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APPLICATIONS OF REMOTE SENSING TO OCEANOGRAPHY & SEA ICE

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Summary

In an introductory chapter (1), designated "Survey of recent development" the author points to the importance of exploring our natural resources in the Arctic and other areas, where the sea is often blocked by floating ice, and the conveyance of the products to southern markets. In any case the best possible position-fixing and a true knowledge of prevailing ice conditions as well as the bathymetry is obligatory, and reliable ice-forecasts desirable.

A general view of the introduction of more and more advanced remote sensing techniques is presented in paragraph 1.1.

A Swedish Arctic Interdisciplinary expedition of a marked international character, planned for June-September 1980, will be made in an icebreaker, "YMER", equipped for satellite navigation and with special electronics for accurate position fixing (see par. 1.2 and chapter 3 below).

Exploration and transportation of arctic oil, gas and minerals, especially in the Canadian Arctic Archipelago, is dealt with in paragraph 1.3. Subsections treat different types of ships developed for arctic expeditions.

In chapter 2 the author describes the results of a comprehensive remote sensing experiment on sea ice, performed in the Bay of Bothnia in March 1975. The programmes for the abovementioned all-round scientific arctic expedition in the Swedish icebreaker YMER, in June-September 1980, (chapter 3) include Ice conditions, Ice-Ocean Interaction in the marginal ice zone, Radar Measurements of Backscatter from September Sea Ice, Physical Oceanography, Chemical Oceanography, Atmospheric and Oceanic Research, Glacial extent and climatic variations, Pollution problems as studied in bottom sediments, Submarine volcanism and the history of the continental margins, and Marine biology.

Since drifting sea ice as well as icebergs may be present also in areas through which heavy transoceanic traffic passes, thereby hazarding the shipping, a careful ice-surveillance by

the aid of advanced remote sensing is of great importance. This is illustrated in chapter 4, "Ice in the Grand Banks area". In chapter 5, the author shows that remote sensing makes under-ice navigation possible. Paragraph 5.1 deals with under-ice piloting by sonar, and par. 5.2 with bathymetric conditions. Paragraph 5.3, finally, gives "Viewpoints on radio communication systems and submarines operating under ice".

Sommaire

Dans un chapitre d'introduction (1) "Survey of recent development", l'auteur attire l'attention sur l'importance d'explorer les resources de la nature dans les régions polaires septentrionales et dans les autres zones où la mer est souvent bloquée par les glaces flottantes et par le transport de produits pour les marchés du sud. En tout cas, un repérage radar parfait, une connaissance exacte des conditions prédominantes des glaces, aussi bien qu' une bathymetrie précise sont obligatoires. Outre cela il est désirable d'avoir à sa disposition des rapports de glace fiables.
Une vue générale de l'introduction des techniques toujours plus avancées de 'remote sensing' est présentée en paragraphe 1.1.
Une expédition arctique interdisciplinaire suédoise d'un caractère bien international conçue à avoir lieu en juin - septembre 1980 sera faite avec l'YMER, bateau brise-glace suédois équipé pour la navigation satellite et pourvu des dispositifs électroniques pour faire des repérages exacts (voir paragraphe 1.2 et chapitre 3 ci-après).
L'exploration et le transport de l'huile arctique, du gaz et des minéraux, surtout dans l'archipel arctique canadien, sont traités en paragraphe 1.3. Les sous-paragraphes decrivent les types de bateau différents qui sont developpés pour les expéditions arctique.
En chapitre 2, l'auteur décrit les résultats d'une grande expérience sur les glaces de mer à l'aide de la technique de remote sensing, exécutée dans le golfe de Bothnie en mars 1975. Le programme de l'expédition interdisciplinaire arctique mentionnée plus haut avec

l´YMER en juin-septembre 1980 (chapitre 3) comprend les conditions des glaces, l´action réciproque entre les glaces et l´océan dans les zones glaciales marginales, les mesures radar de la rétrodiffusion de la glace de mer du mois de septembre, l´océanographie physique, l´océanographie chimique, la recherche atmosphérique et océanique, l´étendue des glaces et les variations climatologiques, les problèmes de pollution étudiés dans les sédiments du fond de la mer, le volcanisme sous-marin et l´histoire de la marge continentale et la biologie marine.
Comme, au détriment de la navigation, les glaces de mer flottantes, aussi bien que les 'icebergs' peuvent être présents aussi dans les zones où passent les bateaux transocéaniques lourds, il est de grande importance de disposer d´une surveillance des glaces exacte utilisant la technique de remote sensing. Cela sera illustré en chapitre 4 "Ice in the Grand Banks area".
En chapitre 5, l´auteur montre qu´en utilisant remote sensing, il est possible de naviger sous l´eau. Paragraphe 5.1 trait la navigation sous les glaces à l´aide de 'sonar' et paragraphe 5.2 les conditions bathymétriques. En paragraphe 5.3, finalement, un compte rendu est fourni sur les "Viewpoints on radio communication systems and submarines operating under ice".

Zusammenfassung
In einem einleitenden Kapitel (1), "Survey of recent development", weist der Verfasser auf das Gewicht hin, unsere natürliche Reichtümer in der Arktis und in anderen Gebieten zu erforschen, wo das Meer oft von fliessendem Eis und von der Beförderung von Produkten nach südlichen Märkten blockiert ist. Eine bestmögliche Ortung und eine exakte Kenntnis von der vorhandenen Eisverhältnissen, sowie genaue Tiefenmessungen sind jedenfalls notwendig. Zuverlässige Eismeldungen sind ausserdem wünschenswert.
Ein allgemeiner Überblick über die Einführung von immer mehr vorgeschrittenen 'remote-sensing'-Methoden ist im Abschnitt 1.1 präsentiert.

Eine schwedische, arktische, querwissenschaftliche Expedition von einem ausgeprägt internationalen Charackter, die für Juni-September 1980 berechnet ist, wirt mit dem schwedischen Eisbrecher YMER gemacht, der für Satellitennavigation und mit Spezialelektronik für genaue Ortung ausgerüstet ist (siehe Abschnitt 1.2 und Kapitel 3 unten).
Erforschungen un Beförderungen von arktischen Öl, Gas und dito Mineralien besonders im Kanadischen Arktischen Archipel werden im Abschnitt 1.3 erörtert. Unterabschnitte behandeln verschiedene Schiffstypen, die für arktische Expeditionen entwickelt sind.
In Kapitel 2 beschreibt der Verfasser die Ergebnisse eines umfassenden remote-sensing-Meereisexperimentes, das im Bottnischen Meerbusen im März 1975 durchgeführt wurde. Das Programm der obenerwähnten querwissenschaftlichen Expedition mit dem schwedischen Eisbrecher YMER im Juni-September 1980 (Kapitel 3) umfasst die Eisverhältnisse, die Wechelwirkung Eis-Ozean in der Randeiszone, Radarmessungen der Rückstreuung vom September-Meereis, physische Ozeanographie, kemische Ozeanographie, atmosphärische und ozeanische Forschung, Gletscherausbreitung und Klimavariationen, Verunreinigungsprobleme, die in den Grundsedimenten studiert sind, unterwasservulkanische Kräfte und die Geschichte der Kontinentalränder und Marinebiologie.
Da Treibeis sowie Eisberge, der Schiffahrt zum Schaden, auch in Gebieten vorkommen können wo ein schwerer Überseeverkehr vorhanden ist, ist eine genaue Eisbeobachtung mit Hilfe vorgeschrittener remote-sensing-Methoden von grosser Bedeutung, siehe Kapitel 4, "Ice in the Grand Banks area".
In Kapitel 5 zeigt der Verfasser dass es durch remote sensing möglich ist, unter dem Eis zu navigieren. Abschnitt 5.1 handelt um Untereisnavigation mit 'sonar', und Abschnitt 5.2 beschreibt die Tiefenmessbedingungen. Abschnitt 5.3 gibt schliesslich "Viewpoints on radio communication systems and submarines operating under ice".

1. SURVEY OF RECENT DEVELOPMENT

The importance of our natural resources, for example minerals, oil and gas, continues to increase all over the world. That is the case also concerning the Arctic and other areas, where the sea is often blocked by floating ice, sometimes most of the year. The exploring and extraction of the resources and the conveyance of the products to southern markets, getting them available for international trade, may therefore cause severe problems of different nature.

The estimated potential of oil and natural gas in the Canadian High Arctic amounts to 166 milliards of barrels, in Alaska 160 milliards, and along the Soviet arctic offshore line as many as 795 milliards of barrels. Together with an estimated potential of 40 milliards of barrels in the Svalbard area those arctic resources represent about 40 % of the oil and gas potential of all the world.

Minerals are other primary products. In Greenland and on some Canadian islands, e.g. Baffin Island, especially high-percentage iron ore is of great economic importance: Outcrops of native copper, chromium, pyrite and platinum, magnetite, nickel, cobalt, native silver, zinc and lead ore are other minerals found on the arctic islands. The mineral resources in the Soviet Arctic are enormous and of many different species, among others iron, copper, nickel, gold, silver and diamonds, platinum, lead, tin, zinc, cobalt, mercury and wolfram. Further, there are great coal deposits, and the Soviet forest resources are the largest in the world, estimated to more than 70 milliards cu.m; most of the timber products being shipped via arctic harbours.

Drifting sea ice as well as icebergs may be present also in areas through which heavy transoceanic traffic passes, thereby hazarding the shipping (see chapter 4 below).

In any case the best possible position-fixing and a true knowledge of prevailing ice conditions as well as the bathymetry is obligatory and reliable ice-forecasts desirable.

1.1 Remote sensing techniques being introduced

Formerly, the navigator was informed of the ice situation ahead of the ship by lookouts in the crow´s-nest on the fore- or mainmast, if necessary also at the ship´s bow.

In the early twenties the reconnoitred sea area was considerably widened by the use of aircraft, equipped for reporting the ice conditions on wireless telegraphy or telephony. Thus, remote sensing techniques were then introduced, further also photography for picturing the ice situation. Later, radio navigation systems came into use, and radar systems were developed. Ice reconnaissance pictures were continuously transmitted from planes or helicopters and received aboard the ships on television-screens. This new remote sensing technique offered the navigator a possibility to choose the most suitable route in the ice fields, a great advance, indeed.

The importance of ice studies and remote sensing as an aid for navigation in ice-covered sea areas was elucidated at the IXth International Congress in London, 1960. Thus, the report on "Photographic Interpretation of Ice" to this ISP-congress by the Chairman of the working group "Interpretation of Ice", Captain *Ragnar Thorén*, Royal Swedish Navy, included a series of papers, all dealing with Ice at Sea. The authors were as follows: Professor, Dr *Geza Teleki*, George Washington University, Washington, D.C., Dr *Terence Armstrong*, Scott Polar Research Institute, Cambridge, Dr *Moira Dunbar*, Directorate of Physical Research, Defence Research Board, Ottawa, and Professor, Dr *Erkki Palosuo*, University of Helsinki. Another paper dealt with glacier ice, entitled "Glacier Inventory from Air Photographs" by Professor, Dr *Valter Schytt*, University of Stockholm (see chapter 3 below). At the main session on "Interpretation of Ice", Dr Armstrong reported that in the Soviet Union television-transmitted pictures from satellites were used for the purpose of receiving information concerning the distribution of the sea ice in different areas.

The Chairman called attention to the Soviet progress in high-altitude photography, which he presumed to be of an outstanding importance for Arctic research in a near future.

In the early sixties satellites were used for ice studies more common, and some years later for making excellent ice charts (by the US Fleet Weather Facility at Suitland, Washington, D.C. The title of Fleet Weather Facility officially changed to "Naval Polar Oceanography Center" on 29 October 1979).

To the Symposium on Photo Interpretation in Delft, in 1962, papers on Photographic Interpretation of Ice were presented among others by *R.W. Popham*, U.S. Weather Bureau, Washington, D.C., entitled "The Use of Satellites for Ice Studies", and by Professor *V.I. Avgevich*, USSR Academy of Sciences, Moscow, entitled "Some Results of the Interpretation of Aerial Photographs of Sea-Ice and Prospects for the Further Development of Aerial Survey for the Study of Ice".

At a session of Working Group 6, Ice, Captain *Ragnar Thorén* gave an introductory speach concerning Ice- and Ground-conditions in the Arctic Ocean, especially along the Eurasian Continental Shelf, stressing the economic importance of shipping in arctic waters.

