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SEDIMENT DISTRIBUTION AND COASTAL PROCESSES IN COOK INLET, ALASKA

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Abstract

Regional hydrologic and oceanographic relationships in Cook Inlet, Alaska have been recognized from sequential ERTS-1 MSS imagery. Coastline configuration is well defined on bands 6 and 7 of images 1103-20513, 1103-20520, 1103-20522, 1104-20572, 1104-20574 and 1104-20581. Current patterns are visible in the inlet because of differential concentrations of suspended sediment. These patterns are most evident on bands 4 and 5. The circulation patterns within Cook Inlet are controlled primarily by the interaction between the semi-diurnal tides and the counter clockwise Alaska current. In general, heavily sediment laden water is seen to be confined to portions of the inlet north of the Forelands and west of Kalgin Island. Tongues of clear oceanic water are observed to enter the inlet through Kennedy Channel along the east shoreline in the vicinity of Cape Elizabeth. A recurring counterclockwise circulation pattern observed around Kalgin Island seems to result from the interplay of the northerly moving water along the east shore and the southerly moving, sediment laden, water along the west side of the inlet. Prominent, fresh water plumes, heavily laden with sediment are visible at the mouths of all major rivers. Relect plumes from as many as three tidal stages have been recognized. Tidal flats and a number of unmapped cultural features appear prominently in bands 5 and 6 of a number of the images.

INTRODUCTION

The Cook Inlet area of south central Alaska (Fig. 1) is a transportation, industry and population center. With pressure mounting rapidly here for extensive development, it is necessary to continue the environmental research required to increase our basic understanding of this region as soon and as vigorously as possible. Environmental disturbances caused by rapid development have potentially deleterious effects on land and water quality. One of the concerns of the Corps of Engineers is to help control and alleviate these adverse effects.

