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RECONNAISSANCE REPORT ON SURFICIAL GEOLOGY OF COASTAL AREA FROM TOLSTOI POINT TO CAPE NOME, NORTON SOUND, ALASKA

By
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(plates in pocket)

METRIC CONVERSION FACTORS

To convert kilometers to miles, divide kilometers by 1.61. To convert meters to feet, divide meters by 0.3048.

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J.R. Riehle[1], K.S. Emmel[1], and J.G. Bolm[2]

ABSTRACT

Distribution of surficial materials, directions of littoral transport, and rates of beach erosion and progradation have been determined for the coastal area of Norton Sound, Alaska, from Cape Nome to Tolstoi Point. Photointerpretation was supplemented by field reconnaissance.

At least two early periods of relatively high sea level are evident in the mapped area, at about 4.5 and 16 m above present mean sea level. The most areally extensive unconsolidated deposit is an undifferentiated, nonsorted silty sand and moderately sorted sandy gravel unit that was formed by marine deposition during high sea stands and modified by weathering and slow creep or flow on gentle to moderate slopes. Deposits of flood plains, active and vegetated beaches, landslides, and intertidal flats were also identified. High terrace levels along streams, thermokarst topography, and prominent ice-wedge polygon areas were noted.

Littoral transport directions are mainly eastward from Cape Nome to Koyuk Inlet, northward from the Ungalik River to Koyuk Inlet, northward from Blueberry Point to the Shaktoolik River, southward from Blueberry Point to the Unalakleet River, and northward from Tolstoi Point to the Unalakleet River.

Erosion has been most rapid along coastal sections where sea cliffs are cut in unconsolidated deposits. For the past 25 years, measured rates of erosion range from 1 to 4 m/yr.

INTRODUCTION

This reconnaissance survey (fig. 1) will assist coastal-zone planners in selecting areas for site-specific surveys along the Alaskan coast from Cape Nome to Tolstoi Point.

Geologic mapping was accomplished by photointerpretation supplemented with data from a July 1978 helicopter-supported field reconnaissance. Field work was done in cooperation with the U.S. Geological Survey, whose personnel collected data on source-rock and reservoir characteristics for the evaluation of hydrocarbon potential in the offshore Norton basin.

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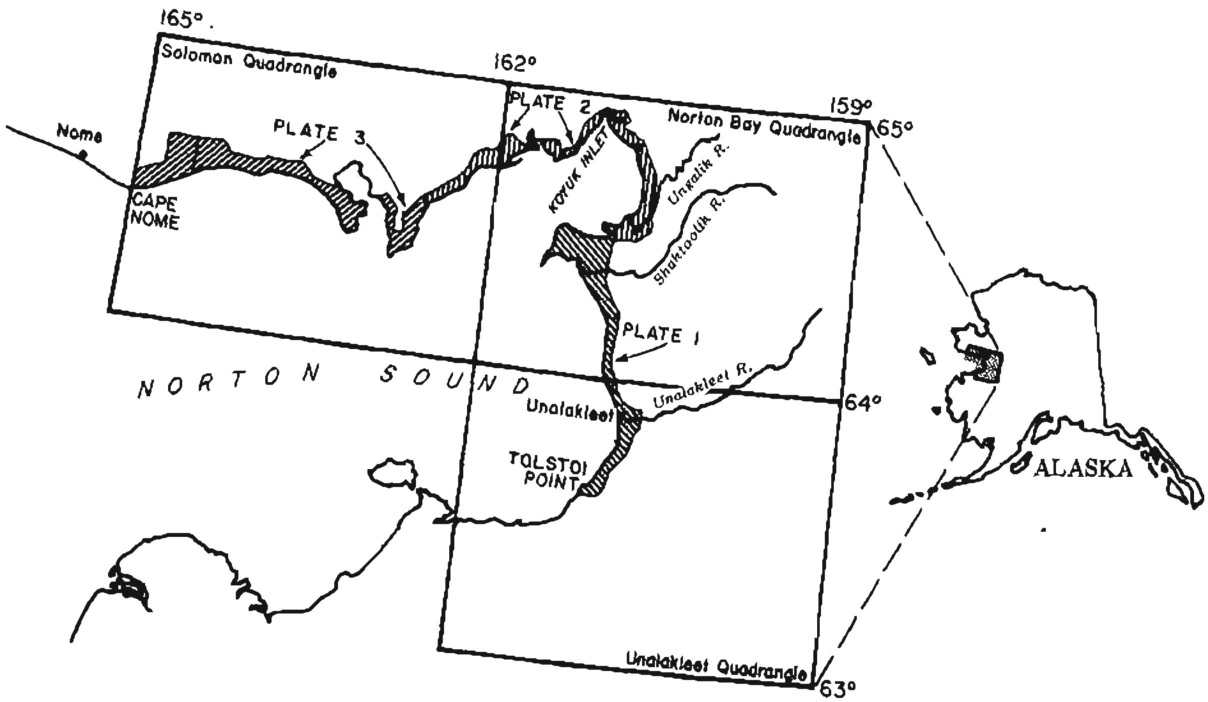

Figure 1.-- Index map showing Tolstoi Point - Cape Nome Area, Norton Sound, Alaska.

Figure 1. Index map of Norton Sound area.

ACKNOWLEDGMENTS

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PHYSICAL CHARACTERISTICS OF MAP UNITS

Bedrock Units

Bedrock unit Qtv crops out at Tolstoi Point (pl. 1A) in the mapped area and consists of upper Tertiary and Quaternary volcanic flows. Hoare and Condon (1971) reported a basaltic composition for equivalent volcanics which include flows, tuffs, and breccias near Saint Michael (54 km southwest of Tolstoi Point). Cass (1959a) compiled field data supplemented by photointerpretation and mapped the rocks at Tolstoi Point as interbedded flows and ash. We saw no significant amounts of ash in sea-cliff exposures southwest of Tolstoi Point, but future site-specific foundation studies should investigate the possible presence of ash, vesicular flow rocks, and breccias at flow margins. Ice-wedge polygons within unit Qtv imply the presence of fine-grained surficial deposits that are probably windblown silt or sand similar to deposits near Saint Michael (see Hoare and Condon, 1971). We did not distinguish such surficial deposits from volcanic rocks.