In an Invited Paper to the ISP Commission VII at the Xth International Congress in Lisbon, September 1964, entitled "The Application of Aerial Photo Interpretation in the Scientific Field of

Ice met at Sea" by *Ragnar Thorén* the author stated: "Synoptic ice data, accurate ice charts, and reliable ice forecasts are of great value for the navigator". He further said: "In developing a true knowledge of the ice conditions, air photo interpretation generally offers the specialist an invaluable aid. Useful for the purpose are verticals as well as obliques, both in colour and black-and-white. The photos may be taken with ordinary air reconnaissance cameras, with a three-camera arrangement for trimetrogon photography, giving horizon-to-horizon coverage, or with precision-built high-resolution cameras, employing scanning principles to obtain successive 180° panoramic photographs. They may also be photographed from radar or TV-screens. Presumably, radar photography will be used more and more for collecting ice data, and the improvement of suitable radar sets, e.g. side-looking radar, may be expected."

The remarkable evolution of the remote sensing technique during the last 15 years has confirmed the author´s presumption.
In the same Invited Paper the author mentioned: "The airborne Ice Observer nowadays generally has effective radar at his disposal, suitable for ice reconnaissance under all conditions, in thick fog and dark polar nights as well. The radar picture is studied directly on the screen, and, when required, recorded automatically in a photographic way. It is possible to measure the dimensions of polynyas, leads and cracks, etc., in radar pictures, further to observe pressure ridges, and to determine the difference between polar ice and young ice, etc."

A pack ice area always has a distinct demarcation at any given time between the open sea and the ice (see Fig. 1). This so-called ice edge shows up quite well on the radar screen, also when the ice concentration is characterized as open or very open pack.

Fig. 1. The concentration of pack ice in western Baffin Bay a midsummer day, as shown in this oblique, looking east-southeast, may normally be characterized as open or very open pack. Independent of its scattered character, however, the pack ice has a distinct demarcation at any given time between the open sea and the ice. This so-called ice edge shows up quite well on the radar screen. Offlying icebergs drift toward the south with the cold Labrador Current (left to right in the picture).
Photo: *Ragnar Thorén*, August 6, 1963, altitude 500 m or about 1,640 ft.

The author again stressed that "Side-Looking Radar" ought to be useful for mapping and surveillance of the Polar Ice Pack. He also mentioned that a recently (1964) developed Synthetic-Aperture Radar provided extremely high resolution with a relatively small antenna.

In the same report to the Xth International Congress, the author further informed on "Passive Microwave Radiometry", "Low Light-Level Televisions Systems", and "The Use of Satellites for Ice Studies".

At the XIIth ISP-Congress in Ottawa, 1972, there was a great interest in satellite-carried sensors, and the Canadians showed their sincere satisfaction when the first Canadian ERTS-picture (ERTS = Earth Resources Technology Satellite) could be demonstrated at this Photogrammetric World Congress. It was taken on July 27, 1972, from NASA´s ERTS-1 at an altitude of 920 km.
The satellite was equipped with two systems for remote sensing,
1:o a multispectral scanner, scanning within four different spectral-zones, viz. green (0.5-0.6 μm), red (0.6-0.7), and the short-wavy infrared bands 0.7-0.8 and 0.8-1.1 μm;
2:o a three-colours TV-camera with a resolution of about 80 m, working on the spectral-bands 0.475-0.575, 0.58-0.68 and 0.69-0.83 μm. At the receiving stations the video-band data were transferred to a 70 mm film and enlarged to photographic pictures of about 23x23 cm, on the scale of 1:1,000,000. On a comparison with topographic maps the correspondence was striking.

In order for Sweden to acquire experience of her own and to assess the capability of remote sensing techniques for surveillance and mapping of sea ice a comprehensive remote sensing experiment was organized in international cooperation in the Bay of Bothnia in March 1975 (see chapter 2 below).

To the ISP Commission VII Symposium in Freiburg, Federal Republic of Germany, in July 1978, the author of this report presented a paper entitled "Remote sensing as an aid for navigation in ice-covered sea areas". In its last chapter the author gives some

viewpoints on the pioneering voyage of the Soviet icebreaker ARKTIKA to the North Pole in August, 1977.
A view of the ice concentration ahead of ARKTIKA, ridged ice zones, level ice unaffected by deformation, cracks and leads, etc., was continuously transmitted from the ship´s helicopters. The picture of the viewed area was received aboard the icebreaker on TV-screens, in that way offering the navigator a possibility to use existing cracks and level ice between the pressure ridges. Thick fog at times made the ice navigation more difficult - then the helicopters could not leave the ship. Thanks to an advanced satellite navigation system presumably with 6 satellites in polar orbits and fixes available with gradually shorter intervals the closer the navigator was to the Pole, the ship´s position was obtained with very high precision, good perhaps to 1-5 m.

In fog-free areas the position was generally determined astronomically.

To the same ISP Commission VII Symposium in Freiburg, in July 1978, *Birger Ekengren* presented a paper concerning L M ERICSSON's SLAR, wich is well suited for ocean surveillance such as oil slick detection and sea ice mapping.

According to a Swedish SAAB-SCANIA-report of June 1978 of a feasibility study on airborne sea ice profiling by radar, the results of the study show that a radar profiler can be constructed for measuring the surface profile of sea ice. Both aircraft and helicopter applications were treated. The best data quality was obtained at low altitude operation (less than 20 m), implying a helicopter as platform. Signal processing gave as outputs the surface profile and the cross section of the ridge response along the track. Statistics of the number of ridges and the distribution of the height as well as the estimated cross section of the ice-ridges could also be obtained along a preselected line.

Compared with laser profilers, the radar profiler seemed to give an improved accuracy over snow-covered sea ice. Priority should therefore be given to the helicopter application. At aircraft applications with a higher altitude of operation, however, the laser profiler probably is preferable because of its narrower sensitivity beam.

Committee for High Arctic Research Liaison and Information Exchange

The "Committee for High Arctic Research Liaison and Information Exchange" (CHARLIE), representing scientific organizations in Canada, Denmark, Germany, Norway, Sweden, Switzerland, the United Kingdom and the U.S.A., presents in the "NEWS BULLETIN" of November 1979 several interesting arctic research programmes, especially for the current year, 1980. In association with the planned Swedish expedition "YMER-80" (see par. 1.2 and chapter 3 below) representatives of, among others, the SCOTT POLAR RESEARCH INSTITUTE, University of Cambridge (coordinator Dr. *Peter Wadhams*), and the INSTITUTE OF PHYSICAL OCEANOGRAPHY, University of Copenhagen (coordinator Professor *Gunnar Kullenberg*) inform of their programmes. Further may be mentioned planned activity of the TECHNICAL UNIVERSITY OF DENMARK, ELECTROMAGNETICS INSTITUTE, Lyngby, including remote sensing flights off the East Coast of Greenland using a C-130 aircraft equipped with imaging microwave radiometers at 5 GHz, 17 and 34 GHz - dual polarization; side-looking radar at 9.4 GHz, and mapping camera. The objectives are to acquire data of sea ice to be related to simultaneous NIMBUS-7 data; to work out analysis methods for sea ice mapping and classification, and to produce geophysical data of interest for the development of ice dynamics models (*P. Gudmandsen*).
The IONOSPHERE LABORATORY of the same Danish Technical University is undertaking a joint Scientific Radio Propagation Experiment in

cooperation with the European Space Agency (ESA). The purpose of the project is to evaluate the quality of low elevation satellite communication in a high arctic environment. Trials have so far been conducted from Mestersvig at 72^{o} 15' N ($+8^{o}$ elevation angle), Danmarkshavn at 76^{o} 45' N ($+4^{o}$ elevation angle) and Station Nord at 81^{o} 45' N (-1^{o} elevation angle). In order further to study the influence of refraction, which makes reliable Satellite communication possible from locations where the satellite is definitely below the geometrical horizon, additional experiments along the zero angle of elevation have been planned for 1980 at Eskimonaes, 80^{o} 30' N. Coordinator is the Scientific Liaison Officer for Greenland, *Jørgen Taagholt*.

Other interesting programmes, mentioned in the News Bulletin, are activities from camps on drifting ice fields at high latitudes, for example 89^{o}-87^{o} N, relating to the Arctic Basin boundaries and the sea floor, point scattering from nearby mid-oceanic ridges and secondary scattering. Ambient noise will be measured to study the effects of ice flow motion and seismic activity along the mid-oceanic ridge. Participating organizations are Massachusetts Institute of Technology (MIT), Woods Hole Oceanographic Institute (WHOI), Bedford Institute of Oceanography (BIO), and Lamont-Doherty Geological Observatory (LDGO). The Bedford Inst. will use their Ocean Bottom Seismometer (OBS) as a receiver.
The LDGO-programme is of an acoustic nature and will emphasize long-range signaling methods, exploiting the unique propagation characteristics of the Arctic channel; transmission loss as a function or range for various source and detector depths, including, as listening devices, geophones on the ice surface; spatial variability of the ambient noise field, including earthquake activity and propagation of these waves at short and long ranges from the Nansen Ridge; reverberation and bottom interaction, including topographic echos in long-range propagation. Additionally, Lamont-Doherty will collect water depth data,

using a continuously operated 12 kHz echo sounder, recording an uninterrupted record of ocean depths during the drift. The system employs transducer, sonar transceiver and flat-bed recorder.

Centre for Cold Ocean Resources Engineering (C-CORE), Memorial University of Newfoundland, St. John´s, Newfoundland, Canada

In the C-CORE Annual Report 1978-79, the Chairman of the Board of Advisors, Mr. *A.E. Pallister*, President, Pallister Resource Management Ltd., emphasizes that C-CORE´s first priority has been to gain an understanding of the properties of sea ice. The second priority was directed towards achieving the remote detection of those properties. Work in both these areas has been largely oriented towards meeting operational requirements for hydrocarbon development beneath Canada´s ice-covered continental shelves across the Arctic and off the East Coast. The ability to sound the draught of icebergs, to measure the thickness of ice and to identify types of sea ice by airborne radar is a tangible measure of achievement by the Centre. Work is continuing on remote measurement of ice strength. An important breakthrough will have been achieved when it has become possible to gather this kind of data, in real or near real time, from instruments mounted in aircraft or satellites.

The C-CORE Publication 79-5, April 1979, REMOTE SENSING, Field Data Report No. 16 of C-CORE Project SAR´77, deals with "Preliminary Radar Analysis SHIP-IN-THE-ICE". Project SAR was a programme for obtaining simultaneous multifrequency synthetic aperture radar data, using the Environmental Research Institute of Michigan (ERIM) four channel radar system, X and L microwave bands (centered about 3 cm and 23 cm respectively) with both cross (horizontal-vertical) and parallel (horizontal-horizontal) polarizations. Leader of the Remote Sensing Group was Mr. *Richard D. Worsfold*, President, REMOTE APPLICATIONS INC, B.Sc. Geological Engineering, M.A. Geography-Glaciology and Remote Sensing.

Imagery of ocean swell patterns in ice in Labrador Sea was obtained during February and March, 1977, under Project SAR´77. The ability to image wave patterns in ice is important in that it may enable ice observers to distinguish between areas of solid ice sheets and unconsolidated pack. The SAR system, mounted on a C-46 aircraft, was used to obtain the imagery. The antenna depression angle for all imagery used was 30°, and the aircraft altitude was 3,200 m. The radar data were supplied in photographic form and for certain areas on computer compatible tapes (CCTs). The imagery was presented in the slant range mode. To provide a research platform and base of operations for pack ice studies in the Labrador Sea, an ice-classed vessel, M/V Arctic Explorer, was used.
The size of the ice floes were in the range 10-15 m in diameter. The resolution of the X-band data was nominally 3 m x 3 m and the resolution of the L-band data was nominally 6 m x 6 m. Therefore, the floes were well within the size of identification. The snow cover was 20 cm thick and had fallen the night before the remote sensing overflight.

Shore based ground verification sites collected information including meteorological measurements and observations, ice characteristics, such as thickness, density profile, salinity profile, electrical conductivity profile, vertical temperature profile and surface character, as well as snow characteristics (depth profile, density profile, thermal profile and surface character).

Another purpose of the Project SAR´77 study was to establish a centre of expertise in the handling of SAR data since the planned SEASAT A experiment was expected to have as its prime sensor an L band SAR.

In the C-CORE news No. 1 January 1980, there are some notes concerning an International Workshop on the Remote Estimation of Sea Ice Thickness, held in St. John´s, Newfoundland, on September 25-26, 1979.

