Grounded ice in the fast ice zone along the Beaufort Sea coast of Alaska
Cover: Side-looking airborne radar image of fast ice and pack ice off northern coast of Alaska — see p. 7. (Imagery acquired for the National Oceanic and Atmospheric Administration by the U.S. Geological Survey.)
Grounded ice in the fast ice zone along the Beaufort Sea coast of Alaska

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Four large grounded multi-year shear ridge formations were found in the grounded ice subzone of the fast ice zone near the Harrison Bay/Prudhoe Bay area of Alaska. A 166-m-long cross section of one of these formations was obtained by leveling and sonar measurements. These measurements revealed that the maximum ridge height was 12.6 m and that the formation was grounded in 17-18 m of water. The salinity, temperature, brine volume and density of the ice were determined on samples obtained by coring. The physical characteristics of the formations as observed in satellite, SLAR and aerial imagery indicate that these formations have not moved between the time of their formation in the fall of 1974 and August of 1976. Evidence of significant aeolian debris discoloring the ice is discussed.
PREFACE

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The author wishes to acknowledge the field assistance of Walter Tucker and Dr. Wilford F. Weeks during the drilling and profiling of the grounded multi-year shear ridge north of Cross Island and of Dr. William Hibler III during the profiling of the two first-year shear ridge fragments near the 1972 AIDJEX camp. The technical review of this paper by Stephen F. Ackley and Dr. Anthony J. Gow is also acknowledged.
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GROUNDING ICE IN THE FAST ICE ZONE ALONG THE BEAUFORT SEA COAST OF ALASKA

Austin Kovacs

INTRODUCTION

The seasonal variation and morphology of the sea ice canopy over the continental shelf of the southern Beaufort Sea are of considerable interest today because of the offshore resource development currently underway. Of particular interest are ice formations which either drifted into shallow water and became grounded or were formed there as a result of local sea ice pressing. Much of the interest is concerned with the displacement of these grounded ice features by pressures developed during movement of the pack ice toward the coast. The associated forces and deep ice keel scoring which can occur with this movement are a threat to proposed bottom-founded wellheads and gathering systems. Thus, for both economic and environmental reasons, sea floor production systems must either be designed to resist these forces or be buried below the deepest contemporary ice scoring.

Large fields of highly brecciated sea ice form in the fall of the year along large sections of the fast ice/pack ice boundary. These formations tend to remain immobile during the remainder of the winter season, not only because portions of the ice keels become firmly grounded, but because the fast ice helps to anchor them in place. This report discusses these ice formations of the outer fast ice zone.

BACKGROUND

In October of 1974 the author observed three large shear ridge fields which had recently formed at the fast ice/pack ice boundary north of Cross Island near Prudhoe Bay, Alaska (Fig. 1). Leads existed beyond these features and the pack ice was in motion. A water depth of 21 m was measured through a lead on the north side of one shear ridge field northeast of Cross Island. The height of the parallel ridges within the fields varied appreciably but many were estimated to be well in excess of 10 m high. Their height, coupled with the measured water depth, indicated that large portions of these shear ridge fields were firmly grounded upon the sea floor. Subsequent trips to the area in February and April 1975 revealed that these fields had remained stationary.

Early in October 1975 another trip was made to the area in preparation for the March-June 1976 CRREL program on the dynamics of near-shore ice. During this field trip, several large shear ridge fields were again observed. These were of considerable interest, not only because they were composed of massive multi-year ice but because they appeared to be large segments of the grounded shear ridge fields observed the previous winter.

During this same field trip Herbert Skibitzke of the USGS passed on the information that he had observed, on SLAR (side-looking airborne radar) imagery of 29 September, a very large ice feature north of Oliktok Point, on the east side of Harrison Bay. His description of the feature as being partially composed of closely spaced, high amplitude linear ridges was that of another shear ridge field which apparently was drifting westward with the pack. These observations, made during 1974-75, stimulated further studies that form the basis of this report.
a. Three shear ridge fields and numerous floebergs incorporated in the fast ice north of Cross Island in the winter of 1974–75.

b. A closer representative view of the surface relief of one field.

Figure 1. Shear ridge fields (views looking east).
FAST ICE STUDY AREA

A brief description of the complex fast ice zone, in which large, thick ice formations are frequently incorporated, may be found in the WMO Sea Ice Nomenclature (WMO 1970): “Sea ice which forms and remains fast along the coast, where it is attached to the shore ... or to grounded ice. Vertical fluctuations may be observed during changes of sea level. Fast ice may be formed in-situ from sea water or by freezing of pack ice of any age to the shore, and it may extend a few meters or several hundred kilometers from the coast. Fast ice may be more than one year old ...”