Bedrock other than Tertiary and Quaternary volcanics is mapped as unit pQb. From Tolstoi Point (pl. 1A) north to the Koyuk River (pl. 2A), bedrock consists mainly of units included in the Shaktolik[3] Group of Cretaceous age (Cass, 1959a,b). Lithologies include graywacke, shale, and conglomerate with local coal stringers and fragments. Shaktolik Group rocks are folded about are folded about northeast-trending axes; bedding dips are subvertical (fig. 2). Numerous faults, mapped by Cass (1959a,b) in the Norton Bay and Unalakleet areas and by Patton and Bickel (1956) in the highlands east of Shaktoolik, strike approximately parallel to the bedding. Besboro Island (about 16 km west of pl. 1B) and Little Mountain (near Reindeer Cove, pl. 1C) are underlain by volcanic flows, breccias, and sedimentary rocks of probable Cretaceous age (Patton, 1973). The Reindeer Hills (pl. 1C) are underlain by metamorphosed sedimentary rocks that are probably lower Paleozoic (Cass, 1959a). During a single low flight, pervasive fractures and color staining were noted in sea-cliff exposures around the Reindeer Hills.

[3]Spelling of this name for geographic localities is 'Shaktoolik.' The name 'Shaktolik Group' has been abandoned by Patton (1973); we use the name here for convenience in referring to these rocks.

Figure 2. Steeply dipping, tightly folded bedding in Shaktolik Group rocks 4 km north of Blueberry Point (pls. 1A, 1B). Height of fold hinge about 10 m.

Bedrock in the coastal section from Ungalik (pl. 2A) north to the Inglutalik River (pl. 2A) consists of the Shaktolik Group and slightly older conglomerate and sandstone of the Ungalik Conglomerate (Cass, 1959b). From the Koyuk River outlet west to Bald Head (pls. 2A, 2B), bedrock consists mostly of lower or middle Paleozoic marble and lesser amounts of sedimentary rocks. These rocks are mapped by Cass (1959b) as equivalent to those underlying the Reindeer Hills. W.C. Mendenhall (cited in Smith and Eakin, 1911, p. 54) described rocks at Bald Head as marble infolded with thinly bedded limestone and schist. A small area centered 2 km northeast of Koyuk is underlain by Shaktolik Group rocks (Cass, 1959b). A north-trending fault just east of Koyuk separates lower Paleozoic rocks from thinly bedded sedimentary and metamorphic rocks of Precambrian age to the east (Hudson, 1977).

From Elim to Walla Walla (pl. 2C), unit pQb comprises the lower or middle Paleozoic rocks and the Precambrian rocks previously described, separated by several north-south- and east-west-trending faults. Smith and Eakin (1911, p. 47) described the Paleozoic rocks in this coastal section as limestone and dolomite with lesser amounts of schist and carbonaceous slate; all are intruded by greenstone, granite, and diorite and are complexly folded. Upper Precambrian or lower Paleozoic biotite- and garnet-rich schist and marble crop out between Walla Walla and Portage Roadhouse (pls. 2A, 3A). These rocks are in apparent intrusive contact with Cretaceous granite, which occurs along the coast to near Cape Darby. The biotite- and garnet-rich schist and marble crop out again for about 8 km in sea cliffs from Cape Darby north to Golovnin Bay, where they are in intrusive contact with Cretaceous monzonite and syenite. These alkalic intrusive rocks are in possible fault contact with upper Precambrian, thinly bedded sedimentary and metasedimentary rocks at Golovin Village. Upper Precambrian rocks (fig. 3) underlie the peninsula and define the west side of Golovnin Bay at Rocky Point (pl. 3B) and the uplands westward beyond Solomon (pl. 3C). At Bluff (pl. 3C) a structural window exposes lower or middle Paleozoic marble and other rocks that are overthrust by Precambrian rocks. Lithologies in the Bluff area were described by A.H. Brooks (cited in Smith and Eakin, 1911, p. 52) as massive limestone, mica schist, and graphitic limestone (Hudson, 1977).

The uplands at Cape Nome (pl. 3D) are underlain by a core area of granitic gneiss of unknown age surrounded by gneiss and marble of Precambrian age (Hudson, 1977).

The contact of bedrock with undifferentiated surficial deposits (unit Qu) is approximately located. Many areas shown as bedrock are covered by thin surficial deposits such as windblown silt and sand, colluvium, and alluvium, all of which may affect foundation characteristics of sites. Only a single large bedrock landslide was identified (northwest of Rocky Point; pl. 3B), but rockfalls occur along many sections of beach that are backed by bedrock sea cliffs.

Site-specific investigations of bedrock should include assessment of potential bedrock movements along steeply dipping bedding planes, fractures, or faults.

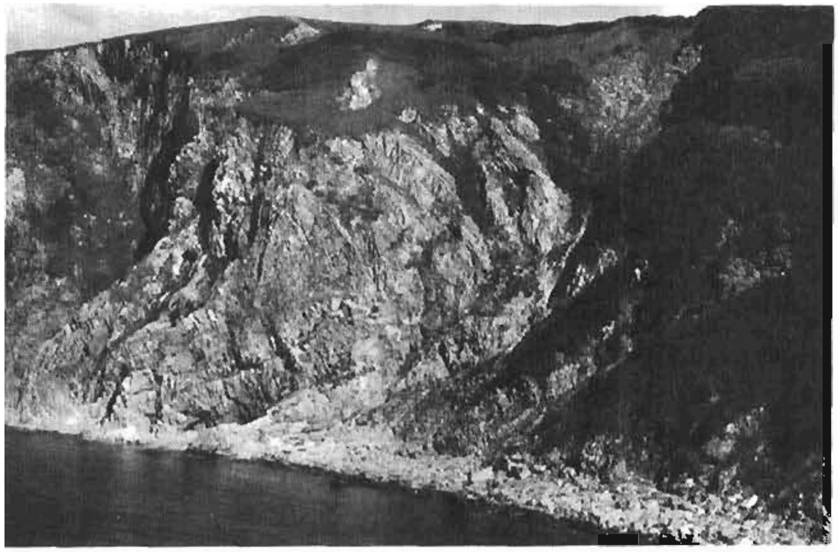

Figure 3. Recumbent fold in upper Precambrian thinly bedded metasedimentary rocks at Rocky Point (pl. 3B). Note abundant angular blocks from rockfalls in the intertidal zone.

Surficial Deposits

Beaches in the mapped area (unit Qba) are generally composed of coarse materials such as sandy gravel. Beach profiles tend to be steep and culminate in a high berm (fig. 4), which is topped by large waves during storms (Sallenger and others, 1977). Beaches also are affected by pack-ice modification such as shoving (fig. 5) and probably by ice-raft deposition (a possible example is the basalt boulders that occur along the beach for several miles north of Tolstoi Point). Beach deposits at the foot of sea cliffs eroded in bedrock are probably no more than 2 or 3 m thick where wave-truncated bedrock is exposed in the intertidal and shallow subtidal zones. Beach deposits on the large barrier beaches are much thicker. A water well drilled at Shaktoolik penetrated 6 m of beach deposits (coarse sand, silt, and gravel), and 11 m of beach deposits (sand, gravel, and some clay) have been penetrated by a water well at Unalakleet. Frozen material occurs below beach deposits to a depth of 23 m at Unalakleet; at Shaktoolik, frost in clay and silt is reported from the base of beach deposits to a depth of 8 m. Bedrock at Unalakleet is at a depth of 31 m. Permafrost ice below the beach deposits may be relict from one or more periods of sea-level retreat prior to 6,000 yr before present (b.p.)