The sixty participants included both researchers and operational users from North America, Europe, and the Soviet Union.
A significant amount of time was spent discussing the electrical properties of sea ice, since most of the remote measurement techniques involved radar sounding. Sea ice is a very complex natural material and discussion focused on the high variability of its electrical properties.
The majority of sounding results presented were based on a broadband impulse radar system that has been used for several years. However, new systems are under development, including synthetic pulse radar, a phase measurement system, and a distributed-source antenna. In the USSR modulated pulse radar and synthetic pulse radar have been used for some years. A new two-frequency phase-pulse system is under development in that country. Professor *V.V. Bogorodsky*, of the Arctic and Antarctic Institute in Leningrad displayed radar returns from Soviet sea ice sounding research. The importance of testing in the real environment was stressed.

Some of the invited papers dealt with the use of a laser and profilometer and a satellite altimeter to determine statistical ice properties over long tracks. The suggestion was made that inertial systems might be developed to extend these types of measurement for synoptic estimates of ice freeboard and hence thickness.

1.2 A planned Swedish Arctic Interdisciplinary Expedition

To celebrate the centenary of *A.E. Nordenskiöld*'s exploring of the North-East Passage in the Swedish Polar ship VEGA - the first ship in the World that successfully navigated from the Atlantic Ocean to the Bering Strait and circumnavigated Asia and Europe in 1878-1880 - a Swedish Arctic interdisciplinary expedition is planned for June-September 1980 in the state icebreaker YMER (see chapter 3 below). In this all-round scientific Arctic expedition there are participants also from several other countries, and therefore the expedition has a marked international character.

The ship will be equipped for satellite navigation and with special electronics for accurate position fixing. Further, there will be a variety of instruments for physical and chemical oceanography, atmospheric and oceanic research, sea ice research, equipment for geophysical studies of the ocean bottom and its sediments, glacial geomorphology, glacial striae and erratics, etc., further for pollution studies and marine biology, studies of the evolution of the continental margins and the history of sedimentation in the Arctic Basin, etc.

1.3 Exploration and transportation of natural resources in ice-covered sea areas

The exploration of the rich natural resources of the Arctic, such as oil, gas and minerals, and the transportation of the products in ice-covered sea areas may, as mentioned above, cause severe problems of various nature.
In some areas there is multi-year ice all the year round, in others most of the year, with open water for less than 30 days or so. In other areas again there is ice cover for a few months only.

In many cases the ice situation brings the transportation problem to the fore, concerning surface-shipping as well as under-ice navigation. In any case advanced remote sensing techniques are of great importance.
As regards under-ice navigation, see chapter 5 below.

Freeze-up and break-up dates vary in different parts of the Arctic, ice growth and ice thickness likewise.
In the Canadian Arctic Archipelago for example the freeze-up at Arctic Bay, Borden Peninsula at the northern coast of Baffin Island (73^{o} 0' N, 85^{o} 18' W) normally starts at the end of September and the break-up in June-July. The mean ice thickness is about 1.4 m. In Resolute Bay, Cornwallis Island, at Barrow Strait (74^{o}

43' N, 94^{o} 59' W) the maximal ice thickness is normally about 2 m, and farther north, in the Sverdrup Basin 3.6 m. At Eureka, Slidre Fiord, on the west coast of Ellesmere Island (80^{o} N, 85^{o} 56' W) the freeze-up normally begins in the first week of September and the break-up at the end of June. The maximal mean ice thickness varies from 1.93 to 2.36 m. The fairway is ice-free at the end of July on an average.
The Sverdrup Basin is characterized by very low temperatures, a large concentration of multi-year ice and stationary conditions throughout the winter. The open-water period is very short. Frequent storms there invariably lead to periods of zero visibility in blowing snow. In this basin valuable accumulations of gas and oil have been found, and from an economic point of view throughout-the-year operations are of great importance.
A task of first priority is to clear a landing strip on the ice for flying in equipment for oil rigs and base camps, etc. While there is still ice the equipment is moved by trucks on outbound roadways to suitable sites, whereupon the rigs and huts, etc., are mounted.

On account of currents and ice-pressure, etc., movements may arise also in an otherwise stable ice field. Because of that extraordinarily accurate position-fixing is an absolute necessity. Satellite systems and other advanced remote sensing techniques have then been used.
In some few cases, pipelines have been built for the transport of oil and gas from the sources to easier ice zones and terminals suitable for marine transport.

Year-round navigation systems necessitate high ice capability class tankers of suitable sizes. Economic analyses have been made for a range of sizes of Very Large Crude Carriers (VLCCs) and Liquified Natural Gas Carriers (LNGCs), etc., of different Artic classes, up to Class 10. They are presented in a careful and very comprehensive, lucid and well-arranged report,* entitled "A Study

on Marine Transportation of OIL and LNG from Arctic Islands to Southern Markets", prepared by Albery, Pullerits, Dickson Associates, Consulting Engineers, Ontario, March 1978.
In order to augment and verify their own data and estimates, the abovementioned Engineers have sent questionnaires to shipbuilders and other organizations and received useful technical information from among others A.B. Götaverken, Sweden; National Swedish Administration of Shipping and Navigation; Research Institute of National Swedish Defence; Oy Wärtsilä, Finland; Aker Engineering A/S, Norway, A.G. Weser, Fed. Rep. of Germany, and Moss Rosenberg Verft A/S, Norway.

On the continental shelf along the Canadian Arctic Islands in the southeastern Beaufort Sea several hydrocarbon zone discoveries have been made by ice-strengthened drill ships. Responsible for most of the drilling operations there has been the Canadian company "Dome Petroleum Ltd". In the summer of 1979 no less than four drill ships participated in the operations, assisted by an icebreaker through the ice to location. The results are promising.

1.3.1 Arctic Bulk Carriers, etc.

As regards arctic bulk carriers some words should be said concerning Götaverken Arendal´s latest project - a 37,000 dwt bulk vessel which meets the demands of Class 10 Icebreakers - the top class in Canada. The hull of the ship is extremely well strengthened so that it can resist the forces from the ice all the year round in the Arctic. She is a twin screw bulk carrier with double skin hull and twin rudders. For good ice performance the hull has an efficient icebreaking bow form and sloped sides; length over all 254.4 m, moulded breadth 32.2 m and designed draught about 12.2 m. The propulsion machinery consists of two steam turbines having a combined shaft power of 56,000 hp; average service speed 17 knots.

This Arctic Bulk Carrier is designed for the transportation of ore from the Arctic. But before an effective exploitation of the Arctic is under way a large amount of goods and material will have to be transported into the Arctic. The size of the cargo-hold openings, therefore, has been chosen so that goods with a length of about 24.4 m (a common standard length for pipes) can be easily loaded. Furthermore diesel oil can be loaded in one of the five cargo holds, and the other holds can be equipped with tanks for cement, mud or similar material used for offshore drilling.
Götaverken Arendal A.B. is also well prepared for the production of ships carrying LNG and has delivered several offshore platforms, giant floating docks for very cold climate with a lifting capacity of 80,000 tons (which means that it can dock vessels of up to 600,000 dwt), and other marine products.

Among Canadian designs may be mentioned Arctic Class 7 LNG-ships of 140,000 cu.m., a projected hovercraft for oil transports from the sources to terminal harbours with a loading capacity of 12,000 tons, etc.
A Finnish-built 16,000 dwt tanker "Lunni" for Arctic shipping is a design of special interest.

The results of the successful Soviet nuclear-powered icebreaker ARKTIKAs pioneering voyage to the North Pole in August 1977 and data assembled in that connection gave the technicians a basis for new constructions, among others 57,000 tons nuclear-powered container ships of reinforced icebreaker class with a capacity of 80,000 hp.

1.3.2 Icebreakers and Arctic Research Ships

The last Canadian icebreakers, PIERRE RADISSON, commissioned in 1978, and FRANKLIN, commissioned in 1979, are relatively shallow-draught (7.2 m) diesel-electric ships with a capacity of 13,600 hp,

2 shafts, 16 knots, displacement 7,594 tons full load; 1 helicopter.
In January 1979 it was announced, however, that a Canadian Class 10, 33,000 ton nuclear propelled icebreaker capable of 20 knots on 90,000 hp and able to deal with about 2.1 m (7 ft.) ice was being ordered; draught 12.19 m (40 ft.).

The U.S. Coast Guard icebreakers POLAR STAR, commissioned in 1976, and POLAR SEA, commissioned in 1978, displacement 12,087 tons full load, have conventional diesel engines for normal cruising in field ice (18,000 shp) and gas turbines for heavy icebreaking (60,000 shp), 3 shafts (cp propellers), 18 knots. The use of controllable-pitch propellers on three shafts will permit manoeuvring in heavy ice without the risk to the propeller blades caused by stopping the shaft while going from ahead to astern. At a continuous speed of about 3 knots the "Polar Star" Class is estimated to break slightly more than 1.8 m thick ice, and by riding on the ice these ships can break 6.4 m pack. They have 2 helicopters, hangar and flight deck aft, and extensive research laboratories provided for arctic and oceanographic research. As an example of scientific missions may be mentioned that the "POLAR SEA", according to an article in U.S. Naval Inst. Proceedings, December 1979, by *Mark T. Clevenger*, entitled "Polar Sea on Patrol in 1979", in February-April that year operated in the northern Bering Sea with a NOAA team of scientists, logging sightings of whales and other wildlife and sampling food supplies. Sonobuoys recorded whales´ vocal sounds.

In April-May the ship participated in two studies, partly in western Alaska waters, partly in the outer continental shelf environment. In the first case scientists and technicians correlated ship performance and ice characteristics to collect information to aid development of year-around commercial traffic in the Bering and Chukchi seas. In the second case scientists sampled water columns for photoplankton, zooplankton, nutrient chemistry, salinity, temperature, and primary productivity analysis.

Doppler shift velocity radar with digital display and oscillograph recorder augmented observations on ice characteristics, ridge profiles, weather conditions, ship´s speed and heading, propeller pitch and r.p.m., and ship´s position during movements, Observers measured ice thickness and snow cover during stoppages. Some of the ice breasted by the icebreaker was about 1.8 to 2.4 metres (6 to 8 feet) thick with pressure ridges not far from 5 m (16 ft.) above the surface. The wind blew steadily, piling the ice into rafts and ridges.
Having spent 56 consecutive days in the Arctic ice pack, the POLAR SEA headed for Antarctic ice in November.

The above-mentioned Soviet nuclear powered icebreaker ARKTIKA and her sistership SIBIR, both built in Leningrad, displacement 24,460 tons full load, have 2 nuclear reactors and steam turbines with a capacity of 66,000 to 75,000 hp; 3 shafts aft, 21 knots; two helicopters with hangar. On her transpolar navigation, ARKTIKA had to force multi-year ice, up to 4 m thick. The speed was then reduced to 1 knot and sometimes less. The 20-year-old nuclear powered icebreaker LENIN, commissioned 1959, (39,200 shp) can maintain a speed of 3-4 knots in about 2.4 m ice, giving a path of some 30 m.
On the basis of the ARKTIKA´s North Polar voyage and SIBIR´s "High Latitude" route in June 1978 the Soviet shipbuilders are designing a new generation of more powerful icebreakers. According to Jane´s Fighting Ships 1979-80 a projected LARGE NUCLEAR POWERED icebreaker will have a capacity of 80,000 hp.

The Wärtsilä-built diesel-electric Soviet icebreakers of "YERMAK" Class, 41,400 hp, are fitted with Wärtsilä mixed-flow air-bubbling system to decrease friction between hull and ice.

The "Icebreaker/polar research ship" OTTO SCHMIDT

The Soviet Polar Research Ship OTTO SCHMIDT is the first research ship in the world designed and built as an icebreaker. She was launched at Admiralty Yard, Leningrad, in 1978 and commissioned in January 1979. Her displacement is 3,650 tons. The main engines are Diesel-electric with a capacity of 5,400 shp, range 11,000 miles. In Jane´s Fighting Ships 1979-80 OTTO SCHMIDT is registered as "Icebreaker/polar research ship". She has 14 specially equipped laboratories, among others for hydrochemistry, hydrology, oceanography, meteorology, ice research and marine biology. To provide the scientists with an opportunity to perform hydrological and marine biological research, etc., direct from the ship also in ice-covered areas, a well is built right through the hull. By the aid of special bathymeters water samples can be taken and temperatures measured at all levels down to a depth of 4,000 metres. The complete equipment of scientific appliances extends considerably the domain of coherent hydrologic and meteorologic research.
The ship is equipped with up-to-date instruments for satellite navigation and accurate position fixing.