According to Kovacs and Mellor (1974) the seaward extent of the fast ice zone in the southern Beaufort Sea varies with the protection offered by the shoreline, the water depth, the time of year, and the magnitude of the forces of the pack ice which are active along each section of the coast. If weather conditions permit, the fall fast ice can extend far out over the continental shelf. The pack ice at this time is relatively loose and in perpetual motion, first compacting and then thinning under the influence of winds and currents.

During the early fall, when the fast ice is thin and subject to deformation, it is often fractured and crushed by the enormous forces exerted by the moving pack ice. If the force of the pack ice is of short duration and of limited intensity, then only the outer periphery of the fast ice is affected. If the pressure from the pack ice is high and of sufficient duration, the blocks of broken ice are pushed into pressure ridges with keels that may extend to the sea floor.

Ridges so formed have been seen grounded in 15 m of water off Herschel Island (Kovacs 1972). Stefansson (1921) measured the height of one grounded ridge at 23 m and he also reported seeing higher ridges along the northwestern coast of Banks Island, grounded in water up to 39 m deep. In 1975 Kovacs (unpublished) observed one ridge estimated to be 18 m high grounded in 10 m of water near the Gore Islands off the northwest end of Banks Island. Peary (1907) and Sverdrup (1904) both reported seeing grounded sea ice pressured to form ridges 24 to 37 m above sea level, while Kolchak (1909) frequently encountered pressure ridges grounded in water 5.5 to 18 m deep. Stockton (1890) reported on a large formation of pressured sea ice 16 km long grounded in 24 m of water north of Cross Island, Alaska.

As the fast ice continues to thicken and strengthen, it becomes more resistant to deformation. Similarly, the loose, mobile multi-year floes which characterize much of the fall pack ice gradually become immobilized, frozen together into larger floes by a matrix of seasonal ice. In this way, the compactness and inertia of the pack ice increase, and its response to sudden changes in windspeed or direction is reduced. As a result, stronger winds of longer duration are required to push the pack ice toward shore. Because the intensity of storms also tends to decrease with the winter season, the overall effect is that the potential for extensive deformation within the fast ice zone gradually decreases as the winter progresses.

In general, late September or early October is when most of the surface morphology of the fast ice is established for the coming winter season along the Alaskan coast of the Beaufort Sea. The ice near the coast is still thin and weak at this time and thus is easily fractured by the pack, which is still relatively mobile. If the pack is driven toward the coast, the resulting pressures frequently exceed the strength of the fast ice and failure occurs. The result can be fracture followed by large area displacements of the fast ice or crushing and piling of the fast ice at pressure points along its boundary. If the intensity and duration of pressuring are great, the ice pileup can thicken until it becomes firmly grounded on the sea floor. When pressuring ceases, these features become immobile, not only because portions of their keels are grounded, but because the fast ice on the shore side helps to anchor them in place.

By late October or early November the fast ice has generally stabilized out to about the 20-m depth contour. Beyond this contour the seaward extension of the fast ice varies from year to year depending upon 1) the compactness of the pack, 2) the magnitude and direction of the forces which are active during slippage of the pack ice at the fast ice boundary, i.e. ice movement at the edge of the shear zone, and 3) the presence or absence of large grounded ice features. While these features can, on occasion, consist of ice island fragments driven aground during a fall storm (Fig. 2), the formations are, for the most part, composed of pressured sea ice which has been driven into shallower waters or accumulated on-site.

The appearance of the deformed ice is either a chaotic rubble of randomly dispersed iceblock structures, i.e. a hummock field (Fig. 3), or a more oriented
Figure 2. A small (about 75 m long, 50 m wide, 6 m high) ice island fragment grounded in 16 m of water north-northeast of Cross Island in April 1976. The bottom view shows the wave-cut channel in the ice wall which indicates the level of the ocean’s surface when the ice island was free-floating.

zone of quasi-parallel shear ridges (Fig. 4), which form when both normal and tangential forces occur at the boundary between the fast ice and the moving pack. The resulting shearing and grinding produce the most compact form of pressured sea ice. Large fields of these ridges are frequently observed grounded in water approximately 15 to 20 m deep. While the area along these depth contours may best be described as the grounded ice zone, it must be understood that the shear ridges and the other forms of ice found stranded there do not necessarily form a continuous belt along the entire coast and are by definition a part of the fast ice zone.

