars. The fetch perpendicular to this shoreline directly along the transect from the north is only approximately 13 miles, but the predominant winds that blow out of the northeast during the fall and winter (assuming the wind pattern at the Kenai weather station applies at this site) have a potential fetch of approximately 48 miles. The southwest winds that prevail in the spring and summer essentially blow offshore at this site. Consequently, waves approaching the shoreline from the northeast are the waves that have shaped this shore profile, even though these waves strike this shoreline at an angle of around 45 degrees. The entire aspect of this station, including the abundance of large logs on the top of the high-tide berm, the roundness of the cobbles on the beach, and the paucity of infauna, plus the notable fetch to the northeast, indicate that wave energy is typically high at this site. The headlands located close to the profile probably create complex wave-refraction patterns. There is no convincing evidence for significant longshore sediment transport at this site, though it presumably is toward the west, because of the dominant wave approach direction (from northeast).

Sediments - The sediments of the berm show a wide range in grain size, from cobbles to fine-grained sand. The concentration of cobbles along the toe of the beachface is probably due to a combination of the larger particles rolling to the bottom of the beachface slope during storm activity and the movement of the finer particles up the beachface during berm buildup. The abundance of gravel throughout the tidal flat area is further evidence of strong wave activity at this location. The sandy sediments of the intertidal bar, in contrast to the dominance of gravel elsewhere, are an indication of the relatively ephemeral depositional conditions that existed at the time of the survey. Such bars are probably not present at this site during the fall and winter storms.

g) Shoal North of Kalgin Island

The northern shoal of the group of shoals north of Kalgin Island, which is approximately 35 nm northeast of Tuxedni Bay (Figure 1-1), was examined. More than 0.5 nm of shoal was exposed on the east-west axis; nearly the entire width was examined. The shoal is composed of moderately fine, well-sorted sand. The surface of the shoal is characterized by strongly developed sand waves. The sand waves are up to 12 inches high in many areas, and significant accumulations of granular sand-sized coal particles were noted in the deeper depressions. Drainage channels run outward from the interior of the shoal to the water's edge in several areas. Generally, the sand was firm enough to support the

Figure 3-17. Photographs showing site characteristics at NW Kalgin Island.

weight of the investigators. However, some areas of instability were encountered, especially along the water's edge.

The surficial features of the shoal provide strong indications of the intensity of the currents impinging on the habitat. Further evidence of the intensity of the hydrodynamics is the fact that no animals were observed during an extensive examination of the exposed portion of the shoal.

1) Physical

The sampled sediment at the shoal north of Kalgin Island classifies as fine sand. Median grain size is 0.247 mm. The material is moderately sorted and the distribution is slightly skewed by the quantity of the finer fractions (Table 3-1, Figure 3-10). Organic content of the sediment, as represented by TOC and TKN, is low (0.04 and 0.004 percent, respectively (Table 3-1). Materials on the exposed portion of the shoal were quite uniform. Therefore, these measurements are representative.

2) Geomorphological

This large, complex intertidal shoal, which is located north of Kalgin Island about half way between the island and West Foreland, is lineated in a north-south direction and is several hundred feet long and considerably wider than the other shoals visited (Figure 3-18a). It is composed of pure sand.

Morphology and Hydrodynamics - When this site was visited, at low tide on 30 August 2000, the shoal was covered with active bedforms, mostly sand waves, that were formed by the falling tide. The bedform orientations are very complex, which indicates that currents flow in conflicting directions across the shoal. With a spring tidal range exceeding 20 feet (Table 2-1), strong tidal currents are to be anticipated both on rising and falling tides. However, waves have built conspicuous intertidal bars along the margin of the shoal. It is probable that the sand waves on the shoal (Figure 3-18b) move tens of feet during each tidal cycle, especially during spring tides. The scour pits that move ahead of the migrating bedforms rework the sediments to depths that may reach two feet or more in places. This high instability of the substrate on the shoal no doubt accounts for the lack of infauna in the sediment.

The shoal is open to a long fetch to the northeast, the predominant direction of the wind during fall and winter months, assuming that the wind data from Homer and Kenai (Hayes et al. 1876) are representative of this area. However, although waves no doubt

Figure 3-18. Photographs showing site characteristics at shoal north of Kalgin Island.

rework the shoal during major storms and modify the shoal margins, tidal currents are most important in shaping and maintaining these shoals. As the tide drops, waves rework the tops of the highest of the sand waves all across the shoal.

Sediments - The sediments of the shoal are primarily sand.

h) Middle Ground Shoal

North of the forelands, Middle Ground Shoal was submerged during the initial attempted visit on the last day of the full survey. CIRCAC staff made a subsequent visit in late September. The shoal appears to be similar in all respects to the previously visited shoals to the south. No sentinel species were found. Patches of unstable sand prone to liquefaction were common.

1) Physical

The sampled sediment at the shoal north of Kalgin Island classifies as fine sand. Median grain size is 0.255 mm. The material is moderately sorted and the distribution is generally unskewed (Table 3-1, Figure 3-10). Organic content of the sediment, as represented by TOC and TKN, is low (0.037 and 0.003 percent, respectively (Table 3-1). Materials on the exposed portion of the shoal were quite uniform. Therefore, these measurements are representative.

2) Geomorphological

Geomorphological features and conditions were not described for this shoal but are undoubtedly quite similar to those described for the other three shoals described.

3. West Side of Middle and Upper Cook Inlet (11 sites)

a) NE Chisik Island

The sampling location at the northeast corner of Chisik Island is located in the middle of the entrance to Tuxedni Bay (Figure 1-1). The transect extended approximately northeast across the beach. The predominant features of the beach are a somewhat wide (about 130 feet), high (nearly 16 feet) and steep (~12%) beachface of pebbles and a wide flat of fine sandy silt overlying firm clay that extends >600 feet out to the subtidal zone (Figure 3-19a).

The elevation at the upper end of the mud flat is about 4 feet above MLLW. A low spit of widely scattered cobbles and boulders up to 4 feet in diameter is located on the mud flat approximately 150 feet east of the transect. This structure is oriented approximately normally to the shoreline. A narrow band of cobbles and boulders is located in the transition zone between beachface and the sand flat.

1) Physical

The sampled sediment at the northeast corner of Chisik Island classifies as sandy silt/clay. Median grain size is 0.053 mm. The material is well sorted and the distribution is moderately skewed by the quantity of the coarser fractions (Table 3-1, Figure 3-20). Organic content of the sediment, as represented by TOC and TKN, is the highest observed at any of the sites sampled during this survey (0.98 and 0.081 percent, respectively (Table 3-1). Sediments below the toe of the beachface at this site were relatively variable. Therefore, these measurements are only partially representative.

2) Geomorphological

This site is located on the east-facing flank of a cuspate spit that projects into Tuxedni Bay from the northwest corner of Chisik Island. The spit extends away from bedrock cliffs that border the east side of Chisik Island (Figure 3-21a). The rocks on Chisik Island, which dip steeply to the east, are composed mostly of dark gray siltstones of Jurassic age (Chinitna and Naknek Formations). A broad tidal mud flat, which is at least partly deposited on a bedrock platform, is located to the east of the spit.

Morphology and Hydrodynamics - Two morphological features dominating the portion of the station located seaward of a grassy flat on top of the spit are: 1) a rather steeply dipping beachface composed of mixed sand and gravel, and 2) a broad, muddy tidal flat. Unlike most of the other stations surveyed, no berm top was observed at the landward end of the beachface, indicating this beachface is either stable or slowly retreating. The beachface is composed of a mixture of sand and gravel (Figure 3-21b). An accumulation of pebbles and small cobbles occurs near the top of the beachface, a zone of relatively pure sand occupies the middle of the beachface, and cobbles dominate the sediment at its toe (Figure 3-21c). The relatively steep slope of the beachface (Figure 3-19a) is typical of beaches that contain a significant amount of gravel.

The tidal flat, which is several hundred feet wide, is composed primarily of mud and sandy or gravelly mud. A zone of algae occurs a few tens of feet out from the toe of the beachface (Figures 3-21b and c). Two lines of evidence indicate that the mud flat is a relatively thin mud deposit on top of a flat rock platform, at least on the inner half or so: 1) the lack of thick soft mud (one can easily walk on the flat); and 2) the occurrence of traces of bedrock layers covered with mud to the east of the transect (visible from air and

Figure 3-19. Beach profiles for sampling locations on the west side of middle and upper Cook Inlet.

