Under Surface Profiles of Sea Ice Obverved by Submarine*

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The first successful dive under sea ice by submarine was made August 1, 1947 in the Chukchi Sea. Scanning sonar and visual observation by periscope was used to guide the U.S.S. BOARFISH from open water under the ice fields for a distance of 3 miles and out again to open water. Many experiments followed each succeeding year, using Fleet type, diesel-battery submarines to develop diving and sonar techniques under ice. In 1957, when nuclear power became available the U.S.S. NAUTILUS cruised 1 300 miles under sea ice, and the Arctic Ocean was truely opened to rapid exploration.

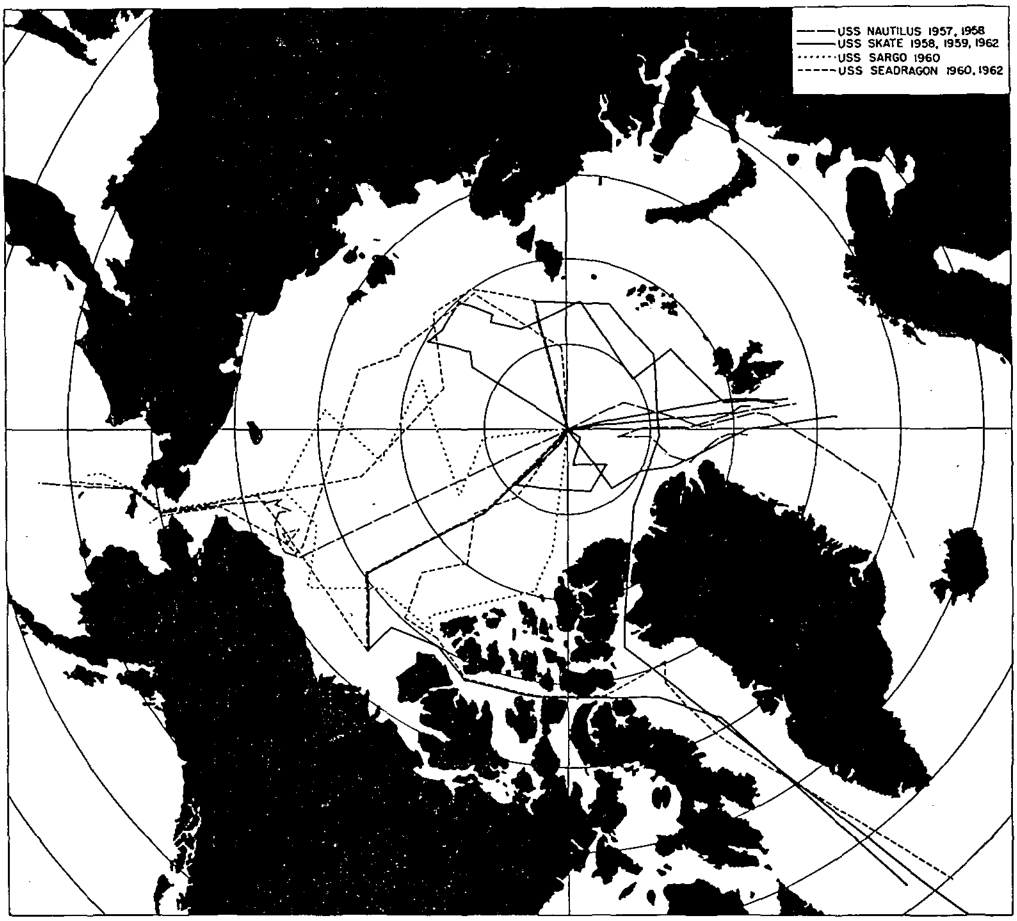

Fig. 1. Submarine cruises, 1957–1962

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A series of submarine cruises quickly followed during the next five years and are summarized in Fig. 1.

Successful operation of a submarine under ice has meant that many oceanographic parameters of the Arctic Ocean could be observed. For example, a precision depth recording is taken wherever the submarine goes, quickly and readily extending bathymetric information. Water temperature, electrical conductivity, and optical transparency, amount of ambient light, earth's gravity and plankton population are observed continuously or sampled periodically by instruments carried on or within the hull. Of course, sea water chemistry *in situ* can be done easily by drawing a water sample and conducting the chemical analysis on board, including the treatment of large samples to concentrate trace elements. Radioactive trace elements are counted expeditiously because by diving deep, the background count due to cosmic rays can be reduced to a low level. The data taken during the various cruises have been or will be reported in papers published by the investigators for whom the data were collected or who are experts in the specific field to which the data apply.

