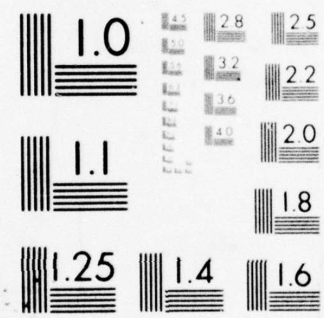
AD-A032 759 NAVAL OCEANOGRAPHIC OFFICE WASHINGTON D C F/G 8/12
CHARACTERISTICS OF POLAR ICE OBSERVED DURING THE 1957 ARCTIC CR--ETC(U)
OCT 58 W I WITTMANN, J F ROPEK

UNCLASSIFIED NOO-TR-40 NL

1 OF 1
AD A032759

END
DATE
FILMED
2-77



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS 1963-A

TECHNICAL REPORT

CHARACTERISTICS OF POLAR ICE OBSERVED DURING THE 1957 ARCTIC CRUISE OF THE USS NAUTILUS

WALTER I. WITTMANN
and
JOHN F. KOPEK
Applied Oceanography Branch
Division of Oceanography

26p.

OCTOBER 1958

Naval Oceanographic office
U.S. NAVY HYDROGRAPHIC OFFICE
WASHINGTON, D.C.

[redacted]

UNCLASSIFIED

ABSTRACT

About 400 15-minute ice summaries were prepared aboard the USS NAUTILUS (SSN 571) during the summer 1957 Arctic cruise. These summaries were analyzed and mean values for ice concentration, size of floes, ice thickness, and open-water features were determined. The mean values are presented for latitudinal and regional increments along the cruise track. The results are compared with data taken during past surface expeditions into the Arctic Ocean. In addition, the tenability of some existing concepts concerning sea-ice growth and distribution is discussed with respect to the new data gathered.

USHO WASH., D.C.

UNCL[illegible] [redacted]

FOREWORD

Increasing military activities in Arctic Regions (including the Arctic Ocean) have stimulated a search for knowledge of the environment of those regions. The advent of the nuclear submarine has not only contributed to this stimulation but also has made available a vehicle with a tremendous range and almost unlimited maneuverability. The use of the nuclear submarine deep within the Polar Pack has provided the investigator with an opportunity to collect data in detail not previously possible.

For the past 12 years the Hydrographic Office has supported military logistical expeditions to the North American Arctic, and more recently has provided a comprehensive sea-ice forecasting service. This support has been confined entirely to surface shipping and can be extended in future years to under-ice operations. The analyses contained in this report represent an initial step in presenting data especially designed to aid under-ice operational units and will provide a basis for expanding prediction capability.

H. C. Daniel

H. C. DANIEL
Rear Admiral, U. S. Navy
Hydrographer

PREFACE

This study is concerned with the distribution of polar pack ice or with that conglomerate of sea ice that exists perennially over the central waters of the Arctic oceanic region. Some knowledge of polar pack-ice behavior was gained initially by inference from the drift of bits of wreckage of the ill-fated JEANETTE after its abandonment by Lt. Delong and his men in 1881. During the famous drift of Friedhof Nansen's FRAM, in the years 1893-96, from a position north of the New Siberian Islands to one off the northern tip of Spitzbergen, additional invaluable knowledge was obtained, especially concerning the wind drift of ice. In 1938 the Russian icebreaker SEDOV repeated, essentially, the drift of the FRAM, although the SEDOV's track was somewhat northerly. In that same year the first of a series of manned drift stations was established by scientists of the USSR. Six additional drift stations were operated from that time to the present by the Russians. A considerable number of scientific articles have been released by the Russians which are based on these ice station experiences, as well as on a great number of aircraft landings made on ice since the early 1930's. The basic data on which these scientific articles are based have been largely withheld. As a result, the only large body of data that has been available to U. S. scientists concerning features of Arctic pack-ice behavior has been obtained from Ice Island T-3 (Fletcher's Ice Island), manned sporadically during the period 1952-55, and more recently from the IGY Ice Stations Alpha and Bravo (the latter representing remanning of T-3).

The data collected by the NAUTILUS, therefore, have been of extreme value to those interested in Arctic ice distribution, especially from an ice forecaster's point of view.

Basic data were obtained primarily from topside fathometer instrumentation developed over the past decade for conventional type submarines operating in sea ice by Dr. Waldo K. Lyon of the Navy Electronics Laboratory (NEL). NK-type fathometers were installed under the direction of Dr. Lyon and were monitored continuously by NEL personnel while the ship was operating under the ice. The 15-minute summarizations made continuously from this instrumentation served as the primary source of data for this report. Dr. Lyon's work on the topside fathometer as a means of studying sea-ice characteristics is still in a developmental stage, and modifications and improvements are continually being incorporated. The capability of interpreting the recordings is also increasing with expanded use of the instrument. In the period since the NAUTILUS returned from her 1958 cruise, Dr. Lyon has established that some of the lighter stylus impressions, ignored in this analysis, were in fact returns indicating protuberance depth. As a result, statistical summarizations in this paper somewhat underestimate the absolute underwater extent of these protuberances. Inasmuch as the portion of this analysis dealing with protuberances is concerned primarily with latitudinal and regional variation, and as the method of tabulating values for this variable is uniform and consistent, these analyses are nevertheless considered significant.

Finally, the excellent cooperation extended to the junior author by the Commanding Office of the NAUTILUS, Commander William R. Anderson, and by the officers and men of that ship during and subsequent to the cruise, has contributed greatly to the production of this report and, more important, to our general knowledge of the polar pack ice.

CONTENTS

FIGURES

TABLE

I. INTRODUCTION

The 1957 Arctic cruise of the NAUTILUS provided a new and virtually untested method of collecting information concerning the characteristics and behavior of pack ice covering the inner regions of the Arctic Ocean. Such information is vitally important for two reasons. First, it furnishes Arctic operational agencies with much more precise knowledge of what may be expected in terms of sea ice during future operations. Second, it furnishes the sea-ice forecaster with much needed knowledge which will undoubtedly enhance existing theories and concepts concerning sea-ice growth, drift, deformation, and disintegration. The only data concerning seasonal changes in sea-ice distribution of the central Arctic regions in the past have been gathered by aerial ice reconnaissance. Although such data are, and will continue to be, extremely useful and important, they are subject to severe limitations. For example, ice thickness and the underwater aspects of sea ice are almost completely undeterminable through aerial observation. Gathering sea-ice data from the submarine must be considered as an additional, and an equally important, means of data collection.

Before discussing the instrumentation and the data collected, descriptive definitions of the sea-ice features and characteristics that are to be considered follow:

1. Concentration is the percent coverage by sea ice of a specifically defined sea-water locale at a given time.

2. Ice thickness is the vertical distance from the top to the bottom of the ice. In measurements and statistical averages of ice thickness, only the relatively level part of the ice is considered, that is, the pressure ridges or deformed parts of the ice are excluded.

3. Depth of underwater protuberance is the vertical distance from water level to the bottom of the deformed part of sea ice. Underwater protuberances are the underwater projections of ridges and hummocks that are caused by deformational forces acting within pack-ice areas. Little attention has been given to underwater protuberances in descriptive ice glossaries in the past because no means for extensive observation of these features deep within the polar pack existed prior to the advent of the nuclear-powered submarine.

4. Open-water features are ice-free regions or regions of lesser concentration existing within pack ice. In this report, open-water features

are divided into one-dimensional and two-dimensional openings. One-dimensional water openings are designated as such because the topside fathometers record only along a single line and give no indication of areal coverage. Two-dimensional openings, which are determined by SQS-4 sonar, indicate approximate areal coverage. One-dimensional openings predominate in the analysis of these data because it is the only manner in which such features could be determined consistently from available instrumentation. The one-dimensional openings are subdivided further for convenience into those having dimensions <300 yards and those ≥ 300 yards. The probable degree of clutter within the openings is indicated in the figures. The openings shown as "apparently clear" are doubtful because of the limitations of available instrumentation. The distinction is made, however, so that a relative determination of the quantity of ice (degree of clutter) within the water openings can be obtained.

