CHAPTER 116

GEOMORPHOLOGY OF THE SOUTHERN COAST OF ALASKA

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ABSTRACT

The shoreline of southern Alaska is a narrow coastal plain dominated by large glaciers, periodic earthquake activity, and strong extratropical cyclones. Studies on the coastal geomorphology and sediments carried out in 1969-71 and in the summer of 1975 were directed at defining geological hazards with respect to developing shore facilities for OCS oil exploration activities. Most of the shoreline was found to undergo rapid changes and experience a variety of serious environmental hazards. The safest potential port areas are located inside Icy Bay and Yakutat Bay. The coastal areas in the vicinity of the Malaspina Glacier and the Copper River delta are examples of the two principal shoreline types (glacial outwash plain and deltaic).

The coastal area surrounding the Malaspina Glacier, the largest piedmont glacier in the world, was classified into 5 categories on the basis of its geomorphology, sediments, and local glacial history:

1. Regional retreating coast: This area, which is located at the mouth of Icy Bay, is eroding rapidly (approximately 1.5 km since 1900) as a result of retreat of a glacier (up the bay) a distance of over 40 km since 1900. Consequently, it should not be developed.

2. Prograding spits: Sandy spits that have built into either side of Icy Bay since the retreat of the glacier are also unstable because of the general recession of the shoreline as a result of erosion at the mouth of the bay.

3. Abandoned glacial coasts: These areas, located on the inner eastern shores of Icy Bay and Yakutat Bay, are coastlines of relatively low wave energy composed of abandoned glacial tills, kame terraces, and outwash sediments. These are the most stable and least hazardous areas on the southern Alaska coast.

4. Actively eroding glacial margins: This area, located at Sitkagi Bluffs on the southernmost terminus of the Malaspina Glacier, is an eroding scarp of glacial till jutting into the Gulf of Alaska.

5. Glacial outwash coasts: These shorelines are highly variable and are usually dominated by prograding spits composed of sand and gravel.

The shoreline of the Copper River delta is made up of a complex of six fine-grained mesotidal barrier islands separated by tidal inlets that increase in size in a westerly direction. The islands have undergone major readjustments since the Good Friday earthquake of 1964, which raised the area 3 m. For example,

Egg Island has increased significantly in size; shoreline accretion of 400 m between February 1970 and May 1975 was measured at a site on the updrift end of the island. The patterns of erosion and deposition on the islands conform to those of the barrier island drumstick model developed during studies of the South Carolina coast.

INTRODUCTION

The southern coast of Alaska (Fig. 1) is an exceptionally dynamic area. Intense tectonic activity, large waves, strong tidal currents, highly variable winds, and active glaciation interact to produce one of the most rugged and variable coastlines in the world. The Chugach and St. Elias mountains, an extension of the Cordilleran Mountain system, control the gross orientation of the coastline. Fronting these mountains is a narrow coastal plain consisting of glacial and fluvial deposits undergoing active modification by tectonic, aeolian, and marine processes. Rapid advance and retreat of the numerous glaciers that border the coastal plain has caused sudden and dramatic shifts in loci of erosion and deposition along the beaches.

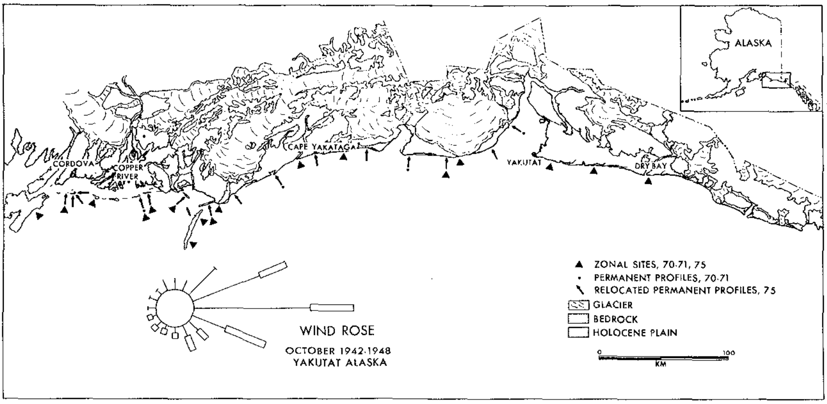

Figure 1. Study area. Note distribution of Holocene coastal plain (max. width = 35 km). Wind rose for Yakutat shows a dominance of easterly winds.