At the end of September 1979 OTTO SCHMIDT performed her first expedition in the high Arctic and reached 82^{o} 14' N in the Arctic Basin north of the Barents Sea. The ice conditions were then favourable up to about 82^{o}. Oceanographers, meteorologists, glaciologists, hydrologists and marine biologists and others were on the staff of scientists.
One of the main programmes for this expedition was studies of ice-ocean interaction processes in the marginal ice zone and the influence of water temperatures on atmospheric conditions, all of importance for compiling long-range weather forecasts.
On the 7th of October, OTTO SCHMIDT arrived at Murmansk, and on October the 20th she started a month´s research expedition into the more or less ice-coated Kara Sea, along the Northern Sea Route. Between Novaya Zemlya and Yamal Peninsula there was an

ice-free area, for the rest young ice with a concentration of 7-8 eighths. A week later the Kara Sea was completely ice-covered. On the 29th of November OTTO SCHMIDT again arrived at Murmansk having accomplished the expedition with success. The scientists had got new data concerning interaction between atmosphere and sea surface, and of the structure of the submarine part of ice massifs.

2 "SEA ICE 75" (A COMPREHENSIVE REMOTE SENSING EXPERIMENT ON SEA ICE, PERFORMED IN THE BAY OF BOTHNIA)

Large areas of our World are more or less ice-covered, and wide waters of sufficient depth for navigating are often blocked by floating ice. Shipping in such areas is, however, in many cases of great importance throughout the year, especially for exploring natural resources and getting them available for international trade. For a successful ice navigation a true knowledge of prevailing ice conditions is obligatory. Reliable ice-forecasts are desirable, and for the navigator it is necessary to be informed of the ice situation ahead of the ship.

Formerly, whalers and sealers, etc., watched the ice from the crow's-nest, and so did ships in winter when navigating in the Baltic as well.

In the first decades of the twentieth century the ice situation was still observed by visual reconnaissance, reported, however, by wireless telegraphy or telephony. Thus, a kind of remote sensing technique was then introduced. In the early twenties the reconnoitred sea area was considerably widened by the use of airplanes and later of helicopters too. At the same time photography was introduced for picturing the ice situation. In the thirties radio navigation systems came into use, and the first radar systems were developed. The picture of the viewed area was continuously transmitted from plane or helicopter and received aboard the ship on a TV-screen. This was a great advance, indeed, and it offered the bridge officer a possibility to choose the most suitable route in the ice fields.

In the early sixties satellites were put to use for ice studies, and some years later for making excellent ice charts.

In order for Sweden to acquire experience of her own and to assess the capability of remote sensing techniques for surveillance and mapping of sea ice, a field experiment (designated SEA ICE 75) was organized in international cooperation in the Bay of Bothnia in March 1975. It was the first time such a comprehensive remote sensing experiment on sea ice was performed in Europe. Five aircraft, three helicopters, one ice-breaker, and about fifty scientists and technicians took part in the experiment. Data were also received from two satellites. The experiment was performed within a general cooperation between Sweden and Finland on winter navigation research.

Installed in aircraft were forward-looking radar (FLAR), omnidirectional radar (ODAR), and side-looking radar (SLAR); further multispectral camera package and measuring camera as well as high-altitude camera and extensive field measurements. In helicopters were installed microwave radiometer, IR radiometer, IR scanner, and radar altimeter. The modern ice-breaker was equipped, in addition to radar, with helicopter, hydrocopter, and sonar for underwater ice profiling.

2.1 Results

The results from the SLAR studies indicated that Side-Looking Airborne Radar had enough proven and demonstrated capabilities to be the primary sensor in a future sea ice surveillance and mapping system.

The major differences between FLAR and SLAR concerned the type of presentation, the resolution and the time of integration. The main advantage of the SLAR was its considerably higher resolution which made the SLAR more suited for detailed mapping. Another advantage was that SLAR, in contrast to FLAR, gave an image which was comparable to an ordinary map.

The ship's radar had a much better resolution than the FLAR and the ODAR. It gave a detailed map of some of the ice parameters close to the ship, i.e. within a radius of 3 km. Heavy ridges could be detected up to a distance of 5 km from the ship.

The radar altimeter gave a clear indication of its capability to map ice roughness, and from the registrations it seemed possible to obtain information on the vertical dimensions of the deformed ice along the flight path.

The results of a passive microwave radiometer with two frequencies, 0.6 GHz and 4.7 GHz showed that the low frequency radiometer was a possible means for determining ice thickness provided the salinity of the ice was very low. The high frequency radiometer, on the other hand, had a much better resolution but it required surface temperatures below -10° C if ice thicker than about 40 cm was to be measured. The passive microwave radiometer also gave certain indications of its capabilities for ice roughness mapping.

The use of infrared thermography was tested by means of the helicopterborne infrared line scanner. The thermal radiation from the ice surface was recorded in the 8-14 µm region simultaneously on photographic film and magnetic tape. The IR-scanner showed clear distinction between thick ice and thin new ice/open water. With appropriate processing also thin new ice could be differentiated from open water. The ice concentration therefore could be obtained from IR-scanner registrations with a high degree of accuracy.

As regards the state of the ice surface, the IR-scanner could distinguish snow-covered ice from bare ice, and that is of interest both for navigation and for ice forecasting. The IR-scanner may also give rough information on the relative thickness of the bare level ice.

The area coverage of the IR-scanner depends on the scanning angle. At an altitude of 5,000 m, a maximum coverage of 17.5 km was obtained with a resolution of better than 10 m.

Infrared thermography is independent of light conditions but very sensitive to fog, clouds and any type of precipitation, which often confines the usable maximum flight altitudes and thus reduces the mapping capacity.

The information from the satellites then used, NASA model LANDSAT-2, was of very good quality. A drawback, however, was their weather dependence and, as concerns the visual part, also the light dependence. They provided information from four spectral channels (MSS) in the visual part of the electromagnetic spectrum. The MSS data gave the best information on ice concentration.

2.2 Brief Conclusions

None of the tested sensors alone gave satisfactory mapping of all the ice parameters required. The FLAR and ODAR gave a general view of the ice fields, identifying major ice/water boundaries as well as major areas of deformed ice. The SLAR gave much more details about the deformed ice fields and also identified more leads and fractures. It appeared that open water areas could be located indirectly in SLAR pictures on the basis of location, shape, size and sharpness of edges. All the radar systems had a good areal coverage.

As regards IR-scanner results the field experiment had shown that thermal infrared sensing can be used to differentiate ice from water and new ice from old, thicker ice. The thermal imagery had a much better capability than visual imagery of differentiating new ice and open water. Special features, such as rafting patterns, ridges and cracks, are correlated to thermal varia-

tions and can be detected and identified in the thermal image. Tape recordings are very useful for studying the objects in detail.
Whenever weather and light conditions permit, it is of great value if aerial photographs could be taken simultaneously with the thermal recordings. The thermal sensing technique itself is, however, independent of illumination and can be used day or night. The weather dependence is less than for the visual and photographic techniques, but clouds or heavy fog cannot be penetrated.

The SEA ICE 75 clearly demonstrated that a future ice mapping system will have to include a combination of sensors if all the required ice parameters are to be mapped.

For the short range operations of icebreakers, within say 20-50 km ahead of the ship, its own radar is an obvious component. In addition the helicopters stationed on board could profitably be equipped with suitable remote sensors. The choice of the sensors will depend on the capability of the long range system to provide detailed real-time information to the icebreakers.

The results from SEA ICE 75 indicate that SLAR could profitably be the main sensor in such a system. The SLAR might be supplemented by other sensors such as an IR-scanner.

3 "YMER 80", A SWEDISH ARCTIC EXPEDITION PLANNED FOR JUNE-SEPTEMBER 1980

3.1 Historical background

With representation from the Royal Swedish Academy of Sciences, the Royal Society of Naval Sciences, and the Swedish Society for Anthropology and Geography a committee was set up in December 1976 to investigate the possibilities of organizing an Arctic interdisciplinary expedition to celebrate the centenary of *A.E. Nordenskiöld's* transit of the North-East Passage in the VEGA and circumnavigation of Asia and Europe in 1878-1880.

In January 1977 the Royal Academy of Sciences circulated an inquiry to a great number of scientists in order to find out their interest in such an expedition. The idea was met with great enthusiasm, and about 40 research proposals were submitted. A committee of five scientists - all Professors - was organized to prepare a coordinated programme and to decide the necessary priorities of proposed disciplines, viz. *Bert Bolin* (atmospheric research), *Erik Dahl* (biology), *Gunnar Hoppe* (physical geography), *Valter Schytt* (glaciology) and *Frans E. Wickman* (geology).

In a Paper to the President, Prof. Dr. *G. Hildebrandt*, and Participants of the ISP Commission VII Symposium in Freiburg, Federal Republic of Germany, July 2-8, 1978, by *Ragnar Thorén*, entitled "REMOTE SENSING AS AN AID FOR NAVIGATION IN ICE-COVERED SEA AREAS", 49 pp., there is a picture showing the Swedish polar ship VEGA passing the easternmost point of Asia, Mys Dezjneva, on July 20, 1979, having explored the North-East Passage - being the first ship of the World which had successfully navigated from the Atlantic Ocean to the Bering Strait and the Pacific Ocean (in 1878-79). In the mentioned picture, near the top of the mainmast, the crow's-nest is clearly visible. From there the lookout watched the ice, informing the navigator, the VEGA's captain, *Louis Palander*, concerning the ice situation ahead of the ship.

After having circumnavigated Asia and Europe the VEGA arrived in Stockholm on April 24, 1880. She there received an enthusiastic welcome by His Majesty the King, the Royal Academies and all Sweden, Finland, Norway, Russia, and many other countries. Ever since, the Swedish almanac has the name Vega for April 24, and this commemoration day has been choosen as the yearly festival day of the Swedish Society for Anthropology and Geography.

Professor *Adolf Erik Nordenskiöld* participated in no less than ten arctic expeditions, eight times as the leader. He always planned them as all-round scientific expeditions for the exploration of polar regions: Svalbard in 1858, 1861, 1864, 1868 and 1872-73, Greenland 1870 and 1883, the Yenisey 1875 and 1876, and the North-East Passage 1878-79.

The above-mentioned organizing committee decided to focus activities on the northern Barents Sea, the Arctic Ocean north and northeast of Svalbard, the sea between Spitsbergen and Greenland, and to the waters outside North Greenland.

The Swedish Government made one of the new state icebreakers available for the expedition, and in the summer of 1979 the National Swedish Administration of Shipping and Navigation decided that "Ymer" with 22,000 shp and 8,000 tons displacement would be the most suitable ship. She is manned by the Navy, and in addition to the crew there will be room for about 50 scientists and technicians. She has been equipped as a research ship and two helicopters will be carried for ice navigation and research purposes. Fig. 2 shows "Ymer" breaking her way in hummocked ice in the Bay of Bothnia.

The expedition will last about three months starting from Sweden on June 24, 1980, and has been given the name "YMER-80".

3.2 Leadership, etc.

Chief of operation is Admiral *Bengt Lundvall*, former Chief of the Swedish Navy, and Scientific leader the well-known Arctic and Antarctic explorer and glaciologist, Professor *Valter Schytt*, at the University of Stockholm. The ship´s captain is Navy Captain *Anders Billström*, assistant to admiral Lundvall Navy Captain *Carl-Gustav Hansson* and to professor Schytt *Hans Dahlin*, M.Sc.

The scientists aboard represent many different research sectors, such as Sea Ice, Physical and Chemical Oceanography, Atmospheric research, Biological and Marine-Geology research, etc.
In this Swedish all-round scientific arctic expedition there are participants also from several other countries, viz. Canada, Denmark, Federal Republic of Germany, Finland, France, Great Britain, Norway, and the U.S.A. Inquiries and invitations have been given also to others showing a keen interest in Polar research. The scientific expedition "YMER-80", therefore, has a marked international character.

The cruise consists of two legs separated by a call at Tromsø, Norway, for exchange of scientists and replenishment of fuel.
In all, 100 scientists or so will be active in the expedition, 36 of them non-Swedes. About 15 professors will be on the staff.

The ship will be equipped for satellite navigation and precision measuring of great depths, etc. Further, there will be special electronics for accurate position fixing, a variety of hydrographic instruments, deep-sea winches, equipment for bottom sampling, chemical, physical and geological research, and a good deal of other instruments.

