A Radar Profile of a Multi-year Pressure Ridge Fragment

A multi-year pressure ridge is one of the most formidable ice formations found in the Arctic pack. It is made up of a solid, resistant mass of low-salinity ice which is an obstacle to ships and a potential danger to proposed offshore bottom-founded structures, cables and pipelines. Multi-year ridges can be driven by the wind or pushed by the pack into shallow waters where they may come aground, deeply gouge the seabed and thereby destroy a seabed installation. Because of this potential danger, and to meet the need for information on the distribution of ice thickness, which is used in studies related to modelling and understanding of the dynamics of the sea-ice cover, a number of investigations have been made to profile the thickness of multi-year ice formations. These studies have included ice thickness profiles obtained with side-looking sonar[1,2,3,4] and direct measurements[1,3,5] made through drill holes or fresh cracks which have split the ice in two[5]. In addition, the thickness of a multi-year floe has also been profiled with impulse radar[6].

In May 1977, impulse radar was used to profile the thickness of an ice island[7] and the first-year sea-ice near our camp site on Narwhal Island, Alaska. At this location, a small fragment of a multi-year pressure ridge was found with good access to the ridge crest (Fig. 1). The impulse radar system was taken to the ridge so that it could be used to ascertain if thick multi-year ice could be measured and if the thickness of the ridge along the crest could be profiled. A cross-sectional profile of the ridge was not attempted, because the ice surface was buried under a thick layer of drift snow.

The impulse radar profiling system consisted of an electronics console, a graphic recorder and an antenna. The system and its operational characteristics have been described in several publications[6,7,8,9]. The radar antenna was pulled for a distance of 21 metres along the top of the ridge. The graphic record obtained is shown in Fig. 2. The signal information shown is the travel time of the radar impulse signal to and from the various reflecting surfaces. These include the surface of the ridge, internal block structure, and the irregular surface of the keel. The reflection from the ridge keel is indicated by the solid line drawn through the data.

Taking the two-way travel time scaled from the graphic record, and using an effective propagation velocity of the radar in multi-year ice[5] of 0.152 m/ns, the ice thickness was determined from:

$$D = V_e \frac{t_d}{2}, \text{ where:}$$

D = depth
V_e = effective velocity of the radar signal
t_d = travel time from transceiver antenna to and from subsurface interface

The calculated ice thicknesses for the stations shown in Fig. 2 are shown in Table 1 along with the height of the ridge sail determined by elevation survey. The thickest ice was 14.0 m. Also listed in Table 1 is the keel depth, determined by subtracting the sail elevation, rounded off to the nearest tenth, from the ice thickness, and the sail height to depth ratio for each station.

The average height to depth ratio is 1:3.28. Surprisingly, this ratio is in reasonably good agreement with the 1:3.13 ratio determined by direct drilling or sonar measurement[4]. Because of its beam spread, the radar antenna can "see" other surfaces besides the one directly below it. It was therefore expected that the graphic record would show returns from surfaces somewhat further away than the bottom of the ridge. If this had occurred to any significant extent, the apparent bottom or ice thickness would have been greater and the average height to depth ratio would have been disproportionately higher.

Using the data listed in Table 1, a cross-section of the ridge was constructed (Fig. 3). Also plotted in Fig. 3 is the keel depth as determined by using the height to depth ratio of 1:3.13. Because this ratio is less than the average one arrived at in this study, the calculated depth shown in Fig. 3 is less. The difference between the two bottom profiles

FIG. 1. West end view of the multi-year pressure ridge fragment.

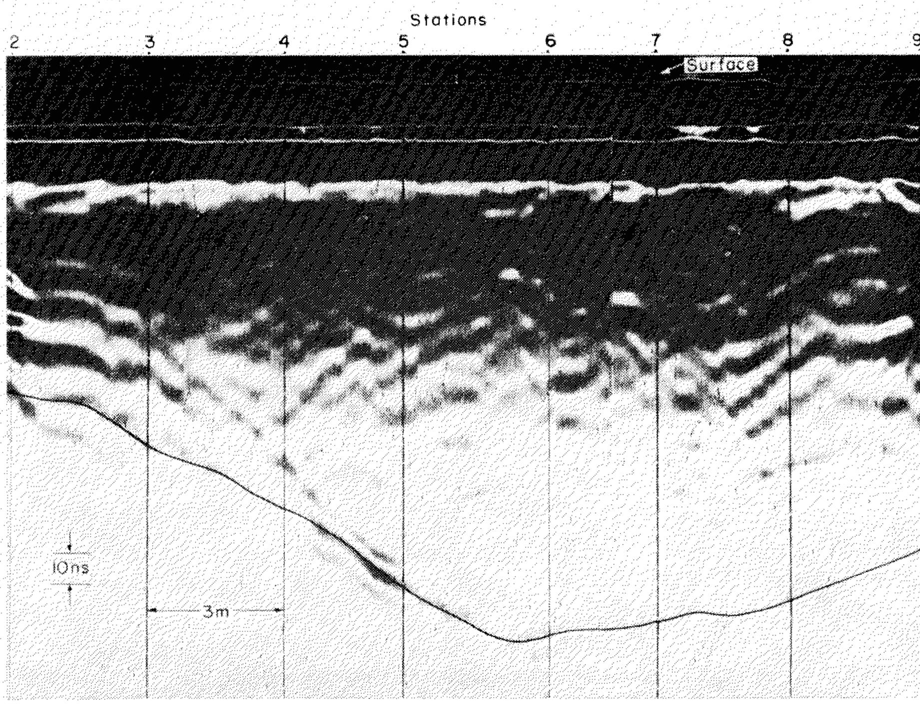

FIG. 2. Impulse radar data taken along crest of the multi-year pressure ridge fragment.

may represent the effect of antenna beam spread as mentioned above. This remains to be verified.