The coastal mountains, formed in response to subduction of the Pacific plate along this collision-type coast, are undergoing rapid uplift. Frequent earthquakes result in large ground displacements. During a single earthquake in 1899, the head of Yakutat Bay was uplifted 15 m. The entire coastal zone of southern Alaska has been subject to modifications resulting from this rapid tectonic activity.

The morphology and sediments of the coastal plain shoreline of southern Alaska were studied on a reconnaissance basis in 1969-71. Fifteen permanent beach profiles were established, 18 detailed specific site studies (zonal studies) were carried out (Fig. 1), and sediment samples were collected at 90 stations, using a 4 km spacing. The area was revisited in the summer of 1975, during which time the permanent profiles were remeasured, and 99 beach profiling stations were occupied in the central portion of the study area (in the vicinity of the Malaspina Glacier). Using a 15 cm coring tube, sediment samples were taken at 3 stations at each of the 99 profile locations. The samples were then analyzed for grain size with a settling tube. Approximately 10,000 ground and aerial photos were taken. They have been analyzed and compared to photos taken during the 1969-71 studies and also compared with vertical aerial photos from various sources.

Extratropical cyclones that generate southeasterly winds dominate the coastal processes. Wind frequency diagrams for the entire Gulf of Alaska area are shown in Figure 2 (from Nummedal and Stephen, 1976). These winds create wave energy flux patterns that trend from east to west in the study area (Fig. 3), and, consequently, generate a dominant east to west littoral sediment transport pattern (Fig. 4).

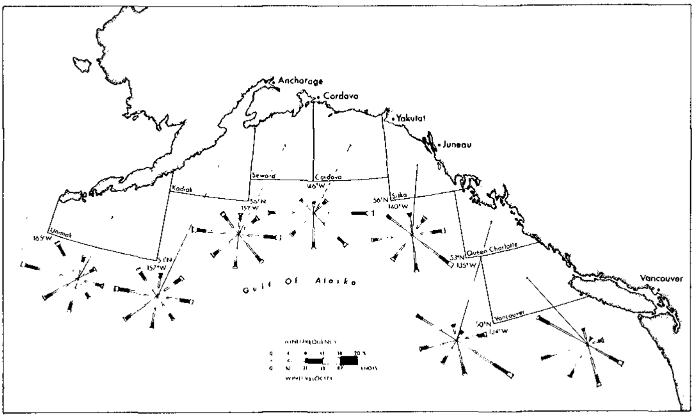

Figure 2. Wind frequency distributions for coastal data squares in the Gulf of Alaska. The diagrams are based on wind observations presented in Summary of Synoptic Meteorological Observations (U.S. Naval Weather Service Command, 1970). The dominant and prevailing winds are generally aligned parallel to the shoreline because of the temperature-induced pressure gradient along the coastal mountains. On the northeast coast of the Gulf, the dominant winds blow toward the northwest; on the northwest coast, they blow toward the east and northeast. (From Nummedal and Stephen, 1976; Fig. 13)

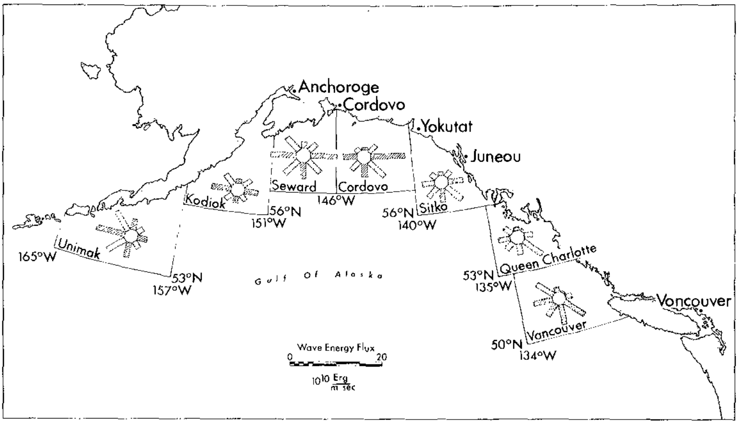

Figure 3. Wave energy flux distributions for the coastal areas of the Gulf of Alaska. The computations are based on deep water wave observations presented in Summary of Synoptic Meteorological Observations (U. S. Naval Weather Service Command, 1970). The wave energy flux is highest out of the southeast for the Vancouver, Queen Charlotte, and Sitka data squares, out of the east at Cordova, and out of the west at Seward, Kodiak, and Unimak. This pattern corresponds closely to that of the winds (Fig. 2). (From Nummedal and Stephen, 1976; Fig. 18)