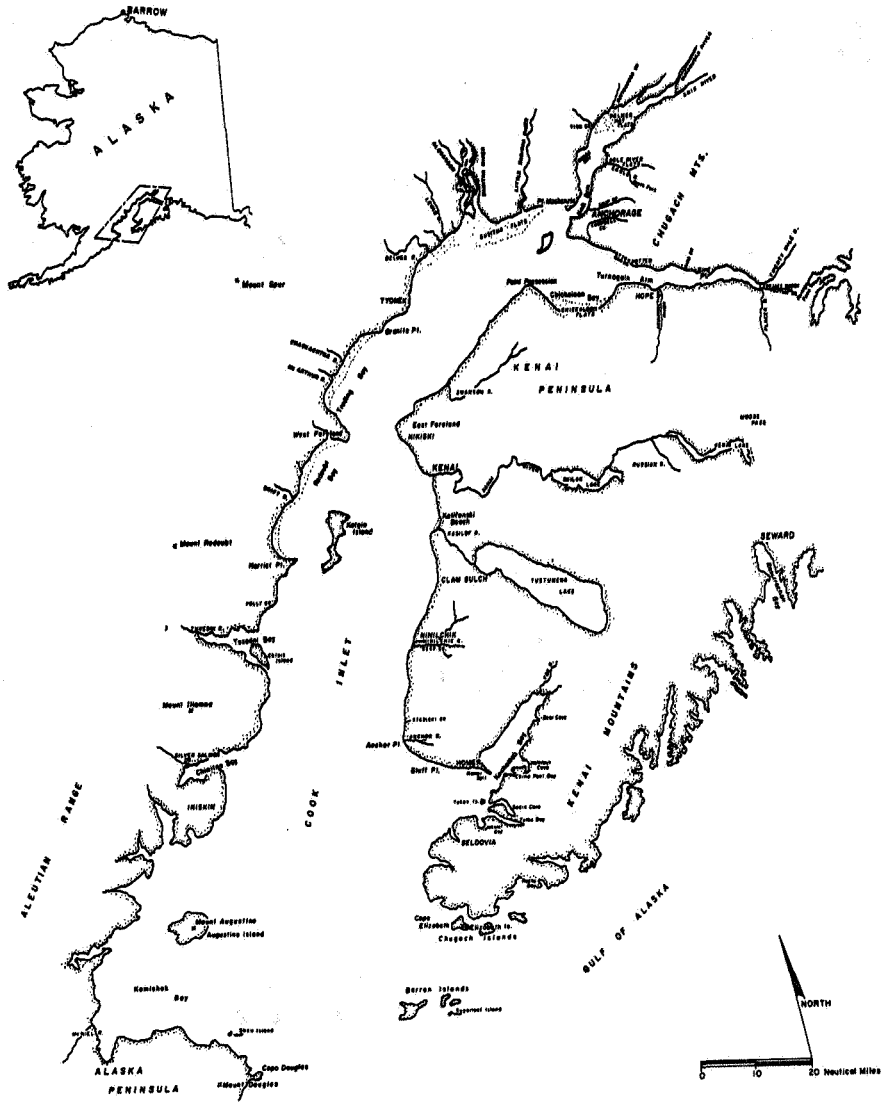

Figure 1. Regional Map of Cook Inlet

Suspended sediment currently is the most serious and detrimental pollutant in all water bodies. It is estimated that newly developing areas may produce as much as 20,000 - 30,000 times more sediment than natural undisturbed areas (Environmental Currents, 1972). High sediment loads are particularly troublesome in navigable rivers, inlets, channels and harbors where siltation is of enormous economic impact. To aid in controlling or to avoid such siltation problems, the Corps of Engineers wants to develop an improved understanding of the hydrology, sedimentation and coastal processes in cold water estuaries and inlets. Cook Inlet is a cold water estuary in which sedimentation and sediment redistribution is of continuing importance and concern. Synoptic views sequentially obtained from the ERTS-1 satellite provide data on transport-circulation processes which influence the sedimentation in Cook Inlet. The purpose of this investigation is to verify the utility and effectiveness of these data in the synoptic survey of coastal sedimentation and related processes in Cook Inlet.

BACKGROUND

In the Cook Inlet area the Corps of Engineers is particularly concerned with providing deep draft and small boat harbor improvements, maintaining deep draft berthing and maneuvering channels, controlling beach erosion and continuing harbor construction. To aid in performing these functions, data have been collected at the specific site locations: efforts directed to the collection of regional data have been minor. This approach was also followed by other investigators. Rosenberg and others (1967 and 1969) examined the oceanographic processes in the Nikiski area. Various petroleum companies active in the area investigated the oceanographic processes around the mouth of the Drift River and in Trading Bay (Marine Advisors, 1966 and 1969). However, few efforts have considered the inlet as an entity. Sharma and Burrell (1970) investigated the distribution of bottom sediments in a large portion of the inlet. Wagner and others (1969) and Evans and others (1972) compiled all available information dealing with the environmental and oceanographic aspects of the region. Although the general oceanographic relationships are beginning to emerge, it is apparent that much remains to be learned.

GEOGRAPHIC SETTING

Cook Inlet is a large tidal estuary in south central Alaska. It is oriented in a northeast-southwest direction and is approximately 180 nautical miles long and increases in width from 20 nautical miles in the north to 45 nautical miles in the south. The inlet is bordered by extensive tidal marshes, lowlands with many lakes, and mountains (Fig. 3). Tidal marshes are prevalent around the mouth of the Susitna River, in Chickaloon Bay, Trading Bay and Redoubt Bay. The Kenai Lowland

separates the inlet from the Kenai Mountains on the upper southeast side. The Susitna Lowland lies between the Talkeetna Mountains on the northeast and the southern Alaska Range on the northwest. The Kenai Mountains are adjacent to the inlet mouth on the southeast; the Alaska-Aleutian Range forms the western border.

ESTUARY CHARACTERISTICS

Coastline Characteristics

The coastal configuration of the inlet is characterized by sea cliffs extending from the head of Kachemak Bay to Turnagain Arm. Pocket beaches that occur along this coast are generally composed of sand and/or coarser sediment while finer grained material is present in lower energy locations. Along the northwest and west coasts from Point Mackenzie to Harriet Point an extensive coastal plain borders a shoreline of scattered sea cliffs and pocket beaches. From Harriet Point to Cape Douglas the steep mountains slope directly into the inlet in most locations and bayhead beaches form in many of the numerous small embayments along this coast. Sea cliffs are generally found only on the promontories along this coast.

Bathymetry

The depth of the upper inlet north of the forelands is generally less than 20 fathoms. The deepest portion, 45 fathoms, is located in Trading Bay just off the mouth of the MacArthur River (Sharma and Burrell, 1970). Turnagain and Knik Arms are the shallowest areas, with much of the bottom exposed as tidal flat at low tide. South of the forelands two channels, one between Kalgin Island and Harriet Point and another between Kalgin Island and the southeast shore, extend southward in the inlet and join in an area west of Cape Ninilchik. The deepest portion of the western channel, located between Kalgin Island and Harriet Point, is approximately 70 fathoms. The eastern channel is deepest just south of a line between the forelands. It is 75 fathoms in this area and rapidly shoals to approximately 30 fathoms until it merges with the western branch to form a single channel. South of Cape Ninilchik this channel gradually deepens to approximately 80 fathoms and widens to extend across the mouth of the inlet between Cape Douglas and Cape Elizabeth.

Tides/Tidal currents

The tides in Cook Inlet are semi-diurnal with two unequal high tides and two unequal low tides per tidal day (24 hours, 50 minutes) and high tide in Anchorage occurs 4.5 hours later than at the inlet mouth (Fig. 2). Mean diurnal tide range varies from 13.7 feet at the mouth

