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SEA ICE IN THE CANADIAN ARCTIC ARCHIPELAGO

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Abstract

Aerial surveys of sea ice in the Canadian Arctic Archipelago have been made by the Polar Continental Shelf Project during the summers from 1961 to 1966. The types of ice and their distribution are described. The patterns of break-up, freeze-up and movement are emphasized. The area of ice imported into and exported from the region is calculated for 1962, 1964 and 1966 and the conditions for 1966, considered to be a typical year, are described in detail. There was a net export of ice during the summer of 1966 equal to less than 1% of the ice cover at the beginning of the season. Further investigations of ice conditions are suggested. The greatest need is for more quantitative measurements and for this an airborne device to measure ice thickness must be developed.

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by

D. G. Lindsay

A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfilment of the requirements for the degree of Master of Science.

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CHAPTER 1

INTRODUCTION

Aims

The distribution of the various types of sea ice found in the Canadian Arctic Archipelago is presented and described in this dissertation.

The descriptions are mainly based on information collected from aerial sea ice reconnaissance surveys conducted by the author during the summers between 1964 and 1966. Additional information from other sources is included because sea ice observations have been made from the time when early explorers pitted their wooden ships and skill against the ice up to the present when steel-clad ice-breakers and large aircraft are used to observe and map the vagaries of sea ice.

The bulk of the background information as well as the methods of collecting data are given in the first two chapters. Specific descriptions of the patterns of break-up movement, freeze-up and a number of maps are presented in chapters three and four to show the distribution and the magnitude of sea ice fluctuations in the Queen Elizabeth Islands. Chapter four includes a general "Mass Balance" of the sea ice found in the area. An evaluation of the study as well as suggestions for further investigations of a more detailed nature are presented in the concluding chapter.

Area Studied

Although the title suggests that the Canadian Arctic Archipelago is the area to be considered, the actual area is shown on the reference map (Fig. 1). The boundary on this map encloses approximately 445,700 km^2 of potentially ice covered sea water. This area is smaller than Davis Strait (738,100 km^2) and more than six times smaller than the Arctic Ocean which has an area of nearly 4.6 million km^2.

Importance of Investigation

This study provides basic geographic information regarding the general trends and distributions of sea ice which is of primary importance for the development of the Canadian Arctic. In addition this information may be used in conjunction with heat balance studies for more accurate forecasts of sea ice conditions.

Transportation

It is apparent that vast reserves of petroleum may be stored beneath the surface of the Canadian Arctic. In order to develop this resource, supplies and equipment must be transported to the Arctic and the crude oil must be moved from the area. Sea-borne transportation is necessary but the presence of sea ice makes surface navigation hazardous.

Various methods have been suggested to cope with the sea ice problem. A special type of plough which is attached to the bow of vessels navigating in ice has been designed but

