Some Characteristics of Grounded Floebergs near Prudhoe Bay, Alaska

INTRODUCTION

During the winter of 1974-75, a large number of floebergs (fragments of multi-year pressure ridges) were found incorporated in the fast ice northwest of Prudhoe Bay, Alaska. Many of them had been driven up onto the sea floor and become stranded, as was indicated by their high free-board. Such grounding of ice on the continental shelves of the Arctic is of considerable interest at the present time to all who are concerned with the safety of offshore producing platforms and bottom-founded structures, both within the oil industry, which is seeking to develop the oil and gas reserves located offshore, and among groups seeking to protect the environment. Much of this interest concerns the forces which develop when large, deep-draughted ice masses become grounded and are then pushed by the pack across the sea floor, which in the process may become gouged and scored, or otherwise extensively modified by the ploughing action of the ice. Thus, for both economic and environmental reasons, sea-floor-based structures must be designed to resist these forces or else be buried below the deepest ice scoring of present time.

FIELD STUDIES

In order to gather information on the shape and structure of floebergs, and their effect upon the sea bed during groundings, studies were undertaken in April 1975 in the area located approximately 35 km northwest of Prudhoe Bay (70°35'N, 148°50'W). These studies included the determination of the surface relief of two floebergs (henceforward designated A and B) by means of standard surveying techniques; snow thickness measurements; the profiling of the floeberg keels by a sonar technique developed by Kovacs;[1] and an examination of the internal structures of the floebergs, including voids and impurities, as observed in fracture faces on their sails and the portions of their keels uplifted upon grounding.

The fast ice surface in the immediate area of the floebergs was highly irregular, due largely to the incorporation of ice fragments into the ice sheet. The surface was covered with a layer of snow that varied in thickness from 10 to 40 cm, depending on the relief of ice.

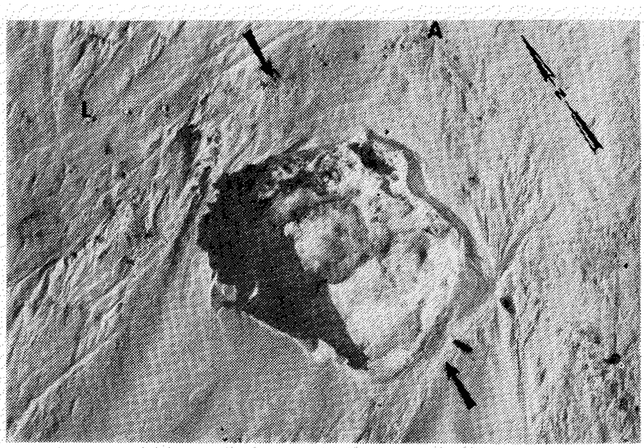
RESULTS AND DISCUSSION

An aerial view of Floeberg A is presented in Fig. 1. This shows the ice surface to be substantially free of voids, that is, the space between the original ice blocks is now thoroughly filled with refrozen melt or rain water. The fracture faces on the east and west sides of the floeberg also lacked voids. Thus, for all intents and purposes, this fragment of a multi-year pressure ridge now consisted entirely of solid ice.

The north face of Floeberg A was found to have an accumulation of broken first-year ice piled upon it. This indicates that it was driven aground, and became immobile, during a storm which pushed the ice from the north toward the coast; that the pressure on the first-year ice to the north of the formation continued to force the ice sheet southward and, unable to resist the stresses developed, it broke against the floeberg, with the result that fragments of ice accumulated in a pile on its north side and a wake of other fragments trailed to the south.

On the east side of the floeberg a distinctive ice shelf or ledge encircled it completely

FIG. 1 Aerial view of Floeberg A. The line of drilled holes marked A-L measures approximately 44 m; arrows indicate the position and direction of the cross-section profile.