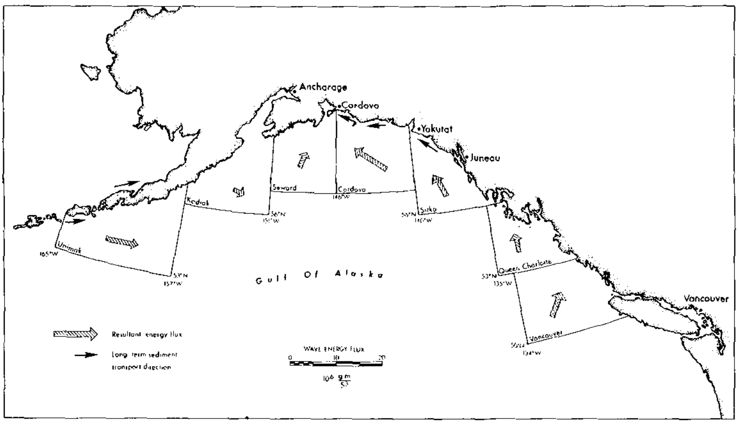

Figure 4. Direction of longshore sediment transportation based on large scale coastal geomorphic features and resultant wave energy flux distribution for the coastal areas of the Gulf of Alaska. Large scale coastal features used in establishing long-term transport directions include spits, inlet offsets, and crescentic embayments. The resultant wave energy flux is determined by vectorial addition of the distributions presented in Figure 3. Note the convergence of wave energy flux toward Prince William Sound. (From Nummedal and Stephen, 1976; Fig. 19)

The coastal morphology consists of (1) an outwash plain shoreline, which is a complex of outwash streams with downdrift beach-ridge plains, and (2) the delta of the Copper River, which has a seaward margin made up of mesotidal barrier islands. It is unusual to find a depositional shoreline of this magnitude (Fig. 1) on a collision coast. It owes its origin to the huge sediment output of glaciers that drain the largest ice field in North America, and to the sediments of the Copper River, which has a mean annual load of 100 $\pm$ x 10^6 metric tons (Reimnitz, 1966; see Table 1).

TABLE 1. Annual Sediment Load of the Copper River (Reimnitz, 1966)

WOOD CANYON	Suspended Load:	66.0 X 10^6 metric tons
	Bed Load:	9.9 X 10^6 metric tons
	Total:	75.9 X 10^6 metric tons
DELTA	Total Load:	100 $\pm$ X 10^6 metric tons
Comparisons:		
COPPER RIVER (at delta)		100 $\pm$ X 10^6 metric tons
MISSISSIPPI RIVER		450 X 10^6 metric tons
AMAZON RIVER		347 X 10^6 metric tons

Figure 5 compares the beach sediments of the outwash plain depositional system with the beach sediments of the barrier islands of the Copper River delta. The outwash plain beaches are both texturally and mineralogically immature. All of the samples have very low percentages of quartz, being classified as litharenites (using scheme of Folk, 1974). The samples show a wide range of values of sorting and mean grain size (Fig. 5).

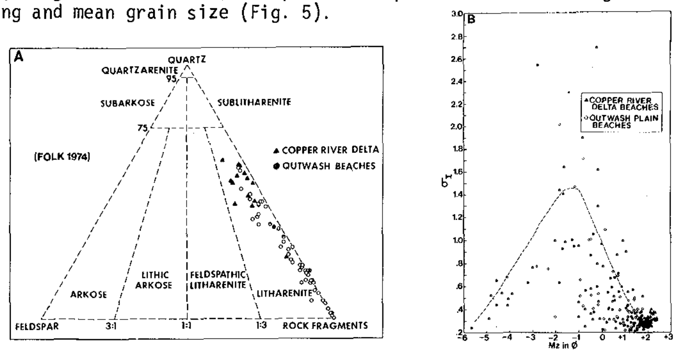

Figure 5. A. Composition of outwash plain and Copper River delta barrier island sediments. All samples are litharenites, with the barrier island sands being more quartz rich. B. Mean grain size (M_Z; Folk, 1974) vs. sorting (σ_I). Copper River delta beaches are moderately sorted medium to fine sand; whereas the outwash plain sediments show a wide range in size and sorting.