5. The <u>size</u> <u>of</u> <u>ice</u> <u>fragments</u> <u>or</u> <u>floes</u> was regularly reported in terms of one dimension. Occasionally, observations were made in terms of length and width. In this report, care was taken to comply with the size types as defined in the Ice Glossary, H. O. Pub. No. 609 (1[illegible]).

A knowledge of these sea-ice features is invaluable for determining the cruising depth of SSN-type submarines, design modifications necessary for surfacing such submarines within pack-ice areas, optimum operational sites on sea ice for scientific observations and for establishing communication, certain types of missile and antimissile bases, and sites for submarine surfacing operations related to possible search and rescue operations.

II. INSTRUMENTATION AND DATA

The data were taken while underway and are based primarily upon continuously recording topside fathometers and an SQS-4 sonar.

NEL analysis of the topside-fathometer records indicated a definite oscillation of the submarine depth. An absolute point by point determination of ice thickness therefore must be in error. This report, however, is based on 15-minute-interval ice summaries made visually by the operator who continuously monitored the recorders. Inasmuch as the submarine depth oscillated about a mean depth, such summarization should provide approximate mean ice thickness over the 15-minute time interval. Although such a presumption is reasonable, further substantiations of the results should be made if possible.

An example of a 15-minute summary, the raw data on which this report is based, is as follows:

5 Sept. '57 2115Z 81°17.5'N, 05°00'W	8/10 conc. Floes 600 yards in size. Average thickness 6 feet. Maximum thickness 15 feet. Water openings less than 100 yards and contain block. SQS-4 reported lead 200 x 600 yds, at least, on starboard side.

In summarizing the above data for statistical presentation, the following procedure was followed. The <u>concentration</u> was converted to percent and tabulated. The <u>thickness</u>, 6 feet, represented the distance from water level to the bottom surface of the level ice; therefore, it was multiplied by a factor of 1.25 in order to take into account, theoretically, that part of the relatively level ice above water level. The <u>depth of underwater protuberances</u> was considered to be the maximum thickness of 15 feet. The <u>number of one-dimensional water openings</u> was considered to be arbitrarily 3 inasmuch as more than 1 is indicated, and the NAUTILUS traveled 5,067 yards during the time of the observation. The <u>size</u> of these openings was, as indicated, less than 100 yards. A <u>two-dimensional opening</u> of 0.03 square nautical mile was computed by using the dimensions of the opening reported by SQS-4 sonar. The openings were tabulated as cluttered as they were reported to contain block ice. The mean size of the floes was tabulated because none was reported in this observation. An example of how maximum floe sizes were reported (included in the 15-minute summary at 1330Z on 8 September) is as follows:

> One floe 10,000 yards in size, remainder floes medium in size.

III. DISCUSSION OF THE DATA GROUPED BY LATITUDE

Sea-ice data procured by the NAUTILUS were compiled and mean values computed for each latitude. Figure 1 shows the latitudinal variation of the mean concentration, thickness, and depth of underwater protuberances. The mean concentration (Fig. 1a), except for the marginal ice-boundary region, shows a consistency within the pack-ice area varying from 80 to 92 percent; a mean concentration of 34 percent was observed in the marginal region south of 80°N. In regions north of 80°N, however, large continuous stretches of consolidated ice (100 percent) frequently occurred.

Figure 1b shows mean ice thicknesses, and Figure 1c shows the mean depth of underwater protuberances. As the original data provided only the distance between the water level and the underwater ice surface, the total ice thickness was reconstructed theoretically. The ice-thickness data presented are the total reconstructed sea-ice thicknesses. A steady, gradual increase of thickness with latitude is reflected in these data, except for nearly uniform thicknesses between 81° to 83°N and 84° to 86°N. The mean ice thickness during the cruise, not shown in Figure 1b, was 9.4 feet. The standard deviation in the means of all thickness observations was 3.7 feet, that is, 68 percent of the ice-thickness observations varied between 5.7 and 13.1 feet.

The mean ice thickness of 9.4 feet corroborates data provided by F. Nansen during the drift of the FRAM in 1893-96, by the drift of the Russian vessel SEDOV during the period 1937-38, and by American and Russian ice floe stations from 1938 to the present. The sparse historical data would seem to indicate a mean thickness of about 10 feet within the sea-ice regions of the Arctic Pack. By utilizing empirical relationships established by Zubov in 1938, ice forecasters are able to approximate theoretical variations of ice growth with time. This approximation is shown in Figure 2. Also shown on Figure 2, for comparison, are thicknesses measured from aboard the FRAM in 1894-95, north of the Siberian Arctic (Sverdrup, 1956); those measured by the Russian drift station, North Pole-1 in 1937-38 (Papanin, 1947), in an area close to that traversed by the NAUTILUS; those by U. S. IGY Floating Station Alpha, 1957-58 (Untersteiner, 1958); and the NAUTILUS data. As shown in Figure 2, the mean ice thickness observed aboard the NAUTILUS during September 1957 is considerably above that approximated from the Zubov formula, that is, 9.4 feet compared to 7 feet. However, the NAUTILUS value is in close agreement with those thicknesses reported by USSR Station North Pole-1 and U. S. IGY Station Alpha. This disparity indicates the need for more