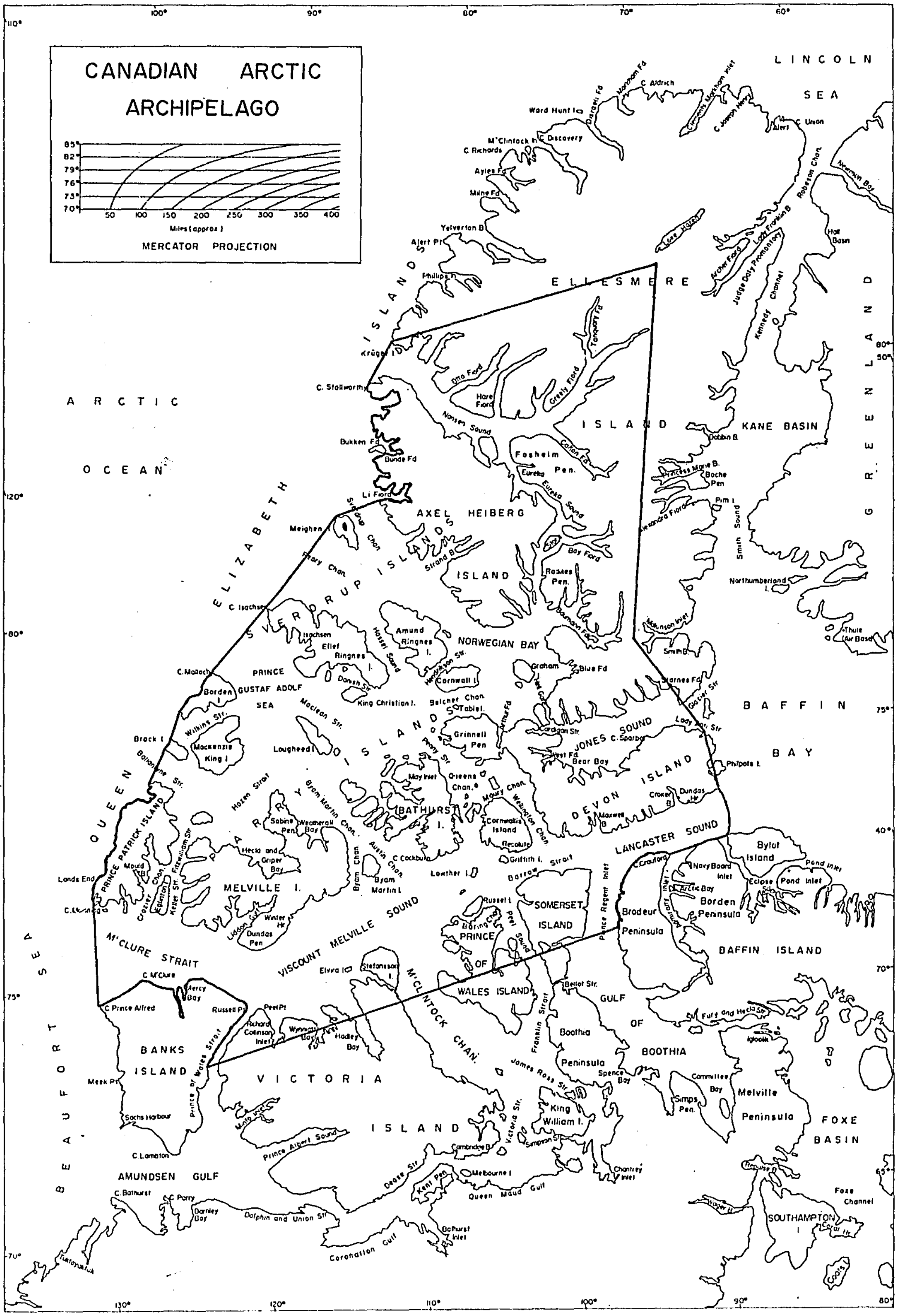


Figure 1

Reference Map Showing the Study Area.

its ability to plow through thick sea ice has not been determined. Hovercraft have been successfully tested on sea ice but no hovercraft has been built which is large enough to economically transport large quantities of bulk materials. It may be possible to use large aircraft to transport resources from parts of the Arctic made inaccessible by sea ice. However, the method of transportation which avoids contact with sea ice and makes use of the water beneath the ice cover may provide the best solution.

The U.S. atomic submarine 'Nautilus' succeeded in navigating under the ice to the top of the world by August 3, 1958. Since that date a number of submarines have travelled considerable distances beneath the sea ice. In the fall of 1960 the U.S. submarine 'Dragon' traversed the North West Passage.

No matter which method is used to transport the resources of the Canadian Arctic a knowledge of sea ice conditions is necessary. For example, the concentration and the types of sea ice must be provided for surface vessels and vehicles, and the areas of open water must be surveyed for the use of underwater vessels. A knowledge of the distribution pressure ridges is required for hovercraft and the thickness and the roughness are demanded by pilots wishing to use the sea ice as a landing strip. Some of this information can be forecast on the basis of past sea ice surveys, but these sea ice reconnaissance missions must be continued so that models and more accurate predictions of sea ice conditions can be made.

Forecasting

Many areas of the Canadian Arctic Archipelago support similar sea ice covers but there are as many more areas which have not been investigated. For example very little is known about the average dates of consolidation of the sea ice cover in the straits and channels of the Archipelago. It is hoped that orbiting spacecraft with advanced sensing equipment can be integrated with computers holding historical records so that accurate forecasts of sea ice distributions can be made. Until such time as orbiting spacecraft can be used, sea ice data will be collected by the traditional airborne reconnaissance missions.