Figure 3-19. Beach Profiles for Sampling Locations on the West Side of the Inlet (cont'd.)

Figure 3-20. Particle grain size profiles for sites examined on the west side of middle and upper Cook Inlet.

Figure 3-20. Particle grain size profiles for sites examined on the west side of middle and upper Cook Inlet.

Figure 3-21. Photographs showing site characteristics at NE Chisik Island.

in Figure 3-21d). Normally, one would assume that this rock platform was carved by wave action, but the mud layer suggests that this station may be too sheltered from waves to have been formed that way, unless this mud deposit is seasonal (or possibly deposited between major storms) and is eroded away during periods of storm activity. Scour by drifting ice in the wintertime may have aided or been the primary process by which the rock platform was formed). The presence of isolated boulders on the flat surface and the lack of abundant glacial deposits on Chisik Island indicate that the boulders may have been carried there by ice rafting. The spit form itself may be activate only during high spring tides, with the platform not being necessarily related to the mechanism that drives the morphology of the spit.

With tides exceeding 20 feet during spring tides (Table 2-1), the outer parts of the tidal flat are undoubtedly swept by some fairly strong tidal currents during falling and rising tides. However, these currents have little effect on the overall morphology of the profile, which is formed primarily by wave activity which has created the cuspate spit and played some role (plus ice scour) in forming the rock platform. The fetch perpendicular to this shoreline in a northeasterly direction is around 50 miles (bypassing the southern end of Kalgin Island), and, if the wind data for Kenai approximate that for this locality, that is the direction from which the strongest winds blow in the fall and winter. The orientation of this shoreline is directly into the northeasterly waves, another clue to the strength of winds from that direction. The morphology of the spit indicates that it is slowly migrating in a westerly direction, with the beach ridges deposited in the lee of the spit (west side) being truncated as the spit migrates to the west (Figure 3-21a). The sediment that forms the spit has probably been derived mostly from erosion of the bedrock on the eastern side of Chisik Island, but stream deposits also may be a minor source.

Sediments - The sediments of the beachface show a wide range in grain size, from cobbles to sand. The concentration of cobbles along the toe of the beachface is probably due to a combination of the larger particles rolling to the bottom of the beachface slope during storm activity and the movement of the finer particles up the beachface during berm buildup. The cobbles at the base of the beachface are spherical in shape and composed of dense materials such as quartzite. The gravel deposits at the high-tide line are mostly platy siltstone fragments. This type of shape sorting on gravel particles (discs and plates at top of beachface and spheres and rollers at toe of beachface) is typical of gravel beaches everywhere.

The unusual occurrence of a mud flat on such an exposed shoreline is somewhat puzzling. Clearly, wave action is much greater on this transect during high tide than at low tide. Possibly, the nearshore topography in the form of submerged rock pinnacles, or other structures, baffles the waves when the tide is lower, allowing the mud to accumulate in the lower portions of the intertidal zone. The source of the mud could be any of the numerous streams or rivers that empty into the inlet or Tuxedni Bay, with the mud being carried to this location by both flood- and ebb-tidal currents.

b) North Tuxedni Bay

The sampling location in Tuxedni Bay is on a spit located just within the mouth of the bay on its northern shoreline, directly across the channel from the Chisik Island site (Figure 1-1). The transect extended approximately south across the beach. The predominant features of the beach are a moderately wide (about 115 feet) and high (nearly 14 feet) and steep (~12%) beachface of pebbles and a wide flat of fine sandy silt overlying firm clay that extends at least 600 feet out to the subtidal zone (Figure 3-19b). Based on the beach profile indexed to the previous high tide, the elevation at the upper end of the mud flat is about 6 feet above MLLW. However, the estimated tidal elevation by Anon. (1995), based on the approximate time that the water level dropped below the toe of the beachface, the elevation at the upper end of the mud flat was about 3 feet above MLLW.

1) Physical

The sampled sediment on the spit on the north side of Tuxedni Bay classifies as sandy silt/clay. Median grain size is 0.061 mm. The material is poorly sorted and the distribution is more skewed than any other site by the quantity of the coarser fractions (Table 3-1, Figure 3-20). Organic content of the sediment, as represented by TOC and TKN, is moderate (0.60 and 0.056 percent, respectively (Table 3-1). Materials below the toe of the beachface at this site were uniform. Therefore, these measurements are representative.

2) Geomorphological

This site is located on the south side of the Crescent River Delta and on the north side of the entrance to Tuxedni Bay. The entire outer margin of the delta (about 10 miles of shoreline) is presently undergoing erosion, presumably because of a decrease in the sediment supply of the river. This probably is the result of the melting of the glacier that formerly occupied the present stream valley. A broad tidal flat occurs offshore of the river mouth. Sand dumped onto this tidal flat by the river has been arranged into a series of swash bars and sand waves by the waves and tidal currents (Hayes et al. 1976). The transect covered in this discussion is located over two miles to the south and west of the main river mouth. An eroding glacial remnant, located to the east of the transect, marks the approximate boundary between the sandy tidal flat off the river mouth and a much muddier flat several hundred feet wide that bounds the southern portion of the eroding delta. The study transect is oriented in a southerly direction across the mud flat.

Morphology and Hydrodynamics - Two morphological features composing the portion of the station located seaward of a grassy flat on top of the eroding delta surface are 1) a rather steeply dipping beachface composed of mixed sand and gravel, and 2) a broad muddy tidal flat. The high-tide portion of the profile is composed of two rather distinct zones, i.e., 1) an upper area with a narrow berm top and moderately steep beachface; and 2) a somewhat flatter area at the base of the sandy upper beachface (Figures 3-22a and b). The upper area is composed primarily of sand and granules whereas lower area is composed primarily of pebbles with a few small cobbles (Figure 3-22c). As noted above, the relatively steep slope of the beachface (Figure 3-19b) is typical of beaches that contain a significant amount of gravel.

The tidal flat, which is several hundred feet wide, is composed primarily of mud and sandy mud and contains an abundance of infauna (Figure 3-22d). The mud flat appears to be a relatively thin mud deposit on top of some kind of an erosional surface, because one can walk on the flat without sinking in more than a foot. Inasmuch as geomorphic evidence suggests that the Crescent River Delta is presently eroding (Hayes et al. 1976), the underlying platform is probably the eroded delta surface. The presence of numerous boulders on the flat surface a few hundred yards east of the profile in front of a small knoll indicates that some glacial deposits are still present on what is now the delta plain. The stream itself, which is braided into several channels, undoubtedly eroded away and covered most of these glacial deposits. The mud flat is probably aggrading at the present time, inasmuch as Tuxedni Bay is choked with extensive mud flats that are rapidly filling in the bay, with some of this mud reaching to the transect area.

With tides exceeding 20 feet during spring tides (Table 2-1), the outer parts of the tidal flat are undoubtedly swept by some fairly strong tidal currents during falling and rising tides. This is clearly the case on the outer flat offshore of the major river mouth. Whereas these currents continue to mold the surface of the tidal flat, including bringing in the mud, the morphology of the profile is formed primarily by wave activity which has created the upper beach and played some role (plus ice scour) in eroding the underlying delta platform. The fetch perpendicular to this shoreline in a southerly direction is about 4.5 miles (at high tide), and extensive tidal flats intervene at low tide. The fetch directly across Cook Inlet in an easterly direction is about 30 miles, but if the wind data for Kenai approximate that for this locality, that is not a primary wind direction. It is likely that strong adiabatic winds blow down Tuxedni Bay at times, but such winds have very little fetch at this locality. The fetch from the outer margin of the Crescent River Delta in a northeasterly direction, the probable direction of storm winds in fall and winter, is 18 miles (to Kalgin Island). These winds are probably the most important ones generating waves that affect the delta area, including the transect site. The geomorphology of the eroding delta front indicates that sediment transport along the beach at the study site is east to west (Hayes et al. 1976). Waves refracting around the margin of the delta during fall and winter storms and some waves out of the east and southeast during other times create the longshore currents in this area, which are probably relatively modest.