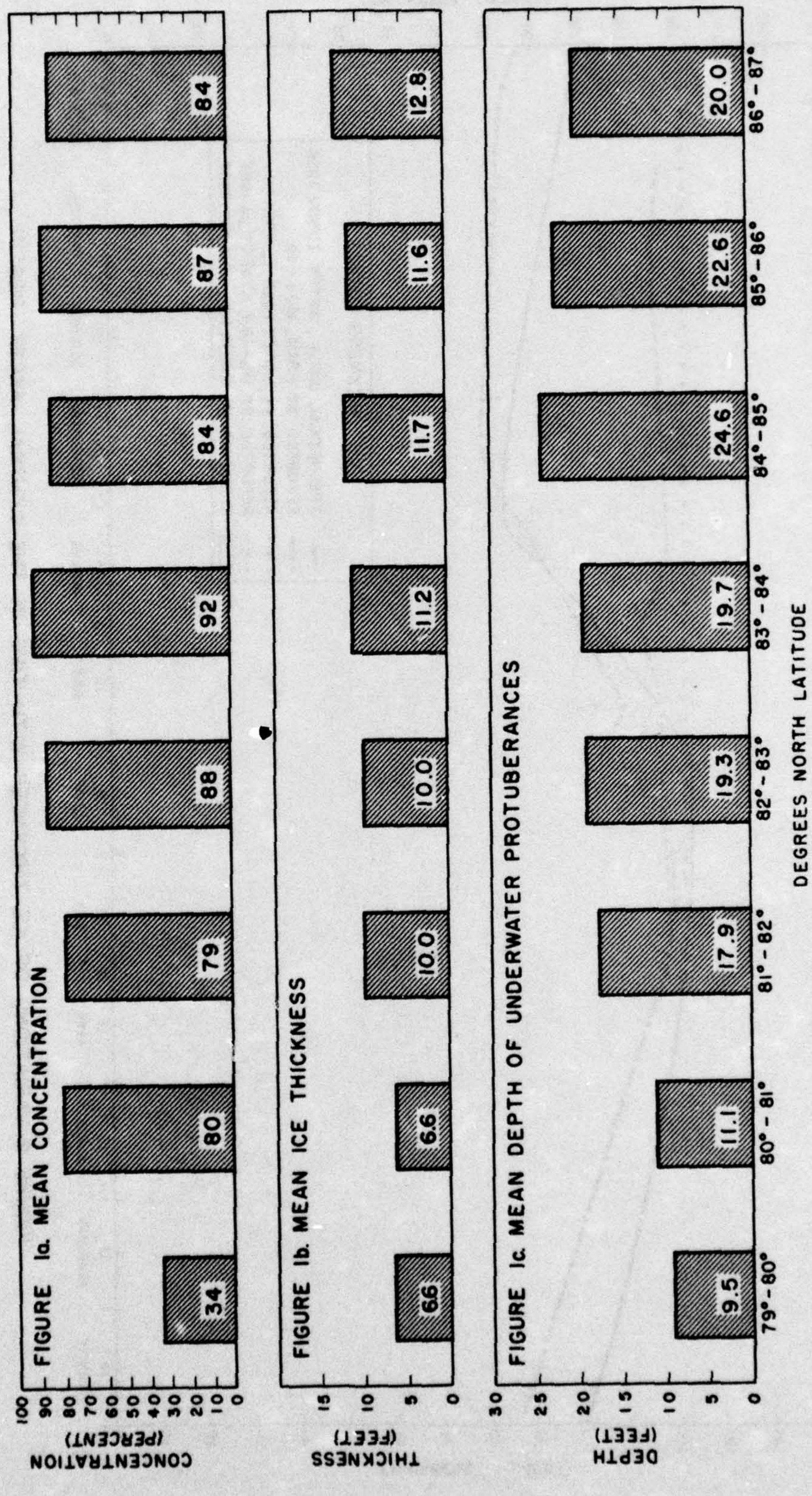


FIGURE 1. PROBABLE DISTRIBUTION OF VARIOUS SEA-ICE FEATURES BY LATITUDE

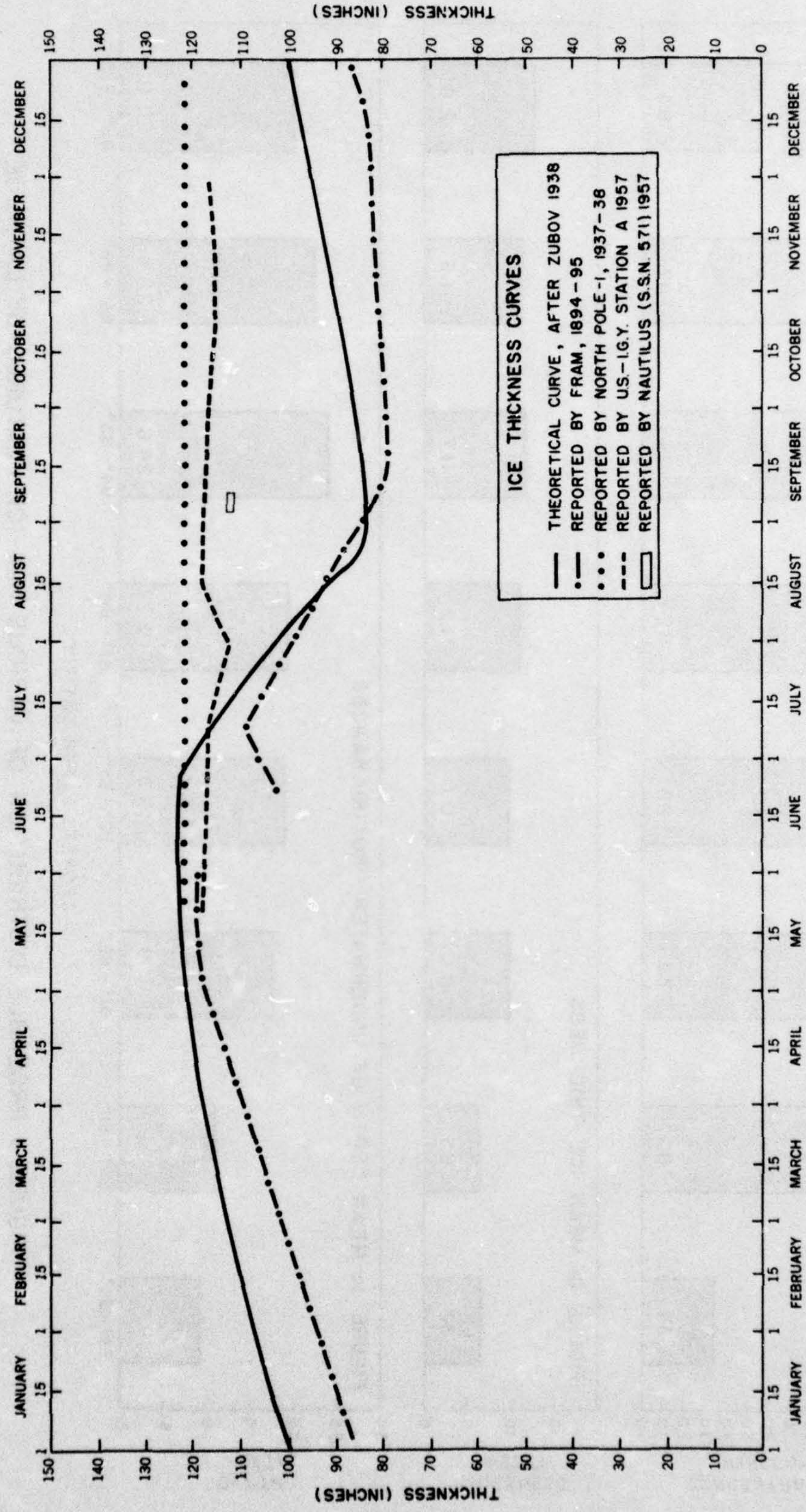


FIGURE 2. VARIATIONS OF ICE THICKNESS WITH TIME IN THE CENTRAL ARCTIC REGION

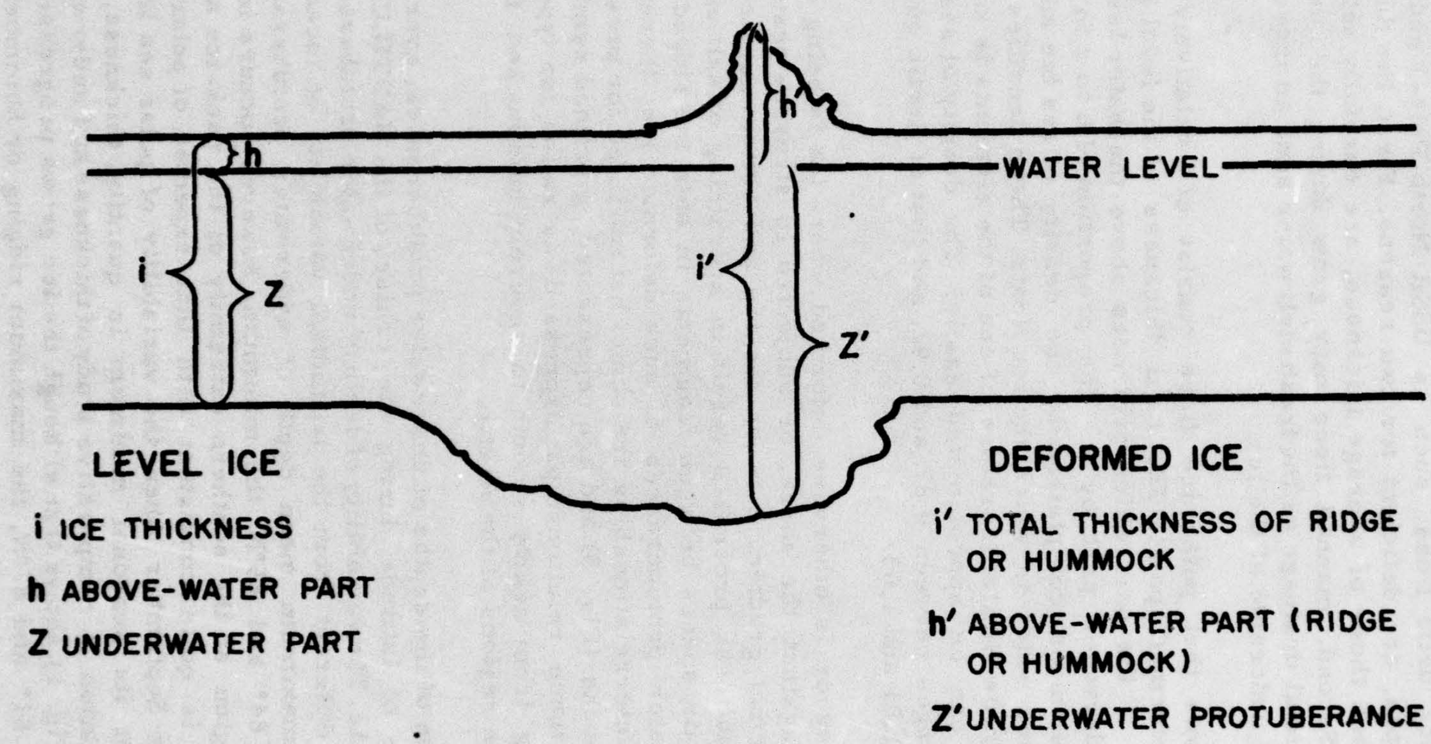


FIGURE 3. SCHEMATIC CROSS SECTION OF TYPICAL POLAR ICE FLOE

data such as those collected by the NAUTILUS. Basic data collected from manned ice drift floes, such as USSR North Pole-1 and U. S. IGY Station Alpha, are deficient for two reasons. First, the thickest floes, rather than those of average thickness, are carefully selected for manning. Second, manned floes may grow during the summer because of artificial drainage as the fresh melt water adds an increment of growth on the underside of the ice.