Unit Qal consists of stream-transported deposits. These include stratified sand and gravel where adjacent streams are meandering; more commonly it consists of poorly to moderately sorted sand and silt of overbank deposits. At the mouths of streams along the coast Qal may include silt and fine sand deposited in brackish water by storm-surge inundation. The contact between flood-plain deposits and adjacent colluvium (Qu, in part) is approximate, especially along smaller streams in which discharge varies.

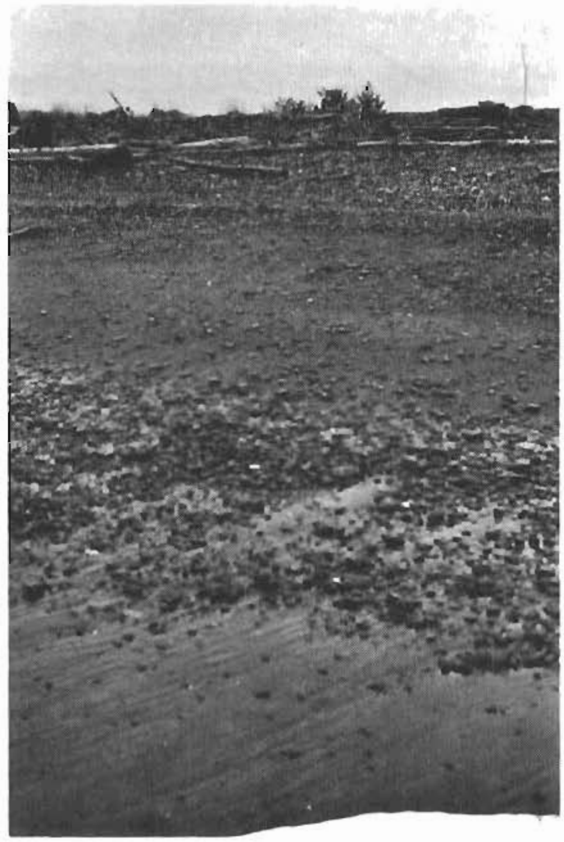

Figure 4. Beach at Powers Creek (pl. 1A) 8 km north of Unalakleet. Note coarse shingle in upper part of beach and well-defined storm berm.

Figure 5. Shingle beach deposits previously disrupted by ice shoving or melting 3 km west of Bluff (pl. 3C).

Constructional terrace remnants above presently active flood plains are designated Qt (pl. 1). Because such terraces are identified only along streams in steep-walled mountain valleys, these deposits may contain coarser sand and gravel than Qal deposits.

Undifferentiated surficial deposits (unit Qu) include organic deposits (tundra mat), emergent marine deposits, slope deposits, windblown silt and sand, and possibly unrecognized glacial deposits. Because we cannot consistently separate these types of deposits by photointerpretion techniques, they are included as a single unit. The contact with bedrock units is approximate. Thin or small deposits of unit Qu may occur within areas shown as bedrock.

Where unit Qu occurs adjacent to steep bedrock slopes, the deposits probably contain a higher proportion of pebbles, cobbles, and boulders than are present away from bedrock exposures. Polygonal ground in unit Qu is generally indicative of fine materials, because polygons are normally not developed in coarser, better drained materials (Ferrians and others, 1969).

Indicators of slope instability in surficial deposits include soil lobes and terraces (fig. 6), rock stripes, and earthflows (fig. 7). Only the larger earthflows are mapped as Qls. Small earthflows, lobes, terraces, and rock stripes occur in areas shown as Qu and in areas of thin surficial deposits within unit pQb. Generally, soil lobes occur on slopes of 20° to 25°, whereas soil terraces may occur on slopes as low as a few degrees (Sigafoos and Hopkins, 1952). Future site-specific investigations should include a detailed assessment of potential instabilities, especially in areas of gentle to moderate slopes.

Figure 6. Soil lobes and soil terraces resulting from downslope movement (creep and solifluction) of unconsolidated deposits on moderate slopes near Unalakleet.

Figure 7. Earthflow in unit Qu 11 km south of Unalakleet (pl. 1A). Earthflow proceeded onto beach (out of view)

Polygonal ground indicates the presence (or former presence) of ice wedges in the subsurface. In addition, horizontal ice lenses with little or no surface expression may develop in fine, poorly drained material. An example of massive ground ice is shown in figure 8. Ground settling due to ice melting is a potential hazard to structures located above such ice.

Parts of areas shown as Qu have undergone some thawing of ground ice, leading to formation of thaw pits and thaw lakes (Ferrians and others, 1969); the symbol Qud refers to areas of unit Qu where such thaw features are predominant. Areas of unit Qud are slightly lower in mean elevation and have a larger proportion of empty or filled lake basins. Drained basins and interbasin highlands within areas of Qud may show polygonal ground development that is indicative of the regrowth of ground ice after thaw settlement. Similarly, Hopkins and Sigafoos (1951) recognized several climatic fluctuations on the Seward Peninsula; features indicative of more severe climatic conditions than now exist within the mapped area may be the net result of several such climatic fluctuations.

REGIONAL SEISMICITY

The Kaltag fault has been mapped by Patton and Hoare (1968) along the Unalakleet River valley.

The trace of the fault extends from the village of Kaltag (outside the mapped area 108 km northeast of Unalakleet) southwestward to Norton Sound just south of Unalakleet. Displacement appears to have been dominantly right lateral. Significant movement probably postdates Cretaceous sedimentary rocks (such as the Shaktolik Group) and may have occurred as recently as late Tertiary. Effects of movement along the fault can be traced through surficial deposits in some places, which suggests that some movement occurred very recently. The projected extension of the fault trace passes just west of Saint Michael (beyond the mapped area 77 km southwest of Unalakleet) where upper Tertiary and Pleistocene basalt flows show no significant lateral displacement across the projected trace (Patton and Hoare, 1968). Limited offshore seismic-survey data indicate that faults parallel to the projection of the Kaltag fault occur in the deep subsurface of Norton Sound northeast and southwest of Saint Michael. At least part of the displacement along these faults has been dip slip (Johnson and Holmes, 1977).

Only a few earthquakes were recorded from the Norton Sound region before 1976 (Meyers and others, 1976), when six seismograph stations were installed. On the basis of 1 year of recording (Dec. 20, 1976 to Jan. 10, 1978), Biswas and Gedney (1978) tentatively conclude that some epicenters of small events (Richter magnitudes between 1.0 and 4.5) align along the surface trace of the Kaltag fault. Although there is no clear evidence of large recent displacements on the Kaltag fault and available data are preliminary, future site evaluations along the Kaltag fault should address the potential for surface displacement associated with moderate to large earthquakes.