Sediments - The sediments of the beachface show a wide range in grain size, from cobbles to sand. The concentration of cobbles along the toe of the beachface is probably due to a combination of the larger particles rolling to the bottom of the beachface slope during storm activity and the movement of the finer particles up the beachface during berm buildup. These cobbles also have the appearance of an armored surface, which is a very common feature on the coarser-grained gravel beaches of the outer Kenai Peninsula, the Barren Islands, and Prince William Sound. The cobbles at the base of the beachface are spherical in shape and appear to be analogous to gravel samples collected near the Crescent River mouth and analyzed by Hayes et al. (1976). The beach gravel in that locality is composed of approximately 85 percent granite and volcanic rock fragments, and the beach sand is made up of approximately 60 percent quartz. These percentages reflect the predominantly igneous sources in the Chigmit Mountains, which are drained by the Crescent River. The bedrock in that area is either the Jurassic Aleutian Range batholith, primarily quartz diorite, or the Jurassic Talkeetna Formation, which is composed of volcanic derivatives such as tuff and lava flows.

The source of the mud could be any of the streams that empty into Tuxedni Bay (primarily), the Crescent River itself during flood, or any of the other numerous streams around the inlet, with mud being carried to this location by both flood- and ebb-tidal currents.

c) Polly Creek

The sampling location at Polly Creek is approximately 8 nm northeast of the Chisik Island site (Figure 1-1). A transect was not established at this site. The predominant features of the beach are a relatively wide and high beachface of pebbles and a wide flat of fine well-sorted sand that extends out to the subtidal zone. Boulders up to 6 feet in diameter (probably glacial erratics) are scattered sparsely on the sand flat. A narrow muddy trough is located in the transition zone between beachface and the sand flat.

Figure 3-22. Photographs showing site characteristics at No. Tuxedni Bay.

1) Physical

The sampled sediment at Polly Creek classifies as silty fine sand. Median grain size is 0.14 mm. The material is poorly sorted and the distribution is skewed by the quantity of the finer fractions (Table 3-1, Figure 3-20). Organic content of the sediment, as represented by TOC and TKN, is low (0.132 and 0.007 percent, respectively (Table 3-1). Materials below the toe of the beachface at this site were uniform. Therefore, these measurements are representative.

2) Geomorphological

This site near the outlet of Polly Creek is located about 6 miles northeast of the mouth of the Crescent River and a mile southwest of an eroding headland composed of glacial deposits. The shoreline faces toward the southeast. A flat lowland area landward of the high-tide line is vegetated with grass for several hundred feet and with a conifer forest on its landward side. This area is the northernmost extent of a deltaic plain composed of sediments deposited jointly by the Crescent River and Polly Creek and its tributaries. The delta front near the Crescent River mouth is eroding (Hayes et al. 1976), but the shoreline at this study site appears to be relatively stable. A wide intertidal sand flat, broadly noted as a commercial and sport fishery for razor clams (*Siliqua patula*), adjoins a high-tide berm composed of sand and gravel. Large boulders scattered over the flat in places are indicative of erosion of glacial deposits as the shoreline has retreated since the last large-scale rise in sea level.

Morphology and Hydrodynamics - Two morphological features composing the portion of the station located seaward of the vegetated deltaic plain are: 1) a depositional high-tide berm; and 2) a broad, sandy tidal flat separated from the beachface by a shallow swale and containing a number of low-amplitude intertidal sand bars. The high-tide berm has a relatively narrow, sandy and pebbly berm top adjacent to the grass flat (Figure 3-23a). A shallow swale containing some muddy sediment separates the beachface from the broad tidal flat. The relatively steep slope of the beachface is typical of beaches that contain a significant amount of gravel.

The tidal flat, which is over 600 feet wide during low spring tides in this vicinity, is composed of fine-grained sand (Figure 3-23a and b). A number of low-amplitude intertidal sandbars occur at different positions along the flat. It is probable that at least the inner part of this flat is positioned on top of a wave- and ice-cut platform in the underlying glacial and deltaic deposits.

With tides exceeding 20 feet during spring tides (Table 2-1), the outer parts of the tidal flat are undoubtedly swept by some fairly strong tidal currents during falling and rising tides. A number in intertidal swash bars and sand waves shaped by such currents and waves are conspicuous off the mouth of the Crescent River. However, tidal currents have little effect on the overall morphology of the profile, which is formed primarily by wave activity which has built the berms, eroded the underlying platform (aided no doubt by ice scour), and shaped the intertidal bars. The fetch perpendicular to this shoreline is approximately 25 miles in a southeasterly direction. However, assuming that the wind data collected at the Kenai weather station apply in this area, wind blows directly out of the southeast along that 25-mile fetch perpendicular to the shoreline a relatively small amount of time. The dominant southwest winds of the spring and summer blow essentially parallel to the shoreline; however, open water stretches more than 75 miles directly south from this site to the Barren Islands. It is most likely that waves generated by southerly winds are the dominant waves at this site. Storm winds blowing out of the northeast in the fall and winter also blow parallel to the coast with a somewhat limited fetch of only 27 miles (to Kalgin Island). The headland to the east of the station (Redoubt Point) also shields the site from the northeast winds. As one would expect under this wind regime, geomorphic evidence indicates that longshore sediment transport is south to north in this area (Hayes et al. 1976).

Sediments - The sediments of the berm show a wide range in grain size, from pebbles to fine-grained sand. An analysis of the gravel and sand composition at this site by Hayes et al. (1976) showed that the gravel is approximately 85 percent granite and volcanic rock fragments, and the beach sand is made up of approximately 60 percent quartz. These abnormally high percentages of igneous material (for Cook Inlet) reflect the predominant igneous sources (Jurassic batholithic and volcanic rocks) in the Chigmit Mountains, which are drained by the Crescent River. Sand is concentrated on the tidal flat where wave energy is least. That is, maximum wave action occurs along this profile at high tide, during which time the waves break and wash up the beachface. At low tide, the waves break across and offshore of the tidal flat.

d) No-name Creek Beach

The sampling location at No-name Creek Beach is approximately 10 nm north of Tuxedni Bay and 2 nm southwest of Redoubt Creek (Figure 1-1). A standard transect was not established at this site. The predominant features of the beach are a relatively narrow and low beachface of pebbly sand and a wide flat of fine well-sorted sand that extends a substantial distance out to the subtidal zone. Soft mud overlies a compact base of mud on the inner portion of the flat. Boulders up to 6 feet in diameter (probably

Figure 3-23. Photographs showing site characteristics at Polly Creek.

glacial erratics) are scattered sparsely on the sand flat. A narrow muddy trough is located in the transition zone between beachface and the sand flat.

1) Physical

The sampled sediment at No-name Creek classifies as fine sand. Median grain size is 0.265 mm. The material is well sorted and the distribution is not skewed by the quantity of the finer or coarser fractions (Table 3-1, Figure 3-20). Organic content of the sediment, as represented by TOC and TKN, is low (0.20 and 0.035 percent, respectively (Table 3-1). Materials below the toe of the beachface at this site were somewhat varied. Therefore, these measurements are only partially representative.

2) Geomorphological

This site is a few hundred feet northeast of a small unnamed stream 2 miles southwest of Redoubt Creek. The unnamed stream has contributed to an extensive, low-amplitude subtidal delta on the broad intertidal platform offshore of the beach. At the transect site, a narrow grassy flat, presumably part of the delta plain surface, separates the high-tide berm from the base of a low heavily vegetated scarp (Figure 3-24a). The well-timbered vegetated scarp, probably composed of Quaternary glacial deposits, parallels the shoreline. Large boulders (glacial erratics) are scattered over the intertidal flat but were not observed on the beachface. The boulders are probably there as a result of gradual retreat of the scarp in the glacial deposits after the sea reached its present level. The scarp is landward of the beach at the transect site, because, over time, the deltaic sediments have built out the subaerial delta surface, which shelters the scarp from further erosion.

Morphology and Hydrodynamics - Three morphological features composing the portion of this station located seaward of the grassy flat are: 1) a relatively broad mixed sand/pebble beachface (Figure 3-24a), 2) an intermediate mud flat, and 3) a broad sand flat on the outer margin of the intertidal zone (Figure 3-24b). The beachface is composed of a mixture of sand and gravel. The base of the beachface merges abruptly into the mud flat. The moderately steep slope of the beachface is typical for beaches that contain a significant percentage of gravel.