Figure 3 shows that polar ice floes consist of a relatively level part and a deformed part. The total thickness of the level ice is represented by i, the part which protrudes above the water level by h, and the underwater part by z. The proportion of h to z in level sea ice is determined completely by the density of sea ice and the density of the sea water in which the ice floats. These densities vary within rather narrow limits; therefore, if one of the elements is known, then the other can be approximated easily. The density of sea ice, for example, ranges between 0.87 and 0.92, and that of Arctic surface waters between 1.01 and 1.03.

The ice buckles or is otherwise deformed where ice is being compacted, driven against the shore, or subjected to stresses resulting from steep thermal gradient between the top and bottom surfaces of the ice. Deformational processes result in a draining of salt and an interspersal of air spaces between fragments in both the ridged part and the underwater protuberances of such deformed ice; therefore, the i, h, and z interrelationships are somewhat modified for pressure ridges or hummocks (Fig. 3) and are represented by primed symbols. Table I shows these relationships expressed as ratios for types of sea ice, ranging from nearly smooth to severely hummocked, found within the sea-ice regions of the Arctic.

The distribution of the depths of underwater protuberances, averaged for each degree of latitude during the cruise of the NAUTILUS, is shown in Figure 1c. The variability of depth of underwater protuberances is considerably different from the latitudinal variability of mean ice thickness. The maximum mean depth of underwater protuberances occurs between 84° and 85°N; the minimum, however, occurs in the ice-boundary region at the southern extremity of the pack-ice area. This variability is quite consistent with that expected of polar sea ice during early September when the variability of polar sea ice is thought to be at its seasonal minimum in quantity, thickness, and degree of deformation. A comparative study of thickness and underwater protuberances (Fig. 1) shows that although the ice grows progressively thicker between 81° and 87°N, the maximum ridging or hummocking occurs where ice has been subjected to the most intense deformational forces. The mean depth of underwater protuberances for all NAUTILUS data was 18.4 feet and the standard deviation of depths 8.5 feet, that is, 68 percent of the underwater protuberances varied between 9.9 and 26.9 feet. The maximum depth of an underwater protuberance was 46 feet at 84°59'N, 5°40'W. A good approximation of the maximum height of ice surface pressure ridges is obtained by multiplying the depth of the underwater protuberance by 0.4 (Table I). The value of 18.4 feet, which is derived from data biased toward a seasonal minimum, is somewhat less than Nansen's value. Nansen gives 26.4 feet as the absolute maximum height of a pressure ridge.

TABLE I

Ratios for estimating ice thickness and height of ridges from measurements of submerged parts of sea ice (Petrov, 1955)

	z/i	h/i	i/z	i/h	z/h	h/z
Level Polar Ice	.83-.86	.17-.14	1.20-1.17	6-7	4.9-6.1	.20-.16
Lightly Ridged Polar Ice	.80-.83	.20-.17	1.25-1.20	5-6	4.0-4.9	.25-.20
Ridged Polar Ice Fields	.75-.80	.25-.20	1.33-1.25	4-5	3.0-4.0	.33-.25
Heavily Ridged Polar Fields	.67-.75	.33-.25	1.50-1.33	3-4	2.0-3.0	.50-.33
Grounded Polar Floes	.50-.67	.50-.33	2.00-1.50	2-3	1.0-2.0	1.00-.50

Figure 4a shows the distribution of one-dimensional water openings (one group all sizes and a second group ≥ 300 yards in width) by latitude. Most of the openings (approximately 72 per 60 nautical miles) occurred near the southern limit of the pack ice or between 80° and 81°N. As the region between 85° and 86°N is adjacent to the region where maximum hummocking occurred (Fig. 1c), this distribution of water openings is a further indication that areas of ice compaction and rarefaction do occur within the deep polar pack. The number of openings ≥ 300 yards in width decreased steadily from 17 per 60 nautical miles between 80° and 81°N to 3 or 4 per 60 nautical miles north of 85°N.

