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NEW INSIGHTS INTO THE INFLUENCE OF ICE ON THE COASTAL MARINE ENVIRONMENT OF THE BEAUFORT SEA, ALASKA[1]

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ABSTRACT

Areal patterns from field data and ERTS-1 imagery have shown a close relationship between geologic processes and the influence of sea ice along Alaska's northern coast, perhaps the nation's least known continental margin. Ice acts as (1) a bottom-gouging agent, (2) an influence on water circulation, (3) a carrier of sediments, and (4) an influence on water types.

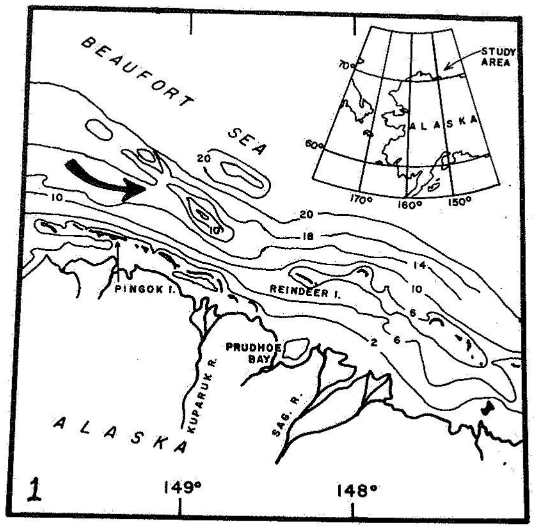
INTRODUCTION

Problems associated with resource management are difficult to solve even when dealing with a region that is well understood. The remote, harsh and little known environment of the Arctic continental margin, coupled with the vast developmental potential that is emerging, underscores the need for an assessment of the region's natural character and the processes operating to maintain or change that character. In an effort to elucidate the geologic character of this area, an extensive series of field studies was carried out in the test site area on the coast and continental shelf of northern Alaska (Fig. 1).

Work began during the period of overflow of Arctic rivers onto sea ice in May and June 1972. Then, during the open-water season, extending from July into September, studies were continued using the Naval Arctic Research Laboratory's research vessel NATCHIK, the Coast Guard ice-breaker GLACIER and the Geological Survey's research vessel LOON.

The primary accomplishment of these studies pertaining to the ERTS-1 program was the acquisition of data on water characteristics (temperature, salinity, turbidity, particulate matter, currents), ice characteristics (thickness, movement, sediment load), and sediment characteristics (texture, depositional history, movement) (see Barnes, and others, 1973 for a discussion of methods and equipment). The ERTS-1 sattelite has been taking high-quality Multi Spectral Scanner images (pictures) in four spectral bands from 0.5 to 1.1 micrometers of a 100-nautical-mile swath of the earth's surface since July 1972. It

[1]Authorized by the Director, U.S. Geological Survey



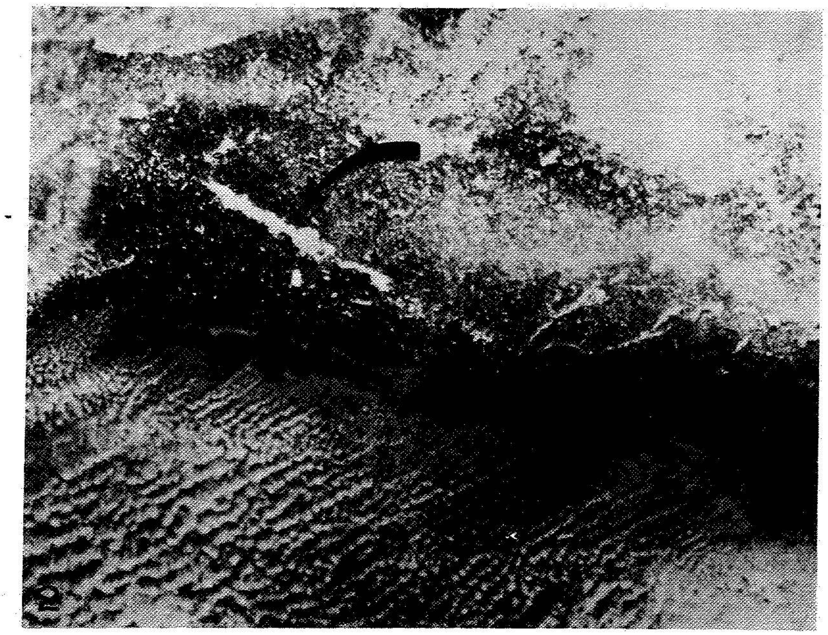


Figure 1. Location of the study area on the northern Alaska coast and continental shelf and bathymetry of a portion of the shelf off northern Alaska. Note the location of ridges northeast of Pingok Island which apparently serve as loci for ice grounding and coincide with the strip of grounded ice in Figure 2.

Figure 2. "Reef" of apparently grounded ice north of Pingok Island which coincides with a submarine ridge (see Figure 1). This ridge is extensively scoured by frequent ice contact (ERTS-1 image on 12 August 1972, 1020-21281-5).

covers the same area every 18 days. At the latitude of our study area (70°N) there is a 70% sidelap of successive orbits and images.