Data of particular interest to this symposium on ice are the under-side profiles of the sea ice canopy, which are readily observed by submarine. The sonar system used for under-ice piloting is diagrammatically shown in Fig. 2. A forward-looking sonar beam, narrow in vertical angle, is used to detect ice projecting down to ship's cruising depth: for example, icebergs or deep pressure ridges. Where there is sufficiently deep water, for example, the central Arctic Ocean, cruising depth is set sufficiently deep to clear all pressure ridges easily, or the very rare ice island, draft perhaps 160 ft. However, in shallow areas, for instance the Bering and Chukchi Seas, the existence of deep pressure ridges necessitates careful piloting and detailed knowledge of the bathymetry and sound transmission conditions.

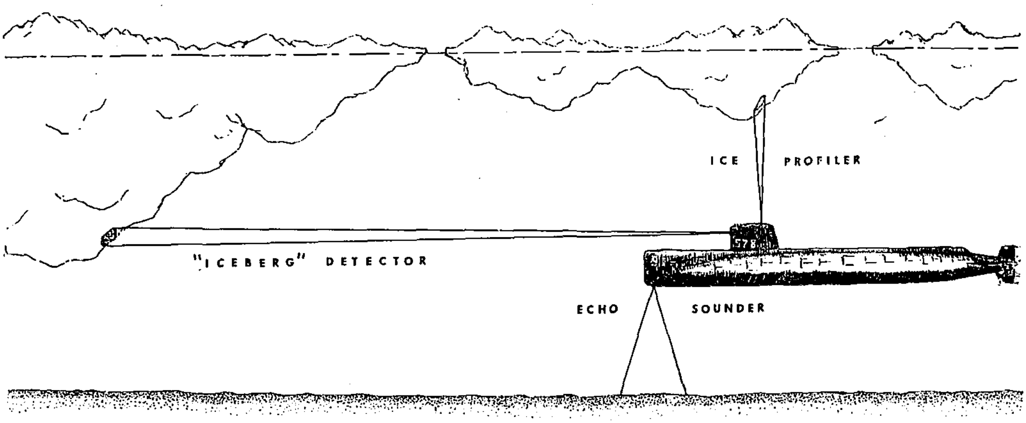

Fig. 2. Under ice sonar

During February 1960, the U.S.S. SARGO entered the Arctic Ocean by transiting 900 miles arcoss the very shallow water of the Bering and Chukchi Seas, depth 125 to 180 ft. During winter the area is covered with drifting sea ice, including many rafted ridges extending down to drafts of 100 ft or more. The sonar system was used successfully to pilot SARGO, cruising 25 ft above sea bottom, threading and twisting her way