MALASPINA AREA

Introduction

Study during the summer of 1975 was focused in the vicinity of the Malaspina Glacier (Fig. 6). The project was designed to provide process information and to continue our study of the coastal morphology and sedimentation. Beach profiles were measured at 3 km intervals over the entire study area (Fig. 6) in order to assess regional trends in beach morphology. The results of these studies allow the subdivision of the coast into five principal geomorphic type areas which are closely related to the local glacial history.

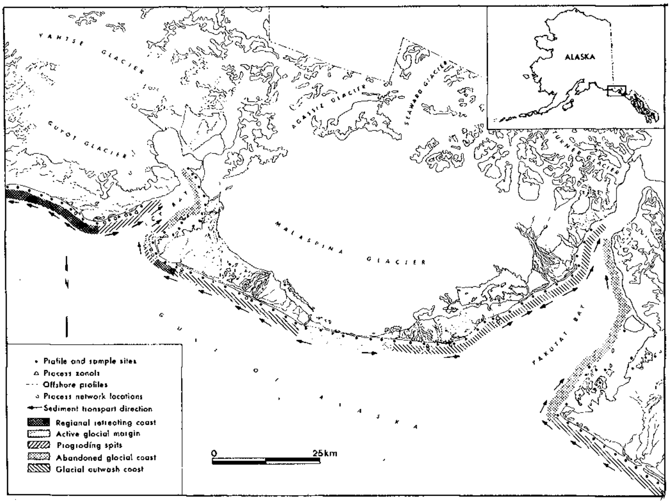

Figure 6. Location of area studied in summer of 1975. Arrows indicate dominant longshore sediment transport direction on the basis of combined morphological and process data. The different classes of shoreline types and location of study sites are also indicated.

Regional retreating coast

This area is located at the mouth of and downdrift of Icy Bay (Fig. 6). The recent retreat of the Guyot Glacier up into Icy Bay resulted in a loss of sediment to this coastal section, causing widespread erosion (approximately 1.5 km since 1900). Beach profiles are generally flat with concave-upward upper beach faces backed by eroding scarps at the spring high-tide swash line (Fig. 7). Sediments are mixed sand and gravel. Heavily forested beach ridges, glacial outwash plains, and till areas on either side of Icy Bay are being cut back severely. Broad overwash terraces are advancing over low-lying areas. This area should be omitted from all considerations for shoreline development.

Figure 7. Regional retreating coast. A. Beach profile and sketch for station DBC-79, which is located approximately 5 km west of the entrance to Icy Bay (Fig. 6). Note the concave upward shape of the profile, the erosional scarp, and the developing washover terrace. LTT = low-tide terrace; A, B, C = sediment sampling localities. B. Station DBC-79 on 14 June 1975.

Figure 8. A. Riou Spit, a prograding sand spit at the eastern entrance to Icy Bay. Photo taken on 4 August 1975. B. Example of abandoned glacial shoreline, eastern margin of Yakutat Bay (Knight Island). Photo taken on 21 August 1975.

Prograding spits

On either side of Icy Bay, sandy spits are prograding into deeper water as the shoreline around the mouth of the bay erodes. The largest, Riou Spit, is located on the east, or updrift, side of the Bay (Fig. 8A). Riou Spit is migrating both alongshore and landward because of recession of the shoreline adjacent to the bay. The beach profiles on the spits are relatively flat with broad berm-top overwash areas. These spit areas are considered to be quite unstable for development purposes because of their rapid rates of change and their exposure to open ocean waves.

Abandoned glacial coasts

These areas, located on the inner eastern shores of Icy Bay and Yakutat Bay, are characterized by deposits of unconsolidated tills, kame terraces, and outwash sediments which supply abundant gravel to the beaches. An example is shown in Figure 8B. Profiles are very steep, short, and often have well-developed multiple cuspate berms. High vegetated storm berms indicate infrequent but violent storms. Sediments are predominantly well-sorted and rounded gravel. Sand and gravel spits occur downdrift of till islands in Yakutat Bay. Because of their protected nature and slow rates of erosion and deposition, these are the most favorable areas available for the development of shore facilities.