3.3 SEA ICE

The Sea Ice programme covers Ice-Ocean Interaction in the marginal ice zone, as well as Ice Conditions and Ice Properties along the ship´s route. Engaged in the first-mentioned part of the programme is Dr. *Peter Wadhams*, Scott Polar Research Institute, Cambridge, England, and in the second part Professor *Erkki Palosuo*, Department of Geophysics, University of Helsinki, Finland. Another interesting proposal, delivered by Professor *Richard Moore*, at the Remote Sensing Laboratory of the University of Kansas Center for Research, Inc, U.S.A., involves measurements of radar backscatter from the sea ice during the last month (September) of the "YMER-80" expedition.

3.3.1 Ice Conditions

To map the ice along the YMER´s route and study the properties of it, visual observations as well as advanced remote sensing techniques will be applied.

As regards visual observations, the ice coverage, floe size, amount of leads and ridges, etc., will constantly be noted. Typical and interesting ice formations are to be photographed. Daily, whenever possible and when navigating through safe ice fields, at short-time stops, the thickness of ice and snow cover, as well as the density and temperature of snow and ice will be observed, and the salinity of ice measured. Equipment to be used are measuring sticks, salinometer, thermometers, drill, and plastic trays for ice and snow samples. To spare the trouble of making drill holes, the ice thickness may be measured from the side of the channel of the ship.

At long-time stops in suitable ice fields not only ridges but also the underwater profile, i.e. the ice keels, will be measured. Levelling instruments, theodolite, sonar equipment, ice auger and chain-saw will be used. When no leads occur, one or several holes will be drilled for the sonar head to be lowered into the water below the ice. Thus, remote sensing technique will be introduced. If possible the strength and remaining salinity of multiyear ice will be measured too.

Fig. 2. The Swedish icebreaker YMER breaking her way in hummocked ice in the Bay of Bothnia. Displacement 8,000 tons, length over all, breadth and draught about 105 x 24 x 7.3 m; D/E machinery output 22,000 shp, 4 propellers, 2 fore and 2 aft, speed 19 kn. Designed in close cooperation between the Swedish and Finnish Administrations of Shipping and Navigation; Builders WÄRTSILÄ HELSINKI SHIPYARD.

(Photo: April 18, 1979, by *Stig Nyberg*, Civilmarin, Norrköping, Sweden)

The ridge profiles will be tape-recorded with a laser instrument, placed on the railing of the bridge, angled down about 45°. The laser profiling equipment has been used aboard Swedish icebreakers in the Bay of Bothnia with good results and can be placed in helicopters as well. By the aid of a special-mounted camera the ship´s radar screen may be photographed at suitable intervals.

3.3.2 Ice-Ocean Interaction in the marginal ice zone

In a paper to the Swedish Academy of Sciences Dr. *Peter Wadhams* emphasizes that a complete understanding of ice-ocean interaction processes in the marginal ice zone cannot be gained without a study of the following phenomena: - the structure and dynamics of the ice cover near the ice margin under various wind and current conditions, including tidal currents in shallow water; - upwelling and downwelling along the ice edge; - oceanic fronts and eddy structures along the ice edge; and the interaction of surface waves with the ice cover, etc.

Throughout her cruise YMER may be receiving Tiros N imagery in almost real time from Tromsø receiving station, and this will be a great help in the planning of the track relative to the ice edge and the location of eddies.

According to a proposed programme for the ice research in question one part ought to take place at or just within the ice margin in the Barents Sea and between Spitsbergen and Greenland for the purpose of an experimental study of ice edge dynamics using radar transponders. Another part of the programme comprises an experimental study of surface eddies at the ice margin in the Strait between Svalbard and Greenland. Dr *Wadhams* intends to study Landsat and NOAA imagery from the whole length of the East Greenland Current in an attempt to estimate the frequency, sizes, lifetimes and velocities of ice edge eddies. To complement this study, he would like to examine a single eddy using the icebreaker. This would be on an opportunity basis, when either current satellite imagery or else helicopter-borne ice reconnaissance has revealed the existence of a feature of the required type.

When a suspected eddy is found, the ship positions herself in the centre while the helicopter is launched and carries out a rapid survey of the size and shape of the eddy and the positions of its ice and open water "arms".

3.3.3 Radar Measurements of Backscatter from September Sea Ice

This radar experiment proposed by Professor *Richard Moore* calls for measurements of the radar backscatter over the frequency range from 8-18 GHz (wave length range 3.75 to 1.67 cm) at angles of incidence of 20^o, 40^o and 60^o relative to vertical.

The measurements are to be made from a helicopter and, if feasible, from a surface-mounted structure, at as many different ice sites as possible, and with as many different types and thicknesses of ice as practicable. The measurements are to be accompanied by measurements of the properties of the ice observed by the radar.

Radar images of the ice have been made since the early sixties. The Soviet Union developed a special radar TOROS (Russian for "ice ridge") for ice surveillance and uses it operationally in mapping the ice north of Siberia. The National Photogrammetric Committee of the USSR presented to the XIIth Congress of the ISP, Commission VII, in Ottawa, Canada, 1972, a paper, entitled "Toros" side-looking radar system and its application for sea-ice conditions study and for geologic explorations.
According to this paper, TOROS-radar images present the following characteristics of the sea ice cap: "its age (using enlarged gradation), degree of packing, relative amount of the floes of different sizes, the degree of hummockness, the amounts, sizes, and orientations of free-water areas and channels, the velocity and direction of the ice drift (by repeated survey), and in specific cases the compression."

Professor Moore mentions that The Atmosphere and Environment Service of Canada now has aircraft equipped with imaging radar used in ice-patrol work.
It may here be added, that *Moira Dunbar*, Defence Research Board/ DREO, National Defence HQ, Ottawa, has published a report on "Fall Ice Drift in Nares Strait, as Observed by Sideways-Looking Airborne Radar" in ARCTIC (Journal of the Arctic Institute of North America), December 1979. The imagery on which her study is based was obtained by a Canadian Forces Argus aircraft as part of a joint Canadian/UK exercise designed primarily to provide top and bottom profiles of ice in the Arctic Ocean. An earlier paper on the interpretation of ice characteristics in the SLAR imagery was published by Moira Dunbar in 1978, as DREO Report No. 770. 36 pp., entitled "Interpretation of ice imagery from original and modified versions of a real-aperture SLAR".
As the aircraft was based at Thule in northwest Greenland, the opportunity was taken to image Nares Strait as often as possible enroute to and from the Arctic Ocean. The resulting imagery provided a considerable amount of information on ice drift in the strait through the tracking of floes from one flight to the next. The radar used was a Motorola AN/APS-94D, a real-aperture SLAR which images on either or both sides of the track, at ranges of 25 and 50 km a side.

The non-imaged strip below the aircraft had a width of about twice the flight altitude. The range resolution was about 30 m, and the azimuth resolution 40 m at 5 km from the track, deteriorating down-range at a rate of 8 m/km. This was quite adequate to allow identification of floes from one image to another.

In spite of the success of these imaging radars on aircraft, an urgent need exists for a satellite radar for mapping the ice because of the logistic problems in getting sufficient coverage of the Arctic basin with aircraft (Moore).

As regards the YMER-80 proposed mode of operation, suitable sites where the ice conditions are appropriate for measurement will be located from the ship´s helicopter. Several adjacent sites, within a radius of 100 m or so, will be marked with dye markers or other kinds of highly visible markers. Then, radar backscatter measurements will be made for each of the sites in the immediate neighbourhood at the angle of incidence set before helicopter take-off. The helicopter will then land by one of the sites and set off a surface truth party. Tre radar operator will change the angle of incidence, whereupon the helicopter will take off and measure the radar backscatter at the second angle of incidence for each of the sites in the area.

The surface truth party will obtain an ice core, a measurement of depth, various temperatures, various photographs and a measurement of roughness for each of the sites in the immediate vicinity. If possible, a measurement of the free water content will also be made.

The helicopter will again land and the angle of incidence will be changed. It will then take off and the measurements will be made at the third angle.

Measurements of backscatter as a function of frequency and angle of incidence will provide a quantitative indication of the ability of the radar at this time of the year to measure the difference between the different kinds of ice and vill provide an indication of the confusion factor that may exist among ice types. In addition, the optimum frequency and angle of incidence will be determined for these conditions.

The results of the measurements will be factored into the existing theoretical model for radar backscatter from sea ice and modifications made to the model if appropriate.

3.4 Physical Oceanography

The main water exchange between the Arctic Sea and the worlds oceans occurs through the passage between Spitsbergen and Greenland.
To the east warm high-saline Atlantic water is transported northward by the current west of Spitsbergen. A return flow of cold, fresher water and ice takes place west of that in the East Greenland Current.

From a climatological point of view these flows are important: 10-20 % of the global northward heat transport at 80° N is carried by oceans. The by far most dominant part of it is transported by these two currents through the small meridional band between Greenland and Spitsbergen. A deeper knowledge of the strength, variability and transformations of the inflowing Atlantic water, which carries the bulk of the heat transport, is therefore of great interest.

When the Atlantic water reaches the area north of Spitsbergen, it follows the continental slope eastward into a region where few available oceanographic data exist. The "YMER-80" expedition offers an opportunity to shed some light over the nature and strength of the processes involved.

It is this flow which maintains the Atlantic layer of the Arctic Ocean, an enormous subsurface reservoir of heat, the integrity of which is maintained solely by the salinity stratification of the overlying water. This latter upper layer extends down to about 200 m and is characterized by a permanent salinity gradient below about 25-50 m, although temperatures are near the freezing point through much of the layer.

As regards the export of sea ice between Greenland and Svalbard, recent studies show that a considerable amount may, at least for shorter periods, be exported through the passages between Nordaustlandet and Franz Josef Land as well.

A joint physical oceanography programme may be divided into five subprogrammes as follows:
1:o Study of the transformation of Atlantic water along the continental slope by means of measuring conductivity, temperature and depth (CTD) in sections from the shelf into the basin;
2:o Study of long period wave disturbances at the shelf by two sections of current meter stations equipped with automatic meters, and also two automatic tidal recorders;
3:o Study of the ocean current structure in the Greenland-Svalbard passage along the 79^{o} N parallel using CTD and current meter casts;
4:o Study of double-diffusive processes north-east of Greenland using numerous CTD-stations coupled with acoustic current meter measurements, and
5:o Investigation of long term average export of sea ice in the two main passages east of Svalbard with the aid of current meters and tidegauges and possibly also automatic self-positioning satellite stations to be placed on the drift ice.

On the staff of the Physical Oceanography programme are Professor *Arne Foldvik*, University of Bergen, Norway, Professor *Knut Aagaard*, University of Washington, U.S.A., researcher *Bert Rudels*, technicians and oceanographers, at the Institute of Oceanography, University of Gothenburg, Sweden, and others.

3.5 Chemical Oceanography

One of the problems in ocean chemistry is the refertilization of the photolayer of different parts of the world seas, reactions leading to dissolved organic matter, hydrogen carbonate, nitrate and phosphate. The reactions in question are catalyzed by enzymes supplied by bacteria on the particles.

Grazing of the primary photosynthetic production is important since the concentration and activity of putrefying (digesting) enzymes is most likely to be very high inside the zooplankton. The microbial activity of sea water follows a general pattern vs. the depth. The thickness of the photolayer depends on the nitrate available due to upwelling and horizontal spreading together with the light level. It varies as a rule between 10-20 m for well fertilized surface water and 120-150 m for practically zero nitrate (e.g. clear tropical waters).

It seems quite reasonable to assume a steady state level of total carbon, nitrogen och phosphorous in the Arctic Sea. To supplement measurements in the Norwegian Sea information is needed on the inflow over the Barents Sea and the outflow from the Nansen Deep over the Yermak Rise, Lena Trough and Greenland Sea (see Fig. 3, Bathymetric chart showing the Arctic Ocean, drawn by the author, *Ragnar Thorén*, on the basis of old and new measurements).

The levels of hydrocarbons and fatty acids is of special interest since the natural decay is probably slow, but the production during the short and intensive Arctic summer may be high. Organic and trace metal pollutants may be low in the Arctic Sea since we are outside the westerlies and the industrial production zone (30° to 70° N) of the northern hemisphere. The following constituents are planned to be analyzed:
Total dissolved and particulate organic carbon, mono- and disaccharides, amino acids, hydrocarbons, chloro-organics and other organic pollutants, fatty acids, dissolved zinc, lead, cadmium, copper and other dissolved trace metals. Precision titrations of alkalinity and total carbonate and pH. Nitrate, nitrite, ammonium, urea and phosphate including particulate nitrogen and phosphate. Triple P (plankton putrefaction products).