Historic Observations

Men have been attracted to the Arctic for various reasons. Each expedition into arctic waters must contend with sea ice. As a result the sea ice conditions are mentioned in the journals and reports of most arctic explorers and scientists.

Many sailing vessels had come in contact with ice in Canadian Arctic seas but the first deep penetration into the Archipelago was made in 1820 (Parry, 1821). In the fall of that year, Captain W. E. Parry piloted his small sailing ship through Lancaster Sound, Barrow Strait and Viscount Melville

Sound. He could not penetrate into M'Clure Strait due to unfavourable ice conditions and was obliged to spend the winter at Winter Harbour (Fig. 1) on the southern coast of Melville Island. After Parry, many forays were made into Arctic waters especially during the search for Sir John Franklin's expedition. The journals of these explorers are well laced with references to sea ice conditions.

Most of these historical references (up to 1905) were collected and put on file cards by the Geographical Branch of Canada (Fraser, 1952). By the end of August 1951 approximately 2700 references had been made. Many, if not all, of these references can be interpreted and restated in the sea ice terminology used today and these historical references may be used to supplement present data.

Interest in Arctic exploration waned after the fate of Sir John Franklin and his men had been determined. However, explorations like that conducted by Sverdrup, and expeditions by Peary and Cook refocused attention on the Arctic. Interest was given an additional boost when the 'Gjoa' was sailed from the Atlantic to the Pacific through the straits and channels of the Archipelago.

Soon after the 'Gjoa' had made headlines, Captain J. E. Bernier began the era of scientific expeditions. He was sent to explore the Canadian Arctic by the Canadian Government. A considerable amount of sea ice information may be had from the log and publication resulting from this expedition (Bernier 1910).

During the 1920's and 1930's the Arctic received very little physical attention although the politicians in the south were attempting to secure the Archipelago for Canada. Their claim that the islands north of the mainland belonged to Canada meant that permanent settlements had to be maintained in the area and R.C.M.P. posts were established on some of the islands. The sea ice observations gleaned from the brief and impersonal reports from these posts provide important clues to the distribution patterns. The era of the R.C.M.P. in the Arctic continues today but it reached its apex when Sergeant H. A. Larsen piloted the 'St. Roch' from west to east and from east to west through the Archipelago (Larsen, 1947).

Two years after the 'St. Roch' made her return trip through the Archipelago a U.S. ice-breaker reached Winter Harbour thereby matching the feat of Parry, Kellett, Bernier and Larsen.

<u>Recent Observations</u>

Although the ice-breaker reached Winter Harbour in 1946 without the aid of sea ice reconnaissance flights more emphasis was placed on the importance of sea ice surveys and forecasts. In order to obtain sea ice information the R.C.A.F. began to fly ice reconnaissance missions in 1947 using American observers. These flights were the first specific sea ice reconnaissance flights carried out to aid vessels attempting to penetrate the waters of the Canadian Arctic Archipelago.

American Observations

The U.S.A.F. began to collect sea ice information in 1946 when B-29 Superfortress aircraft flew over the Arctic Ocean. The number of these 'Ptarmigan' flights was increased in 1947 and it was in the spring of that year when Target X, an ice island subsequently named T-1, was sighted. By 1951 the U.S.A.F. was sending daily flights to the North Pole and other areas of the polar ocean. It was not until 1951 and 1952 when sea ice presented a hazard to the Thule resupply convoys that U.S. sea ice reconnaissance came into its own. The U.S. Navy Oceanographic Office commenced an ice observing and reporting programme in the Arctic in 1952. During the period between 1952 and 1957 the U.S. flights obtained periodic coverage of the sea ice conditions in the Canadian Arctic. The findings of the U.S. ice reconnaissance flights began to appear in published form after 1953 (U.S. Navy Hydrographic Office 1953-1959 and U.S. Navy Oceanographic Office 1962-1965). The U.S. Navy

Oceanographic Office initiated 'Bird's Eye' ice reconnaissance flights over the Arctic Basin in March 1962 and these flights occasionally provided sea ice data for the areas fringing the Archipelago.