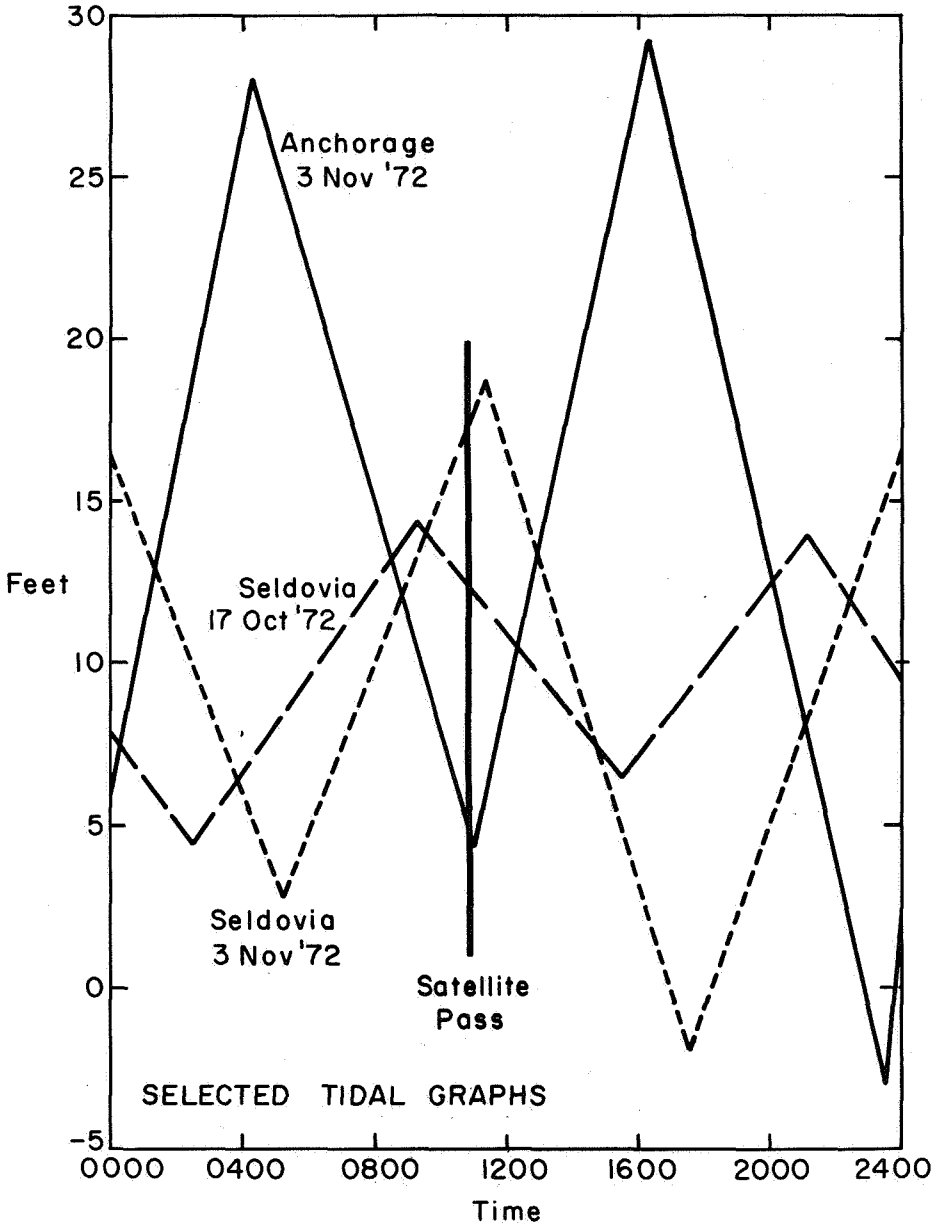

Figure 2. Selected Tidal Graphs

to 29.6 feet at Anchorage. It varies within the lower portion of the inlet from 19.1 feet on the east side to 16.6 feet on the west side (Wagner et al., 1969). The extreme tidal range produces tidal currents typically 4 knots and occasionally 6 to 8 knots (Horrer, 1967). The high Coriolis force at this latitude, the strong tidal currents and the inlet geometry produce considerable cross currents and turbulence throughout the entire water depth during both ebb and flood tides (Burrell et al., 1967). The turbulence is especially active along the eastern shore of the inlet.

Surface Circulation

The circulation of the inlet is influenced by bathymetry, morphometry and fresh water drainage (Evans et al., 1972). The water in the upper inlet is well mixed due to the large tidal fluctuations in this shallow, narrow basin. During summer when surface runoff is high there is a net outward movement of water from the upper inlet. With reduced runoff in the winter there is virtually no net outflow (Murphy et al., 1972). The middle inlet has a net inward circulation of cold, saline oceanic water up the eastern shore and a net outward flow of warmer and fresher inlet water along the western shore (Evans et al., 1972). These water types are well mixed vertically along the eastern shore but separated laterally resulting in a shear zone. In the lower inlet this lateral temperature and salinity separation is maintained butin the western portion vertical stratification occurs with colder, saline oceanic water underlying warmer, less saline inlet water. During tidal inflow the deeper oceanic water rises to the surface at the latitude of Tuxedni Bay and mixes with the inlet water (Kinney et al., 1970).

Sediment Distribution

The currents and circulation patterns are especially important in determining the distribution of suspended and bottom sediments throughout the inlet. The suspended sediment is mostly of glacial origin with the highest concentrations in the northern portion of the inlet, a well-mixed turbulent zone of strong tidal currents. Suspended sediment is nearly absent in the waters of the central and eastern portions at the inlet mouth. Bottom sediments have been grouped into three facies: a predominantly sand facies in the upper inlet, a sandy gravel with minor silt and clay facies in the middle inlet, and a gravelly sand and minor interspersed silt and clay facies in the lower inlet (Sharma and Burrell, 1970).