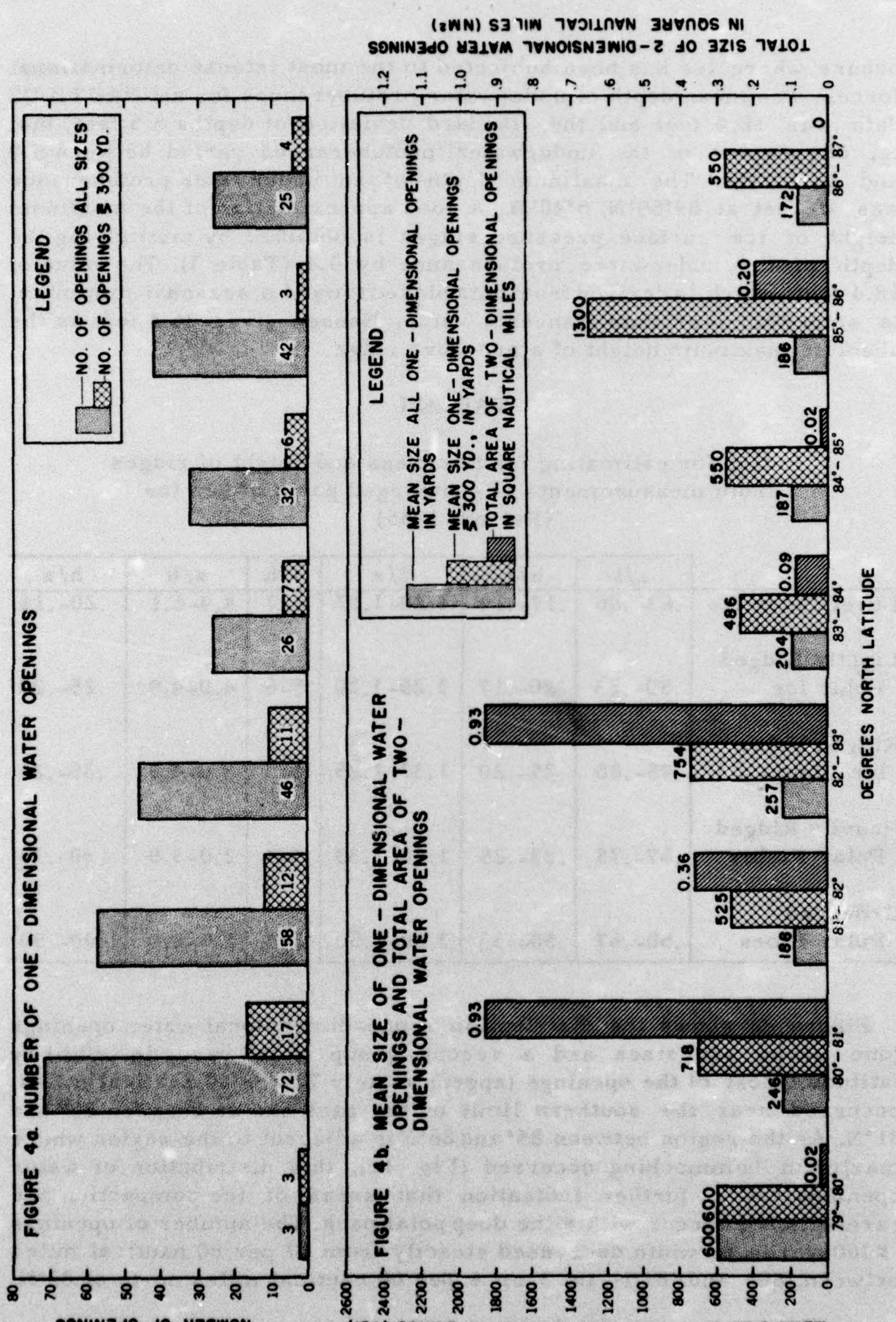


FIGURE 4. PROBABLE NUMBER AND SIZE OF OPEN-WATER FEATURES BY LATITUDE

In addition to one-dimensional water openings, a limited number of two-dimensional water openings were reported. The ability to discern two-dimensional openings was restricted by the narrow cruise track and by instrumentation. As a result, these two-dimensional openings are very difficult to describe statistically. These openings could not be included either quantitatively or graphically in Figure 4a. However, the total combined area in square nautical miles of these two-dimensional openings is included in Figure 4b. Also shown in Figure 4b is the mean size of the one-dimensional openings shown in Figure 4a. Figure 4b further reflects rarefaction within the polar pack ice region by the relatively large mean size (1,300 yards) for the water openings, noted between 85° and 86°N. The two-dimensional openings between 85° and 86°N were also large in comparison with those of adjacent latitudes: they totaled 0.20 square nautical mile between 84° and 85°N and an insignificant amount between 86° and 87°N.

One must be extremely cautious in drawing conclusions from the data depicted in Figure 4; openings are rarely completely free of ice. Figure 5a shows the probable degree of clutter for one-dimensional openings. Figure 5b shows the clutter for those openings ≥ 300 yards. In a large percentage of observations (as high as 93 percent), the degree of clutter could not be determined. "Apparently clear" openings do not take into account widely scattered, thick fragments of pack ice and probably also exclude thinner layers of newly formed ice.

A thorough understanding of floe sizes is needed not only for operational considerations but also for solution of theoretical problems. Until the cruise of the NAUTILUS, a quantitative distribution of floe sizes within the sea-ice regions of the Arctic pack has been almost impossible to obtain. Aerial reconnaissance offers a crude approximation of floe sizes, but unfortunately, few ice reconnaissance flights have been conducted by U. S. agencies on a systematic basis over polar pack regions. Figure 6a shows the percent frequency of floe sizes reported from the NAUTILUS data grouped by 1° latitudinal increments. South of 81°N, most of the pack ice is in the form of brash and block (fragments 30 feet in width). Between 81° and 83°N, considerable quantities of brash and block (42 to 46 percent) are still evident, whereas north of 83°N the greater part of the pack ice consists of larger size types. Between 84° and 85°N small floes predominate and, between 85° and 86°N, giant floes. Giant floes are numerous north of 83°N. Although floe sizes generally increase with northerly latitudes, a random variation appears in their relative amounts. Inasmuch as fracturing of floes into smaller sizes usually accompanies compaction, one would expect to find a relatively large percentage of smaller size