Along those sections of the coastal shelf where grounded ice does not occur, the fast ice boundary generally terminates at about the 20-m depth contour. Where grounded ice exists, a seaward extension of the fast ice frequently occurs. This extension on occasion reaches the 30-m depth contour. The anchorage provided by the grounded ice near the 20-m depth contour as well as the overall thickening and concomitant strengthening of the fast ice as the winter season progresses make this seaward extension possible.

The fast ice zone can be subzoned as follows:

1. An ice foot composed of beach ice resulting from storm wash and ice which has thickened sufficiently by natural growth to become grounded to the sea floor. This ice is unmoved by tidal fluctuations.
Figure 3. Irregular relief of a hummock field.

Figure 4. High, aligned ridges in a large shear ridge field.
2. A tidal fast ice zone located between active tidal cracks. The ice in this zone touches bottom at low tide.

3. A floating fast ice zone beginning beyond the tidal cracks and extending to the fast ice boundary, i.e. the demarkation between the fast ice and the pack ice.

4. A grounded ice zone located approximately between the 15- and 20-m depth contours. The grounded ice in this zone may form a dense field or a scattering of first- and multi-year pressure ridges as well as an infrequent ice island fragment.

5. A floating seaward extension of the fast ice beyond the grounded ice zone. The extent of this zone depends upon fast ice thickness, pack ice motion, and the anchorage provided by the ice in the grounded ice zone.

The first three subzones always exist as part of the winter fast ice zone. The latter two may or may not exist in any given year or at any given site along the coast.

RESULTS AND DISCUSSION

The availability in recent years of satellite imagery has permitted the sea ice investigator to see and monitor large area fluctuations in the seasonal ice cover of Arctic seas. To determine if the large multi-year shear ridge fields seen in October 1975 were part of the grounded shear ridge fields observed the previous winter, Landsat imagery of the area was inspected. Side-looking airborne radar imagery and aerial photography, collected periodically as part of the National Oceanic and Atmospheric Administration's Outer Continental Shelf Energy Program, as well as Landsat, NOAA and Defense Meteorological Satellite Program (DMSP) satellite imagery were also inspected to ascertain the position and motion of the large feature reported by Skibitzke.

Ice conditions in the Prudhoe Bay region as seen from the Landsat satellite on 18 July 1975 are shown in Figure 5. The three grounded shear ridge fields north of Cross Island are clearly visible. The largest (westernmost) formation is approximately 5.5 km long, the center feature is 3.5 km long and the easternmost and smallest of the fields is only a kilometer in length. A composite Landsat image of 9-12 September (Fig. 6) shows ice conditions shortly before freeze-up and reveals that the three grounded ice features have not moved.

Another interesting feature, which appears in both the July and September Landsat imagery, is a large elongated area of shear ridges located some 60 km north-northeast of Oliktok Point. The feature was approximately 40 km long on 9-12 September 1975.

![Figure 5. Landsat image 2177-21110 showing ice conditions in the area of Prudhoe Bay on 18 July 1975. The locations of the three grounded shear ridge formations are indicated by the arrows.](image-url)
This formation of shear ridges is also grounded as all other ice shown surrounding it on 18 July (Fig. 5) had broken up and moved westward. It is the same ice feature observed by Skibitzke on SLAR imagery. The formation is clearly outlined in the SLAR image shown on the front and back covers as are the three grounded shear ridge formations north of Cross Island. The black areas on this image are thin first-year ice.

On the 1973 Coast and Geodetic Survey map, No. 9400, Arctic Coast of Alaska, a shoal varying from 12 to 18 m below sea level is shown at the location of the large shear ridge formation. Studies of pressure ridge keel depth distributions in the Arctic Ocean indicate that there is virtually an unlimited opportunity for ice keels 12 or more meters in depth to pass a given location during the course of a year. Therefore, the potential for ice becoming firmly stranded upon this shoal is great. Subsequent movement of the ice pack past such stranded ice can add further accumulations of ice to the area through failure and pressing processes. It is believed the large formation of grounded shear ridges north of Oliktok Point developed through a similar course of events.