INTERPRETATION OF ERTS IMAGES

Coastal Configuration

The coastal landforms and cultural features along the Cook Inlet shoreline are most distinct on ERTS MSS bands 5, 6 and 7. The

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mountainous borders of the inlet on the southeast and the lower northwest and the coastal plain border on the upper northwest and east are easily recognized (Fig. 3). Homer spit and the Susitna River delta are apparent. The major cities and towns (Anchorage, Nikiski, Kenai, Homer and Seldovia) and some previously unmapped developments south of the mouth of the Drift River (6 on Figure 5) and on the southern shore of the West Forelands are readily identifiable.

Tidal Flat Distribution

The high sediment load in glacial rivers is the main source of material found in the tidal flats throughout the inlet. MSS band 5 and 7 images are ideal for analysis of these tidal flats. Because the major portion of sediment deposited in the inlet is carried by the Susitna and Knik Rivers (Rosenberg et al., 1967) the major portion of the tidal flats is located in the inlet north of the forelands (Fig. 3). In the lower inlet the tidal flats occur as bayhead bars in the numerous embayments along the western shore and northeast of Homer in Kachemak Bay. The high current velocities and frequent changes in current directions of the inlet water produce variations in the distribution and configuration of the flats. The migration of some major tidal flat channels and the redistribution of some tide flats in Knik and Turnagain Arms can be detected on MSS frame 1103-20513-5 (compare with the National Ocean Survey Navigational Chart 8553). A knowledge of these changes is particularly important in maintaining navigation channels and harbor facilities.

River Plumes

The sediment- laden rivers that discharge into the inlet produce sediment plumes which are visible on MSS bands 4 and 5. Figure 3 shows the distribution of plumes from some of the major rivers around the inlet. Although the Knik and Matanuska Rivers at the head of Knik Arm contribute a major portion of the sediment deposited in the inlet (Wagner et al., 1969) these rivers do not have distinct sediment plumes. The river-borne sediment is dispersed so quickly in this high energy area and the sediment concentration is so high (approximately 1350 mg/l;Kinney et al., 1970) in the inlet water at that location that a distinct plume is not formed. The Susitna River, another major sediment contributor, has only a small plume because the river discharge is reduced (Rosenberg et al., 1967) during the winter months (Fig. 3). In addition, the plume is less distinct because the inlet water at the mouth of the Susitna River has a high suspended sediment concentration (approximately 1540 mg/l; Kinney et al., 1970). MSS frame 1015-21022-5 (Fig. 4), taken 7August, shows the sediment plumes from the Drift (3) and Big (4) Rivers during flood tide. The shape and location of the plumes can be used to infer the current direction along the west shore between MacArthur River (1) and Tuxedni Bay (2). Currents appear to be moving in a northerly direction. Relict sediment plumes in this area are visible far offshore and indicate the