Preliminary analysis has been completed for all images of the test site area obtained before the spacecraft shut down due to low sun angle on 1 November. Images have been selected that (1) are coincident with and can be correlated with our field data and (2) demonstrate events within the test area. The following information has been extracted from the images in conjunction with field data:

(a) surface distribution of suspended matter, temperature and salinity along the coast.

(b) coastal current directions from grounded ice and ice-distribution patterns.

(c) determination of ice-movement patterns from successive, overlapped images.

(d) correlation of grounded ice with topographic highs.

RESULTS

Ice Scour

Although it has long been known that ice in many forms interacts with the sea floor in Arctic coastal regions (Rex, 1955; Kovacs, 1972; Pelletier and Shearer, 1972; Reimnitz, and others, 1972) the details have remained sketchy. Bathymetric, side-scan sonar, high-resolution sediment profile records, and SCUBA diving observations, coupled with imagery show ice-grounding to be dependent on bottom relief. An elongate ridge with a crest at a water depth of 8-15 meters extends from some 25 miles west of Reindeer Island (Fig. 1). The seaward flank of this ridge is extensively marred with grooves up to 1.5 meters deep, while the landward slope is essentially free of these features (Reimnitz and Barnes, 1972). Diving observations reveal the grooves to be sediments plowed up into unstable ridges. Similar relations were found on other ridges and seaward slopes of the offshore islands. Imagery from August 12, 1972, shows the ridge west of Reindeer Island to be the locus of a mass of grounded ice (Fig. 2). The congruity between the location of intensively gouged bottom and the grounded ice mass confirms the source of the grooves as grounding ice. Furthermore, it is apparent that ice is actively scouring the bottom at present.

The practical implications of these observations are twofold: (1) the safety of offshore platforms, structures, and pipelines depends on the rate, depth, distribution and intensity of ice gouging. (2) Shipping will be guided by the presence or absence of barriers to onshore movement of ice.

Ice Dynamics

Ice movement and distribution in the Beaufort Sea play an important part in any shipping and economic development along this coast. It has been known that wind and ice-movement directions correlate well (Sverdrup, 1928; Campbell, 1965). Our summer observations confirm this. In addition a set of overlapping ERTS-1 images on October 7th and 8th, 1972, quantify the same relation (Fig. 3). However, these images also show that there is considerable variance between wind direction and ice drift, probably due to the added influence of currents and coastline shape (Nikiferov and others, 1967). These photos also show the separation of new bay ice from the coast due to wind stress (Fig. 4).

In Harrison Bay maximum drift of newly forming ice was about 0.5 km/hr in a northeasterly direction (Fig. 3). Offshore at a distance of 100 km, ice movement varied from a northwesterly direction at up to 0.8 km/hr paralleling the coast and the average current (H.O. Office, 1958), to a northeasterly direction at up to 0.4 km per hour. The winds during the 24-hour period averaged about 17 km/hr from the southwest. It appears that the movement of thin new ice in Smith and Harrison Bays more closely parallels wind directions and is affected more positively than the thicker pack ice offshore. Evidently the pack ice is influenced more by currents and/or intra-pack forces.

Water Characteristics

Coastal circulation along the Arctic shores of Alaska is poorly understood (Kinney, and others, 1972). Interpretation of oceanographic conditions is complicated by the 9-month ice cover, relatively large meterologic tides, and the paucity of data.

The surficial coastal water masses encountered during the summer reflect three major sources. The earliest to manifest itself (late June thru July) is the low-salinity (0-10 ppm), relatively warm (1-11°C), and turbid (>15 light attenuation coefficient--α) river runoff. During July river water fills the zone between the coast and the yet unmelted sheet of seasonal ice. As melting progresses (middle of July to August) a second water type develops, formed as a result of the contribution of melt water from pack ice. This water is of moderate salinity (5-15 0/00), low temperature (0-2°C), and low light attenuation (<3α). The first two surface-water types are generally 1-2 meters thick and probably never more than about 5 meters in some of the deeper lagoons.