Actively eroding glacial margins

This area, located at Sitkagi Bluffs, on the southernmost terminus of the Malaspina Glacier, is an eroding scarp of glacial till on the shoreline of the Gulf of Alaska. Beach profiles in front of the Bluffs are extremely short and steep, backed by eroding till scarps (Fig. 9A). Beach material ranges from sand and angular gravels to large erratics left behind as the scarps retreat (Fig. 9B). These retreating scarps, and their adjacent boulder beaches, are virtually inaccessible for any kind of human activity at high tide.

Glacial outwash coasts

These beaches are generally prograding, with abundant mixed sand and gravel spits trailing toward the west, except inside Yakutat Bay, where a major transport reversal occurs. Beach-ridge plains often develop downdrift of the major river mouths. Beach profiles are relatively flat with abundant ridge-and-runnel systems, resulting in a shoreline with a characteristic rhythmic topography. Typical examples of glacial outwash coasts are illustrated in Figure 10. When glacial sources are distant, sediments tend to have a high sand to gravel content. The beaches in these areas are relatively stable and are considered to be the second most desirable areas for shoreline development in southern Alaska.

Process data

Process observations were obtained at two levels during July-August, 1975:

A) Process Network (Fig. 6). Regional process variability was determined by multiple observations during stable meteorological conditions.

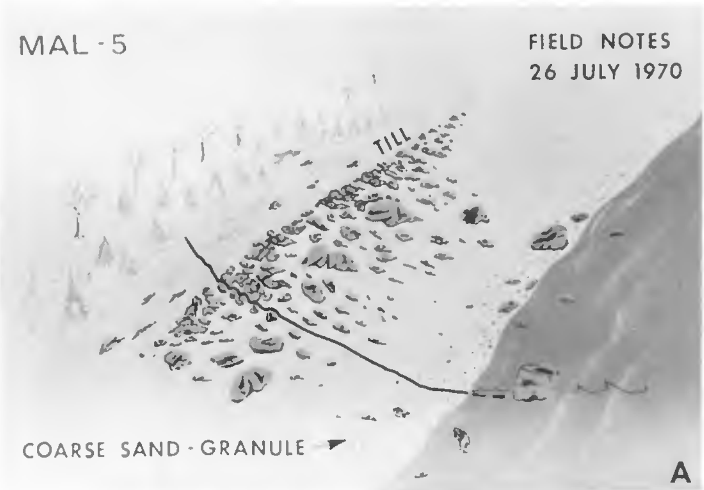

Figure 9. Actively eroding glacial margins. A. Field sketch of profile Mal-5, located in front of the Malaspina glacier. B. Station Mal-5 (sketched in A) on 26 July 1970.