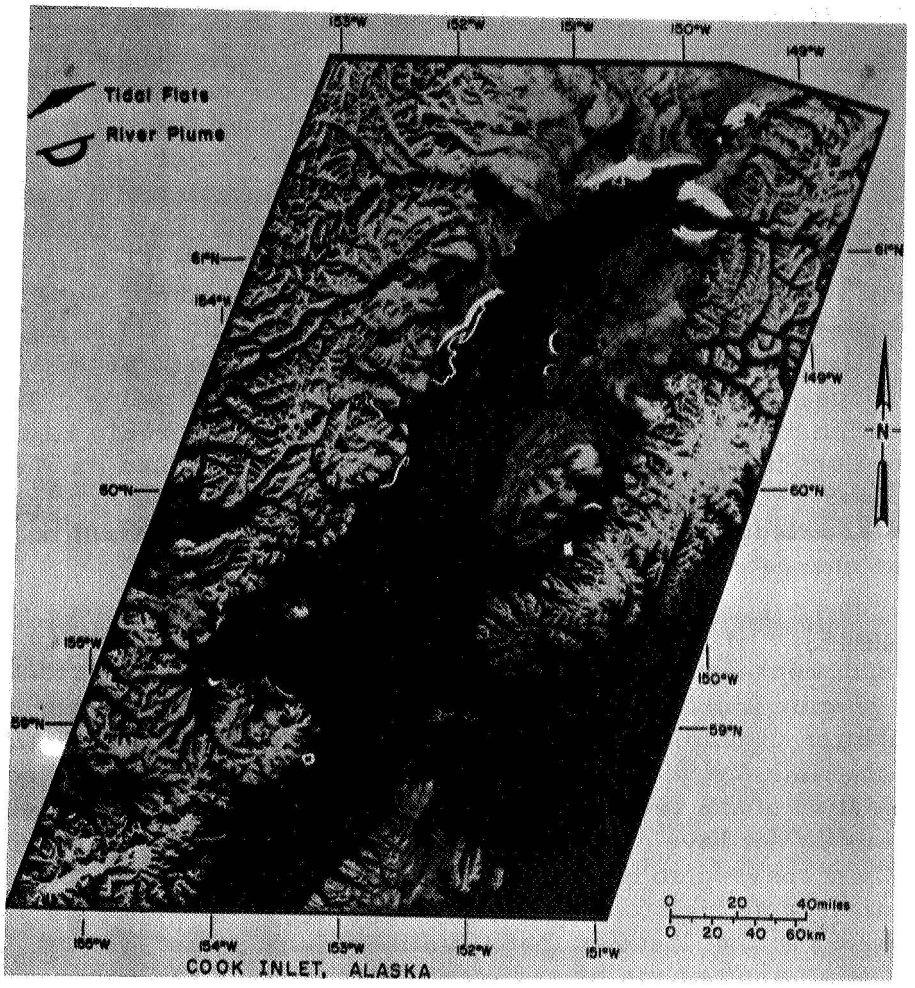

Figure 3. Tidal flat distribution and river plumes

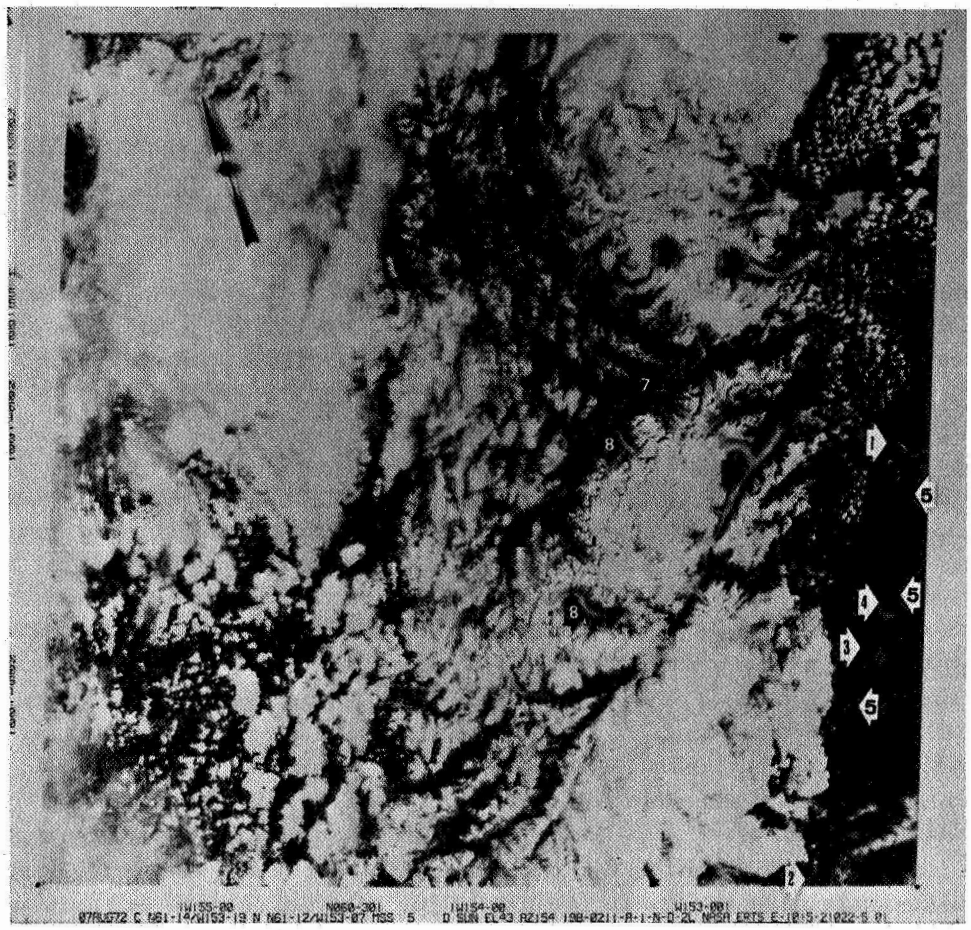

Figure 4. The west shore of Cook Inlet between MacArthur River and Tuxedni Bay

net water movement through several tide cycles. Tidal flats (5) are discernible as a gray border along the coastline. Mt. Spurr (6), one of the many volcanoes in the Chigmit Mountains, Lake Chakachamna (7) and numerous glaciers (8) are also apparent in this scene.

Tidal changes in the sediment plumes of the Big (5) and Drift (6) Rivers are shown in MSS scene 1049-20512-5 (Fig. 5) taken 10 September 1972. The southerly direction of the near-shore current during ebb flow in Redoubt Bay (7) is inferred by the shape of these river plumes. The sediment-laden water from Tuxedni River (12) is transported along the coast in a southerly direction between Chisik Island (13) and the mainland. This movement also indicates that the coastal currents were moving south along the west shore when the image was taken. The shape of the sediment plumes of the Kenai (15) and the Kasilof (14) Rivers indicate a southern current along the east shore in this locatinn. Other features on this scene are: snowcapped Kenai Mountains (1), Kenai Lowland (2), the East (3) and the West (4) Forelands, a counterclockwise current pattern (8) around Kalgin Island (9), tidal flats (10), Harriet Point (11), and Lake Tustumena (15) with a high sediment concentration.