Figure 8. Massive ground ice 1 to 2 m below ground surface in unit Qu near outlet of Coal Mine Creek (pl. 1A) 11 km south of Unalakleet.

SEA-LEVEL HISTORY AND ORIGIN OF UNIT Qu

The most informative exposures of unit Qu are south of Unalakleet. From the outlet of Glacier Creek (pl. 1A) to the southern edge of the mapped area, the coastline consists of a steep sea cliff and a narrow beach. Bedrock is exposed in the basal 4.6 m of the sea cliff north of Poker Creek, and the upper part of the sea cliff is unconsolidated deposits (unit Qu). The top surface of bedrock in the sea cliff is inferred to be a wave-cut platform formed during an earlier high sea stand. The unconsolidated deposits vary from stratified sand and gravel to massive pebble-bearing silt. The stratified deposits, located mainly between Glacier Creek and Poker Creek, consist of subangular to rounded pebble and cobble gravel that is locally imbricated. At the mouths of Spruce Creek and Glacier Creek the stratified deposits form a terrace between 12 and 16 m high (fig. 9). We interpret the stratified deposits to be emergent nearshore and beach deposits.

The top of the bedrock platform exposed in the sea cliff slopes northward and passes below present sea level a few hundred meters north of Glacier Creek. Massive pebble-bearing silt constitutes most of the unconsolidated deposits along the sea cliff north of Glacier Creek. The contact between the stratified sand and gravel (described above) and the massive silt is probably gradational. Locally, the massive silt contains stratified silty sand and sandy gravel that is probably an emergent offshore deposit of the same age as the stratified sand and gravel exposed in sea cliffs farther south.

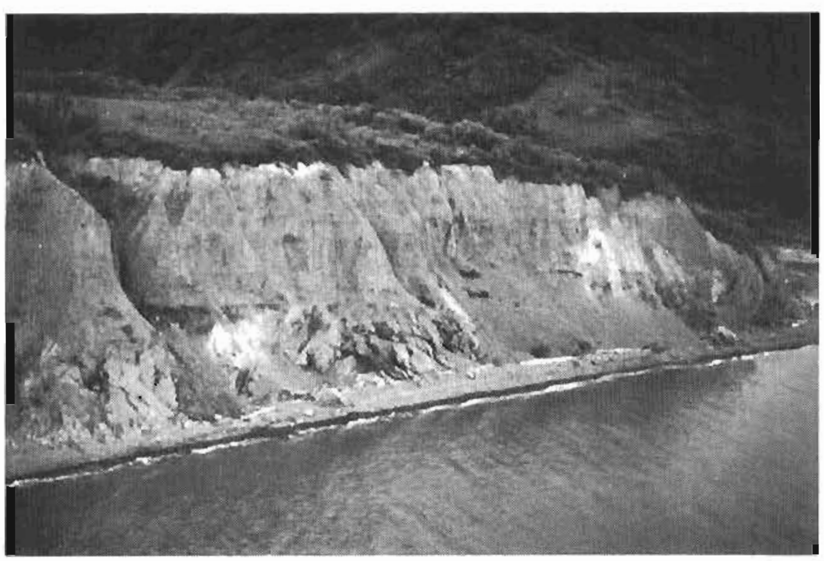

Figure 9. Imbricate gravels of unit Qu form 12-m-high terrace at mouth of Glacier Creek. Note trace of 4.5-m-high wave-cut platform (dark line halfway up cliff face) in bedrock of lower part of modern sea cliff.

The following tentative model explains the origin of unit Qu. Hopkins (1973) proposed that sea stands in the Bering Sea region were higher than the present sea level at about 105,000, 120,000, 175,000, and 220,000 yr b.p.; evidence for the high stands came from areas other than eastern Norton Sound. Because of the possibility of crustal warping between the sites studied for this report and those studied by Hopkins, the presumed elevations of the high stands are not stressed. Hopkins (1973, p. 536) suggested that sea level 105,000 yr b.p. was about 5 m above present sea level, that at 120,000 yr b.p. it was 10 to 15 m higher, and that it was perhaps 5 to 10 m higher 175,000 yr b.p. Clearly, the 4- to 6-m bedrock platform north of Poker Creek was cut during the high sea stand of about 175,000 yr. b.p., and the unconsolidated deposits which underlie the 12- to 16-m-high terrace were deposited during the higher stand 120,000 yr. b.p. If our correlation with Hopkins' high stands is correct, then there should be evidence of the high stand of 105,000 yr. b.p. Higher fluvial terraces along Spruce Creek (pl. 1A) are graded to the 12- to 16-m-high terrace along the sea cliff, but a lower fluvial terrace, 10 m above present sea level at the creek outlet, might represent that youngest high stand.

Elevated marine deposits occur elsewhere in the study area. Poorly to moderately sorted, interstratified silt, sand, and imbricated sandy gravel (Qu) are exposed in the south-facing sea cliff north of Rocky Point along the west side of Golovnin Bay (fig. 10, pl. 3B). The measured height of the exposure at one locality is 11 m. These deposits are probably those ascribed by Hopkins (1973, p. 525) to the high sea stand 120,000 yr. b.p. Unit Qu is composed of silty, sandy gravel where exposed in a 2-m-high sea cliff near the outlet of Iron Creek (9 km west of Moses Point, pl. 2C) and in a sea-cliff exposure about 6 m high, located 3 km west of Bluff (pl. 3C). Several other limited exposures of similar crudely stratified unconsolidated deposits were observed in sea cliffs between Safety Sound (pl. 3D) and Moses Point (pl. 2C). Such occurrences of coarser stratified deposits of unit Qu may have been controlled partly by proximity to upland areas of high elevation and relief during older high sea stands.

The highest sea stand proposed by Hopkins (1973) was about 30 m above present sea level and occurred about 220,000 yr b.p. In theory, coarse shoreline facies deposited during that sea stand should occur locally within unit Qu at about the 30-m elevation. Such deposits were not recognized. A long, gently curving ridge (unit Qbv, pl. 1C) in the tundra plain east of the Reindeer Hills could be an emergent offshore bar constructed during the 30-m stand, but we interpret this feature as an emergent beach ridge. The present surface elevation along most of the ridge is slightly higher than 15 m, and in sec. 30, T. 12 S., R. 12 W., it exceeds 23 m. Modern beaches at Unalakleet and Shaktoolik are from 5 to 8 m high. Allowing 5 to 8 m for increased elevations due to storm surges, we infer that the ridge was constructed during the proposed high sea stand 120,000 yr b.p.