Canadian Observations

Beginning with the 1957 summer season the responsibility for carrying out sea ice reconnaissance in the Canadian sector of the Arctic was left to the Basic Weather Division of the Meteorological Branch. In 1957 the observations were made by Meteorological Branch personnel from aircraft supplied by the R.C.A.F. The first publication of sea ice information came two years later (Meteorological Branch, 1959). Between 1957 and 1960 the Meteorological Branch continued to expand its sea ice reconnaissance programme in the Canadian Arctic. Even with this expanded programme the sea ice conditions in some parts of the Archipelago distant from the regular shipping lanes were not observed.

In an attempt to survey these relatively inaccessible areas, the P.C.S.P. (Polar Continental Shelf Project) initiated, and has continued a systematic programme of sea ice reconnaissance since 1961 (Black, 1961, 1963a, b, c, 1965 and Lindsay 1964, 1965, 1966). Like those of the Meteorological Branch the P.C.S.P. sea ice surveys have continued to expand until at the present time nearly all of the straits and channels in the Canadian Arctic Archipelago are surveyed by one group or the other.

P.C.S.P. Investigations

Of the three groups which collect sea ice information relating to the area chosen for this study, the sea ice surveys made by the P.C.S.P. are the most meaningful. Data collected for the P.C.S.P. sea ice programme includes the nature, distribution and movement of sea ice, the time of formation and decay, the relief and the general drift of ice in the channels of the Archipelago. The P.C.S.P. ice surveys are carried out from the beginning of the melt season until freeze-up or until darkness limits the range of the aircraft. In addition to its own aerial observations the P.C.S.P. makes use of the data collected by the other groups in order to maintain and augment a complete file of sea ice information.

Logistic Support

Most of the sea ice information collected in the Canadian Arctic results from surveys made by observers riding in multiple engine aircraft. The exception to this is the information gathered from observers on the ice-breakers and those observations made from shore stations. The greater part of the data presented in the following text was collected from a twin engine Beechcraft 18, although some observations were made from an 'Otter', a DC-3, a Bristol Freighter, a DC-4 and other types of aircraft. Each of these aircraft was designed and built for tasks other than moving an ice observer about. The visibility afforded to the observer varies greatly from aircraft to aircraft. Each has specific merits such as the low airspeed in the 'Otter', the long range of the DC-3 and DC-4, and good lateral vision (one side) from the Bristol. But it is the Beechcraft which allows the greatest visibility for the ice observer. The cockpit of this aircraft is narrow and allows the observer a good view from the port as well as the starboard side. The windscreen is relatively large with few obstructions made by the supports or the nose of the aircraft. Ice observations from the Beechcraft are restricted by the wings and the engines which are located just below and behind the cockpit. These two factors restrict lateral and rear vision considerably. Although these drawbacks exist they are adequately compensated for by the forward vision and the low costs of chartering and maintaining such an aircraft for sea ice observations in the Arctic.

From 1961 to 1963 Isachsen on Ellef Ringnes Island was the main base for the P.C.S.P. sea ice reconnaissance programme. After 1963 the base was moved to Mould Bay on Prince Patrick Island and it was from this base that the writer carried out the programme during three summer seasons 1964, 1965 and 1966.

Although Mould Bay served as the main base from late June until early October there were a number of other Arctic stations used for refueling stops and for overnight accommodation. In order of the frequency visited these stations were Resolute, Eureka, Isachsen, Alert, Cambridge Bay and Sachs Harbour. Usually the visits to these stations were just long enough to refuel the aircraft and give the personnel on board a chance to eat. However the weather sometimes made it necessary to remain in one place for a number of days.

Procedure For Ice Reconnaissance Flights

The procedures followed for the sea ice programme remained relatively constant during the various field seasons. A number of flights, usually nine or ten, are planned for each summer season. During each flight an attempt is made to cover the whole survey area or at least the parts of the survey area where disintegration, movement or regeneration are most prevalent. The flights are scheduled so that complete coverage of the area can be made every 10-12 days in the early part of the summer. This interval gradually decreases to allow coverage every 4-5 days in the latter part of the Arctic summer. Unfortunately for the sea ice programme and the various personnel depending on the ice reconnaissance aircraft for transportation, the schedule means very little once field conditions are experienced. The schedule usually becomes ineffective after a few weeks due to the vagaries of the weather and other factors which affect air transport in the Arctic. Ideally, each flight requires approximately