Water Types

Bands 4 and 5 of MSS scenes 1103-20513, 1103-20520, 1104-20572 and 1104-20574 clearly show the disfinction between the more sediment-free, saline oceanic water in the southeastern portion of the inlet and the sediment-laden, fresher inlet water in the northern and southwestern parts of the inlet. Recognition of this relationship is possible because the sediment in the inflowing fresh water functions as a tracer, making sediment distribution patterns visible. Daily changes and changes that occur every 18 days in this regional sediment distribution can be detected. Figure 6a shows differences in the main boundary between the oceanic and fresh water in the southern inlet on two successive days. The boundaries separate the water types during low tide in Anchorage and high tide in Seldovia (Fig. 2). The irregularity of the western portion of these lines may be due to the upwelling of cold, saline oceanic water that occurs in the western portion of the inlet (Evans et al., 1972; Kinney et al., 1970). The northern portion of the 4 November boundary is also quite irregular, possibly due to this upwelling effect. According to Bowden (1967) some estuaries are characterized by a salt wedge that moves headward into the estuary along the bottom while the fresh water outflow moves over this wedge and out the estuary. In Cook Inlet this subsurface tongue of oceanic water progresses headward and moves up the shoaling bottom of the inlet to the latitude of Tuxedni Bay where it rises to the surface south of Kalgin Island during flood tide (Kinney et al., 1970). The upwelling waters appear as a large area of clear water surrounded by sediment-laden water. This process produces a zone