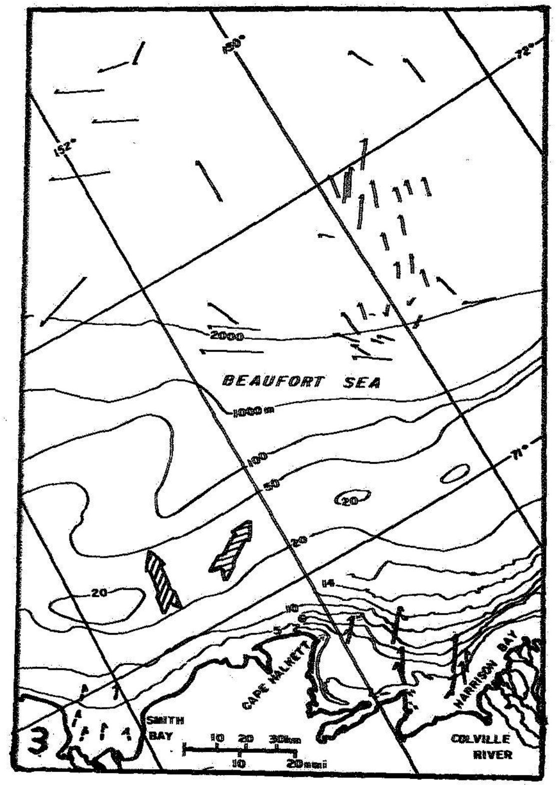


Figure 3. Ice movement vectors (small arrows) derived from overlapping ERTS images of passes on October 7 and 8. Vector scale is the same as the map scale. The large (crosshatched) arrows are average wind directions for October 7 and 8 from ground stations 250 km east and west of this area. The broken arrows in Smith Bay indicate sense of direction (see Figure 4) of movement as cloud cover precluded vector determination. (Plotted from ERTS images 1076-21392-7, 21394-7, and 1077-21451-7 and 21453-7.)

Figure 4. Smith Bay and Cape Halkett showing offshore movement of newly formed ice due to southerly and southwesterly wind stresses (ERTS image 1077-21453-7). (See also Figure 3.)

A third water type is characterized by moderate salinity (25-30 0/00), low temperature (<1°C), and relative clarity (<5 α). This "oceanic" water is seen as a background influence, interacting with the river and ice melt waters to create intermediate types.

Using field measurements of the period from the 27th through the 30th of July 1972, and ERTS-1 images from 25 July covering the same region, these three water types could be readily distinguished (Figs. 5 & 6). The circulation patterns seen in the imagery compare favorably with the turbidity and salinity measurements. In general there is an offshore decrease in turbidity as the distances to source of suspended matter (rivers and coastal erosion) increases. Salinity initially increases in an offshore direction then decreases as the offshore pack is approached (Fig. 5). Visually only the turbidity gradient is obvious in the spacecraft imagery (Fig. 6), however. The observed offshore decrease in salinity correlates well with the location of the pack ice and its melt waters.

One of the most interesting features noted in this image and confirmed by field data is an area of clearer, more saline water close inshore just east of the Colville River (Fig. 5). Apparently this influx of "oceanic" water is a fairly permanent feature. Upon comparing temperature and salinity data available for the entire 1972 summer season and the seasons of 1970 and 1971, a similar pattern of colder, more saline water is found here. This region represents either an area of upwelling under the influence of the dominant northeast winds, or reflects a clockwise circulation in Harrison Bay and an entrainment of offshore water. In any event, the image and field data strongly suggest that Colville River detritus is being carried westward towards Cape Halkett.

CONCLUSIONS

Although the coastal environment of Arctic Alaska is far from being understood, it is apparent, that ice is perhaps the most important agent affecting modern geologic processes. Ice is the source of a coastal water type, disrupts and bulldozes bottom sediments, and influences shelf-circulation patterns. ERTS-1 imagery has aided in interpreting the complex field relations. Furthermore, it will continue to be an aid in monitoring the changing geologic and oceanographic processes, as this remote area becomes exploited.

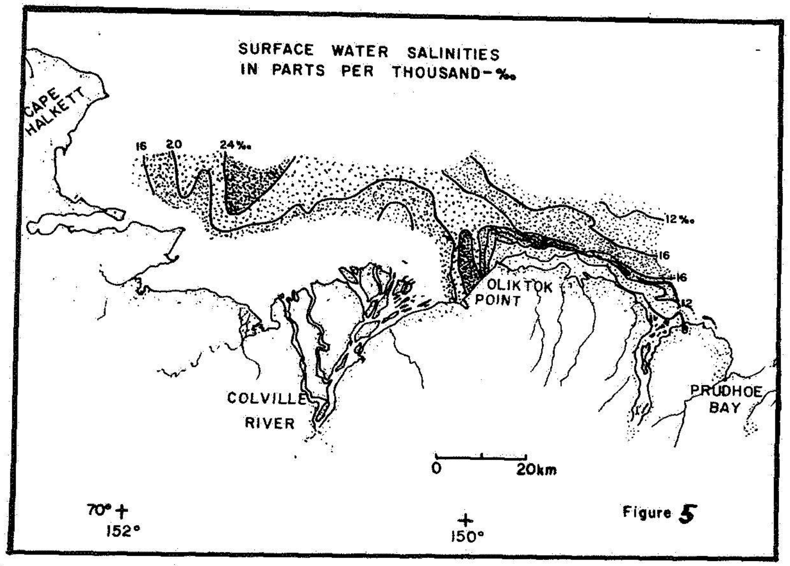


Figure 5. Salinity of surface waters in parts per thousand, mainly from values measured on July 27-31, 1972. Interpretation and contouring were aided by data obtained in August and September of 1970, 1971, and 1972. Note the high salinity water near Oliktok Point.

Figure 6. ERTS-1 image (RVB 3) of July 25 covering area of field data (Figure 5). A turbid water mass can be seen close in along the coast and off the delta of the Colville River. The large accumulation of ice fragments blocked up against the offshore islands NE of the Colville delta is "streaming" bits of ice to the west. Note the intrusion of more saline, clearer water near the coast just east of the Colville delta (from ERTS-1 image 1002-21300-3).

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