35 hours of flying time to cover the necessary areas. Each flight is broken down into a number of tracks. The number of tracks made for each flight varies considerably in accordance with the time of the season and the weather. Even though the weather is the main factor which controls the number of flights and tracks completed, there are a number of minor factors such as unserviceable airstrips and aircraft maintenance problems. The combination of all these influences can seriously restrict the sea ice reconnaissance programme and Table 1, while entitled Record of P.C.S.P. Sea Ice Reconnaissance Flights, (1961-1966) could be entitled The Effects of an Arctic Climate on Sea Ice Reconnaissance Flights. Table 1 reveals that the hours devoted to each flight increase from the end of June until the latter part of August after which time the number of hours decline. This variation is attributed to the weather improving toward midsummer and then deteriorating in the autumn. In addition to the colder weather, the longer periods of darkness in the latter part of the season have a considerable effect on a V.F.R. (Visual Flight Rules) ice reconnaissance operation. The hours recorded under each flight on Table 1 represent the amount of time devoted to specific ice reconnaissance flights. However, it was the general policy (at least from 1964 to 1966) that the ice observer accompany any P.C.S.P. aircraft flying over areas not generally covered. In addition to extra

information collected in the above fashion the pilots or interested scientists returning from flights over sea ice would (if requested) make a few observations concerning the general ice conditions. The total hours given at the bottom of Table 1 show the expansion of the sea ice reconnaissance programme since its inception. It is believed that the 306 hours recorded in 1966 between June 2 and October 10 will approach the maximum flying time which can be completed during an average sea ice reconnaissance summer season using the procedures and equipment provided by the P.C.S.P.

The choice of the specific tracks flown during each flight depended on the weather, whether or not an area had been recently surveyed and the committents made for the aircraft. For example, if men or supplies had to be moved from Resolute to Mould Bay and the weather was clear, a survey could be made of southern Parry Channel, mid-Parry Channel or northern Parry Channel. If these areas had been surveyed the day before and little change in the sea ice conditions was expected the route chosen would probably include coverage of Penny Strait, Desbarats Strait, Hazen Strait and so on to Mould Bay. It was not always feasible to combine sea ice flights with routine support flights but the two were integrated as much as possible. A record of the areas covered during specific P.C.S.P. sea ice reconnaissance

TABLE 1

RECORD OF P.C.S.P. SEA ICE RECONNAISSANCE FLIGHTS (1961-1966)

Flight No.	1961	1962	1963	1964	1965	1966
A						June 2-10 28.2 hrs
1	June 18 4.6 hr	June 21-23 25.4 hr	June 21-24 34.7 hr	June 21-25 24.6 hr	June 23-28 24.7 hr	June 19-30 39.3 hr
2	June 26-30 18.1 hr	July 5-6 24.9 hr	July 4-9 33.7 hr	July 7-15 36.8 hr	July 5-7 24.8 hr	July 4-10 26.8 hr
3	July 25-28 23.6 hr	July 17-21 26.7 hr	July 18-20 32.2 hr	July 24 Aug. 8 21.2 hr	July 16-22 29.9 hr	July 17-23 33.2 hr
4	July 30 5.9 hr	August 4-5 23.4 hr	Aug. 23 Sept. 2 41.3 hr	August 10-13 30.0 hr	August 3-12 35.0 hr	July 29 Aug. 11 31.2 hr
5	August 3-5 11.8 hr	Aug.26 Sept. 5 34.7 hr	Sept. 10-15 26.5 hr	August 18-23 20.2 hr	August 14-23 43.8 hr	August 15-31 52.2 hr
6	August 11-12 14.0 hr	Sept. 24-29 27.4 hr	Sept. 28-30 25.0 hr	Sept. 2-5 18.4 hr	Aug. 28 Sept. 3 16.3 hr	Sept. 3-7 22.0 hr
7	August 27 3.9 hr			Sept. 15-24 10.0 hr	Sept. 13-22 21.4 hr	Sept. 16-25 35.7 hr
8	Sept. 6-8 15.4 hr			Sept. 26-29 18.8 hr	Sept.28 Oct. 4 25.9 hr	Sept. 27 Oct. 4 19.2 hr
9	Sept. 19-23 8.7 hr					October 6-10 18.5 hr
Total hours	106	162	193.4	180	221.8	306

flights from 1961 to 1966 is included as Appendix I.