After emergence, stratified and massive marine deposits of unit Qu were covered by varying thicknesses of colluvium or were themselves involved in downslope movement. In one locality large pieces of woody stems and roots occur in the thick silts of unit Qu within 2 m of the gently sloping ground surface. The silt around the wood has an almost horizontal fissility. The wood may be primary, but it seems more probable that it was incorporated into a solifluction lobe after emergence of the silt. The contact between marine

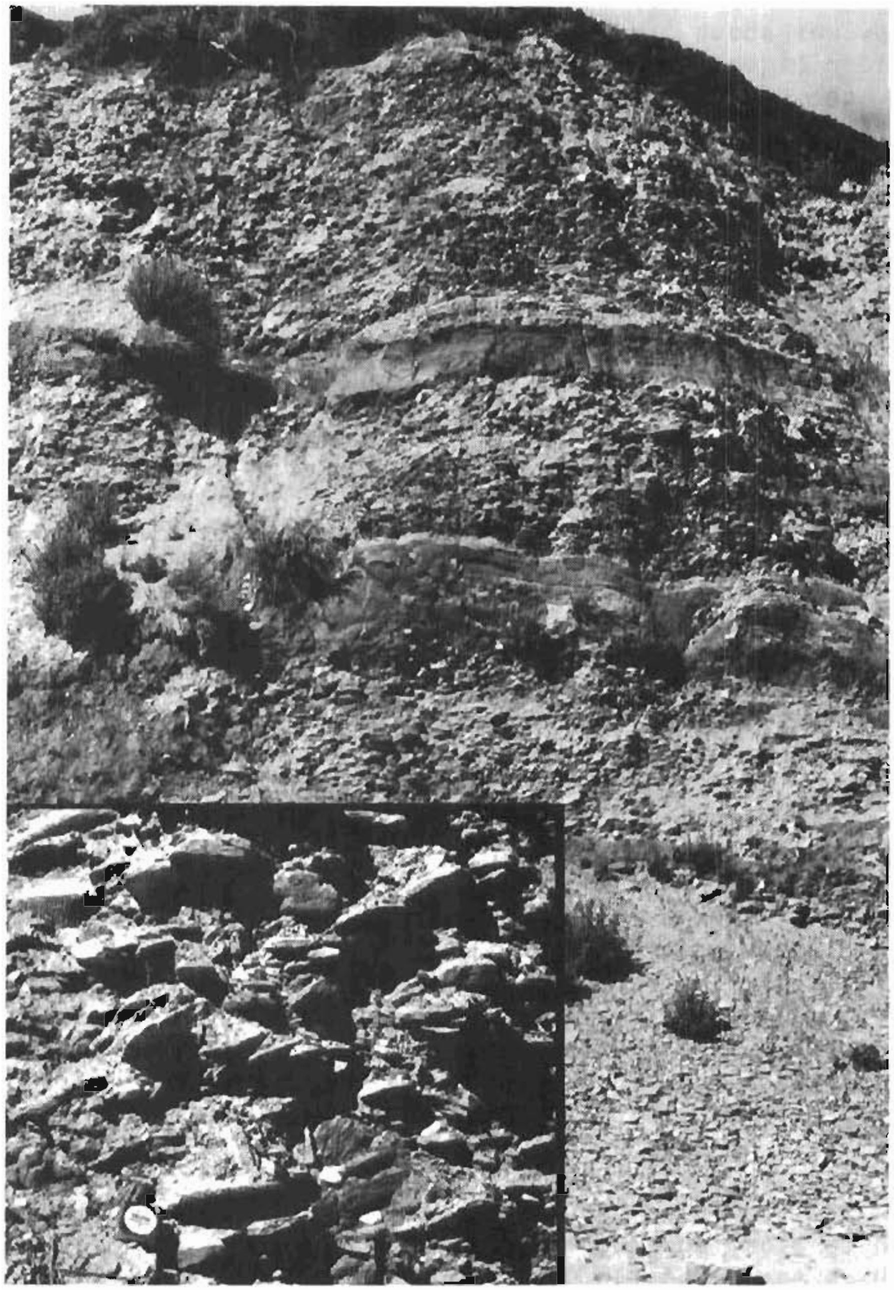

Figure 10. Emergent beach and lagoonal deposits exposed north of Rocky Point along west shore of Golovnin Bay. Lower left photograph shows imbricate fabric of sandy gravels.

deposits and colluvial cover is obscure and complex. Because we could not consistently distinguish colluvial deposits from undisturbed marine deposits on the aerial photographs, we included colluvium with marine deposits in unit Qu.

In some places the contact between bedrock and unit Qu follows the base of aligned cliff segments located above and behind the present sea cliff. These segments were interpreted as the eroded remnants of an emergent sea cliff. Because multiple wave-cut platforms may be concealed beneath colluvium and marine deposits at the base of the cliff segments, we were unable to correlate the age of this obviously older sea cliff with any of the former sea stands recognized by Hopkins (1973). Evidently, the emergent nearshore and beach deposits of unit Qu were locally deposited at the base of a sea cliff. Possible relict sea cliffs have been identified south of Unalakleet between Glacier Creek and Poker Creek and along the east side of Kouwegok Slough north of Unalakleet (plate 1A). Also evident is the expression of such a cliff at the south end of Beeson Slough (plate 1B). Other areas of aligned scarps that may be relict sea cliffs are west of Moses point (plate 2C), between of Walla Walla (pl. 2C) and Portage Roadhouse (pl. 3A), and north of Safety Sound (pl. 3D).

MODERN BEACH DEPOSITS AND PROCESSES

Tolstoi Point to Island Point (pl. 1)

Some changes in the position of the seaward limit of vegetation were noted when comparing aerial photographs taken in 1950-51 with others taken in 1976. Because the water line varies slightly from photograph to photograph, the vegetation limit, rather than the water line, was used to determine shoreline changes. The scale of the photographs was from about 1:35,000 to 1:40,000, and changes as small as 8 to 10 m on the ground were calculated by reference to fixed objects visible on both sets of photographs. Optical distortion increased displacement outward from the center of each photograph and was the source of greatest uncertainty. A precise and accurate measurement of shoreline changes would require a triangulated survey at each site and an adjustment of distances determined from the 1950-51 photographs. Thus, the determinations of shoreline change are approximate, and changes of less than 10 m are not reported.

Shoreline changes are reported as the rate of change measured perpendicular to the shoreline; total change may be derived by multiplying the given rate by 25 yr---the difference in age of the two sets of photographs. Our reproducibility of measurement is about $\pm$ 10 m, or $\pm$ 0.4 m/yr. Some sections of coastline have eroded at rates too slow to be detected. At other sites erosion may be severe during major storms and minimal during the intervening periods. Thus, rates of shoreline change reported here are averaged over a 25-yr period and do not necessarily represent uniform annual increments.