The tidal flat closest to the beachface is a mud flat that appears presently to be depositional. The mud appears to have been deposited inshore of the sand bar observed offshore (Figure 3-24b) and the general paucity of larger infaunal organisms suggests it is unstable. The outer portion of the tidal flat at the transect probably contains a number of low-amplitude intertidal sandbars that would have been formed by wave action at the study site. Also, with tides exceeding 20 feet during spring tides (Table 2-1), the outer parts of the tidal flats are undoubtedly swept by strong tidal currents during falling and rising tides, which would erode away any mud that may have been deposited there during slack-water periods and create sand waves. In the past, this outer sand has been commercially exploited for razor clams (Chuck Rediske, pers. comm.), suggesting that it is relatively stable.

The overall morphology of the shore profile at this site is probably the result of a complex interaction of a number of factors, including the initial erosion of the subtidal platform upon which the tidal flats are deposited, the large tides, and wave action. The fetch perpendicular to this shoreline, which faces to the southeast, is approximately 31 miles. However, assuming that the wind data collected at the Kenai weather station apply in this area, wind blows directly out of the southeast along that 31-mile fetch a relatively small amount of time. The dominant southwest winds of the spring and summer blow essentially parallel to the shoreline; however, open water stretches more than 75 miles directly south from this site to the Barren Islands. It is most likely that waves generated by southerly winds impinge on this site, though the presence of the mud flat would imply they are not especially large. Storm winds blowing out of the northeast in the fall and winter blow parallel to the coast with a somewhat limited fetch of only 9 miles (to Kalgin Island). The headlands at Harriet Point and Redoubt Creek also shield the site somewhat from the northeast winds. There is no clear-cut geomorphic evidence for the direction of longshore sediment transport in this area.

Sediments - The sediments of the berm are mixed sand and gravel. Sand is deposited on the outer tidal flat where wave energy is highest and tidal currents are strongest, and mud is deposited in the lee of the offshore shoal. The sand and gravel is probably derived from both the erosion of the scarp in the glacial deposits and some of the local streams. The mud on the tidal flat is probably derived both from creeks in the local area and the ebb-tidal flow that impinges on this coast because of the Coriolis effect (Sharma et al. 1973), delivering the muddy waters from the upper portion of Cook Inlet.

Figure 3-24. Photographs showing site characteristics at No-name Creek.

e) Redoubt Creek[1]

This sampling location is approximately 50 m north of Redoubt Creek, about 12 nm north of Tuxedni Bay, and 3 nm southeast of Harriet Point (Figure 1-1). The area examined extended about o.25 nm across the flat from the beachface. The transect extended approximately northeast across the beach. The predominant features of the beach are a relatively narrow (about 65 feet) and low (~7 feet) but moderately steep (~9%) beachface of sand and a wide flat of soft mud overlying compact clay that extends out nearly 0.5 nm to the subtidal zone (Figure 3-19c). Many drainage channels about 6 inches deep dissect the surface of this mud flat. The elevation at the upper end of the mud flat is about 12 feet above MLLW. Just north and offshore of the transect area, the sediment becomes sandy. Boulders up to 10 feet in diameter (probably glacial erratics) are scattered sparsely across the beachface and sand flat. A narrow band of cobbles and boulders is located in the transition zone between beachface and the sand flat.

1) Physical

The sampled sediment at Redoubt Creek classifies as sandy silt/clay. Median grain size is 0.062 mm. The material is the most poorly sorted of those examined during this survey and the distribution is skewed by the quantity of the coarser fractions (Table 3-1, Figure 3-20). Organic content of the sediment, as represented by TOC and TKN, is low (0.22 and 0.018 percent, respectively (Table 3-1). Materials below the toe of the beachface at this site were quite varied. Therefore, these measurements are only partially representative.

2) Geomorphological

This east facing shoreline is located ~3.0 miles southwest of Harriet Point, and 150 feet north of the outlet of Redoubt Creek. A vegetated scarp composed of Quaternary glacial deposits parallels the shoreline a short distance behind the beach. At the transect site, a narrow grassy flat separates the high-tide berm from the base of the vegetated scarp, but the scarp is highly erosional closer to Harriet Point. An abundance of large boulders (glacial erratics) is scattered over the intertidal zone throughout the area. The boulders are probably there as a result of gradual retreat of the scarp in the glacial deposits after the sea reached its present level. A large, sandy intertidal shoal projecting south away from Harriet Point attains its greatest width offshore of this site, providing protection.

Morphology and Hydrodynamics - Four morphological features composing the portion of this station located seaward of the grassy flat include: 1) a small depositional high-tide berm, 2) a narrow beachface; 3) an intermediate mud flat, and 4) a broad sand flat on the

[1] The intended survey area was on the north side of Redoubt Point. However, when examining the coordinates recorded on two different GPS units, we found that we had been erroneously transported to Redoubt Creek southwest of Harriet Point.

outer margin of the intertidal zone. The high-tide berm has a relatively narrow sandy berm top (Figure 3-25a). The beachface portion of the berm is dominated by sand at the upper levels and an accumulation of pebbles near the seaward margin (foreground in Figure 3-25b). The base of the beachface merges abruptly into the mud flat (Figure 3-25c). The moderately flat slope of the beachface is typical for beaches that contain a significant percentage of sand.

The tidal flat closest to the beachface is a mud flat that is presently undergoing erosion (Figure 3-25c). The slightly elevated subtidal delta building away from the mouth of the unnamed creek created a partially sheltered area where the mud was originally deposited (Figure 3-25d). Numerous shallow scallops a few inches deep and oriented more-or-less perpendicular to the shoreline cut across the mud flat, indicating recent erosion, probably primarily by wave action. Similar, but more extreme, examples of erosion of mud flat sediments occur at the Nikolai Creek and Chickaloon Bay stations. The erosion of the mud flat at Chickaloon Bay is attributed (by us) to the sinking of the landmass in that area by about three feet during the Good Friday earthquake of 1964 (Plafker 1969; see Figure 3-8). According to Plafker, this study site at Redoubt Creek Beach may have also sunk a few inches during the earthquake. If so, this would have allowed the waves to impact the previously deposited mud flat more vigorously than before the land sank.

In addition to the sand on the bars between the channels on the subtidal delta of the creek, the outer two-thirds or so of the tidal flat at the transect contains a number of low-amplitude intertidal sand bars that appear to have been formed by wave action. South of Harriet Point, 2 miles to the north, the intertidal sandbars are oriented obliquely to the shore, indicating that waves driven by the strong northeast winds have played a major role in the formation of the bars. In addition, with tides exceeding 20 feet during spring tides (Table 2-1), the outer parts of the tidal flats are undoubtedly swept by strong tidal currents during falling and rising tides, which should assist in the formation of large sand waves.

The overall morphology of the shore profile at this site is probably the result of a complex interaction of a number of factors. These include: a) the initial erosion of the subtidal platform upon which the tidal flats and the subtidal delta are deposited; b) the deposition of the subtidal delta; c) the large tides; and 4) wave action. The fetch perpendicular to this shoreline, which faces to the east, is approximately 7 miles. However, assuming that the wind data collected at the Kenai weather station apply in this area, wind blows directly out of the east or southeast (a 27-mile fetch) a relatively small amount of time and the wind waves would be baffled while passing across the extensive shoals south of Kalgin Island. The dominant southwest winds of the spring and summer blow essentially parallel to the shoreline; however, open water stretches more than 75 miles directly south from this site to the Barren Islands. It is most likely that waves generated by southerly winds are the dominant waves at this site even though they need to wrap around the minor point just south of the creek. Storm winds blowing out of the northeast in the fall and winter blow parallel to the coast with a somewhat limited fetch of only 11 miles (to Kalgin Island). The headland at Harriet Point also shields the site from the northeast winds. As one would expect under this wind regime, geomorphic evidence indicates that longshore sediment transport is south to north in this area (Hayes et al. 1976).