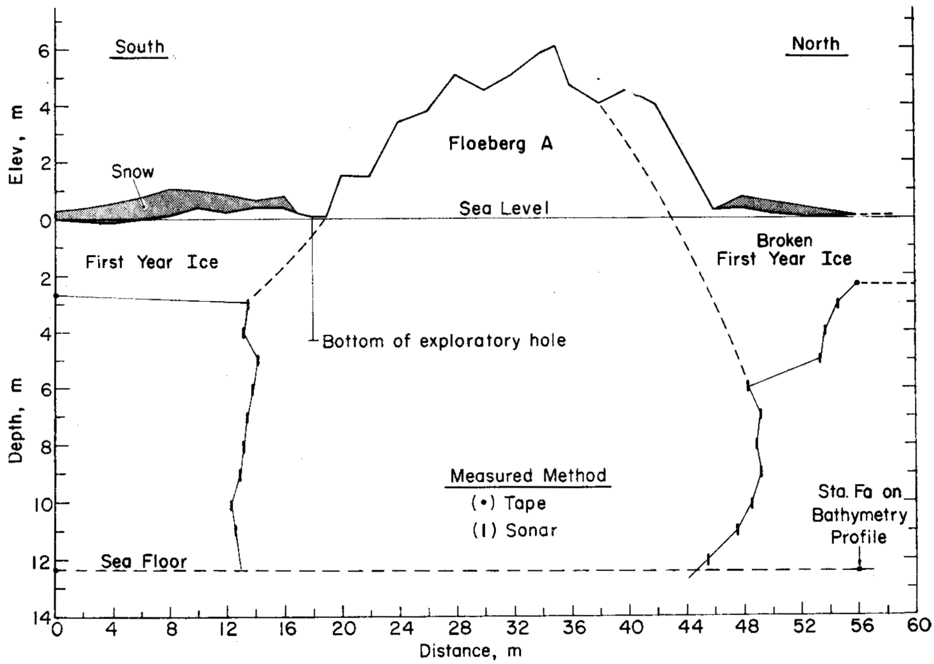


FIG. 2 Cross-section of Floeberg A.

and marked the position of the water line when the ice formation was free-floating. The ledge was elevated approximately 1.85 metres above the surrounding ice surface, indicating that the floeberg had been driven upward onto the sea floor by this amount during grounding.

A cross-section of Floeberg A is presented in Fig. 2. No voids were encountered at the site of the exploratory hole, indicating that this part of the floeberg was composed of a solid mass of ice blocks. The maximum sail height of Floeberg A was 6.06 m; the keel depth measured approximately 12.4 m. If these dimensions are adjusted to take account of the uplift of 1.85 m associated with grounding, then the sail height reduces to 4.21 m and the keel depth increases to 14.25 m. A sail height to keel depth ratio of 1 to 3.38 is thereby obtained which agrees well with the 1 to 3.3 ratio of sail height to keel depth found by Kovacs *et al.*,[2] and the 1:3.13 ratio found later by Kovacs,[3] for multi-year pressure ridges.

To determine if the ice keel had scored the sea floor during grounding, a series of holes (marked A-L in Fig. 1) were drilled through the ice cover along a line parallel to the north side of the floeberg, and the depth to the sea floor then measured by lowering a weighted tape through the holes. Results of these measurements, presented graphically in Fig. 3, reveal some micro-relief between stations A and C, where depths were measured every metre, but no major depression was observed that would indicate the keel had scored the sea floor significantly. Soundings made along the east and west side of the floeberg also

FIG. 3 Profile of sea floor from directly behind Floeberg A.

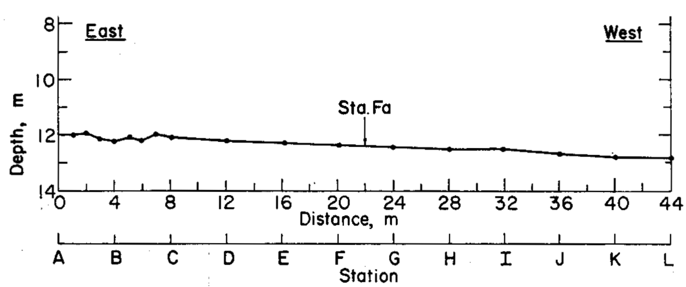
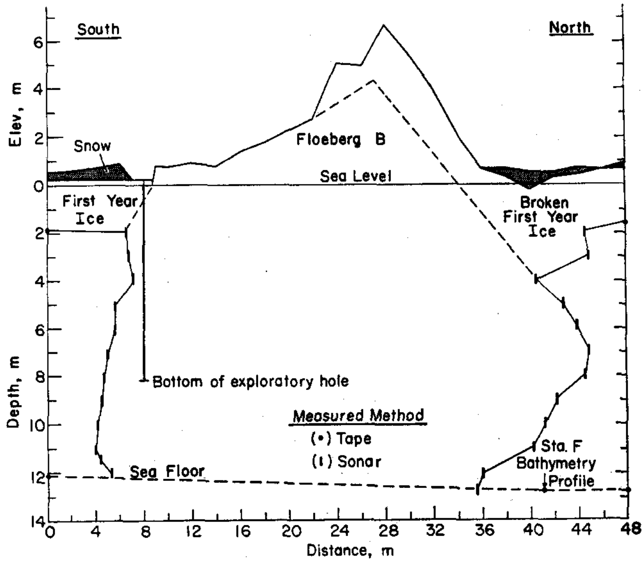


FIG. 4 Cross-section of Floeberg B.



failed to reveal any definite trace of scoring of the sea bed. This lack of scoring behind Floeberg A might be attributed to a flat-bottomed keel that "slid" along, rather than "ploughed" through the sea floor which, at this location, was composed mainly of coarse sand.