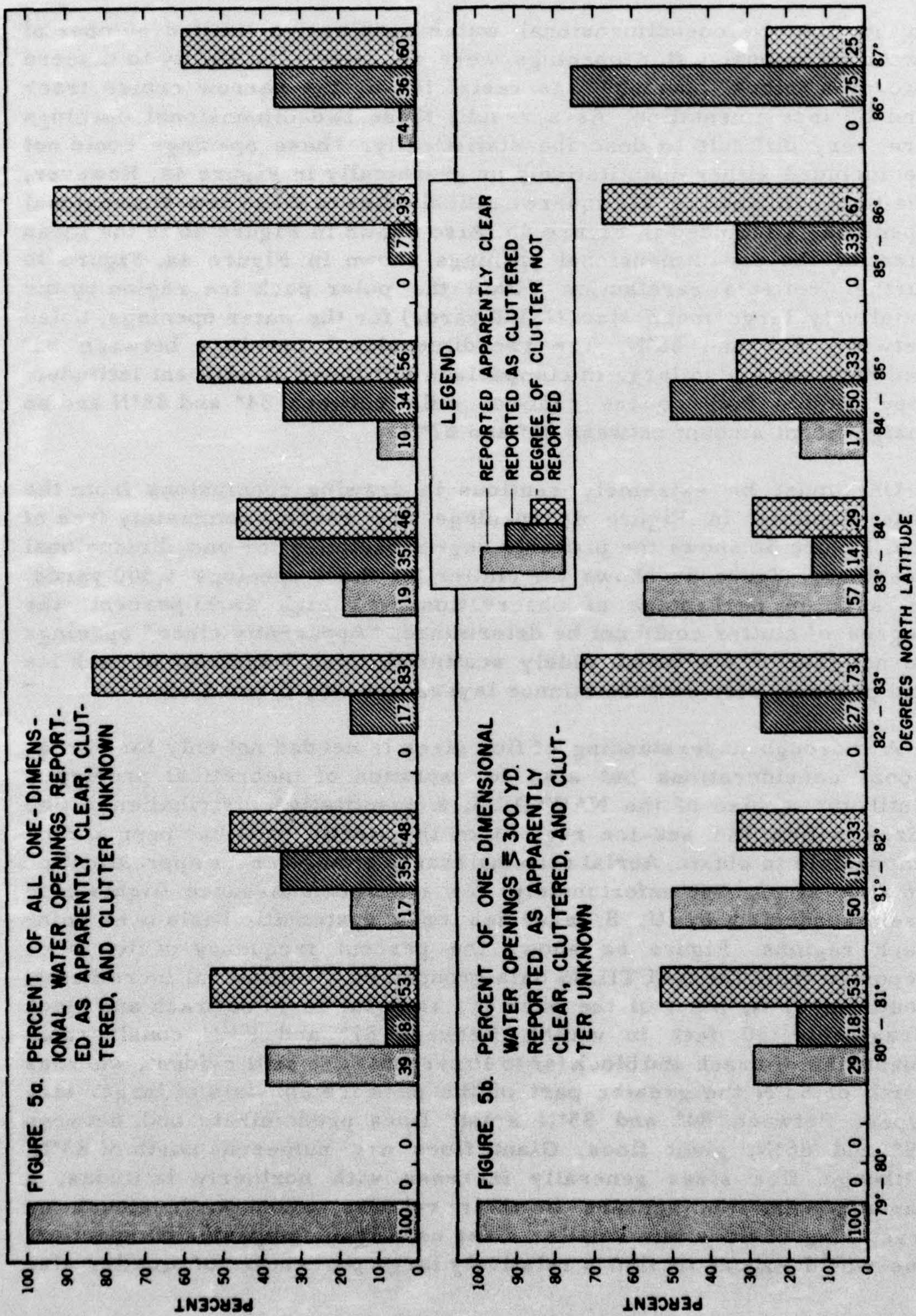


FIGURE 5. DEGREE OF CLUTTER IN ONE-DIMENSIONAL WATER OPENINGS BY LATITUDE

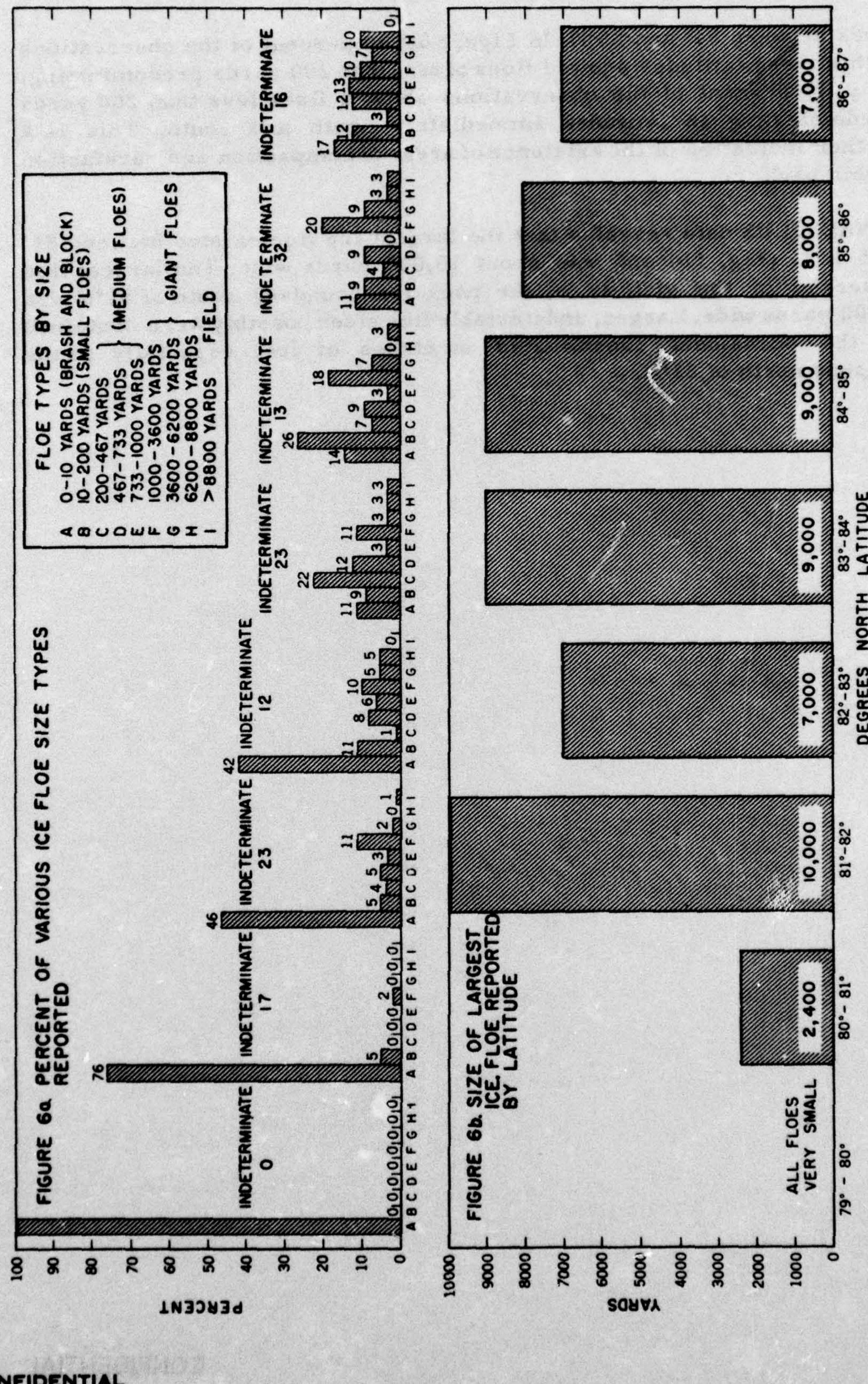


FIGURE 6. PROBABLE DISTRIBUTION OF ICE FLOE SIZES BY LATITUDE

types between 84° and 85°N. In Figure 6a, 40 percent of the observations within these latitudes showed floes of less than 200 yards predominating. Only 30 percent of the observations showed floes less than 200 yards predominating in latitudes immediately north and south. This is a further indication of the existence of areas of compaction and rarefaction within pack ice.

NAUTILUS data revealed that the largest ice floe existed between 81° and 82°N (Fig. 6b) and was about 10,000 yards wide. The largest floe observed in the vicinity of the pack-ice boundary south of 81°N was 2,400 yards wide. Larger, undetectable floe sizes possibly were contained in the occasional consolidated stretches of ice, especially in the regions north of 81°N.

IV. DISCUSSION OF THE DATA GROUPED REGIONALLY

Figure 7 shows the track of the NAUTILUS segmented in order to facilitate a study of offshore and nearshore regional variations within the pack. The segments are labeled alphabetically from south to north and primes are added to the letters from east to west. In Figure 8, three of the more important sea-ice features are depicted regionally. Figure 8a shows that ice thicknesses increase on approaching the coast of Greenland along the approximate latitude of 81°30'N. As the ice off this part of the Greenland coast has been under heavy pressure almost continuously during the past season, this increase in thickness is expected. Northward of 82°N, no other east-west thickness pattern seems apparent from examining the data. Figure 8b shows that the depths of underwater protuberances also increase shoreward at both 81°30' and 82°30'N. However, the mean depths of underwater protuberances have an even greater value northward from the coast between 84° and 85°N. This indicates that compaction or deformational forces acting deep within the pack ice can be considerably greater than in the pack ice near the coast during the culmination of the Arctic summer. The existence of greater quantities of deformed ice offshore rather than near the coast, represents new knowledge never before ascertained by data. Ignoring seasonal considerations, sea ice in the central North American Arctic experiences a regional maximum in thickness and hummocking north of the coast of Greenland and Ellesmere Island (Zubov, 1945, and Schule and Wittmann, 1958). Furthermore, more warming occurs near coastal regions than deep within the Arctic pack during summer. Evidence of the relative importance of these conflicting concepts has been supplied by NAUTILUS data. Figure 8c shows the distribution of one-dimensional water openings $\geq$ 300 yards in width; two significant conclusions can be drawn from an examination of these data. First, the most numerous openings at 81°30'N, probably caused by occasional offshore winds, occur near the coast of Greenland, the same region where the greatest mean thickness of the underwater protuberances occurred (Fig. 8b). Second, openings northward of 81°30'N definitely decrease in number as latitude increases; no consistent east-west pattern is reflected in this portion of the data.