Sediments – The sediments of the berm show a wide range in grain size, from small cobbles to sand. The concentration of fine gravel along the toe of the beachface is probably due to a combination of the larger particles rolling to the bottom of the beachface slope during storm activity and the movement of the sand up the beachface during berm buildup. Sand is deposited on the tidal flat where the channels of the stream rework the subtidal delta and on the outer portion of the tidal flat where wave energy is highest and tidal currents are strongest. The source of the sand and fine gravel is predominantly the creek, with a minor contribution from the eroding glacial deposits along the shore. The mud on the tidal flat is probably derived both from the creeks in the area and the ebb-tidal flow that impinges on this coast because of the Coriolis effect (Sharma et al. 1973), which delivers the muddy waters from the upper portion of Cook Inlet. The sand on the outer sand flat could be partially derived from sand transported to the site from the Harriet Point area by tidal currents and possibly wave-driven currents.

f) Harriet Point North

The sampling location at Harriet Point is located on the north side of the point approximately 0.25 nm west of the point and about 15.5 nm north of Tuxedni Bay (Figure 1-1). The transect extended approximately northeast across the beach. The predominant features of the beach are a relatively wide (about 165 feet) and high (nearly 18 feet), steep (~11%) beachface and a wide flat that extends out to the subtidal zone (Figure 3-19d). The substrates are complex. The upper slope of the beachface is composed mainly of pebbles and cobbles whereas the lower slope comprises tightly

Figure 3-25. Photographs showing site characteristics at Redoubt Creek.

packed boulders. The flat grades from fine well-sorted sand inshore to soft mud offshore. The sand forms a low bar just below the lower margin of the beachface. The elevation at the upper end of the mud flat is about 1 foot above MLLW. Boulders up to 6 feet in diameter (probably glacial erratics) are scattered in clumps or sparsely on the beachface and to a lesser extent in the mud flat.

1) Physical

The sampled sediment at the site on the north side of Harriet Point classifies as fine sand. Median grain size is 0.28 mm. The material is well sorted and the distribution is skewed by the quantity of the coarser fractions (Table 3-1, Figure 3-20). Organic content of the sediment, as represented by TOC and TKN, is low (0.053 and 0.004 percent, respectively (Table 3-1). Materials below the toe of the beachface at this site were somewhat varied. Therefore, these measurements are only partially representative.

2) Geomorphological

This site is located on the northeast flank of Harriet Point, about one-third mile northwest of the point. The shoreline is backed by a vegetated scarp that is cored with Quaternary materials, related in some way to glacial activity (i.e., glacial till, glacial lake deposits, etc.) An abundance of large boulders (glacial erratics) is scattered over the intertidal zone throughout the area, especially in the upper intertidal zone. The boulders are probably there as a result of gradual retreat of the scarp in the glacial deposits when the sea reached its present level. In fact, most of the coarser-grained sediments on the transect probably are derived from erosion by wave action of these Quaternary deposits, both locally and elsewhere along the shore. The scarp behind the transect has not been eroding actively for some time, but the scarp on the point and to the southwest of it was eroding dramatically in 1976 (Hayes et al. 1976).

Morphology and Hydrodynamics - Three distinct morphological features composing the portion of the station located seaward of the vegetated scarp are: 1) a depositional high-tide berm with a moderately steep beachface, 2) a more gently sloping cobble/boulder platform, and 3) a slightly muddy intertidal sand flat with superimposed low-amplitude intertidal sand bars. The storm high-tide line is marked by the presence of a few large logs and the beachface of the high-tide berm is composed mostly of pebbles and small cobbles, with a small percentage of sand intermixed (Figure 3-26a). A gravel storm berm, such as the ones so common in Prince William Sound, is not present at this locality. However, a gently sloping cobble-boulder platform is located seaward of the high-tide berm in a similar fashion to those found in Prince William Sound. The cobbles and boulders are relatively well sorted and form a stable armor over the surface of that portion of the beach (Figure 3-26b). The moderately steep slope of the beachface is typical of beaches that contain a significant percentage of gravel (Figure 3-19d). The cobble/boulder platform slopes seaward at a smaller angle.

The inner part of the tidal flat contains an abundance of cobbles and boulders encased in sand (Figure 3-26c). A prominent intertidal bar composed of sand is present a short distance from the toe of the cobble/boulder platform, and a number of low-amplitude, relatively small intertidal sand bars occur further out on the flat. The sand on the flat contained some mud in places at the time of the survey, possibly deposited during the last falling tide or perhaps during neap tides when the waves are less energetic. Sand ripples are present across the surface of the bars across the flat, indicating that currents are active on the flat during high water (Figure 3-26d). The presence of the boulders at random positions over the surface of the flat indicates that the sediments on the flat most likely overlie a wave-cut platform carved into glacial deposits from which the boulders were derived.

With tides exceeding 25 feet during spring tides (Table 2-1), the outer parts of the tidal flat are undoubtedly swept by some fairly strong tidal currents during falling and rising tides. The strength of these currents is indicated by the presence of large intertidal sand waves oriented obliquely to the shore south of the point. However, these currents probably have little effect on the overall morphology of the profile, which is formed primarily by wave activity. This energy has built the berm and cobble/boulder platform, eroded the underlying glacial deposits, and shaped the intertidal bars. The fetch perpendicular to this shoreline directly along the transect from the northeast is about 68 miles, with some potential, though probably minor, damping effect caused by the constriction of the inlet between East and West Forelands. The long fetch is oriented parallel to the predominant storm winds that blow during the fall and winter, assuming the wind pattern at the Kenai weather station can be applied at this site. The southwest winds that prevail in the spring and summer essentially blow offshore. Consequently, waves approaching the shoreline from the northeast are the waves that have shaped this shore profile. The entire aspect of this station, including the coarseness of the beach, the armoring of cobbles and boulders on the cobble/boulder platform, and the roundness of the gravel fragments on the beach, plus the notable fetch to the northeast, indicate that wave energy is typically high at this site. There is no convincing evidence for longshore sediment transport along this beach, and it probably is not significant, because the dominant waves strike the shoreline straight on.

Sediments - The sediments of the upper intertidal zone show a wide range in grain size, from huge boulders to sand. The concentration of cobbles and boulders on the cobble/boulder platform is evidence of their stability after the armoring process took place. Smaller gravel fragments and sand are easily transported across the armored surface during storms and periods of even modest wave activity. The predominant igneous composition of the gravel, both volcanic and batholithic, indicates that the gravel was carried to the shoreline by either streams or glaciers from the mountains to the west where the Jurassic-age rocks are mostly of that origin. Whether or not the sand on the outer intertidal zone is removed during fall and winter storms is a significant question. The presence of primarily juvenile macroinfaunal organisms suggests these sediments are unstable. The mud on the tidal flat is probably derived from both the creeks in the local area and the ebb-tidal flow that impinges on this coast because of the Coriolis effect (Sharma et al. 1973), delivering the mud-saturated waters that drain the upper portion of Cook Inlet.

g) Old Cannery Creek, SW of Drift River

The sampling location near Drift River is approximately 1 nm southwest of Drift River, 0.25 nm north of the mouth of Old Cannery Creek, and 30 nm north of Tuxedni Bay (Figure 1-1). A small platform terminal for oil piped from the Drift River oil facility lies about 1.5 nm offshore. The transect extended approximately southeast across the beach. The predominant features of the beach are the complete absence of a beachface and the extremely wide flat that extends over 3000 feet out to the subtidal zone (extent is based on visual inspection and a 1700-foot walk over the flats; Figure 3.19e). The sediment comprises fine well-sorted sand for ~300 feet and grades into relatively firm mud covered with a blue-green algal mat. The surface of the mud flat is marked with shallow drainage channels and pools.

1) Physical

The sampled sediment at Old Cannery Creek classifies as silt/clay. Median grain size is 0.053 mm. The material is well sorted and the distribution is not skewed by the quantity of the finer or coarser fractions (Table 3-1, Figure 3-20). Organic content of the sediment, as represented by TOC and TKN, is moderate (0.47 and 0.03 percent, respectively (Table 3-1). Materials on this beach, which lacked a well-defined beachface, were relatively uniform. Therefore, these measurements are representative.

Figure 3-26. Photographs showing site characteristics at Harriet Point North.

2) Geomorphological

This transect is located a little over a mile southwest of the mouth of Drift River and a few hundred feet northeast of the outlet of Old Cannery Creek. Facing toward the southeast, this coastline is part of a broad deltaic plain fed by a number of streams, particularly the Drift and Big Rivers, that drain the Double Glacier and surrounding mountains to the west. Consequently, the shoreline is prograding into the inlet at a rapid rate, building broad tidal flats in the process. The area at the high-tide line is extremely flat compared to other beaches in Cook Inlet, with a very subtle high-tide berm and beachface obviously impacted by rather small waves most of the time (Figure 3-19e). A tidal flat extends about 3000 feet offshore of the beachface at the study site. The surface of the flat drops a mere 2.5 feet in elevation from the high-tide line to 400 feet out on the flat and that rate of change appears to be uniform across the flat.