System Used To Collect Information

The methods used by various agencies conducting sea ice surveys are basically the same. First observers are chosen, then they are given training and sent off in airplanes to make observations. The author became involved with a sea ice programme in the early spring of 1964 and the initial training involved the study of various sea ice reports and other articles written on the subject. With the conclusion of the academic year specific instructions were given concerning the types of ice, as well as a basic introduction to air navigation. The observations were recorded on 1:1,000,000 W.A.C. Charts (World Aeronautical Charts) and navigation was based on the same map. Near land, navigation was not difficult as V.F.R. conditions existed. However during surveys at some distance from land recourse was made to the dead reckoning navigation system. This system requires a knowledge of the T.A.S. (True Air Speed) and the heading of the aircraft. There are a number of factors which must be considered for accurate aerial navigation. For example in order to estimate the wind shifts which may occur while flying from one area to another the isobaric maps have to be checked before taking off. The gyro compasses are affected if a large number of meridians are crossed during one track. In addition, gyros precess and recess so that periodic sun shots must be made to reset these instruments. The fluctuations in the weak horizontal component of the magnetic force vector make the magnetic compass useless especially in the region of the magnetic pole. Besides the airspeed indicators, the gyros and the altimeters, the A.D.F. (Aerial Direction Finder) was used for navigation. The ice reconnaissance aircraft was not equipped with radar, Doppler, Tacan or other sophisticated navigation aids though a Decca navigation system was used in some areas during the early portions of the survey seasons.

Generally the observer recorded the sea ice data while sitting in the right hand seat of the cockpit. Some observations have been made from the cabin. In the latter case a seat was chosen from which the observer could get a good view of the ice and the instrument panel. Surveys were carried out from altitudes ranging from a few tens of feet to 11,000 feet. The level flown at depended largely on the cloud ceiling. Altitudes near 2000 feet were chosen when surveying sea ice which was particularly difficult to identify.

Although the airspeed was varied for specific reasons it was generally maintained at about 170 miles per hour or approximately 150 knots. The range and endurance of each track depended on the weather, altitude, load and pilot. With clear weather, little wind, no load and a conscientious pilot the aircraft could stay airborne for a maximum of five and one half hours. During this time about 800 line miles of sea ice could be observed. All the above conditions seldom existed at one time. As a result, the average time on each track was slightly more than $3\frac{1}{2}$ hours which means approximately 525 statute miles per track.

It is relatively easy to give an average number of line miles per track but the extent of vision varies greatly. For example, from 10,000 feet on a clear day with the sun at the proper angle it is possible to get a good idea of the types and distribution of the sea ice 10 miles on either side of the aircraft. If the type of ice is already known a much wider sweep can be made from 10,000 feet. On the other hand when the reconnaissance aircraft is restricted to lower altitudes it is sometimes barely possible to see straight down to the ice. The conditions affecting visibility varied considerably throughout the flights and could change rapidly during each track. These fluctuations were allowed for both in collecting and reducing the data.

The time period between observations made during each track varied with the concentration, the number of types of ice, the air speed, the visibility and the scale of the plotting map. Under normal circumstances one observation was recorded every five minutes on a W.A.C. Chart when the altitude was about 4000 feet and the air speed about 170 miles per hour. When visibility and altitude were reduced, at least two, and sometimes three observations were recorded every five minutes. In some areas such as Penny Strait and Queens Channel the air speed was reduced in order to plot the many boundaries and ice types. Sometimes the observations were complicated by the presence of an ice type which was difficult to classify. In these instances, the location was noted and a picture was taken from the F-24 camera mounted in the nose of the aircraft. Later, while reducing the data into its final form the pictures could be referred to if the problem had not been resolved before then.

Although weather problems such as wind, fog, icing conditions, cold, darkness and the distance between weather stations affect the sea ice reconnaissance programme to the greatest degree, the mechanical problems of the aircraft and the type of pilot must be considered. During the summers from 1964 to 1966 few mechanical problems hampered the operation and pilot interest and cooperation was very good.