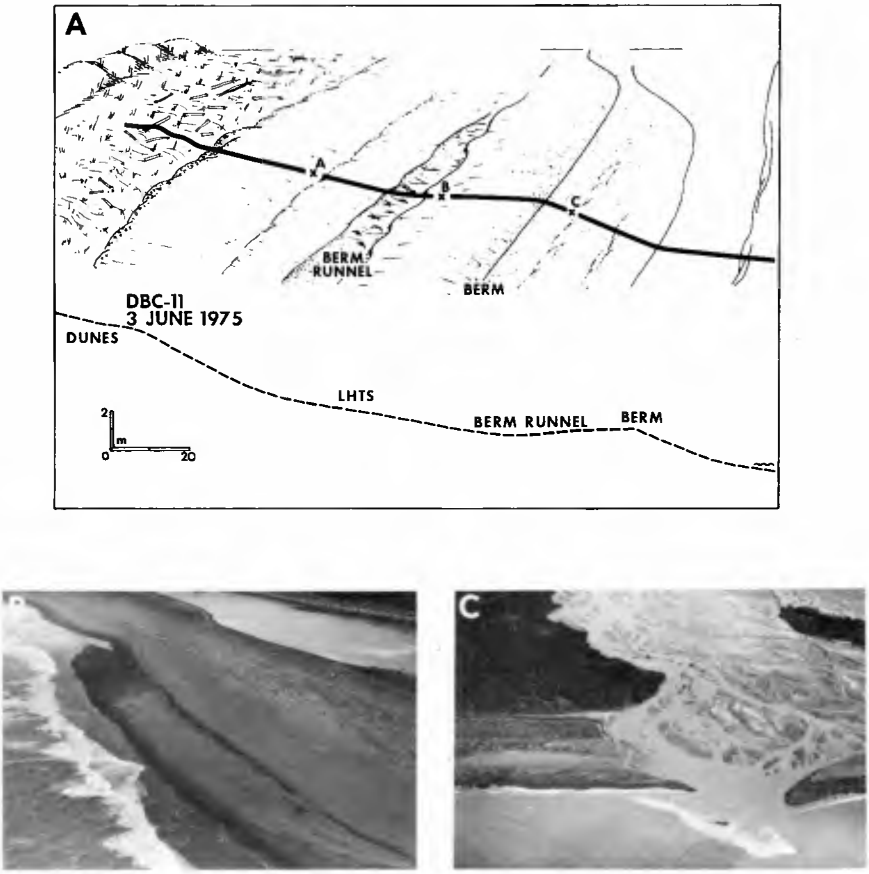

Figure 10. Glacial outwash coasts. A. Field sketch of station DBC-11, a fine-grained (sand dominant) spit on the outwash plain of the Yakutat foreland. B. Station DBC-11 on 3 June 1975. Note welded berm. C. Coarse-grained (gravel dominant) outwash plain near Malaspina Glacier. Photo taken in summer of 1970.

B) Six Process Zonals (Fig. 6). Continuous 48-hour monitoring of meteorological, wave, littoral, and morphological variability was maintained at single sites selected as representative of shoreline segments.

Regional process parameters document littoral transport in directions that correlate with regional morphology. Dominant south and southeast waves yielded sediment transport toward the west away from eroding till cliffs and from the mouths of outwash streams.

Process zonal measurements allowed documentation of the passage of a complete storm cycle. Commonly, two distinct wave trains were monitored. Under such conditions, drift directions and velocities were erratic and strong rip currents were prevalent. Dominant wave approach was a function of the path of low pressure systems moving through the Gulf of Alaska. Southerly waves were characteristic of calm conditions, and southeasterly waves were characteristic of storm conditions.

Breaker heights averaged 1.5 to 2.0 m, with a maximum measured height of 4 m recorded during a storm. Suspended sediment concentrations taken from the bore of plunging waves were as high as 150 gms/liter. Measured beach profiles revealed up to 15 cm of accretion to the beach face during one tidal cycle.

COPPER RIVER DELTA AREA

Introduction

The barrier island shoreline of the Copper River delta was uplifted 3 m by the Good Friday earthquake of March 1964 (Fig. 11). This has brought about many adjustments of the morphology of the islands in response to changes in the level of wave erosion and deposition. The sands of the barrier islands are mineralogically immature, averaging about 50% quartz and 50% metamorphic rock fragments (Fig. 5). They are moderately sorted, medium- and fine-grained sands.

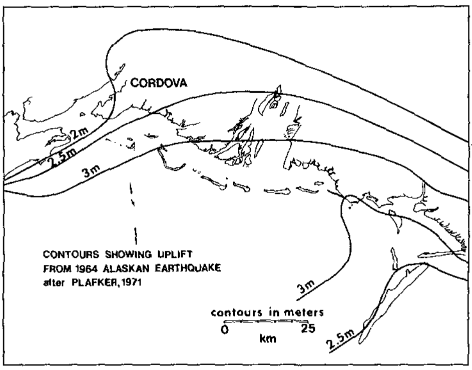

Figure 11. Uplift (in meters) of the Copper River delta area during the Good Friday earthquake of 1964.

Mesotidal barrier islands

A tidal range of 3-4 m places the Copper River delta in the mesotidal class of Davies (1964). As has been pointed out elsewhere (Hayes et al., 1973; Hayes and Kana, 1976), mesotidal barrier islands have two distinctive morphological characteristics:

1. In coastal areas with dominant waves that approach the shoreline at an oblique angle, the tidal inlets commonly show downdrift offsets; that is, the barrier beach downdrift of the inlet protrudes further seaward than the one on the updrift side (Hayes et al., 1970). The tidal inlets of New Jersey, the Delmarva Peninsula, and South Carolina are good examples. The present downdrift offset at Price Inlet, S. C., which has changed from downdrift offset to updrift offset and back to downdrift offset again since 1941, is discussed in detail by FitzGerald (1976).