Morphology and Hydrodynamics - Four morphological features composing the portion of the station located seaward of a wide grassy flat, a part of the lower delta plain surface located behind the high-tide line. This complex habitat includes: 1) a very flat high-tide beach area composed of fine-grained sand; 2) an inner sand flat that extends about 300 feet offshore of the beachface; 3) a flat central area composed of a mixture of mud and sand that contains a number of minor drainage channels; and 4) an outer sand flat covered by large bedforms (Figures 3-27a and b). The extreme flatness of the slope of the beachface is similar to beaches in other parts of the world similarly composed of fine-grained sand (e.g., beaches of the barrier islands of South Carolina and Georgia and the Copper River Delta, Alaska).

Wave-formed ripples covered the sandy inner tidal flat at the time of the survey (Figure 3-27c). The sediment of the inner sand flat contains some mud in places. The central tidal flat area, which is composed of a mixture of mud and sand, has a number of drainage networks of small channels over its surface as well as some shallow indentations probably created by ice. Fairly dense blue-green algal mats blanket the surfaces of the interfluves between the channels as well as some broader flat areas. A topographically lower swale containing water marks the boundary between the central flat and a ridge-like outer sand flat that contains numerous large, flattened bedforms.

With tides approaching 25 feet during spring tides (Table 2-1), the outer parts of the central flat, as well as the outer sand flat, which has some aspects of a tidal sand ridge or shoal, are subject to strong tidal currents during falling and rising tides. The fetch perpendicular to this shoreline in a southeasterly direction is approximately 8.5 miles (to Kalgin Island), and the fetch straight across the inlet to the east is 17 miles. Because the

Figure 3-27. Photographs showing site characteristics at Old Cannery Creek.

predominant winds blow from the northeast (fall and winter) and southwest (spring and summer) directions, assuming the data at the Kenai weather station are valid for this site, this shoreline is essentially parallel to these stronger winds. Furthermore, this site is sheltered somewhat from these winds by the West Foreland to the northeast and Harriet Point to the southwest. Additionally, with such broad tidal flats offshore of the beach, the waves crossing the flats at high tide expend much of their energy on the outer flats. Thus, the morphology of this station is the result of a combination of tidal flow that has created the flats and relatively modest wave action that has shaped the subtle beachface at the high-tide line.

Sediments - The sediments of the high-tide beach are composed almost entirely of fine-grained sand, which is probably derived from the river and streams that have formed the delta plain. The mud on the tidal flat is probably derived from both the streams in the local area and the ebb-tidal flow that impinges on this coast because of the Coriolis effect (Sharma et al. 1973), delivering mud-saturated waters that drain the upper portion of Cook Inlet. Although, as implied above, this is a relatively sheltered site, the sediments on the tidal flat are not as muddy as those located in more sheltered areas throughout the inlet (e.g., inner portions of Tuxedni Bay), because, however small, waves still impinge upon this coastline in a fairly consistent manner and the tidal currents that sweep the area are exceptionally strong, especially during spring tides.

h) West Foreland South

One sampling location at the West Foreland is on the south side approximately 1.5 nm west of the foreland and 12.5 nm northeast of Drift River (Figure 1-1). The transect extended approximately south across the beach. The predominant features of the beach are a quite narrow (about 45 feet), moderately high (~10 feet) but steep (~23%) beachface of pebbles and a wide flat of relatively firm mud that grades into fine well-sorted sand extending out >3000 feet to the subtidal zone (extent is based on visual inspection and a 1700-foot walk across the flat; Figure 3-19f). The elevation at the upper end of the mud flat is about 12 feet above MLLW. Boulders up to 6 feet in diameter (probably glacial erratics) are scattered sparsely on the flat.

1) Physical

The sediment sampled at the West Foreland South site classifies as silt/clay. Median grain size is 0.053 mm. The material is well sorted and the distribution is not skewed by the quantity of the finer or coarser fractions (Table 3-1, Figure 3-20). Organic content of the sediment, as represented by TOC and TKN, is moderate (0.38 and 0.022 percent, respectively (Table 3-1). Materials below the toe of the beachface at this site were somewhat varied. Therefore, these measurements are only partially representative.

2) Geomorphological

This site is on a south-facing shore about 1.5 miles west of the southeast point of the headland at West Foreland. On its landward side, the intertidal transect abuts a six-feet-high scarp in eroding peat. The peat was apparently originally deposited on the surface of a delta formed by the Kustatan River, the eastern flank of which adjoins a vegetated high scarp a few hundred feet east of the transect. This vegetated scarp, which is probably composed of Quaternary glacial deposits, was obviously erosional when sea level first rose to its present level and before the delta was formed. The scarp is still erosional near the end of the foreland, where numerous boulders have been deposited on the intertidal zone as the scarp retreats. The fact that the older deltaic deposits are presently eroding could be the result of one or both of two possible causes: 1) a diminishing of the sediment supply to the Kustatan River, such that the river can no longer sustain a protruding delta lobe; and 2) the abrupt rise in sea level during the Good Friday earthquake in 1969.

Morphology and Hydrodynamics - Three morphological features composing the portion of this station located seaward of the eroding peat scarp include: 1) a high-tide beachface minus a berm top, 2) an intermediate mud flat, and 3) a broad sand flat on the outer margin of the intertidal zone. No conspicuous depositional high-tide berm is found at the high-tide line but rather a narrow, steeply dipping beachface composed of sand and gravel (Figures 3-28a-c). This configuration of the beach alone is a clue that this beach is erosional on a long-term basis. The beachface is dominated by sand at the upper levels and an accumulation of pebbles (with a few cobbles) near the seaward margin. The base of the beachface merges abruptly into the mud flat (Figures 3-28-a and 3-19f). The steep slope of the beachface is typical for beaches that contain a significant percentage of gravel.

The tidal flat closest to the beachface is a mud flat that is presently undergoing significant erosion (Figure 3-28d). Numerous shallow scallops a few inches deep and oriented more-or-less perpendicular to the shoreline cut across the mud flat, indicating recent erosion, probably primarily by wave action. A blue-green algal mat commonly is attached to the surfaces of the erosional remnants (humps) between the scallops, indicating that the erosional process is not extremely fast. Similar, but more extreme, examples of erosion of mud flat sediments occur at the Nikolai Creek and Chickaloon Bay stations. The erosion of the mud flat at Chickaloon Bay is attributed (by us) to the

Figure 3-28. Photographs showing site characteristics at West Foreland South.

sinking of the landmass in that area by about three feet during the Good Friday earthquake of 1964 (Plafker 1969; see Figure 3-8). According to Plafker, this study site at West Foreland may have also sunk as much as one foot during the earthquake. If so, this would have allowed the waves to attack the previously deposited mud flat more vigorously than before the land sank. That would also provide a probable explanation for the erosion of the peat deposit at the back of the beach.

The tidal flat at the transect is about 3000 feet wide. The outer two-thirds or so is an exposed sand flat containing numerous bedforms. With tides exceeding 25 feet during spring tides (Table 2-1), this outer portion of the tidal flat is undoubtedly swept by strong tidal currents during falling and rising tides, which would erode away any mud that may have been deposited there during slack-water periods.

The overall morphology of the shore profile at this site is probably the result of a complex interaction of a number of factors, including the initial erosion of the subtidal platform upon which the tidal flats are deposited, the large tides, and wave action. The fetch perpendicular to this shoreline, which faces to the south, is approximately 13 miles (to Kalgin Island). The dominant southwest winds of the spring and summer blow across an open fetch of about 20 miles (across Redoubt Bay). Also, open water stretches more than 80 miles in a general southerly direction from this site to the Barren Islands, but waves in that open stretch of water are baffled somewhat by Kalgin Island. Furthermore, assuming that the wind data collected at the Kenai weather station apply in this area, this site is shielded from the strongest winds of the year, during fall and winter storms, by the headland at West Foreland. Therefore, it is most likely that waves generated by southerly winds are the dominant waves at this site. It is also possible that the largest of the waves generated by storm winds blowing out of the northeast in the fall and winter may, at times, be refracted around the headland and impact this study site. Under this wind and wave regime, given the orientation of the shoreline (facing south), the longshore sediment transport is probably not very significant at this site.