Aerial photography of the feature was taken by Skibitzke on 21 October 1975. The west and east ends of the formation are shown in Figures 7 and 8. The linear shear ridges composing much of the formation are clearly in evidence. These figures show that the northern (seaward) side of the feature contains the higher, more massive accumulation of shear ridges, some estimated to be well in excess of 10 m in height.

A large lead extending from Point Barrow at least to Mackenzie Bay is shown in the DMSP image of 8 December 1975 (Fig. 9, 10). The lead clearly outlines the northern boundary of the fast ice at this time. The area of the three grounded multi-year shear ridge formations north of Cross Island and the large grounded multi-year shear ridge feature north of Oliktok Point is also visible. It is interesting to note that at this time the fast ice appeared to extend about 5 km beyond the latter feature to an apparent water depth in excess of 25 m.

In April 1976 an investigation was made of the largest of the three grounded multi-year shear ridge formations north of Cross Island. An oblique aerial view showing the formidable relief of this feature is presented in Figure 11. This and two views from the ice surface (Fig. 12) show that the angular ice blocks which were incorporated in the ridges at their formation had become subangular (where they were still discernible on the surface), that the overall relief had been smoothed by ablation, and that the inter-block voids were no longer visible, having been filled with ice formed by the freezing of surface snow and ice melt and rain water. Between the ridge sails deep
Figure 7. Shear ridges and ice conditions at the west end of the large shear ridge field on 21 October 1975.
Figure 8. Shear ridges and ice conditions at the east end of the large shear ridge field on 21 October 1975.
accumulations of drifted snow were encountered and the ice and snow surface was found to be noticeably discolored by a layer of fine aeolian dust similar to that found by Kovacs and Gow (in press) on the grounded floebergs they studied in April 1975 a short distance to the west.

A profile of the ice surface was made over a short (166-m-long) segment of the formation shown in Figure 13. Many of the elevation survey stations, which were 2 m apart, are visible in this figure. Also visible is the varying surface discoloration associated with aeolian dusting. A tide crack can also be seen along the right side of the figure. Side-looking sonar measurements were also made at 2-m depth intervals to determine the profile of the ridge keel at the south end of the survey line. The resulting cross section is shown in Figure 14. The highest point on the elevation profile was 11.49 m. The highest ridge elevation in the area was 12.6 m, shown in Figure 13 at location a and seen as the high point in Figure 12. The slope angles of the multi-year shear ridge sails in the formation were characteristically “steep.” On the cross section they are shown to be 30°, steep enough to require steps to be cut in the ice surface to provide the rod man with firm footing. The formidable appearance of the multi-year shear ridge formation on the south side of the profile is shown in Figure 15. The varying surface discoloration associated with fallout of wind-transported dust from the mainland is again in evidence.

The slope of the keel was 51° at the site of the profile (Fig. 14). At a depth of 17 m the sonar return indicated a surface only 5 m away. However, the uniform slope of the keel below a depth of 8 m indicates that this return was not from the ice surface. The reflection was probably from the wall of an ice-scored trench which the sonar system contacted at a depth of 18.4 m. Another measurement
Figure 10. Enlargement of portion of Figure 9 showing the large grounded shear ridge field (3).

Figure 11. Oblique aerial view of the surface relief of the largest multi-year shear ridge formation north of Cross Island.
nearby gave a water depth of 17.15 m. In any event the sonar measurements indicate that the keel is in contact with the sea bed.

The sail slope measured for this multi-year shear ridge (30°) is 10° steeper than the average of the slope angles found by Kovacs et al. (1973). It is also 6° steeper than the average slope angle reported by Kovacs (1972) for first-year pressure ridge sails. However, the sail slope is not as steep as those of two first-year shear ridge fragments found floating in the pack near the 1972 AIDJEX camp. The cross sections of these two fragments are presented for the first time here in Figure 16. An aerial view of the two features is given in Figure 17 and a ground view of one is shown in Figure 18. The slope of the sails shown in Figure 16 varies from 42° to 70° but averages 60°, 30° more than the Cross Island formation's sail. A direct comparison between the Cross Island multi-year shear ridge and the two first-year shear ridges near the AIDJEX camp is, however, not appropriate as the former has
Figure 13. Aerial view of the multi-year shear ridge formation profiled. Arrows show the ends of the elevation survey line. The highest ridge elevation near the survey site was at a.

passed through one melt season, and as a result has undergone significant surface ablation and modification. In addition, the latter ridges are fragments which have separated from a larger formation. The sail and keel faces are thus fracture surfaces which are not representative of the sail and keel slopes developed during ridge building.