The directions of recent littoral transport in the study area were estimated on the basis of offsets of stream mouths and directions of spit growth. Net littoral transport directions for the shoreline of Norton Sound were first described by Sallenger and others (1977; see also Hunter and others, 1979). Our data are at a larger scale and include one or more recent reversals of direction at each of several sites. On a regional scale our directions agree with those of Hunter and others (1979), which were intended to be the average direction over several years.

Beach deposits from Tolstoi Point to Glacier Creek (pl. 1A) are mainly coarse shingle and sandy gravel (see Sallenger and others, 1977, for additional descriptions of beach materials within the study area). A vegetated backshore is absent, and high water reaches the base of the sea cliff. Scattered boulders of dark, fresh volcanic rocks along this section of coastline were probably carried by ice rafting from a major volcanic field south of the mapped area. A sea cliff extending from 1.5 to 7 km north of Glacier Creek is eroded in silt (unit Qu), and wave erosion at the base of the cliff has led to recurring small earthflows or mudflows onto the beach (fig. 7).

From Summer Creek northward to Powers Creek (pl. 1A) the beach consists of a sandy gravel barrier that separates the flood plain of the Unalakleet River from Norton Sound. Littoral transport is northward south of the Unalakleet River outlet and southward from the Unalakleet River outlet north to Blueberry Point. Although littoral transport tends to seal off the Unalakleet River outlet, the opening is maintained by currents which pass through the outlet.

At the outlet of the Unalakleet River, the northern tip of the southern beach has receded eastward along the outer shoreline about 1.5 m/yr whereas the tip of the beach has extended northeastward about 3.3 m/yr. The southern tip of the northern beach has receded northeastward by about 3.3 m/yr. The barrier beach has no measurable shoreline changes north or south of the river outlet, although there may be a slight landward shift south of the river outlet.

Segments of older beach ridges (unit Qbv) have been identified in the vicinity of the Unalakleet airport. Two segments probably formed when the outlet of the Unalakleet River was 1 to 3 km north of its present outlet, because the orientation of ridges in one segment implies that they were formed as a northward extension of the southern beach-ridge plain. Radiocarbon ages of materials from four house pits on a segment of one ridge located north of the former river outlet range from 1,682 to 2,282 yr b.p. (Lutz, 1972). The elevation of the highest of the older ridges is only 0.5 m below that of the modern outer beach ridge at Unalakleet (Lutz, 1972). Presumably, the ridges were formed after sea level had risen to about its present position. On the basis of the sea-level history of Hopkins (1973), the maximum age of the ridge is about 5,000 years.

From Blueberry Creek (pl. 1A) north to the south side of Beeson Slough (pl. 1B), the shoreline consists of steep bedrock cliffs and a shingle or sandy gravel beach. Scattered rock piles indicate active erosion of the cliffs by rockfalls. Littoral transport is from Blueberry Point northward to the outlet of the Shaktoolik River (pl. 1C). A well-developed barrier beach extends northward from the south end of Beeson Slough to the outlet of the Shaktoolik River. Beach materials appear to fine northward, from cobble shingle at the south end to sandy gravel and sand at the north end. Such fining implies sorting by littoral currents. No significant changes of shoreline position can be seen between Unalakleet and the Shaktoolik River, although there may have been minor amounts of beach erosion between Beeson Slough and Shaktoolik Bay.

A set of older beach ridges in unit Qbv north of Beeson Slough is slightly discordant to and truncated by the present outer beach ridge (fig. 11). House pits on these older ridges are of unknown age (Lutz, 1972, p. 407). The maximum elevation of these older ridges appears to be about the same as that of the present outer beach ridge; these ridges probably formed at the same time as the older beach ridges at Unalakleet.

Figure 11. Shaktoolik barrier-beach plain. Note segment of older beach ridges (unit Qbv) truncated by active ridge (unit Qba); view toward northwest.

Beaches are narrow or nonexistent from the Shaktoolik River outlet northwest to the Reindeer Hills (pl. 1C). Beach materials appear to consist predominantly of sand and sandy gravel deposited in part atop low tundra bluffs that are undergoing erosion. The shoreline is mainly a tidal flat underlain by a wave-cut platform in unit Qu. Large bedforms (bars or sand waves) in the intertidal and shallow subtidal zones imply active bed-load movement. Littoral transport appears to be eastward from the Reindeer Hills to the outlet of the Sineak River (pl. 1C) and westward and eastward between the outlets of the Sineak and Shaktoolik Rivers. The Shaktoolik River may partially interrupt the westward littoral sediment supply and the Sineak River may interrupt the eastward sediment supply. These postulated interruptions of sediment supply help explain the 3.3-m/yr erosion rates observed in low tundra bluffs between the Shaktoolik and Sineak Rivers. Slight erosion of tundra bluffs between the Sineak River and the bedrock cliffs at the south end of Reindeer Hills may have occurred during the past 25 years.

The shoreline around the Reindeer Hills consists mainly of steep bedrock cliffs that in places extend below mean sea level. Local pocket beaches are steep and narrow and consist of coarse shingle and rockfall deposits.

Littoral transport in Reindeer Cove is eastward east of Point Dexter (pl. 1C). A narrow, sandy gravel beach extends eastward from Point Dexter for about 5 km. Low tundra bluffs occur a very short distance behind the beach. Erosion rates vary with location and are nowhere greater than about 1.2 m/yr. Beaches are narrow to nonexistent from the sharp inflection in the shoreline 5 km east of Point Dexter to the head of Reindeer Cove. The tundra bluffs along this section of shoreline have retreated at measured rates of about 1.2 m/yr, with maximum rates of about 1.8 m/yr at some headlands. The shorelines of both Little Mountain (which is underlain by bedrock) and Reindeer Cove are not discernibly eroded. East of Island Point (pl. 1C) the low tundra bluffs appear to have eroded from 1.2 to 2.5 m/yr. Erosion rates as high as 5 m/yr were measured along the coast 1 to 3 km west of the outlet of the Ungalik River (pl. 2A).

Ungalik to Walla Walla

The low barrier beach from the Ungalik River outlet northward 2.5 km (pl. 2A) has been eroded at rates of 1.1 m/yr or less. Northward to a point 12 km south of the Inglutalik River outlet, the coast consists of sandy gravel or gravelly sand beaches (Qba) at the base of low vegetated bluffs eroded in units Qu or Qud. A narrow intertidal flat lies seaward of the beach along most of this coastal section. No significant erosion of the bluffs was observed, although erosion was detectable over some short sections of coast. Littoral transport is northward (fig. 12), with two observed exceptions shown by direction arrows on the map (pl. 2A).

Figure 12. Shoreline 10 km north of Ungalik. Note vegetated and currently stable bluffs cut in unit Qu and offset of river outlet to north by Littoral transport.