Sediments - The sediments of the beachface show a wide range in grain size, from small cobbles to sand. The concentration of fine gravel along the toe of the beachface is probably due to a combination of the larger particles rolling to the bottom of the beachface slope during storm activity and the movement of the sand up the beachface during calmer periods. Sand is deposited on the outer portion of the tidal flat where wave energy is highest and tidal currents are strongest. The source of the sand and fine gravel on the transect is probably the Kustatan River and other streams in the area, with a minor contribution from the eroding glacial deposits to the east. The mud on the tidal flat was probably derived from both the rivers and streams in the area and the ebb-tidal flow that impinges on this coast because of the Coriolis effect (Sharma et al. 1973), delivering the muddy waters that drain the upper portion of Cook Inlet.

i) West Foreland North

The other sampling location at the West Foreland is approximately 4.5 nm northwest of the foreland and 16.5 nm north of Drift River (Figure 1-1). The Dolly Varden and

Grayling platforms are located offshore within about 3 miles. The transect extended approximately northeast across the beach. The predominant feature of this beach is the relative weakness of the beachface. The elevation of the beach declines gradually out to about 1 foot below MLLW (Figure 3-19g). The distribution of substrates is complex. The upper portion of the slope is primarily pebbles. The middle portion of the slope is predominantly tightly imbricated, flattened boulders 1-3 foot in diameter which give a tiled appearance. At a lower intertidal level, patches of fine well-sorted sand are interspersed among patches of cobbles and small boulders. In the lower intertidal zone, sand and cobble give way to sloppy mud over very compacted clay. The elevation at the upper end of the mud flat is about 12 feet above MLLW. A few boulders up to 4 feet in diameter (probably glacial erratics) are scattered sparsely on the beach. This site appears to be exposed to strong physical forces, e.g., wave action, currents, and ice floes.

1) Physical

The sampled sediment at the site north of the West Foreland classifies as silty fine sand. Median grain size is 0.169 mm. The material is well sorted and the distribution is not skewed by the quantity of the finer or coarser fractions (Table 3-1, Figure 3-20). Organic content of the sediment, as represented by TOC and TKN, is low (0.113 and 0.008 percent, respectively (Table 3-1). Materials below the toe of the beachface at this site were quite varied. Therefore, these measurements are only partially representative.

2) Geomorphological

This site is on a northeast-facing shore about five miles northwest of the outermost point of the headland at West Foreland. On its landward side, the intertidal transect abuts a 150 feet high erosional scarp that is partially vegetated. This near-vertical scarp, which is composed of Quaternary glacial deposits (probably glacial till at this locality), has obviously been erosional off and on since sea level rose to its present level (about 4500 years ago). This deduction is based on the occurrence of large glacial erratics well out into the intertidal zone, which were eroded from the glacial till and are too large for the waves to transport them from their initial resting place at the toe of the retreating scarp.

Morphology and Hydrodynamics - Three morphological features composing the portion of this station located seaward of the eroding scarp include: 1) a high-tide beachface, 2) a fairly broad cobble/boulder platform, and 3) a narrow, muddy sand flat on the outer margin of the intertidal zone. A conspicuous depositional high-tide berm is lacking at the high-tide line, and the beachface composed of sand and gravel is relatively flat. This configuration alone is a clue that this beach is erosional on a long-term basis. Also, a gravel storm berm similar to the ones so common in Prince William Sound has not developed behind the beach. The beachface contains some sand at the upper levels and an accumulation of gravel, dominated by cobbles, near the toe of the gently sloping beachface. The relatively flat slope of the beachface is not typical for beaches that contain a significant percentage of gravel, perhaps another clue to the intense erosional aspect of this beach. The toe of the beachface grades almost imperceptibly onto a broad, even more gently sloping, platform that has a tightly armored surface of relatively well-sorted cobbles and boulders, with a number of exceptionally large boulders (glacial erratics) also present (Figures 3-29a-c and 3-19g). Armored cobble/boulder platforms are a common phenomena on the gravel beaches of Prince William Sound and the Barren Islands, but not nearly so common in the central and upper reaches of Cook Inlet. During the *Exxon Valdez* oil spill, oil penetrated the armored gravel on such platforms and remained in place for many years, because, once beaches are armored liked this, the waves only rework the gravel that makes up the armor during the most intense storms (not for more than ten years in Prince William Sound). The thickness of the sediment on this intertidal area is a significant issue. It is probable that the sediment layer on the platform eroded by the waves into the glacial deposits is relatively thin. In effect, this is probably a thin veneer of sediment on what would otherwise be an exposed, wave-cut platform (perhaps aided by ice scour).

A considerable amount of sand is mixed with the cobbles and boulders on the outer third of the cobble/boulder platform. This is contrary to what would normally be expected on such cobble/boulder platforms, which are formed by intense wave scour. According to Plafker (1969; see Figure 3-8), this study site at the West Foreland may have sunk a foot or so during the Good Friday earthquake of 1964. If so, this would have allowed the sand from the outer flat to encroach upon the lower reaches of the cobble/platform, which was formed before the land sank. The presumably sunken outer end of the cobble/platform, with its enriched sand content, is joined by a relatively narrow, exposed sand flat containing sand ripples and some mud layers (Figure 3-29d). With tides exceeding 25 feet during spring tides (Table 2-1), this sandy tidal flat is undoubtedly swept by strong tidal currents during falling and rising tides. One would assume that such currents and

Figure 3-29. Photographs showing site characteristics at West Foreland North.

waves would erode away any mud that may have been deposited there during slack-water periods. However, this may be true only during spring tides or during stormy periods.

The overall morphology of the shore profile at this site is no doubt the result primarily of intense wave action and possibly some ice scour. The fetch perpendicular to this shoreline, which faces to the northeast, is approximately 30 miles. Assuming that the wind data collected at the Kenai weather station apply in this area, the strongest winds of the year, during fall and winter storms, blow straight down this long fetch and impact on this beach. Therefore, this site is the most exposed station of any studied with respect to these strongest winds of the year. The dominant southwest winds of the spring and summer blow offshore at this locality. Under this wind and wave regime, given the orientation of the shoreline (facing northeast), the longshore sediment transport is probably not very significant.

Sediments - The sediments of the beachface show a wide range in grain size, from small cobbles to sand. The source of the gravel is primarily the eroded scarp in the glacial deposits. The gravel fragments have a wide range in composition, with igneous rocks, both volcanic and batholithic, being very common. This composition is to be expected from deposits laid down by glaciers that flowed out of the mountains to the west. Sand is deposited on the middle portion of the tidal flat where tidal currents are strongest and wave energy is also considerable at low tide. However, sloppy, probably ephemeral, mud overlies a base of compact mud in the lower intertidal zone. The source of the sand is probably both the eroding scarp and the numerous streams in the area. The mud on the sand flat was probably derived from both the rivers and streams in the area and the ebb-tidal flow that impinges on this coast because of the Coriolis effect (Sharma et al. 1973), delivering the muddy waters that drain the upper portion of Cook Inlet.

j) Nikolai Creek

The sampling location at Nikolai Creek is approximately 32.5 nm north of Drift River and 9.5 nm southwest of the North Foreland (Figure 1-1). A transect was not established at this site but the areas examined extended approximately southeast across the beach approximately 1000 feet. The predominant features of the beach are a relatively narrow (~50 feet) and low (~8 feet) beachface of pebbles (Figure 3-30a) and a very wide flat of soft mud over compact clay that extends >3000 feet out into the subtidal zone (Figure 3-30b). A narrow trough containing cobbles and soft mud is located in the transition zone between beachface and the mud flat. Immediately offshore of the trough, the surface of the mud flat, dissected by numerous drainage channels, is covered by a blue-green algal mat. This mat becomes denser with increasing distance offshore. This site is immediately inshore of five oil production platforms (Figure 3-30b).

1) Physical

The sampled sediment at Nikolai Creek classifies as silt/clay. Median grain size, at 0.052 mm, is among the finest at the sites sampled during this survey. The material is well sorted and the distribution is not skewed by the quantity of the finer or coarser fractions (Table 3-1, Figure 3-20). Organic content of the sediment, as represented by TOC and TKN, is among the highest observed (0.89 and 0.058 percent, respectively (Table 3-1). Materials below the toe of the beachface at this site were quite uniform. Therefore, these measurements are representative.