2. Many mesotidal barrier islands have a drumstick shape, with the bulbous part of the drumstick being located on the updrift side of the barrier (Fig. 12A). Drumstick-shaped mesotidal barrier islands from Alaska, the Netherlands, South Carolina, and Georgia are outlined in Figure 12B.

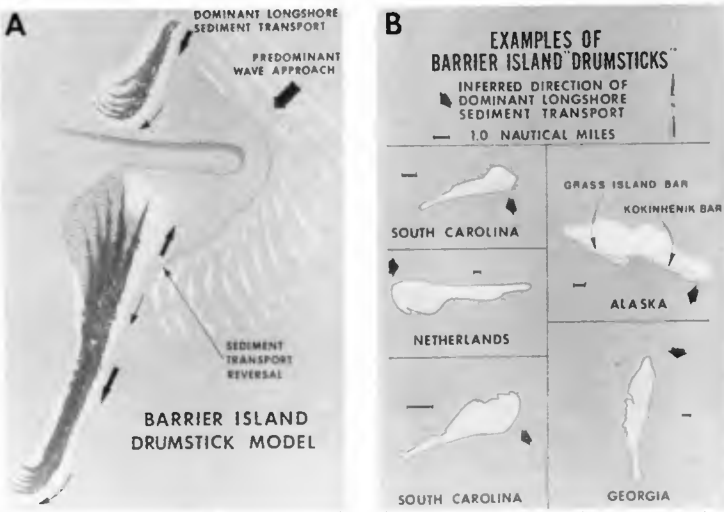

Figure 12. A. Barrier island drumstick model. B. Examples of barrier island "drumsticks" from South Carolina, Georgia, the Netherlands, and Alaska.

Barrier islands of the Copper River delta

The mesotidal barrier islands of the Copper River delta conform well to the drumstick model discussed above. Four systematic east to west changes in the barrier island system are apparent (Fig. 13):

(1) The downdrift offset increases in an east to west direction, except at the westernmost spit, which is anchored to bedrock;

(2) The size of the ebb-tidal delta increases from east to west;

(3) Inlet width increases from east to west; and

(4) The drumstick shape of the barriers becomes more pronounced in a westerly direction.

These changes are thought to be brought about by two interrelated factors. The river is rapidly filling in the eastern portion of the estuarine system; hence, smaller tidal prisms and smaller ebb-tidal deltas are developed on the east side of the delta. A 20 km long island, Kayak Island (see Fig. 1), is located to the east of the delta, which partially protects the eastern end of the delta from the dominant southeasterly waves. It is, thus, the western part of the delta that is more strongly affected by the oblique wave approach of the dominant waves. Therefore, the effect of wave refraction around the ebb-tidal deltas is greater on the west side of the delta. The drumstick shape of the barriers becomes more accentuated as the wave refraction increases.

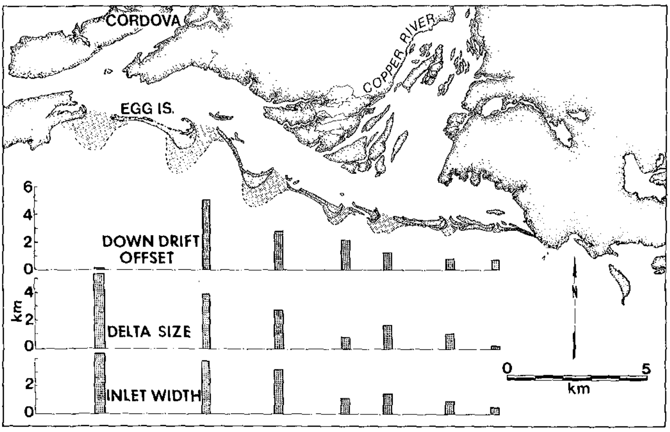

Figure 13. Barrier islands of the Copper River delta.