Another technique[5] may be used to construct a cross section of multi-year ice with a thickness greater than 5.5 m. The ice thickness is first multiplied by 0.2425 to obtain the surface elevation. Subtracting this height from the total thickness gives the keel depth. The result of applying this analysis gives the top and bottom profiles shown as no. 3 in Fig 3. The resulting cross-section agrees quite well with the cross-section constructed from the data in Table 1.

This report demonstrates the potential usefulness of impulse radar for determining the thickness of multi-year pressure ridges. Although reasonably good correlation was shown between the profile as arrived at in this study and that of others[4], it must be cautioned that radar profiling of multi-year ice is still in its infancy. Further field work

TABLE 1. Elevation, thickness, depth and height-to-depth measurements for the multi-year pressure ridge fragment.

Station	Sail elevation	Ice thickness	Keel depth	Height: depth ratio
1	1.89 m	8.3 m	6.4 m	1:3.37
2	2.29	9.8	7.5	1:3.26
3	2.71	11.0	8.3	1:3.07
4	3.02	13.4	10.4	1:3.47
5	3.29	14.0	10.7	1:3.24
6	3.08	13.9	10.8	1:3.48
7	2.78	13.3	10.5	1:3.75
8	2.89	10.5	7.6	1:2.62
				(Mean) 1:3.28

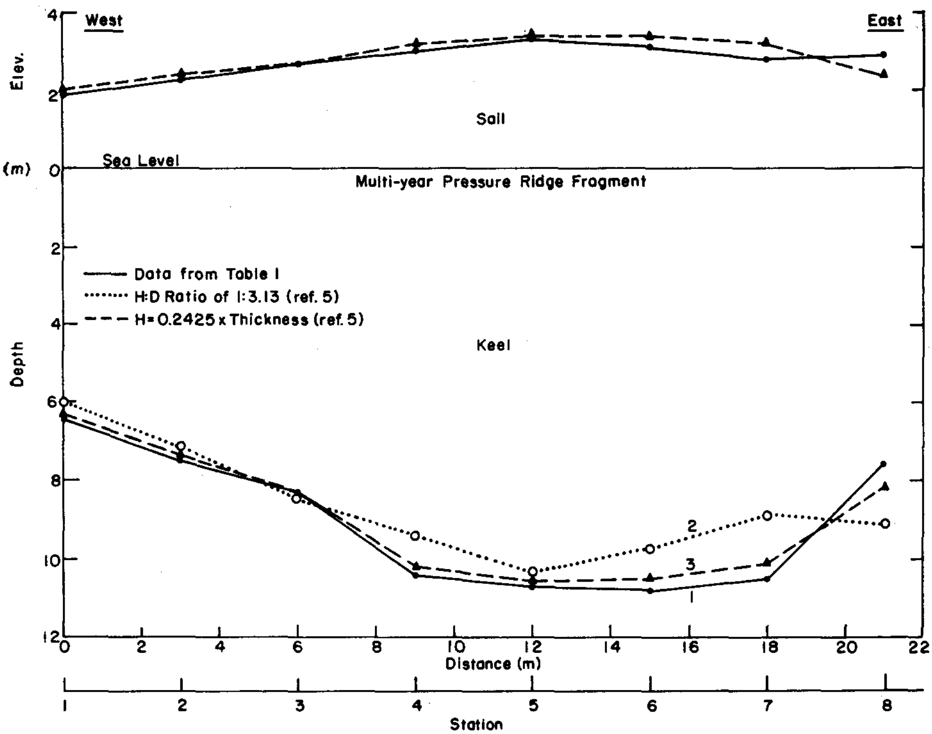

FIG. 3. Cross-section of the multi-year pressure ridge fragment, as determined: 1, from impulse-radar results of the present study; 2 and 3, from results of Kovacs 1977 (reference no. 4).

must be carried out to cross-correlate measurements of ice thickness obtained from radar with those obtained from a drill hole. This study is therefore only a first step. Nevertheless, with guarded optimism, it is considered that such tests will demonstrate that radar can provide useful information on the thickness of multi-year pressure ridges. However, unlike multi-year ridges which are composed of solid ice, first-year pressure ridges generally consist of a random accumulation of ice blocks. Below sea level, the voids between these blocks are filled with salt water into which the radar impulse cannot penetrate because of the water's high conductivity. Therefore, there is no expectation that impulse radar will be usable for profiling the thickness of first-year pressure ridges.

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