The maximum elevation of first-year shear ridge 1 is 5.7 m. Insufficient sonar cable prevented determination of the maximum keep depth at this ridge. The maximum freeboard and depth for shear ridge 2 are 4.6 and 18 m respectively for a sail height to keel depth ratio of 1 to 4. This is similar to the ratio found for floating first-year pressure ridges by Kovacs (1972). The sail height to keel depth ratio for the Cross Island ridge is about 1 to 1.5. This ratio is clearly low compared with the above 1 to 4 ratio for the first-year shear ridge and the 1 to 3.13 ratio for multi-year pressure ridges (see Table I), indicating how firmly grounded the Cross Island shear ridge formation must be. From the above ratios it can be estimated that a sea level rise of about 2.8 to 4.3 m would be necessary to float this formation free. As the chance of such a change in sea level is remote for these waters, even during a storm surge, it must be reasoned that the three grounded multi-year shear

<table>
<thead>
<tr>
<th>Ridge*</th>
<th>Sail height (m)</th>
<th>Keel depth (m)</th>
<th>Sail:keel ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.9</td>
<td>2.9</td>
<td>1:3.22</td>
</tr>
<tr>
<td>2</td>
<td>3.4</td>
<td>11.5</td>
<td>1:3.38</td>
</tr>
<tr>
<td>3</td>
<td>3.9</td>
<td>12.0</td>
<td>1:3.08</td>
</tr>
<tr>
<td>4</td>
<td>3.9</td>
<td>13.0</td>
<td>1:3.33</td>
</tr>
<tr>
<td>5</td>
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<td>3.9</td>
<td>1:3.0</td>
</tr>
<tr>
<td>6</td>
<td>2.75</td>
<td>8.5</td>
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</tr>
<tr>
<td>7</td>
<td>2.95</td>
<td>8.5</td>
<td>1:2.88</td>
</tr>
</tbody>
</table>

Average 1:3.13

* Sources: ridge 1, Cox (1972); ridges 2-4, Kovacs et al. (1973); ridges 5-7, Kovacs (1972 data on file).

ridge formations north of Cross Island will not move off intact but will gradually diminish in size by fragmentation and ablation.

An exploratory hole was augered to a depth of 18.8 m at the location on the cross section shown in Figure 14 to obtain core samples. The samples were used for determining the temperature, salinity, brine volume and density of the ice in the ridge. The hole
Figure 14. Cross section of a small portion of the grounded multi-year shear ridge formation.

Figure 15. South side of the grounded multi-year shear ridge formation at site of profile study. Man on the ridge gives some perspective of the ice relief.
Figure 16. First-year shear ridge fragments profiled near the 1972 AIDJEX camp (75°N, 149°25'W).
Figure 17. Aerial view of the two first-year shear ridge fragments profiled in Figure 16. Arrows indicate location of cross-section profiles. Shear ridge 1 is on left. Shear ridge 2 is on right.

Figure 18. Ice block structure on south side of shear ridge 1.
was made using a hand-held, lightweight motorized continuous aluminum flight auger system with core barrel attachment. This system was developed by the author to permit rapid augering to, and then core sampling of ice at, any desired depth in multi-year pressure ridges and ice islands. Arrival of the helicopter transport supporting the field party brought drilling and sampling to a halt at a depth of 18.8 m.

Drilling revealed the existence of three cavities. All were encountered in the top 3 m; two were less than 10 cm in height; the other measured 15 to 20 cm in height. Never before had more than one cavity been encountered during drilling of a single hole in other multi-year ridges, as reported by Kovacs and Mellor (1971), Kovacs et al. (1973), Kovacs and Mellor (1974) and Kovacs and Gow (in press). The unusual number of cavities encountered during drilling was perhaps due to the fact that this grounded shear ridge formation had only persisted through one melt season. The interior of the structure had therefore not received sufficient surface drainage to allow complete filling and refreezing of the interblock voids. The formation's high sail exposure to the sun and the warm summer temperatures at this southern location may also have affected void freezeback. Also, unlike the conditions found by the above authors when drilling in other multi-year ridges, the soundness of the ice at this drill site decreased with depth as indicated by augering resistance.