These barrier islands have undergone some remarkable changes in the past twelve years. They have largely prograded since they were uplifted by the March 1964 earthquake. Data for Egg Island (Figs. 14 and 15) illustrate these changes. A wave-cut scarp on a permanent profile at the east end of the island (EG-1; Fig. 14) eroded 56 m between February 1970 and May 1975. On the other hand, station EG-4, which is located at the widest point of the updrift bulge of the island, prograded 400 m during that same time. This process of overall aggradation of the barrier just downdrift of the inlet accentuated the drumstick shape of the barrier. This process of downdrift accretion is illustrated by the photographs in Figure 15.

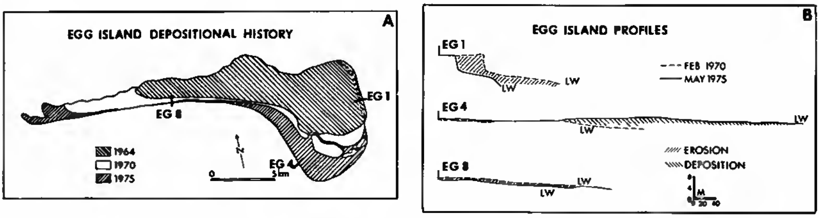

Figure 14. Changes of Egg Islsnd, Copper River delta, Alaska, after the Msrch 1964 earthquake, which raised the delts 3 m. Note continual accentuation of the drumstick shape of the islsnd through time.

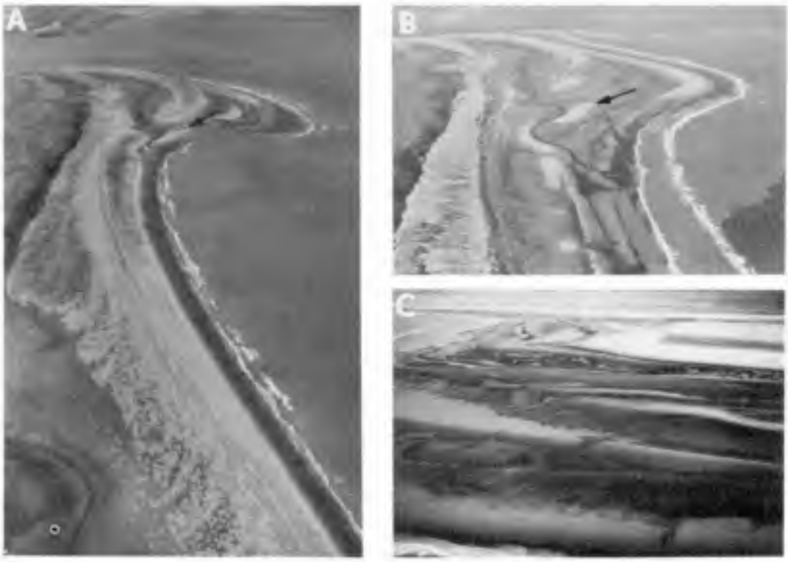

Figure 15. Egg Island, Alsska. A. Low-tide view taken in June, 1971. B. Low-tide view of east end of Egg Island taken in May 1975. Arrow points to same sand bar as the one indicated by the srrow in A. This beach accreted 400 m between February 1970 and May 1975 (see Fig. 14; profile EG-4). C. Multiple intertidal ridges welding on the beach at station EG-4. Photograph taken in the summer of 1969.

These remarkable changes, plus the occurrence of severe storms that overwash the islands, make the barrier islands of the Copper River delta an undesirable place to develop. On the other hand, Cordova, which has a sheltered harbor on Price William Sound, shows considerable promise.

CONCLUSIONS

1. In the Malaspina Glacier area, the most desirable shorelines for coastal development are the stable, sheltered abandoned glacial coasts inside Icy Bay and Yakutat Bay. The least desirable area is the regional retreating coast at the mouth of Icy Bay, which is eroding rapidly.

2. Southeasterly storms (extratropical cyclones) play a primary role in shaping the morphology of the coastal zone.

3. Combination of wave hindcast data, field process measurements, and studies of coastal geomorphology indicate a dominant littoral sediment transport from east to west.

4. The mesotidal barrier islands of the Copper River delta area show characteristics typical of other mesotidal shorelines (downdrift offsets and drumstick shapes).

5. Major changes in the barrier islands have occurred since the area was uplifted during an earthquake in 1964. Changes continue to accentuate the drumstick shape of the islands.

ACKNOWLEDGEMENTS

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