2) Geomorphological

This shoreline is located about 2 miles west of Granite Point and faces directly south. The high-tide berm is similar to that described at Chickaloon Bay, thus probably indicating relatively high wave energy. As a rule, depositional macrotidal coasts have extensive marshes and mud flats at the high-tide area. Mud flats form there because waves usually break on tidal sand ridges and sand flats located far seaward of the high-tide line. In areas where large volumes of suspended sediments are available, mud settles out along the shoreline during slack water periods at high tide, building out the mud flats. At this location, the mud flats extend out more than 3000 feet. This site probably sank more than 1 foot during the Good Friday earthquake of 1964 (Plafker 1969; see Figure 3-8). With this sinking, the high-tide area was exposed to much greater wave action than before, allowing the high-tide berm to develop to its present size and causing the mud flat to erode.

Morphology and Hydrodynamics

Two morphological features composing the portion of the station located seaward of the shoreline are: 1) a small high-tide berm; and 2) a broad erosional mud flat. As shown in Figure 3-30a, the high-tide berm is composed of a mixture of sand and gravel. Scattered cobbles occur at the toe of the beachface, especially in the narrow swale between the beachface and the mud flat. The beachface slope is relatively steep, which is typical of beaches that contain a significant amount of gravel. The slope decreases abruptly where the base of the beachface joins the near-horizontal surface of the mud flat. A narrow swale has been scoured out at the base of the beachface by backwash of waves at high tide. This depression is lined largely with gravel and small cobbles.

The tidal mud flat, which is several thousand feet wide, is composed of hummocks of mud located between numerous scour pits and eroded channels caused by an increase in wave action since the earthquake (Figures 3-30a and b). At its upper level, this mud flat is densely inhabited by a large burrowing nereid worm *Laonnates* sp. Burrows constructed by this worm perforate the edges and floor of the channels crossing the flats (Figure 3-30c).

With tides exceeding 25 feet during spring tides (Figure 2-1), the outer parts of the mud flat are subject to strong tidal currents during falling and rising tides. Thus, the morphology of this station is the result of a combination of tidal flow that has created the flats and waves that have shaped the high-tide berm.

The fetch perpendicular to this shoreline in a southerly direction is approximately 17 miles to the East Foreland, but to the southwest, about 150 miles to the Barren Islands.

However, at low tide the fetch is only about 7 miles because the exposure of Middle Ground Shoals. Assuming the data at the Kenai weather station is valid for this site, the predominant northeast winds in the fall and winter blow offshore at this site. However, because predominant spring and summer winds blow from the southwest, this shoreline may be vulnerable to some wave action during that period.

Sediments

The sediments of the berm show a wide range in grain size, from medium-sized cobbles to sand. The concentration of cobbles along the toe of the beachface is probably due to a combination of the larger particles rolling to the bottom of the beachface slope during storm activity and the movement of the finer particles up the beachface during berm buildup. Mud was originally deposited on the tidal flat where wave energy was least, but exposure to higher waves is now causing the flat to erode. The mud on the outer part of the tidal flat is probably derived both from the creeks in the local area and the ebb-tidal flow that impinges on this coast because of the Coriolis effect (Sharma et al. 1973), which delivers mud-saturated waters from the upper portion of Cook Inlet.

k) Beluga River SW

The sampling location near Beluga River is approximately 4 nm northeast of the North Foreland and 7 nm southwest of the river (Figure 1-1). It is the northernmost location visited during this reconnaissance. The transect extended approximately southeast across the beach. A predominant feature of this beach is the absence of a defined berm. The beach is moderately steep (~8.5%). The upper portion of the beach is composed of mainly pebbles. The middle portion of the beach comprises fine well-sorted sand, which

Figure 3-30. Photographs showing site characteristics at Nikolai Creek.

extends down to about MLLW. Below that, the sediment becomes mud, which extends out into the subtidal zone (Figure 3-19h).

1) Physical

The sampled sediment at the site south of the Beluga River classifies as sandy silt/clay. Median grain size, at 0.054 mm, is among the finest at the sites sampled during this survey. The material is well sorted and the distribution is not skewed by the quantity of the finer or coarser fractions (Table 3-1, Figure 3-20). Organic content of the sediment, as represented by TOC and TKN, is among the highest observed (0.898 and 0.037 percent, respectively (Table 3-1). Materials below the toe of the beachface at this site were quite uniform. Therefore, these measurements are representative.

2) Geomorphological

This site is located on a southeast-facing shoreline about two miles southwest of the mouth of Threemile Creek. The shoreline is backed by a highly erosional vegetated bluff about 100 feet high that is cored with Quaternary materials, related in some way to glacial activity. The absence of large boulders (glacial erratics) in the intertidal zone and the incorporation of sand layers plus gravel deposits in the material exposed in the scarp indicate that glacial outwash sediments underlie the bluff. In fact, most of the coarser-grained sediments on the transect probably are derived from erosion by wave action of these Quaternary deposits, both locally and elsewhere along the shore. An abundance of dead tree trunks, some of which still have limbs and leaves attached, at the base of the scarp indicates that the erosion is probably active during each high spring tide and/or stormy period. In fact, the previous high tide had washed up onto the base of the scarp and the high-tide wrack line was difficult to discern.

Morphology and Hydrodynamics - Two distinct morphological features composing the portion of the station located seaward of the eroding scarp are: 1) a moderately sloping beachface composed of mixed sand and fine gravel, and 2) a narrow intertidal sand flat with superimposed low-amplitude bedforms. The high-tide line is marked by the presence of numerous large logs and tree limbs, and the upper part of the beachface is primarily sand (Figure 3-31a). A band of relatively pure pebbles stretches along the middle of the beachface, and another band of sand separates these pebbles from a mixture of pebbles, sand, and a few randomly distributed cobbles at the toe of the beachface (Figure 3-31b). The absence of a well-defined high-tide berm is another indication of the continuing erosion along this beach. The only moderately steep slope of the beachface is unusual for beaches that contain a significant percentage of gravel (Figure 3-19h). The beachface merges almost imperceptibly into the mud flat, the entire profile having a concave-upward shape, which is also typical of eroding shorelines. Near the bottom of the beachface, a layer of sand overlies pockets or layers of mud and finely ground coal.

The inner part of the tidal flat contains a band of pebbles (Figure 3-31b), and low-amplitude bedforms (ripples mostly) are common over the surface of the flat. Mud is present on the outer reaches of the flat, possibly deposited during the last falling tide or perhaps during neap tides when the waves are less energetic (Figure 3-31c). However, based on the abundance of the clam *Macoma balthica*, it is likely these sediments are relatively stable.

With tides exceeding 30 feet during spring tides (Figure 2-1), the outer parts of the tidal flat are undoubtedly swept by some fairly strong tidal currents during falling and rising tides. However, these currents probably have little effect on the overall morphology of the profile, which is formed primarily by wave activity, which has eroded the scarp, formed the beachface, and probably eroded a wave-cut platform in the glacial deposits on upon which the sand flat is perched. The fetch perpendicular to this shoreline directly along the transect from the southeast is about 17 miles, but the predominant winds blow out of the southwest in the summer and spring and northeast during the fall and winter (assuming the wind pattern at the Kenai weather station applies at this site). The southwest winds that prevail in the spring and summer essentially blow alongshore. On the other hand, a fetch directly to the east into the entrance of Turnagain Arm stretches for about 30 miles. Thus, the fall and winter storm winds blowing across this long fetch should generate significant waves that have undoubtedly shaped this shore profile. There is no convincing evidence for significant longshore sediment transport along this beach, but considering that the dominant waves strike the shoreline at an oblique angle from the north, the transport direction should be fairly strongly from northeast to the southwest at this station.

Sediments - The sediments of the upper intertidal zone show a wide range in grain size, from small cobbles to sand. The gravel fragments have a wide range in composition, but the predominantly igneous composition of the gravel, both volcanic and batholithic, indicates that the gravel was carried to the shoreline by either streams or glaciers from the mountains to the west where igneous rocks are abundant. The mud on the outer part of the tidal flat is probably derived from both the creeks in the local area and the ebb-tidal flow that impinges on this coast because of the Coriolis effect (Sharma et al. 1973), which delivers mud-saturated waters from the upper portion of Cook Inlet.

Figure 3-31. Photographs showing site characteristics at Beluga River SW.