From 12 km south of the Inglutalik River north to the Koyuk River, the coast consists mainly of intertidal flats seaward of low tundra bluffs eroded in unit Qud. Beaches are narrow and occur only south of the Inglutalik River.

Intertidal flats 8 to 12 km south of the Inglutalik River consist of a wave-cut bedrock platform and a thin cover of unconsolidated deposits. Erosion rates range from 0 to 2.5 m/yr along the coast south of the Inglutalik River and from 0 to 2 m/yr along 4 km of low marshy plain northwest of the Inglutalik River.

We could not determine the rate of erosion in the coastal section from Koyuk Inlet 10 km to the southeast because we did not have comparative photo coverage. But such coverage was available for the coastline westward from the west headland of Koyuk Inlet; some erosion has occurred on the low alluvial plain that extends 6 km southwest from Koyuk Inlet. The Kuiuktulik River has breached the active beach ridge near its outlet (fig. 13) because the shoreline retreated. The rate of shoreline erosion which contributed to this breaching was at least 5 m/yr. A beach spit has grown northward across the former river outlet by 11 m/yr; perhaps this rapid growth reflects a sudden decrease of current scouring at the former outlet because of the breaching upstream.

Figure 13. Shoreline to southwest of Kuiuktulik River outlet 12 km southwest of Koyuk. Note breaching of river by shoreline erosion and subsequent sealing of breached meander by beach deposits. Prevalent littoral transport is eastward (right to left across scene).

Beaches of shingle or sandy gravel occur locally at the base of steep bedrock cliffs from the Kuiuktulik River outlet southwest to Bald Head (pl. 2B). Littoral transport is northeastward toward Koyuk Inlet. Some erosion is apparent at the outlet of the unnamed river 4.5 km southwest of the Kuiuktulik River, where erosion occurred at a maximum rate of 5 m/yr on the north side of the outlet and at lower rates for 0.5 km south of the outlet. Beaches around Bald Head (about 10 km to the southwest) include coarse talus from rockfalls.

From Bald Head to the Kwik River outlet (pl. 2B), the coastline consists of wide intertidal or shallow subtidal flats seaward of low tundra bluffs in unit Qud. These flats have bed forms, such as bars and sandwaves, that indicate the presence of at least a thin unconsolidated cover. Depth to bedrock is unknown. Beach materials in the swash zone east of the Kwik River outlet consist of gravelly sand (Qud); sandy gravel atop the tundra (fig. 14) was probably deposited by large waves breaking against the low bluffs. West of the Kwik River outlet for about 2 km, beaches appear to be gravelly sand or sandy gravel. The amount of sand at the surface of the beach appears to increase farther to the west in Kwiniuk Inlet. Beach materials appear to be gravelly sand or sandy gravel on the surface of the spit at Moses Point (pl. 2B). From Bald Head westward 3 km, unit Qud has been eroded at a rate of at least 5 m/yr (note position of Qba 2 to 3 km west of Bald Head, pl. 2B).

Figure 14. Shoreline west of Bald Head, showing sandy gravel deposited atop low tundra bluffs eroded in unit Qud.

Only 1976 photographs were available of the shoreline from 3 km west of Bald Head to Moses Point Village. Comparison of the location of beach deposits on the 1976 photographs with shoreline features on the topographic base (drawn from 1950 aerial photographs) indicates possible progradation by deposition along the north-northeast-trending section of coastline 5 km southwest of Moses Point (sec. 10, T. 9 S., R. 16 W.; pl. 2B). In comparing the new photos to old base map, a slight amount of erosion was also discerned in the coastal section from 2 to 3.5 km east of the outlet of the Kwiniuk River (pl. 2B).

Bed forms such as bars and sand waves are visible in the intertidal or shallow subtidal zone on the west side of the Kwiniuk River outlet (pl. 2C) and eastward for about 4.5 km. Such bed forms are absent offshore from the coastal section east of the Kwiniuk River where erosion is supposedly taking place, but the bed forms occur to the east and west of that coastal section.

Comparison of the 1950-51 and 1976 photographs shows no discernible change of shoreline position from Moses Point Village to a point 6 km to the west. However, as much as 1.4 m/yr of erosion has occurred in a section of coastline from 6 km west of Moses Point to a point about 0.8 km north of the outlet of Iron Creek (the point is on the boundary between secs. 25 and 36, T. 9 S., R. 18 W.; pl. 2C). Except for a slight amount of erosion at the outlet of Walla Walla Creek (pl. 2C), no other changes are discernible westward to Portage Roadhouse.

Portage Roadhouse to Cape Nome

Sequential photographic coverage is not available for the coastline from 1 km south of Portage Roadhouse around Cape Darby to 6 km north of Cape Darby on Golovnin Bay (pl. 3A). However, there have probably been no significant changes in shoreline position in the past 25 years in this area of bedrock sea cliffs. No significant changes in shoreline position are discernible from Golovin Mission for 3 km southward. North of Golovin Mission to the outlet of Portage Creek, the only apparent significant change is the growth of one small beach cusp or spit.

Beach materials from Moses Point to Golovin Mission appear to be gravelly sand or sandy gravel. Sand and gravel beach deposits occur along only a small part of the shoreline around Cape Darby. Coarse rockfall materials occur near bedrock cliffs.

From Rocky Point to Taylor Lagoon (pl. 3C) beach materials vary from bouldery shingle to gravelly sand. At most headlands, rockfalls have deposited boulders larger than 1 m in maximum dimension in the intertidal zone. The most significant shoreline changes that were observed northwest of Rocky Point are at the outlet of the Solomon River (pl. 3C), where the outlet through the barrier beach has migrated eastward at a rate of 12 m/yr. Along the barrier beach, erosional retreat of the vegetation line is difficult to distinguish from apparent retreat caused by wave deposition of gravelly sand over beach vegetation. Allowing for such uncertainty, the outer beach from the present outlet of the Solomon River eastward for 2.6 km appears to have retreated; the maximum rate of erosion may be as much as 2 m/yr. Farther east of Taylor Lagoon and west of Solomon River outlet, changes in shoreline position consist of alternating erosion and accretion over segments of beach a few hundred meters long. Sallenger and others (1978) measured changes along the Safety Sound (pl. 3D) barrier spit that occurred during 1974 storms. Such changes probably resulted when bars and cusps changed size or migrated laterally along the beach in a complex manner; prestorm cusps (average wavelength along the shore of 415 m) were replaced by larger cusps (average wavelength, 868 m) and their associated bars. In addition, lateral migration of cusps eastward along Safety Sound barrier beaches was noted during a 1-mo period of nonstorm-wave conditions. The changes we have noted along the outer beach between Solomon River and Safety Sound have probably resulted from such bar and cusp activity and do not necessarily imply shoreline erosion that is irreversible over a period of decades. If there was a net landward or seaward shift between 1951 and 1976 in the average position of these barrier beaches, it was not detected on the aerial photographs.