Knowledge about the carbon is of greatest importance in studies of the climate and in predicting the changes of the climate which will arise from human activities. The percentage of carbon dioxide in the atmosphere has increased since the industrial revolution although the increase is less than the CO_2 release. This means that there is a sink for carbon dioxide.

The relative C-14 content also decreased but less than a simple dilution would imply. Later on the tests of nuclear weapons have added C-14 to the atmosphere. Since a decrease of the relative C-14 content of the surface water of the oceans was seen followed by an increase it can be assumed that the oceans constitute at least part of the sink. The biosphere also shows a decrease followed by an increase and since the biosphere may change in size it may act as a source or as sink. To determine the C-14 activity in deep water, in surface water and in the atmosphere, to yield data for exchange rate studies, it is proposed to include a study of the radiocarbon concentration in sea and atmosphere during the "YMER-80".

It will be of great interest to compare coming results of this expedition with the situation at the end of last century. At the Swedish scientific Arctic expedition in 1898 with Professor *Alfred Gabriel Nathorst* as leader, bacteriological researches were performed on several places. At Björnöya, for example, the filtered air was absolutely free from bacteria, and a few moulds only, were found. At the Recherche-fiord in southwestern Spitsbergen, the bacteriologist (Dr *E. Levin*) had the same result, every day not a single bacteria in thousands of litres of air, and exceedingly few moulds. Some few bacterias were found in the sea, about one bacteria per cu.cm; at greater depth only one bacteria per 6 to 7 cu.cm (according to "SVENSKA ARKTISKA EXPEDITIONER UNDER 1800-TALET" - Swedish Arctic Expeditions during the 19th Century, by *Ragnar Thorén*, 1978, 365 pp., Marinlitteraturföreningen, Stockholm).

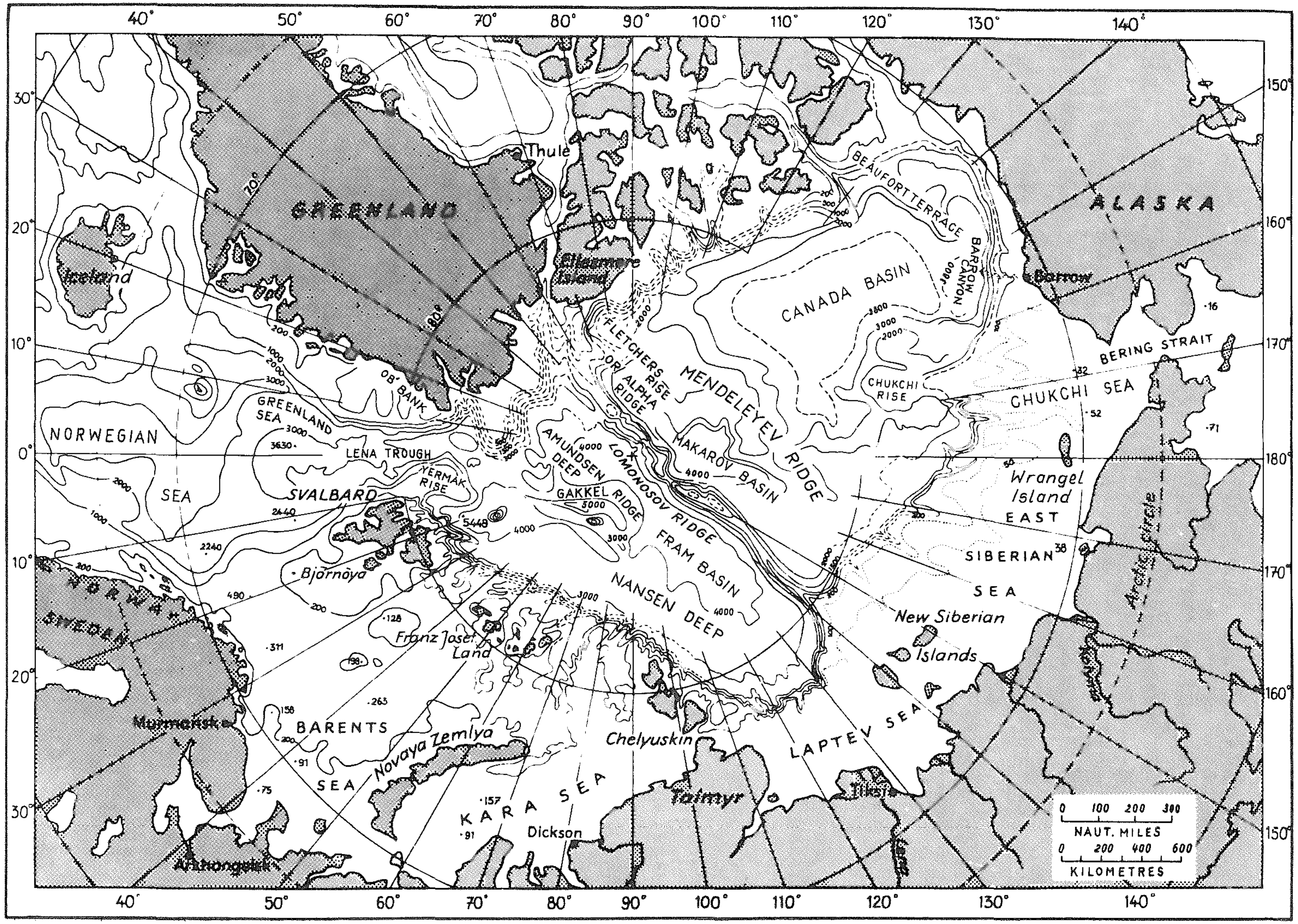

Fig. 3. Bathymetric chart showing the Arctic Ocean, drawn by the author on the basis of old and new measurements (Fig. 1 in PICTURE ATLAS OF THE ARCTIC by *Ragnar Thorén*, Elsevier Publishing Company, Amsterdam - London - New York, 1969, 449 pp.).

On the staff of the Chemical Oceanography programme are, among others, Professor *David Dyrssen*, Dr. *Lars-Göran Danielsson* and several assistant researchers at the Institute of Analytic Chemistry, University of Gothenburg, Dr. *Elis Holm* and Ass. Professor *Bertil Persson* at the Institute of Radiation Physics, University of Lund, and the researcher *Jorge Valderrama* at the National Fishery Board, Sweden; Dr. *Tomas Gosink*, University of Alaska, U.S.A., *Malcolm Lowings*, Dalhousie University, Canada, and *Leon Mart*, Kernforschungsanlage, Jülich, Fed.R. of Germany.

3.6 Atmospheric and Oceanic Research

The atmospheric chemistry programme will be a joint effort between several institutions, and the problems of interest to be studied include:
1:o, how anthropogenic compounds, especially with origin in Europe, are transported to the Arctic region;
2:o, transformation during this transport, including gas to particle conversion, changes in size distribution due to coagulation and removal;
3:o, removal rates of gases and aerosols, and
4:o, physical, optical and chemical properties of the Arctic aerosol in particular with regard to its possible interference with the radiation balance.

Participants of the research programme are among others Ass. Professor *Lennart Granat* (responsible for the scientific work), University of Stockholm, Ass. Professor *Björn Holmgren*, University of Uppsala, Professor *Bengt Forkman*, *Hans Lannefors*, M. Eng., and *Hans Christen Hansson*, M. Eng., at the Institute of Nuclear Physics, Technical University of Lund, Sweden; Dr. *Kenneth Rahn*, University of Rhode Island, *Wolfgang Raatz*, University of Alaska, U.S.A., and *R. Jaenicke*, University of Mainz, Fed. R. of Germany.

3.7 Glacial extent and climatic variations

Several university departments in Sweden have for many years been involved in studies of climatic variations and of the extent of the Pleistocene ice sheets. Expeditions to the Spitsbergen area in the 1950ies and 60ies could convincingly show that a large ice sheet once covered the Svalbard archipelago, Franz Josef Land and northern (probably also central) parts of the Barents Sea. The rapid deglaciation of Spitsbergen and Nordaustlandet about 11,000 years ago is clear. It is also clear that the 7,000 year-isobases have a culmination over central Barents Sea, but no one has quite convincingly shown if the Scandinavian ice sheet ever grew together with the Barents ice sheet.

The "YMER-80" expedition will try to get definite evidence for or against coalescence of the two ice sheets but also establish a chronology of the glacial events in the Barents Sea.

The extent of the ice sheet(s) will also be studied along the continental slope north of Svalbard. At the end of the season, if time permits, the expedition will move west to the coasts of North Greenland and make comparative studies of glacial extent over the Greenland shelves.

Most of the information on the extent of the ice sheet will certainly be obtained from various geophysical studies of the ocean bottom and its sediments. Sediment cores of 15 to 20 metres in length will offer the most detailed information. Certain work will be done on land, where the glacial geomorphology, glacial striae and erratics etc., will be studied. Sediment cores from lakes at different elevations above sea level will be used for studies of land uplift, time of deglaciation, Holocene climatic fluctuations and as complement to the cores from the sea bed.

3.8 Pollution problems as studied in bottom sediments

During the last decade the interest in pollution studies has grown rapidly, particularly in highly industrialized countries. A major problem, however, is that the natural back-ground level for a given component usually is unknown.

Sometimes this problem is successfully solved by studying the variations with depth in the sediments of a given component. However, there are also many sediments where pronounced element variations with depth exist, variations that are due to authigenic, diagenetic and climatic conditions. It is therefore obvious that metal enrichments in a sediment top layer are not always caused by pollution.

Several pollution studies have recently been made in the Baltic, but great difficulties exist for the interpretation of the abundance patterns for Cu, Ni, Cr, etc. To circumvent these difficulties one must find an area that is geologically and oceanographically similar to the Baltic - and as unpolluted as possible.

The Barents Sea is therefore of great interest in this context. Sediments, deep water samples, etc., will be studied within a framework of a general bio-geo-chemical and geological research.

3.9 Submarine volcanism and the history of the continental margins

Considerable interest has been shown by several scientists to obtain geological samples from the continental margins north of Spitsbergen and the Barents Sea - and particularly from the Yermak Plateau and the Morris Jessup Rise.
A study of the evolution of the continental margins and the history of sedimentation in the Arctic Basin should comprise:

1:o Geophysical investigations;
2:o Geological sampling for rock specimens;
3:o Coring of pre-Quaternary sediments - if such sediments can be reached by a piston corer, and
4:o Coring of Quaternary sediments.

3.10 Marine biology

A substantial faunal interchange between the Atlantic and the Arctic has taken place and is still in progress. It affects in the first place shallow water and upper slope faunal elements. Very little is known concerning the history of faunal interchange through the narrow waterways of the East Canadian - North West Greenland area.

During the Cenozoic great climatic fluctuations have occurred in the Arctic. The Eocene was still warm, but recent results indicate that the Oligocene was much colder than generally presumed, probably even with ice formation in the Polar Basin. During the Miocene and early Pliocene a warmer period intervened before the late Pliocene-Pleistocene glaciations. Consequently the fauna invasions from the Pacific took place during periods with a temperate climate and the invading elements were boreal, not arctic forms.

One of the biological groups will be active on Kong Karls Land under the guidance of Professor *Christine Dahl*, University of Uppsala. Leader of the marine biology is her husband, Professor *Erik Dahl*, head of the Zoological Institute, University of Lund, Sweden. Some of his collaborators are Professor *Hjalmar Thiel*, University of Hamburg, Lector *Ole Tandal*, University of Copenhagen, Professor *Jarl-Ove Strömberg*, Marine Biology Station of Kristineberg, Professor *Birgitta Norkrans*, Inst. of Marine Microbiology, University of Gothenburg, Dr. *Anders Warén*, Zool. Inst., University of Gothenburg, *Thor Larsen*, Norwegian Polar Institute, *Mitchel Taylor*, U.S. Fish and Wildlife Service, and *Erik Born*, Zoological Museum, Copenhagen, Denmark.

Members of Christine Dahl´s group are Dr. *Ingvar Kärnefelt* and *Roy Danielsson*, University of Lund, further *Peter Gjelshup*, Natural-History Museum, Århus, Denmark.

Participants of the Marine Geology programme are among others Professor *Kurt Boström*, Technical University of Luleå, Professor *Jörn Thiede*, University of Oslo, *Anders Elverhöi*, Norwegian Polar Institute, *Wayne Bock*, University of Miami, U.S.A., Ass. Professor, Dr *Olav Eldholm*, Department of Geology, University of Oslo, *Kathlene Crane*, Woods Hole, U.S.A., researchers *Lennart Widenfalk* and *Christer Pontér*, Technical University, Luleå, Sweden.