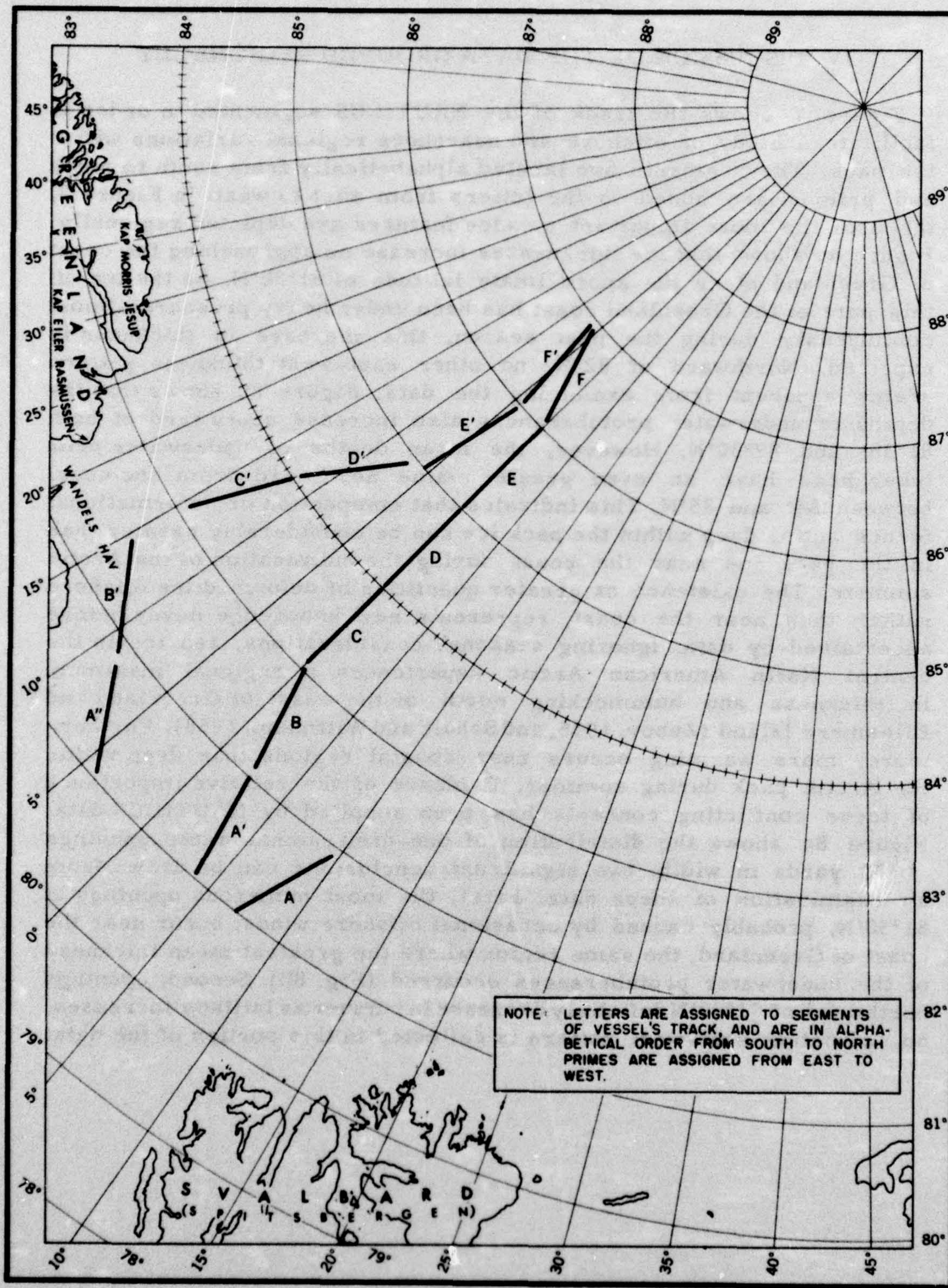


FIGURE 7. SEGMENTED CRUISE TRACK

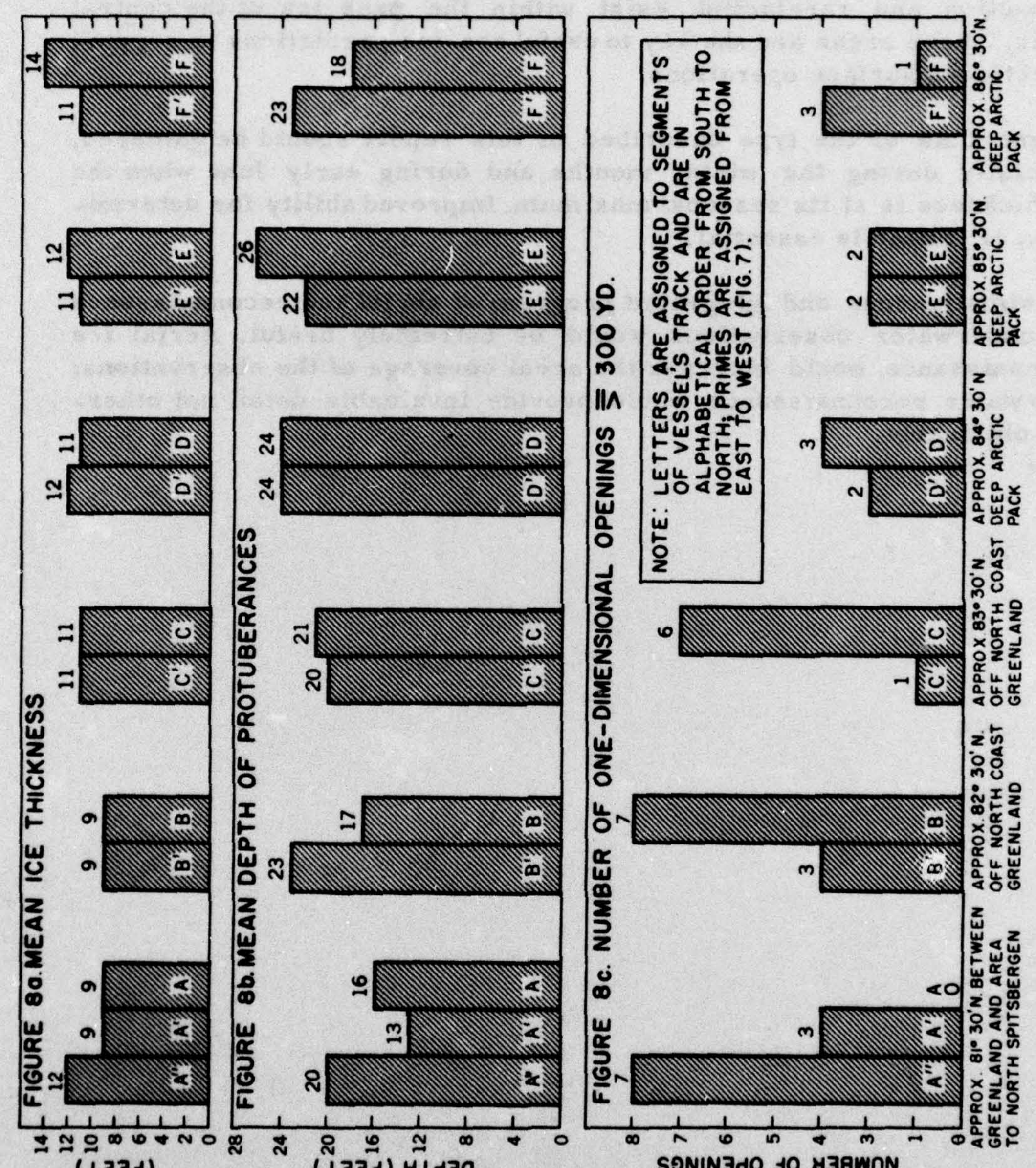


FIGURE 8. PROBABLE REGIONAL DISTRIBUTION OF VARIOUS SEA-ICE AND OPEN-WATER FEATURES

V. CONCLUSIONS AND RECOMMENDATIONS

The NAUTILUS data have added considerably to our knowledge of sea ice in the Arctic Ocean. They repeatedly indicate that areas of compaction and rarefaction exist within the pack ice of the central Arctic. These areas are the key to useful sea-ice predictions in support of Arctic subsurface operations.

More data of the type described in this report should be gathered, especially during the winter months and during early June when the ice thickness is at its seasonal maximum. Improved ability for determination of clutter is essential.

A simultaneous and integrated program of aerial ice reconnaissance and underwater observations would be extremely useful. Aerial ice reconnaissance would increase the areal coverage of the observations; underwater reconnaissance would provide invaluable detail not otherwise obtainable.

BIBLIOGRAPHY

PAPANIN, IVAN. Life on an icefloe. London: Hutchinson and Co. Ltd. 240 p. 1947. Translated from the Russian by Fanny Smitham.

PETROV, M. K. Sailing in ice. (Plavaniye vo l'dakh) Moscow: Marine Transportation. 1955. Translated by F. R. Preveden, Office of Naval Intelligence. ONI TR. No. A-845. 384 p. 1955.

SCHULE, J. J. JR., and WITTMANN, W. I. Comparative ice conditions in North American Arctic, 1953 to 1955, inclusive, Transactions of the American Geophysical Union, vol. 39, no. 3, p. 409-419. 1958.

SVERDRUP, H. U. Arctic sea ice. In: U. S. OFFICE OF NAVAL OPERATIONS. The dynamic north, vol. 1, section VI. 17 p. 1956.

U. S. HYDROGRAPHIC OFFICE. A functional glossary of ice terminology, Hydrographic Office Publication No. 609. 88 p. 1952.

U. S. S. NAUTILUS (SS(N)571). Report of Patrol No. 1. Letter from Commanding Officer, to Chief of Naval Operations, SSN571/JS A5 Ser 087 dated 15 September 1957. Various paging. Confidential.

UNTERSTEINER, N. Preliminary results of thermal budget studies on Arctic pack ice during summer. Seattle: National Academy of Sciences - National Research Council, Division of Earth Sciences. 18 p. 1957.

ZUBOV, N. N On the maximum thickness of sea ice of many years' growth (O predel'noi tolshchine morskikh mnogoletnikh l'dov). Meteorologiia i Gidrologiia, vol. 4, no. 4, p. 123-131, 1938. Translated by L. H. Robbins, U. S. Hydrographic Office, U. S. H. O. Translation No. 191. Unpublished. 16 p.

- - - V tsentre Arktiki (In the center of the Arctic). Moscow: izdatel'stvo Glavsevmorputi. 390 p. 1948.

UNCLASSIFIED

[redacted]

U. S. NAVY HYDROGRAPHIC OFFICE
CHARACTERISTICS OF POLAR ICE OBSERVED DURING THE 1957 ARCTIC CRUISE OF USS NAUTILUS (SSN 571) by Walter I. Wittmann and John F. Ropek. October 1958. 19 p. including 8 figures, 1 table (H. O. TR-40).