Profiles showing the salinity, temperature, brine volume and density of the ice with depth, as determined from core analyses, are presented in Figure 19. The salinity profile is typical of those obtained from core analysis at other multi-year ridges, i.e. the salinity is nearly zero at the surface but gradually increases with depth. The wet cores obtained at approximately 5 and 8 m below sea level are indicative of warm sea ice with open brine drainage channels. Also, the temperature profile shows that the ice is quite warm, -1.8°C, below sea level. This is not typical of multi-year ridges where temperature of the ice at sea level is generally 2 to 4°C lower. The higher ice temperature and salinity, and therefore lower strength of the ice with depth, is the reason for the reduced drilling

Figure 19. Salinity, temperature, brine volume and density of the ice at the location (Fig. 14) of the drill hole on the grounded multi-year shear ridge.
Figure 20. SLAR image of 11 May 1976 showing location of water depth measurements (a-d) and six of the radar transponder sites (1, 2, 3, 4, 5 and 8) at which ice movement was monitored from stations on Cross and Narwhal Islands. (Imagery obtained by U.S. Army Electronics Proving Ground, Fort Huachuca, Arizona.)
resistance noted with depth. The brine volume profile is, of course, a function of the salinity and temperature of the ice and is an indication of ice porosity. As the brine volume (and porosity) of the ice increase, both the strength and resistance to drilling of the ice decrease. Ice densities above sea level are also lower than those usually found in multi-year pressure ridges (Kovacs and Mellor 1971, Kovacs et al. 1973). The lower density is the result of brine channels and drainage cavities not sealing and refilling with refrozen melt water.

A flight was made on 5 June along the southern edge of the grounded ice zone from Pole Island to the large grounded ice formation north of Cross Island. At four locations the water depth along this boundary was measured with a lead line. The locations of these measurements are shown in Figure 20 as positions a-d. The water depths were 15.1, 15.3, 15.2 and 17.15 m respectively. From these measurements it would appear that the southern or inner boundary of the concentrated ice in the grounded ice zone occurs approximately along the 15-m depth contour.

Also shown in Figure 20 are the locations of six remote radar transponders forming part of the strain array for the CRREL program on the dynamics of near-shore ice (report in preparation). From about mid-March to the end of May the movement of these stations was measured every 4 hours. Stations 5 and 8 experienced total movements of less than 5 m. This movement is small and is similar to that which can occur in the fast ice south of the grounded ice zone. Because of this small motion, it may be inferred that the seaward extensions of the fast ice from March to June 1976 reached at least to station 5 which is in 25 m of water.

By 5 June solar radiation was becoming intense, air temperatures were frequently above freezing and some rain had fallen. The resulting snow-ice melt and ponding of water had significantly changed the surface appearance of the three grounded multi-year shear ridge formations near Cross Island (Fig. 21). Numerous pools of water were in evidence between the ridges and the exposed aeolian dust on the surfaces of the ridge sails had given the ice a very dirty appearance in contrast with the level first-year ice seen at the top of the figure.

On 25 August 1976, Walter Tucker of CRREL made a reconnaissance flight past Cross Island. He observed the multi-year shear ridge formations still stranded to the north of the island and noted that they were completely surrounded by open water. The edge of the pack was at this time some 5 km north of the formations.
a. 14 July (ERTS No. 1356-20542).

b. 1 August (ERTS No. 1374-20541).

c. 6 September (ERTS No. 1410-20533).

Figure 22. 1973 Landsat images showing changing ice conditions near Barter Island (arrow).
While zones of grounded ice occur each year in the shallower waters of the continental shelf of the southern Beaufort Sea, they generally fragment and move away during the spring/summer break-up. An example of this is shown in the 1973 Landsat imagery presented in Figure 22. The imagery shows the size of a large grounded ice field near Barter Island on 14 July, its reduced size on 1 August and its complete disappearance by 6 September. Similar events have been observed at other locations along the Alaskan coast.

The four grounded multi-year shear ridge formations observed near Harrison Bay and Prudhoe Bay have been shown to have remained stranded from the winter of 1974-1975 to the spring of 1976. It remains to be seen if they survive another summer.

**LITERATURE CITED**


Kovacs, A., H.L. McKim and C.J. Merry (1975) Islands of grounded ice. *Arctic*, vol. 28, no. 3.


Side-looking airborne radar image of 29 September 1975 showing the three grounded shear ridge formations (1-3) north of Cross Island (4) and the large shear ridge field (5) shown in Figures 5 and 6. See text, page 7. (Imagery acquired for the National Oceanic and Atmospheric Administration by the U.S. Geological Survey.)