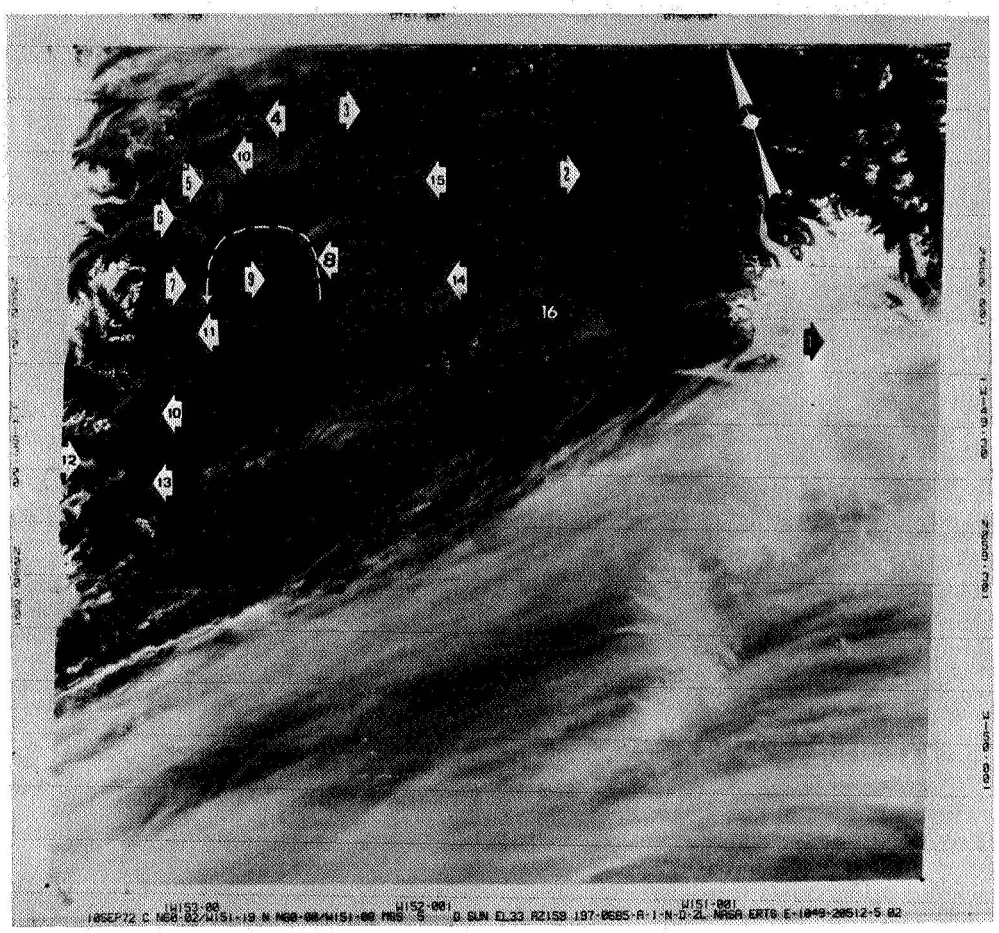

Figure 5. Central portion of Cook Inlet

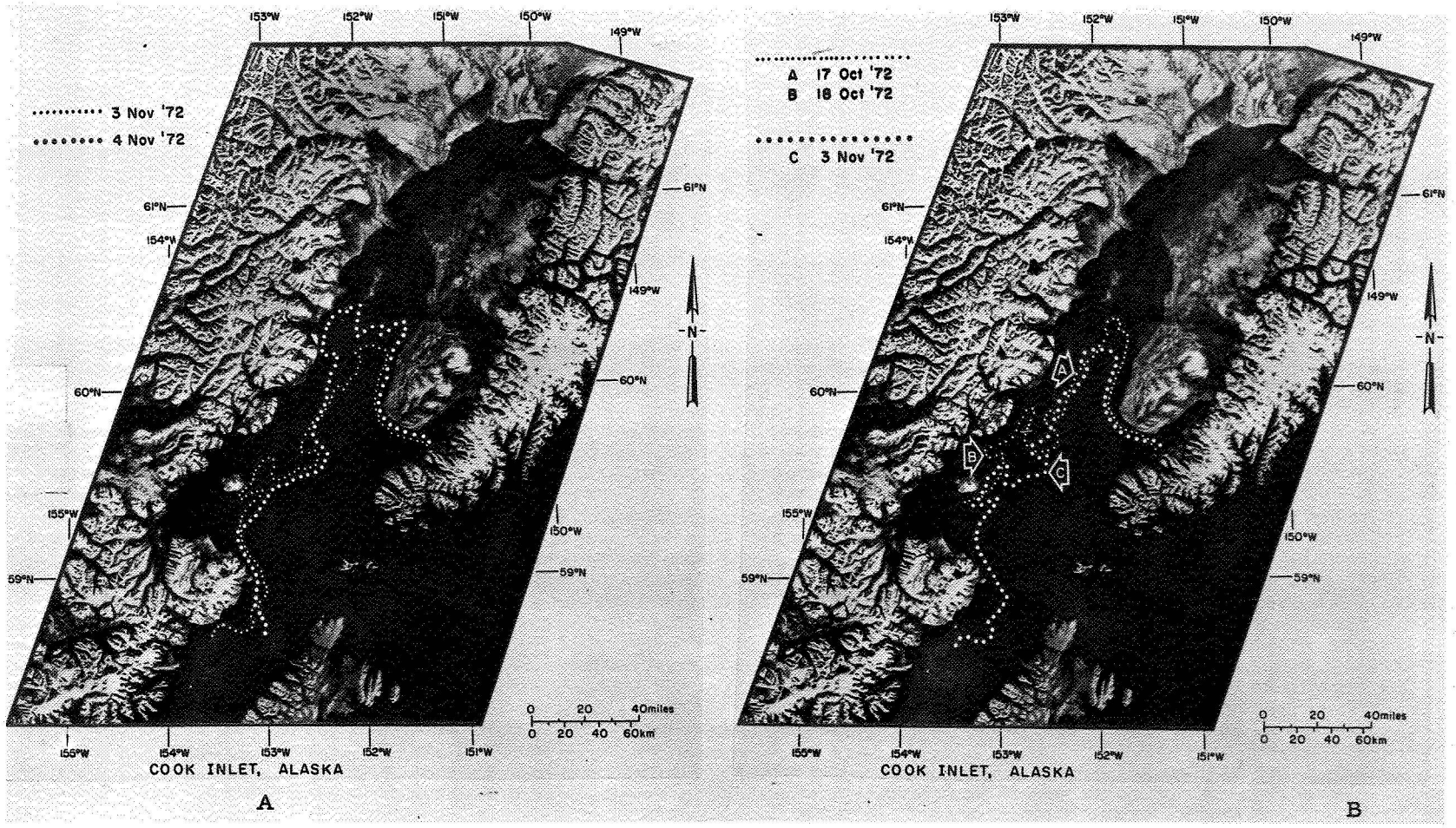

Figure 6. Boundaries separating oceanic and inlet water

of high nutrient concentration in the photic zone at this location. This may be significant to the fishing industry since certain species of fish may tend to concentrate in this high nutrient area. Changes in the boundary over an 18-day cycle are shown in Figure 6b. These boundaries are generally comparable to those in Figure 6a. Although changes in the sediment distribution and surface circulation produce some obvious minor alterations in the regional distribution of water types, the major relationships appears to remain consistent with time.

Surface Circulation

The high suspended sediment concentration in the inflowing fresh water and in the inlet water functions as a natural coloring agent by which the surface circulation of tidal and long-shore currents can be observed. The currents are most visible in MSS bands 4 and 5. Figure 7 shows the surface circulation in the inlet based on published data (Evans et al., 1972) and inferred from ERTS-1 imagery. The regional circulation of the inlet water as previously understood was observed and verified with few changes in the ERTS images. The clear oceanic water enters the inlet at flood tide along the east side around the Barren Islands. A portion of this clear water is forced into the inlet by the counterclockwise Alaska Current in the Gulf of Alaska. A distinct tongue of this oceanic water, which can be seen on MSS frames 1104-20574-5 and 1103-20520-4, occupies the southeastern portion of the inlet and becomes less distinct in a northeast direction by mixing with the sediment in the upper inlet water around Ninilchik. The tide front progresses up the inlet (nearly 150 miles) in approximately 4 1/2 hours. It moves faster along the east shore, being diverted in that direction by the Coriolis force. A back eddy not previously reported (dotted arrow) was apparent on MSS frames 1103-20513-5, 1103-20520-5 and 1104-20574-5 just offshore from Clam Gulch. The eddy forms in the slack water area northeast of Cape Ninilchik during flood tide. The tide front continues past the East Foreland, a large peninsula protruding some 10 miles into the inlet and is partially diverted across the inlet, where it abuts the West Foreland. At this point, part of the diverted front moves south of the West Foreland and the remainder moves north. This circulation pattern is repeated twice daily during the two daily flood tides. The result is a counterclockwise circulation pattern around Kalgin Island (Fig. 5). The circulation of surface water north of the forelands appears to be similar to that previously reported (Evans et al., 1972). The ebb flow in the inlet moves predominantly along the northeastern shore past the forelands. This pattern was discernible on the imagery except for a previously reported counterclockwise pattern (dashed arrow) formed north of the forelands. This pattern is formed as the ebbing waters abut the West Foreland and some are diverted across the inlet and move headward with the flood current along the east shore.