On the basis of aerial observations, the barrier beaches from Taylor Lagoon to Cape Nome vary from sandy gravel to gravelly sand. Observations of beach materials were made on the ground at points 3 km northeast and southwest of the ferry crossing on Safety Sound. Materials at both sites consist mainly of gravelly sand to a depth of about 10 cm (fig. 15). Above the recent high-tide swashes, wind has moved the sand in the nonvegetated beaches, resulting in local sand concentrations and gravel lags. Some cobble-sized clasts were seen at the southwest end of the map area.

Figure 15. Barrier beach at beach profile station northeast of ferry crossing at Safety Sound. Mixed sand and gravel are main components (compare with fig. 4).

Littoral transport is primarily eastward from Safety Sound across Norton Sound to Rocky Point. At Rocky Point the prevailing direction of transport appears to turn northward into Golovnin Bay, pass South Spit on the west shore of the bay, and turn westward past Golovin Village into Golovnin Lagoon. The direction of littoral transport varies along the east shore of Golovnin Bay south of Golovin Village. At three locations along the south shore of the lagoon, west of South Spit, transport appears to be eastward toward South Spit.

STORM SURGES AND COASTAL FLOODING

'Storm surge' is an abnormal, sudden rise of sea level along an open coast during a storm, caused primarily by onshore-wind stresses. Less frequently, storm surges are caused by reduced atmospheric pressure, which 'piles up' water against the coast. The effectiveness of the wind in raising sea level is greatest in shallow water near shore. Lines of debris concentrated by wave runup commonly mark the farthest inland penetration by a storm surge.

Sallenger and others (1977) determined elevations of storm-surge and debris lines around Norton Sound. In most areas, the highest debris line was caused by either or both of two storms in November 1974. Surging during those storms probably is the maximum recorded for most parts of Norton Sound. Consequently, the single debris line observed on 1976 aerial photographs and during field checking in 1978 is presumably the debris line from the 1974 storms.

Debris lines are shown on the plates and in figures 16 and 17. In only a few places does the debris line occur landward of the 25-ft contour on the topographic base map; in most places the debris line closely follows the seaward side of that contour. At selected sites measured by Sallenger and others (1977, fig. 8), debris is found at elevations that range from about 3.3 to 4.5 m in the Nome area, from 2.4 to 4.1 m in Norton Bay, and from 4.0 to 4.9 m in the Unalakleet area. In general, those debris lines were determined on the open coast, whereas the debris lines determined in this study are those preserved on the landward shores of protected lagoons. A rise in water level in lagoons may be caused by waves topping the barrier beach, by flooding through gaps in the barrier beach, by partial damming of river outlets, or by some combination of these mechanisms. Clearly, the effect of wave runup should be less in lagoons behind a barrier beach than on the adjacent outer beach, and the elevations of debris lines in protected lagoons, as determined in this study, coincide only approximately with debris lines reported by Sallenger and others (1977).

Figure 16. View northwest toward Kouwegok Slough (pl. 1A); flood plain of Unalakleet River in middle foreground. Note light-colored debris line to right of flood plain; debris line may be caused by storm surges on Norton Sound, flooding on Unalakleet River, or both.

Debris lines are not continuous along the coast. Where the ground slopes steeply, wave backwash may have been sufficient to remove debris. Furthermore, embayments in the coastline such as small stream valleys may have acted as traps for floating debris, thereby reducing the amount of debris found some distance downdrift. Most debris lines shown (pls. 1-3) were observed during 1978 flights and on 1976 aerial photographs. The lack of a mapped debris line

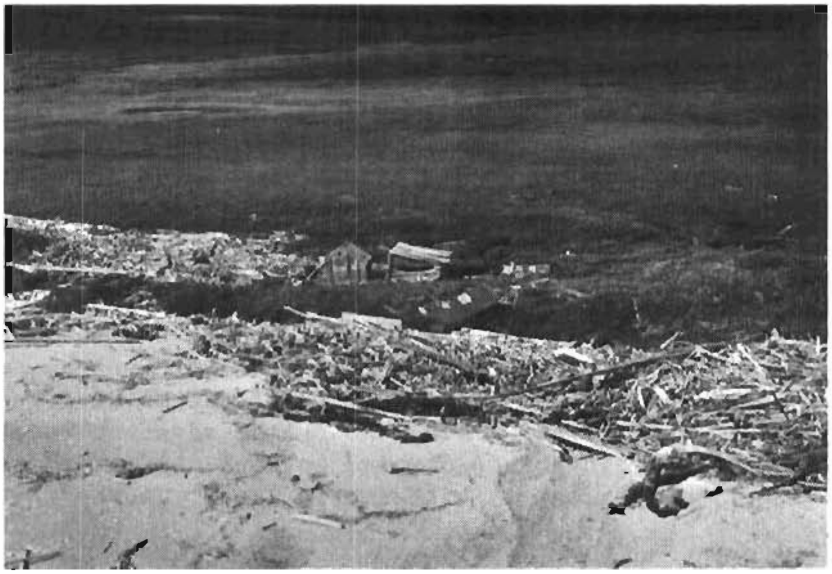

Figure 17. Debris from storm surges and wave runup west of Taylor Lagoon (pl. 3C).

CONCLUSIONS

This is a reconnaissance report and provides only a regional overview of surficial geologic aspects that may bear on future coastal development. The report provides a framework for site-specific studies, but some general conclusions may be drawn.

Coastal areas below about 6-m elevation may be inundated during major storm surges. The precise elevation of inundation at any particular location is determined by coastal configuration and bathymetry as well as by meteorological conditions causing the surge.

Coastal erosion rates are greatest where fine, unconsolidated deposits are present in low sea cliffs. Few changes in shoreline were noted in areas of wide barrier beaches, but such areas may be dynamically balanced with large volumes of sediment in littoral transport without net gain or loss. Site-specific studies in such areas should consider the nature of shoreline equilibrium and the potential effects of interruption of littoral transport on beach stability.

Seismic activity is recognized in the Norton Sound area, and some earthquake epicenters have been associated with the Kaltag fault. Other faults in the area may also be active.

Foundation suitabilities should be assessed in site-specific surveys. Bearing capacity, settling due to melting of ice-rich permafrost, and mass movement of unconsolidated sediments are obvious potential constraints on development.

Sand and gravel deposits are located mainly in the following settings: a) active, nonvegetated beaches and adjacent vegetated beaches of the modern shoreline, b) ancient beaches associated with uplifted shorelines (to elevations of as much as 30 m), and c) active and abandoned channels and point bars in river flood plains. Shallow excavations or borings should be made to prove the extent and suitability of any given deposit prior to exploitation.

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