ICE IN THE GRAND BANKS AREA

The presence of pack ice and drifting icebergs in the North Atlantic around the Grand Banks of Newfoundland means hazards for the shipping, and loss, perhaps, of life and property. Through that area passes the World's heaviest transoceanic traffic.
During the iceberg season thick fog, created by the confluence of the cold Labrador Current and the warm Gulf Stream, is present most of the time, further endangering the navigation. The season in question normally lasts from the end of February to the middle of July with its maximum in April-May.

As a result of the loss of the transatlantic liner "Titanic" on April 15, 1912, in latitude 41° 46' N., longitude 50° 14' W., with a toll of 1,517 lives, an International Conference for "Safety of Life at Sea", held in London 1913, established an International Ice Patrol for the purpose of surveying this most treacherous area of the North Atlantic during the ice season. The United States was asked to undertake the management of the patrol, and the task was delegated to the U.S. Coast Guard. Ever since, except for the years of the two World Wars, this organization has carried out the work with vigilance and success. There has never, as a matter of fact, been a more successful international effort for the preservation of life and property at sea. No lives have been lost in collisions with bergs in the area the Patrol serves.

The United States and 18 other maritime nations share the costs of the patrol. One of them is Sweden. Because assessments are based on the tonnage moving through North Atlantic shipping lanes, the United Kingdom pays the largest share. But responsibility for carrying the assignment rests with the U.S. Coast Guard alone. Their duty is to report and survey all ice and all icebergs drifting south of the 48th parallel. Patrol planes on routine ice-surveillance missions fly north as far as the Strait of Belle Isle, however. Southern limits of the patrol vary, depending on the position of the southernmost icebergs.

Most of the icebergs have calved from west Greenland glaciers. At first the bergs drift northward, borne on the West Greenland Current, to the Melville Bay. Their route then angles west, until they slip into the southward-flowing cold Labrador Current. There they are usually trapped by sea ice, slowly drifting with the ice field towards south and warmer water (illustrated by the U.S. Coast Guard photo, Fig. 4). The icebergs that come down the Labrador Current in the spring are those which were trapped by the sea ice in the Melville Bay area the preceeding winter. The second winter the same bergs may be in the vicinity of Cape Dyer, the easternmost cape of Baffin Island, and the next spring, at the earliest, in the Grand Banks region. Thus, the trip from Greenland glaciers to the Grand Banks may take as long as two and a half to three years.

Measurements of the specific gravity of ice in Greenland´s western bergs have given values close to 0.90, while the cold sea water in which they float has a specific gravity of about 1.027, so that about seven-eights of the mass is submerged. These ratios, however, hold good only for mass, and not for linear dimensions. The U.S. nuclear-powered submarine "Seadragon", on her way to the North Pole in August 1960, to explore a new Northwest Passage (see chapter 5 below), was the first submarine to go under an iceberg. In Baffin Bay she measured several bergs, the largest one having a bottom of 268 x 448 m (879 x 1,470 ft.) and a mass of three million tons (*STEEL*, 1962).

Of the many thousands of icebergs which break off the glaciers every year - estimated at about 7,500 sizable bergs - an average of about 400 ultimately drift south of latitude 48^{o} N into the Atlantic shipping lanes southeast of Newfoundland. The numbers vary, however, from year to year, and according to an article in National Geographic, June 1968, by *William S. Ellis*, entitled "Tracking Danger With the Ice Patrol", 1929, for example, was a peak year with 1,351 bergs sighted below the 48th parallel.

In the years 1971-1972, Canada had exceptionally cold winters in the North and the most severe ice conditions registered during the last 20 years. The iceberg season was unprecedented with not far from 1,600 (entirely 1,587) bergs south of the 48th parallel or 4 times more than normally. The season did not finish until the 4th of September.
During the next iceberg season about 1,200 bergs passed the 48th parallel, and in 1974 the number of icebergs south of the parallel in question was in total 1,386.

When, in October 1974, the author of this ISP-report visited the Headquarters of the International Ice Patrol, the ice experts explained this remarkable increase of icebergs in the Grand Banks area by greater masses of cold water in the arctic current from the Lincoln Sea via the Nares Strait to the Baffin Bay - Labrador Sea through which more icebergs had been kept alive on their travel southwards. According to Canadian reports concerning ice conditions in the Beaufort Sea, the 1974-season was the worst ice year on record, a situation well corresponding with observations made on Sovietic drifting scientific Ice Stations pointing to a colder climate in the Arctic Basin. The severe ice conditions in 1978 and 1979 confirm this prophecy, in any case as regards the 70-ties.

When drifting in warmer water, bergs quickly disintegrate. It has been observed that small bergs disintegrate within 5 days upon reaching 4^{o} C (about 40^{o} F) water, medium-size bergs within about 10 days, and large bergs last approximately 2 weeks or more in 4^{o} C water.

As regards visual reconnaissance may be mentioned that U.S. Coast Guard planes mark icebergs by "bombing" them with a dye - a mixture of rhodamine-B for colour, calcium chloride for penetration - for quick identification in driftpattern studies. Coast Guard ships do the same with a bow and dye-tipped arrows. Sightings of the colour-flagged bergs will help scientists determine their speed and direction.

Fig. 4. Shipboard view of an iceberg stalled in pack ice offshore Kap York, west of Melville Bay, northwest Greenland. (Photo: courtesy U.S. Coast Guard; June 13, 1963; Fig. 59 in PICTURE ATLAS OF THE ARCTIC by *Ragnar Thorén*, Elsevier Publishing Company, Amsterdam - London - New York, 1969).

Calcium chloride pellets burrow an inch deep into the ice, which allows the dye to become imbedded so that it does not wash off with melting.

In the early sixties and seventies ice information by visual reconnaissance and aerial photography was completed with effective surveillance systems based on remote sensing techniques. It was possible to study the ice situation clearly on radar, and to register the conditions continuously through radar photography. As early as in 1962 side-looking airborne radar (SLAR) was tested with good results, and in 1964 a multifrequency SLAR system was in use. Four independent transmitters were operating: within the X-band (at 8910 MHz), the C-band (4455 MHz), the L-band (1228 MHz) and the P-band (428 MHz), in several cases in combination with equipment for laser profiling.

In the early seventies the SLAR antenna, used on U.S. Coast Guard´s C 130 aircraft, consisted of two 2.4 m (about 8 ft.) long, absolute plane slot aerials, one on each side of the body. Within the K_u-band, at 16 GHz (1.9 cm wavelength), the resolution was quite good. At an altitude of about 2,400 m an ice-breadth of about 10 nautical miles was registered on each side of the aircraft.

In March 1966 a new radiometric detection system was installed in HC-130B aircraft assigned to monitor icebergs. The new device, known as a microwave radiometric iceberg detector, was operating in the K_u-band, at frequencies ranging from 13.5-16.5 GHz, with a nominal temperature sensitivity of 1.75^{o}K. The antenna beam-width was 2.2^{o} by 1.7^{o}. The design was based on the principle that all matter sends out electromagnetic impulses. By measuring differences in thermal energy, the device then determines whether the object under study is an iceberg or some other floating material. This airborne microwave radiometric search set was designed to operate in conjunction with the aircraft´s radar system. While the radar scanned ahead to search out objects, the radiometric equip-

ment mapped the surface below and astern. A facsimile recorder displayed an instantaneous graphic map of the area being searched, and an oscillograph simultaneously plotted temperature amplitudes of objects being scanned.
Since the early 70-ties ice zones are scanned and icebergs tracked by satellites too.

As regards methods for measuring the ice thickness a device often used is a specially constructed radiometer, a so-called radio spectrometer, for simultaneous transmission on two frequencies and measuring the temperature of the reflected radiation (in Kelvin-degrees). The frequencies being chosen so that the transmitted energy in one case is refelcted from the upper side of the ice, in the other from the water, which is the boundary surface of the underside of the ice. As an example of suitable frequencies the wavelengths 9 cm and 4.5 cm respectively may be mentioned. An accuracy of 0.1^{o} K is possible.

Ever since the 50-ties the ice reconnaissance is mostly carried out by aircraft. During severe iceberg seasons ships as well, however, participate in ice surveying, and every large berg is then continuously guarded by a ship.

Complete ice bulletins from the Headquarters are broadcasted via radio stations in U.S.A. and Canada twice a day, shortened reports eight times, and facsimile ice charts once a day.
In urgent need ice reports are transmitted also from Canadian coast radio station St. John´s/VON, Newfoundland.
Such transmissions are always preceded by the signal TTT (the International Safety Signal) at 500 kHz.

5 REMOTE SENSING MAKES UNDER-ICE NAVIGATION POSSIBLE

Pack ice, especially in the Arctic, is often heavily *hummocked* with one piece haphazardly piled over another to form an uneven surface, *rafted*, i.e. deformed ice formed by one piece of ice overriding another, or patterned with *ridges*, i.e. lines or walls of broken ice forced up by pressure. An area in which much ridged ice with similar characteristics has formed is called *ridged-ice zone*. Pressure ridges are often several miles long and may in winter be about 6 m (20 ft.) high or more, e.g. 9 to 10 m.

The floes, however, may also be pressed beneath each other, thereby forming downward-projecting ridges, so-called *ice keels*. Ice keels may extend as much as 50 m below sea-level. In the early sixties ice keels were often registered with a thickness, measured to the surface of the water, of 30 m (about 98 ft.) or more, and in October 1976 the British nuclear submarine HMS SOVEREIGN measured with a sidescan sonar to the north of Ellesmere Island an ice keel 38 m in depth.

5.1 Under-Ice piloting by sonar

In the forties the U.S. Navy developed methods for "under-ice navigation", using effective sonars as sensors. Transmission at sonic frequencies was studied, and special sonar systems for "cruising under sea ice" as well as "for surfacing in ice" were developed. A decade later, in the summer of 1958, the U.S. nuclear-powered submarine NAUTILUS crossed the Arctic Ocean *under the ice*. She was the first ship in the world to reach the North Pole (on August 3). Her remote sensing system consisted of a foreward-looking sonar beam, used to pilot the submarine past ice keels that extend deeply, a downward-beamed echosounder giving clearance above sea bottom, and an upward-looking sonar recording a continuous profile of the under-surface of the ice canopy.

As regards the submarine's upward-looking sonar, it is mentioned in an article in Polar Record, Vol 18, No 116, 1977, pp. 487-491, by *Peter Wadhams*, entitled A BRITISH SUBMARINE EXPEDITION TO THE NORTH POLE, 1976, that the sonar transducer had an overall beam width of 17° fore-and-aft and 5° athwartships, feeding a Kelvin Hughes MS45 recorder operating at 45 kHz. This produced a continuous profile over 4000 km in length which was analysed by computer at Scott Polar Research Institute, Cambridge. He further mentions that SOVEREIGN was equipped experimentally with a *sidescan sonar*. The transducer was from Offshore Acoustics Ltd, feeding a Klein recorder, and was bolted to the forward casing under a protective cage of steel tubing. The sonar was set to 150 m extreme range, and features, he says, that could be distinguished clearly include thin ice in polynyas, open water, smooth thick ice, pressure ridge crest orientations, and rough multi-year ice.

According to an article published in Morskoy Sbornik, 1/1978, by a high-ranking Soviet naval officer and scientist, *Sj. Sverbilov*, Soviet submariners have had a great deal of experience in ice navigation ever since the thirties, and in the sixties sovietic nuclear-powered submarines explored wide areas of the Arctic Basin under the ice cover. In 1962 one of the Sovietic Fleet Submarines, LENINSKY KOMSOMOL, made a renowned under-ice cruise to the North Pole, where she surfaced. In his very instructive article Sverbilov gives some views on navigating and handling submarines in and under ice. He points to the importance of an all-round study of the planned route, on the basis of information concerning the ice situation, including coordinates of the ice limit, cracks, polynyas, and the direction of the ice drift, etc. By the aid of radio-technical means and *ice hydrophones*, the navigator is able to measure the ice thickness and study the under-ice canopy. The echo-ice-measurer is continuously drawing the ice pattern on a tape.

It is further worth mentioning that in 1960 The Arctic Institute of North America undertook an analysis of environmental factors affecting operations in the Arctic Basin. The report of that study stated that "the location of the Arctic Basin between the major world powers makes it an area which cannot be ignored. It will increase in importance as world populations expand; as natural resources are developed; and, as transportation systems over the North Pole are expanded" (*John E. Sater*).