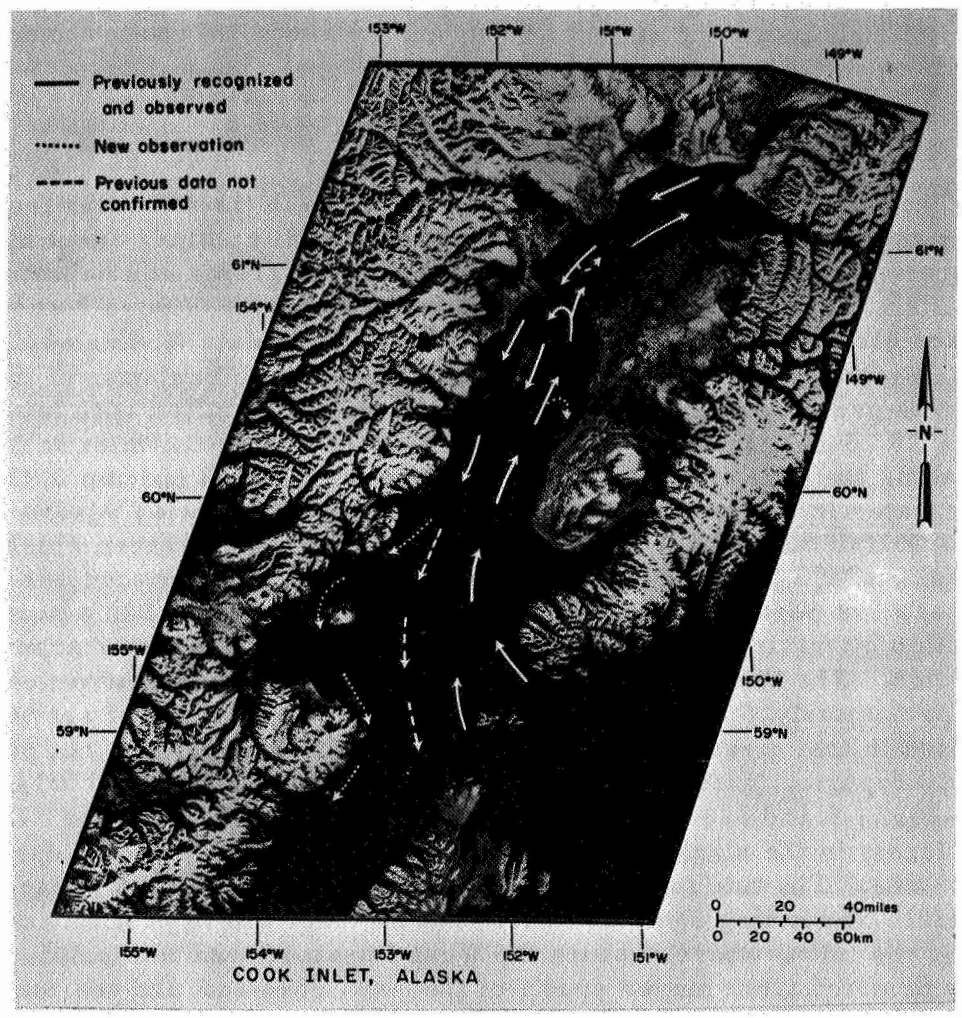

Figure 7. Surface current patterns

As the sediment-laden ebbing water moves past the area of Chinitna Bay (Fig. 1) it appears to flow along the shoreline and circulate around the west side of Angustine Island in Kamishak Bay. It continues to parallel the coast past Cape Douglas and progresses through Shelikof Strait. This circulation pattern in Kam ishak Bay was not previously reported but is clearly visible on the MSS imagery.

CONCLUSIONS

The richness of the ERTS satellite imagery in information on ocean circulation and coastal processes is clearly evident. The changes in the distribution and configuration of tidal flats can be monitored with MSS band 5 and 7 images. Knowledge of these changes is particularly important in maintaining navigation channels and harbor facilities. Upwelling, which produces a region of high nutrient concentration, can be detected on MSS bands 4 and5. This is significant to the fishing industry of Homer, Ninilchik and Kenai, since certain species of fish may tend to concentrate in this region. The distribution of sediment and the surface circulation are also visible on MSS bands 4 and 5. ERTS-1 will permit the collection of sufficient observational data on transport-circulation processes to develop an understanding of the regional relationships between river hydrology, sediment distribution and near-shore oceanography in Cook Inlet.

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