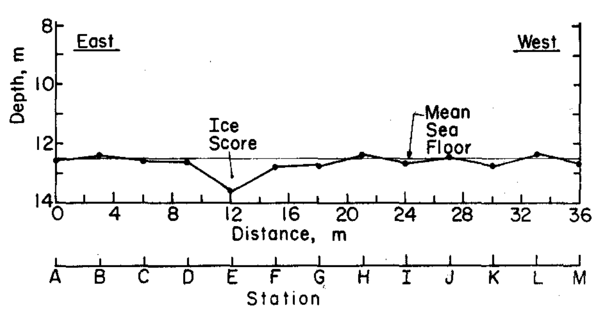
Floeberg B was roughly triangular in shape and, as with Floeberg A, a large accumulation of fragmented first-year ice was piled along its north side and a wake of broken ice trailed to the south. These observations imply that Floeberg B had also gone aground during a storm which had driven the ice cover southward toward the coast, that the grounding was accompanied by an uplift of the floeberg into its present position, and that eventually it became so firmly grounded that the thin first-year sea ice broke against it and began to pile up on its northern face. In this particular instance, the weight of additional ice caused the floeberg to acquire a tilt to one side which prevented any accurate assessment being made of the total uplift associated with grounding.

The cross-section of the floeberg is shown in Fig. 4. The highest elevation on the surface profile was 6.65 m and the keel is shown to be grounded in approximately 12.5 m of water. The extent to which first-year ice has piled up on the north side of the floeberg is also indicated.

The profile of the sea floor immediately behind the floeberg is shown in Fig. 5. The sea floor has a deep depression near the centre of the north face of the floeberg at Station E. On each side of this depression the sea bed has an undulating relief, with a mean depth of approximately 12.5 m. The depression is attributed to the keel of the floeberg as it ploughed into the sea floor during grounding. The maximum depth of the score below the mean sea floor depth is 1.1 metres. The score is approximately 15 m wide and has an average depth of 32 cm.

Large numbers of ice keels, coming aground on the arctic shelf, have caused widespread scoring of the sea floor. The effect of

FIG. 5. Profile of sea floor from directly behind Floeberg B.



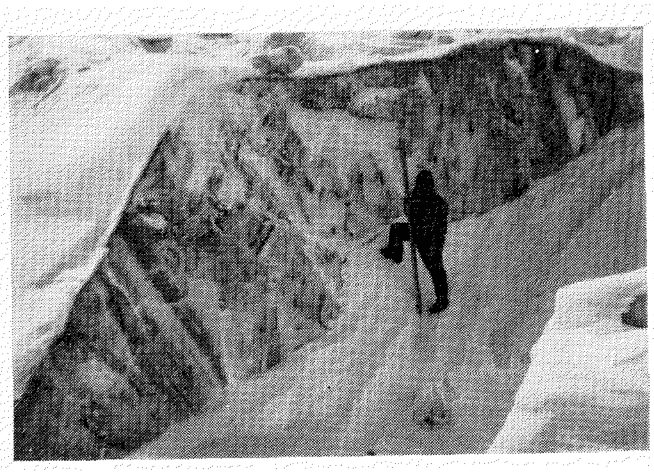


FIG. 6 Exposed section through centre of floeberg showing structural arrangement of ice blocks. Ice contains abundant algal remains and some sedimentary material (dark patches).

this scoring on biological activity of the sea floor is significant for, as Geikie,[4] Wright and Priestley,[5] Rex,[6] Kovacs and Mellor,[7] Kovacs,[8] Reimnitz and Barnes,[9] Barnes and Reimnitz[10] and others have reported, ice scoring of present time does cause a mixing of sea bed deposits, disrupting stratification and causing oxygenation of the sediments. Such interaction of ice with the sea floor not only disturbs bottom conditions sufficiently to hinder the growth of plants, but also inhibits the occupation of the sea by many marine species which might otherwise inhabit the area.

Visual examination of some 50 additional floebergs in the general area of Floeberg A and B indicated that all were composed of tabular blocks and assorted fragments of ice, ranging in size from a few centimetres to several metres across, and firmly frozen together with no trace of interblock voids. Internal structure was best revealed in the exposed faces of floebergs that had split apart, and a typical example of such structure is presented in Fig. 6.

All floebergs contained variable quantities of debris enclosed within the blocks of ice and between them. Most of this debris was organic in nature, composed principally of brown algae that had obviously been trapped in the ice during freezing. Sedimentary material was identified mainly as of silt-clay composition, though coarse sandy debris was occasionally observed. The finer sedimentary particles are probably of aeolian origin, but the exact source and manner of entrapment of the coarser particles have not been firmly established.

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