The present situation undoubtedly verifies those conclusions. Submarine transportation in the Arctic may well become a principal means of sea transportation sometime in the future. Areas impassable to surface shipping because of ice conditions with mighty pressure ridges and deep ice keels are no hindrance to the submariner using effective sonar equipment. He is free to move in any direction and at any speed under the sea-ice canopy, provided that he has a true knowledge concerning the bathymetry.

This corresponds well with the report (Invited Paper) to the XIIth ISP-Congress in Ottawa, 1972, by *Gomer T. McNeil*, concerning UNDERWATER PHOTOGRAPHY, including Cameras, Films, Lighting, and Systems.
Television and photography systems as well as side-scan sonar, altitude sonar, and slant range transponder equipment were discussed. A chart was also shown of side-scan sonar imagery incorporating the use of rectified side-scan sonar records with image triangulation. The *bottom topography* is, as a matter of fact, always of great interest to the under-ice navigator.

5.2 Bathymetric conditions

The entrance to the Arctic Ocean between Norway and Greenland is characterized by depths of about 2,000-3,500 m. Farther north in the Greenland Sea, Soviet oceanographic expeditions have surveyed (1956 and 1958) a trough with depths of 3,000-4,000 m, named Lena Trough. Before then, geographers had believed that a submarine ridge, the so-called Nansen Sill, there joined Spitsbergen with

Greenland. North of the Greenland Sea the ocean bed slopes down to the western part of the deep-water basins of the Arctic Ocean, with depths of 4,000-5,000 m or more. In this region, not far from Svalbard, at latitude 82° 23' N, longitude 19° 31' E, the Soviet icebreaker "Fedor Litke" measured a depth of 5,449 m on September 24, 1955 (Fig. 3). This is the greatest depth yet recorded in the Arctic Ocean.

The Bering Strait, connecting the Pacific Ocean with the Arctic Ocean, on the other hand, is a shallow entrance with depths of only about 30 m. North of the strait the shallow continental shelf extends into the Chukchi Sea with depths of 35-50 m, and farther north a submarine peninsula - Chukchi Rise, including the Chukchi Plateau - extends to about 80° N. The Eurasian Continental Shelf extends far out into the ocean as shallow submarine plateaus. In the Barents Sea the depths vary between 75 and 500 m, and in the Kara Sea they are less than 200 m. Remarkably small depths characterize the East Siberian Shelf, where the 50 m curve may extend to 600 km from the shore.

The Arctic Ocean Basin is not a single, bowl-shape, deep depression, as was earlier supposed, but consists of two halves - the Amerasia Basin and the Eurasia Basin - separated by a submarine mountain range about 1,800 km, or more than 970 n.m. in length, named Lomonosov Ridge. This ridge was discovered by the Russians, thanks to methodical and very extensive Arctic reserach, especially during the years 1948-1949, at more than 200 temporary so-called flying stations on the ice in central parts of the basin and at drifting ice stations which took deep-water soundings. The late Soviet scientist, Gakkel (1957), has been given the credit for this very important geographic discovery.

The ridge extends northward from the submarine plateau north of the New Siberian Islands - east and close to the Pole - to the continental shelf off Ellesmere Island. It rises to 2,500-3,000 m (about 8,200-9,800 ft.) or more above the ocean bed and has very steep slopes. There is deep water above Lomonosov Ridge, however, and the depths vary between 900 and 1,450 m. The range is folded and covered with a comparatively thick layer of sediment (*RASSOKHO*[x]), 1966). The width of the ridge varies at the base between 60 and 200 km; and at the part of the summit where the American nuclear-powered submarine "Nautilus" passed the range on her submerged crossing of the Arctic Ocean from the Pacific side to the Atlantic Ocean via the North Pole, it was measured to 26 km.

On the North American side of Lomonosov Ridge, and about 500 km from this range, there is another submarine ridge; it is about 900 km long, extends parallel to Lomonosov Ridge, and has a minimum depth above the summit of about 1,400 m. Its main section is often named Mendeleyev Ridge (*RASSOKHO*, 1966), see Fig. 3. The Canadian side of the ridge is called Alpha Ridge or Fletchers Rise (in consideration of the valuable scientific research performed by the American drifting ice stations Alpha and Fletcher´s Ice Island, T-3, in these waters).

East of the ridges just mentioned there is a deepwater basin about 1,100 km long, named the Canada Basin, bounded by the continental shelves along the Canadian Arctic Archipelago, Alaska, and Chukchi Rise. The ocean bed there is practically flat, and the depth about 3,940 m. Along the Atlantic side of Lomonosov Ridge there is a basin with depths of about 4,000 m. The ocean bed here is also sediment-covered and even. At the North Pole, "Nautilus" recorded a depth of 4,290 m, and at latitude 88° 54' N, longitude 20° W, Ivan Papanin´s station NP-1 equally measured 4,290 m, and so on.

Among the many entrances to the Arctic Ocean Basin, used by nuclear-powered submarines, may be mentioned, besides the Greenland Sea and the Bering Strait, first the new Northwest Passage from Baffin Bay through the Lancaster and Melville sounds, and then through McClure

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x) Admiral *A.I. Rassokho*, one of the main editors of the unexampled Ocean Atlas "ATLAS OKEANOV, ATLANTICHESKIY I INDIYSKIY OKEANY", 1977, and Head of the Supervisory Board of Navigation and Oceanography, Defence Department USSR.

Strait to the Canada Basin, explored by "Seadragon" in August 1960, secondly the channel between Greenland and Ellesmere Island, the so-called Nares Strait.
Judging from published reports of the Soviet expedition to the North Pole in 1962, the nuclear-powered submarine "Leninskiy Komsomol" put into the deepwater basins via the Norwegian Sea and the Greenland Sea (Izvestiya, January 27, 1963). In this same report it was further stated that "Leninskiy Komsomol" had earlier completed several expeditions under the ice between Ostrov Victoria and Zemlya Frantsa Iosifa.

Future operations would probably involve, for example, the commercial transport of petroleum products by submarine tankers. The U.S. Navy has made conceptual studies of submarine-towed containers, and within the petroleum industry consideration is being given to the possibilities of using submarine tankers (see "The Arctic Basin" coordinated by *John E. Sater*, 1969).
According to Sater it is assumed that arctic submarine operations will continue to expand as the design of submarine hulls improves, further *under-ice sonar* is developed, and knowledge of the Arctic Ocean itself increases. The submarine in the Arctic provides a vehicle for transporting men and materiel to any ice-covered area that has sufficient sea room beneath the ice to permit submarine operations.
Under-ice piloting is done almost entirely by sonar in correlation with a local knowledge of the bathymetry and ice conditions of the operating area.

5.3 Viewpoints on radio communication systems and submarines operating under ice

In accordance with ITU "Radio Regulations", Geneva 1959, the succeeding bands in the electromagnetic frequency spectrum comprise frequency ranges as follows: LF (low frequency) 30-300 kHz, VLF (very low frequency) 3-30 kHz, and ELF (extremely low frequency) $3 \cdot 10^2$ Hz - 3 kHz.

VLF radio provides good possibilities for reaching submarines in transit beneath the polar pack ice, not only with ordinary messages but with navigational signals as well. The communication, however, is always limited to one-way transmission - from shore stations, etc., to under-ice submarines.
In the early thirties the author of this report experimentally used radio transmission with VLF frequencies to submarines in the northern Baltic Sea area and had good results down to about 30 m keel depth. During World War II the German VLF station *Goliath* at Calbe, in the middle of the country, used a frequency of 16 kHz and 1 MW efficiency for transmitting orders to the submarines in different parts of the oceans. It may be mentioned that in the Barents Sea and the Arctic Ocean, submarines were reached down to 13 to 18 metres depth of water above their frame antennas at distances of about 2,300 km (according to TELEFUNKEN-ZEITUNG, Jg. 33, Juni 1960, Heft 128). Thanks to improved receiving technique, however, the penetrating depths in sea water have nowadays increased considerably.

Of great importance is the salinity. Sea water with high salinity has, as a matter of fact, much greater damping effect on the radio waves than fresh water. Ordinary sea water is continuously undergoing convection while cooling, and does not begin to freeze until the entire column has been cooled to the freezing point. Sea water with a salinity of 35 $^{o}/oo$ begins to freeze at -1.9^{o} C (28.6^{o} F), and water with a salinity of about 30 $^{o}/oo$ at about -1.62^{o} C (29.1^{o} F) - as is normally the case in the surface layer of the central part of the Arctic Ocean Basin. Because no other mixing process is at work, it is necessary for only this surface layer to be cooled to the freezing point for ice to form. In shallow continental shelf areas on either side of the basin, on the other hand, convection currents may reach to the bottom, and the temperature of the entire water body has to decrease to the freezing point before ice will begin to form.

As freezing continues, the small crystals of pure ice in the surface zone of the water increase in size with depth. On further cooling, bridges form between the platelets, thereby trapping the brine surrounding them. When the crystals cement together the brine is trapped in vertical pockets, or in cells of circular or elliptical cross-section. A piece of newly formed ice, therefore, will have an appreciable salt content, perhaps 8-10 $^{o}/oo$ at the surface. As the ice sheet grows downward, the salt is found as highly concentrated pockets of liquid brine, formed vertical to the plane of the sheet. Salt, as a matter of fact, has almost no solubility in solid ice. Thus, the brine is initially at the boundaries between the growing crystals; and these boundaries, therefore, provide continuous channels for brine drainage. Since the brine cells have a greater specific gravity than the ice crystals, the ice in contact with the bottom of each brine cell is under slightly greater pressure than the rest of the block. Ice directly under a cell, therefore, is slowly melting, and the brine travels downward under the influence of gravity.

The migration of the brine pockets therefore contributes to the elimination of salt in the ice. With time, the salinity decreases, so that even young ice normally has a salt concentration at the surface of only about 5 $^{o}/oo$. During the following summer season, the salinity will have reached a value less than 0.1 $^{o}/oo$, and the ice will have become potable.

Heavy ice, which is very nearly free of salt, facilitates the receiving conditions of submerged submarines. As an example, the depth of penetration in salt-free ice at about 15 kc is about 100 times greater than in sea water with a salinity of 30 $^{o}/oo$ (corresponding to the average salinity of the surface layer of the Arctic Ocean Basin). Because of this, receiving conditions at a specific diving depth will be more favourable if the submarine leaves open water and moves in beneath an ice field (*Thorén, R.*, 1963. Navigation Systems and Aids to Navigation for Nuclear-Powered Fleet Ballistic Missile Submarines and View-points on Conventional Submarines Operating under Ice). Radio transmission on the VLF band to under-ice submarines therefore may always be of current interest in the Arctic.

As regards the above-mentioned ELF (extremely low frequency) band there was an interesting announcement, published in the September issue, 1979, of DEFENSE ELECTRONICS, entitled "VLF and ELF communications with ballistic missile submarines (TACAMO)". In view i.a. of the fact that LF and VLF communications suffer from jamming vulnerability in higher degree than extremely low frequency (ELF) communications, it is mentioned in the announcement that signals at ELF frequencies can penetrate seawater to a depth of several hundred feet.
The words "several hundred feet" point to a remarkable increase of the penetrating depth in sea water - 300 ft. (more than 90 m), for instance, is about twice the depth (measured from the upper edge of the conning-tower to sea-level) which submarines normally use when navigating beneath ridged-ice zones, where downward-projecting ridges, so-called ice keels, always may be expected.

As a comparison and complementary information to the announcement in DEFENSE ELECTRONICS, September 1979, an article, published in Aviation Week & Space Technology, September 3, 1979, entitled "Laser Communications Plan Studied" by *Philip J. Klass*, may finally be mentioned. By a way of introduction Mr Klass mentions a program to explore the feasibility of communicating with deeply submerged submarines using high-energy *laser beam*. In the same article the well-known scientist *Lowell Wood* at Lawrence Livermore Laboratory says that the laboratory group he heads several years ago developed an extremely sensitive detector that could be used by a submarine to receive signals modulated on the beam of a *blue-green laser*, adding that such a laser communications system could be "viewed as a useful supplement" to ELF.

He further points to the desirability that the laser in question would be modulated with digitally coded messages and designed for satellites in geosynchronous orbits. Deeply submerged submarines have to be equipped with very sensitive receivers and filters that allow only the wavelength of the laser transmitter to pass.