Sea-ice features over that portion of the Polar Pack transited during the 1957 Arctic cruise of the NAUTILUS are discussed and described. Latitudinal and regional comparisons of sea-ice features are made. Data collection methods and instrumentation are described. Recommendations are advanced for future use of the nuclear submarine as a data-collection vehicle.

1. Arctic Ocean, Ice
2. Ice Forecasting
3. Submarines, Ice
4. Nautilus, USS (SSN 571)

i. title: Characteristics of Polar Ice Observed During the 1957 Arctic Cruise of USS NAUTILUS, (SSN 571)

ii. authors: Walter I. Wittmann and John F. Ropek

iii. H. O. TR-40

UNCLASSIFIED

[redacted]

U. S. NAVY HYDROGRAPHIC OFFICE
CHARACTERISTICS OF POLAR ICE OBSERVED DURING THE 1957 ARCTIC CRUISE OF USS NAUTILUS (SSN 571) by Walter I. Wittmann and John F. Ropek. October 1958. 19 p. including 8 figures, 1 table (H. O. TR-40).

Sea-ice features over that portion of the Polar Pack transited during the 1957 Arctic cruise of the NAUTILUS are discussed and described. Latitudinal and regional comparisons of sea-ice features are made. Data collection methods and instrumentation are described. Recommendations are advanced for future use of the nuclear submarine as a data-collection vehicle.

1. Arctic Ocean, Ice
2. Ice Forecasting
3. Submarines, Ice
4. Nautilus, USS (SSN 571)

i. title: Characteristics of Polar Ice Observed During the 1957 Arctic Cruise of USS NAUTILUS, (SSN 571)

ii. authors: Walter I. Wittmann and John F. Ropek

iii. H. O. TR-40

UNCLASSIFIED

[redacted]

U. S. NAVY HYDROGRAPHIC OFFICE
CHARACTERISTICS OF POLAR ICE OBSERVED DURING THE 1957 ARCTIC CRUISE OF USS NAUTILUS (SSN 571) by Walter I. Wittmann and John F. Ropek. October 1958. 19 p. including 8 figures, 1 table (H. O. TR-40).

Sea-ice features over that portion of the Polar Pack transited during the 1957 Arctic cruise of the NAUTILUS are discussed and described. Latitudinal and regional comparisons of sea-ice features are made. Data collection methods and instrumentation are described. Recommendations are advanced for future use of the nuclear submarine as a data-collection vehicle.

1. Arctic Ocean, Ice
2. Ice Forecasting
3. Submarines, Ice
4. Nautilus, USS (SSN 571)

i. title: Characteristics of Polar Ice Observed During the 1957 Arctic Cruise of USS NAUTILUS, (SSN 571)

ii. authors: Walter I. Wittmann and John F. Ropek

iii. H. O. TR-40

UNCLASSIFIED

[redacted]

U. S. NAVY HYDROGRAPHIC OFFICE
CHARACTERISTICS OF POLAR ICE OBSERVED DURING THE 1957 ARCTIC CRUISE OF USS NAUTILUS (SSN 571) by Walter I. Wittmann and John F. Ropek. October 1958. 19 p. including 8 figures, 1 table (H. O. TR-40).

Sea-ice features over that portion of the Polar Pack transited during the 1957 Arctic cruise of the NAUTILUS are discussed and described. Latitudinal and regional comparisons of sea-ice features are made. Data collection methods and instrumentation are described. Recommendations are advanced for future use of the nuclear submarine as a data-collection vehicle.

1. Arctic Ocean, Ice
2. Ice Forecasting
3. Submarines, Ice
4. Nautilus, USS (SSN 571)

i. title: Characteristics of Polar Ice Observed During the 1957 Arctic Cruise of USS NAUTILUS, (SSN 571)

ii. authors: Walter I. Wittmann and John F. Ropek

iii. H. O. TR-40

UNCLASSIFIED [redacted]

U. S. NAVY HYDROGRAPHIC OFFICE
CHARACTERISTICS OF POLAR ICE OBSERVED DURING THE 1957 ARCTIC CRUISE OF USS NAUTILUS (SSN 571) by Walter I. Wittmann and John F. Ropek. October 1958. 19 p. including 8 figures, 1 table (H. O. TR-40).

Sea-ice features over that portion of the Polar Pack transited during the 1957 Arctic cruise of the NAUTILUS are discussed and described. Latitudinal and regional comparisons of sea-ice features are made. Data collection methods and instrumentation are described. Recommendations are advanced for future use of the nuclear submarine as a data-collection vehicle.

1. Arctic Ocean, Ice
2. Ice Forecasting
3. Submarines, Ice
4. Nautilus, USS (SSN 571)

i. title: Characteristics of Polar Ice Observed During the 1957 Arctic Cruise of USS NAUTILUS, (SSN 571)

ii. authors: Walter I. Wittmann and John F. Ropek

iii. H. O. TR-40

UNCLASSIFIED [redacted]

U. S. NAVY HYDROGRAPHIC OFFICE
CHARACTERISTICS OF POLAR ICE OBSERVED DURING THE 1957 ARCTIC CRUISE OF USS NAUTILUS (SSN 571) by Walter I. Wittmann and John F. Ropek. October 1958. 19 p. including 8 figures, 1 table (H. O. TR-40).

Sea-ice features over that portion of the Polar Pack transited during the 1957 Arctic cruise of the NAUTILUS are discussed and described. Latitudinal and regional comparisons of sea-ice features are made. Data collection methods and instrumentation are described. Recommendations are advanced for future use of the nuclear submarine as a data-collection vehicle.

1. Arctic Ocean, Ice
2. Ice Forecasting
3. Submarines, Ice
4. Nautilus, USS (SSN 571)

i. title: Characteristics of Polar Ice Observed During the 1957 Arctic Cruise of USS NAUTILUS, (SSN 571)

ii. authors: Walter I. Wittmann and John F. Ropek

iii. H. O. TR-40

UNCLASSIFIED [redacted]

U. S. NAVY HYDROGRAPHIC OFFICE
CHARACTERISTICS OF POLAR ICE OBSERVED DURING THE 1957 ARCTIC CRUISE OF USS NAUTILUS (SSN 571) by Walter I. Wittmann and John F. Ropek. October 1958. 19 p. including 8 figures, 1 table (H. O. TR-40).

Sea-ice features over that portion of the Polar Pack transited during the 1957 Arctic cruise of the NAUTILUS are discussed and described. Latitudinal and regional comparisons of sea-ice features are made. Data collection methods and instrumentation are described. Recommendations are advanced for future use of the nuclear submarine as a data-collection vehicle.

1. Arctic Ocean, Ice
2. Ice Forecasting
3. Submarines, Ice
4. Nautilus, USS (SSN 571)

i. title: Characteristics of Polar Ice Observed During the 1957 Arctic Cruise of USS NAUTILUS, (SSN 571)

ii. authors: Walter I. Wittmann and John F. Ropek

iii. H. O. TR-40

UNCLASSIFIED [redacted]

U. S. NAVY HYDROGRAPHIC OFFICE
CHARACTERISTICS OF POLAR ICE OBSERVED DURING THE 1957 ARCTIC CRUISE OF USS NAUTILUS (SSN 571) by Walter I. Wittmann and John F. Ropek. October 1958. 19 p. including 8 figures, 1 table (H. O. TR-40).

Sea-ice features over that portion of the Polar Pack transited during the 1957 Arctic cruise of the NAUTILUS are discussed and described. Latitudinal and regional comparisons of sea-ice features are made. Data collection methods and instrumentation are described. Recommendations are advanced for future use of the nuclear submarine as a data-collection vehicle.

1. Arctic Ocean, Ice
2. Ice Forecasting
3. Submarines, Ice
4. Nautilus, USS (SSN 571)

i. title: Characteristics of Polar Ice Observed During the 1957 Arctic Cruise of USS NAUTILUS, (SSN 571)

ii. authors: Walter I. Wittmann and John F. Ropek

iii. H. O. TR-40