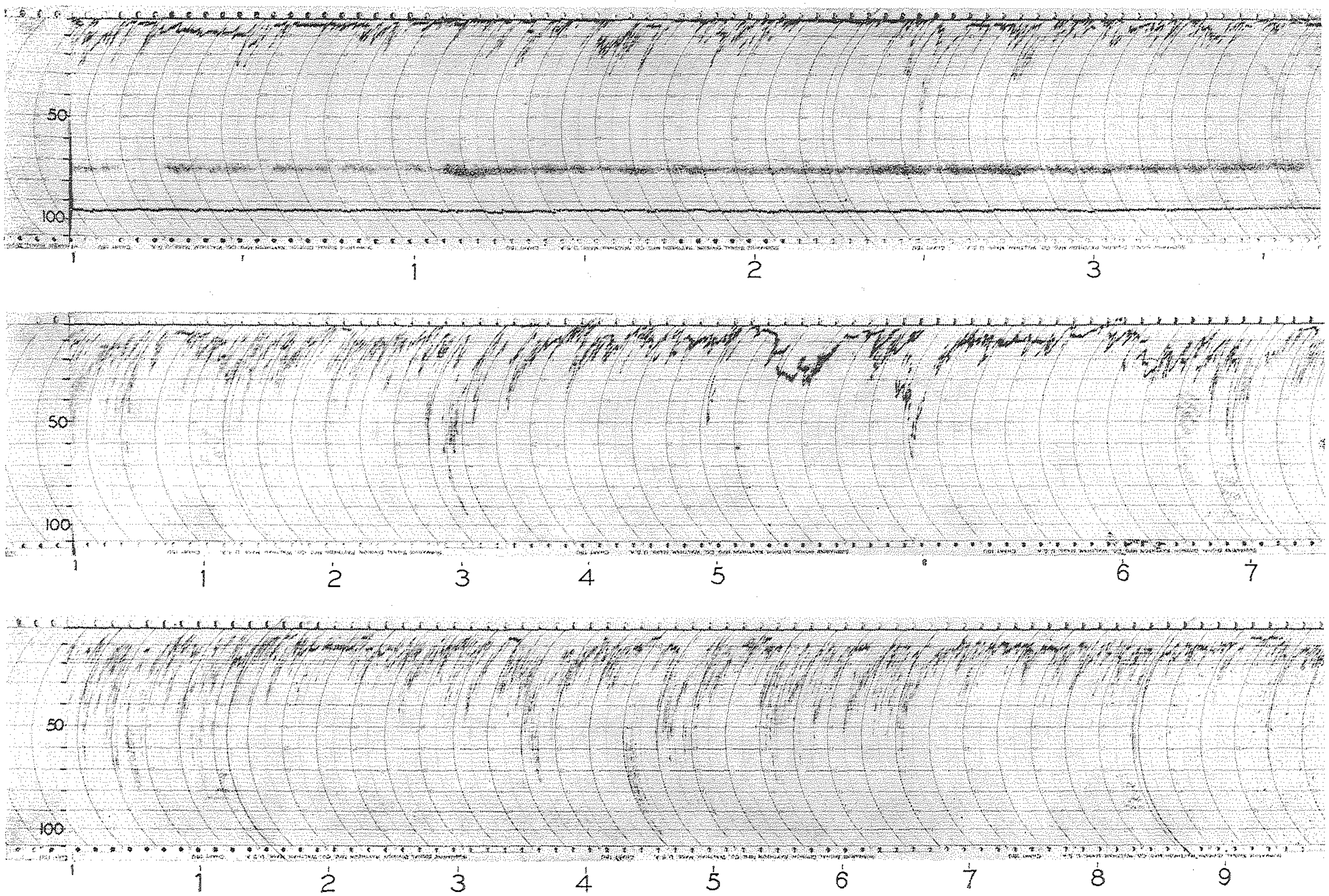

Fig. 3. Examples of ice profile record, U.S.S. SARGO

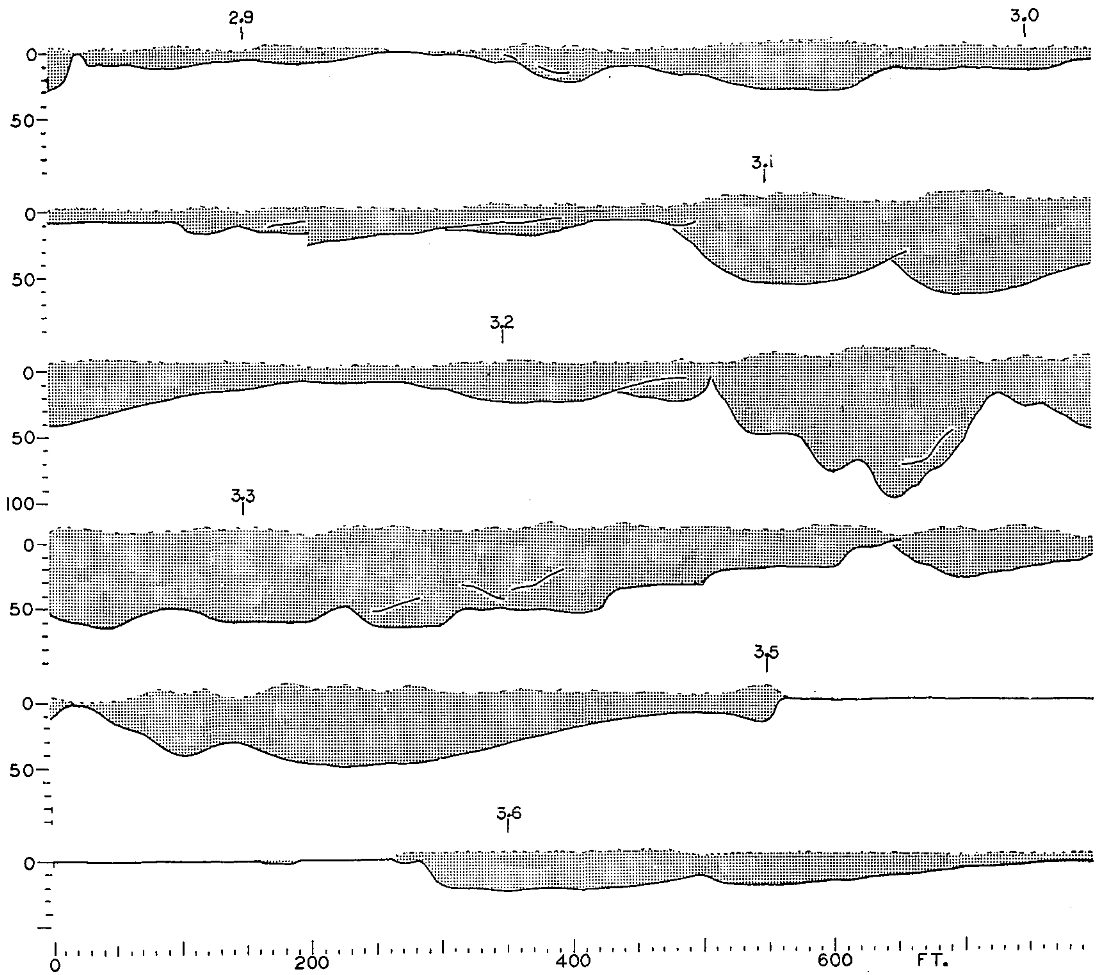

Fig. 4. Horizontal expansion of small section of ice profile in Fig. 3

between the deepest ice ridges. The upwardlooking sonar records a continuous profile of the under surface of the ice canopy. The zero depth (open sea) reference level is determined by a high precision, pressure-sensitive device, which senses the hydrostatic depth of the submarine and controls the timing circuitry of the sonar recorder through a suitable servomechanism. An example of the recorded profile obtained on SARGO is shown in Fig. 3 (top sample trace). The horizontal scale is in nautical miles, and the vertical scale is in feet beneath open water surface. The dark, nearly level trace at about 95 ft scale depth is a record of the outgoing pulse. (The broad, intermittent trace at about 75 ft scale depth was due to reflections from a trailing antenna cable streaming aft from the top of the sail.) Additional examples of under-ice profiles are given in the middle and bottom sample traces which were observed in the central Arctic Ocean on board SARGO and illustrate the frequent occurrence of pressure ridges per mile, characteristic of the ice canopy just north of the Queen Elizabeth Islands.

Many thousands of miles of under-ice profiles have been collected during the many submarine cruises. However, the difficulties of analyzing these profiles and presenting the data in a useful, summarized form have been nearly insurmountable. The records are highly complex with much intricate detail that must be carefully measured to obtain the full value of the records. Manual, point by point reading is impossible. However, very small sections of the records have been read. For example, the small section near the 3 mile mark of Fig. 3 (middle sample trace) was read point by point and replotted as shown in Fig. 4 to illustrate the information available in the profile records. Various methods of mechanical reading and summary analysis have been attempted. Recent advances in the art of curve following devices offer a means of transposing the records into digital form. It will then be possible to quickly analyze the profile records by conventional computer techniques.

We fully recognize the importance of the information inherent in these ice profile records; for example, information urgently needed in calculation of the ice budget of the Arctic Ocean and associated oceanographic/meteorological problems, as well as in consideration of attenuation of sound under sea ice. If, and when we are successful in editing and digitalizing the profile records, we shall publish brief summaries of the results. The processing of the profile records into digital form will take twelve to eighteen months. Then, since the information will be stored on magnetic tape, a specific summary, for example, frequency distribution of perssure ridges of specified drafts, or geographical variation in mean ice draft, etc., can be read out by appropriate computer program. Anyone desiring specific summaries are invited to write to us in San Diego.