CHAPTER 2

CLASSIFICATION AND MAPPING

Classification

There are many organizations which conduct sea ice surveys besides the three North American groups. Although the basic reasons for these surveys are similar, the terminology used varies from country to country. As a result, the W.M.O. (World Meteorological Organization) has endeavoured to standardize the system of sea ice classification. In addition the W.M.O. has attempted to develop standard methods of recording and transmitting sea ice information. These are difficult tasks but they are necessary, especially in the description of ice for the use of ships in international waters.

The methods used to classify and present sea ice information which are described in this chapter are not completely compatible with the W.M.O. system because they were not devised for tactical or real time transmission to surface vessels navigating in sea ice. The following description illustrates the system and methods used by the P.C.S.P. to record the ice conditions in that part of the Canadian Arctic Archipelago previously defined (Fig. 1) as the study area.

Types of Sea Ice

There are a number of variables which must be recorded during any sea ice survey. The main features which must be noted are the types and concentrations of ice. The three main types of sea ice, young, winter and polar, are age dependent. This means that polar ice is older than winter ice and winter ice is older than young ice. Each main type is made up of sub-types and each of these may be modified by subsequent freezing, melting or morphologic changes. The concentration or coverage of the various types, the floe size, the amount of open water and the boundaries must also be recorded in order to present a complete picture of the sea ice conditions. There are additional variables such as thickness which should be recorded but an airborne sensor for thickness measurements has not yet been perfected.

The following information explains figure 8, the legends on the sea ice maps given in the next chapter and the maps in Appendix II.

Young Ice

This type includes all newly-formed sea ice up to about 30 cm in thickness or until the ice cover loses its black and moist appearance. Young ice may have a number of sub-types. Slush ice is one of the primary forms of young ice and it usually adds a greyish tinge to the normally black sea water. Sludge or slob ice is formed as slush ice becomes more concentrated. Sludge is whiter and less homogeneous than slush and the wave patterns are visible in both these sub-types.

Very young ice can be distinguished from the previous forms because it is easily broken up by waves. The thickness of very young ice varies but usually remains within the five cm range. Additional sub-types of young ice such as frazil ice, grease ice, ice rind, nilas, and pancake ice (Armstrong, 1966), may occur but usually they do not remain in existence for more than a few days. It is important to record the sub-types of young ice because they indicate the temperature of the sea water.

Winter Ice

This type of ice comes into existence once the young ice cover exceeds 30 cm in thickness. Winter ice is usually dark green in colour. If winter ice formed in the Archipelago is not completely ablated one year after its formation the ice is referred to as winter^2. The ^{2} denotes a sub-type of greenish-blue winter ice more than one year old. Usually winter ice is quite smooth with the exception of the relief caused by snow drifts and occasional pressure ridges. As this ice undergoes ablation the relief is accentuated because the troughs of the snow drifts form puddles while the crests of the drifts protect the ice beneath from ablation. Thus ice which becomes winter^2 is considerably rougher than the original winter ice. Although most of the roughness on winter^2 ice is a result of differential deposition and melting, some roughness is a result of pressure ridging.

Polar Ice

This ice forms only on the Arctic Ocean but it may drift into the Archipelago to mix with the other types. Sea ice designated as polar is usually more than two years old and blue in colour. Unlike the ice in the Archipelago, the polar pack continues to move throughout the entire year. The great pressures exerted on individual floes caught in this perpetual movement causes the ice to crack, raft, and ridge to form sea ice of great thickness. The ridges and hummocks on polar ice dwarf similar features found on winter^2 ice. Polar ice undergoes ablation during the summer months and the relief is subdued but because of the size of the features prior to ablation the resulting relief is still considerable. Very old polar ice is sometimes referred to as polar^2 ice.

<u>Relationship Between Winter and Polar Ice</u>

Polar ice may enter the Archipelago through one of the northern channels such as Nansen Sound, Sverdrup Channel, Peary Channel, Prince Gustaf Adolf Sea or M'Clure Strait. For the first few years it is possible to separate the sub-types by means of colours but they are usually differentiated on the basis of surface roughness because the relief of winter^2 ice does not seem to be as irregular nor as massive as that on polar^2 ice.

After the two sub-types have existed together for two or more years in the same part of the Archipelago it is very difficult to distinguish polar^2 from winter^2 ice because polar^2 ice continues to lose its relief through successive ablation reasons while the relief of winter^2 ice is accentuated. Of course this process does not continue until winter^2 ice attains a great relief but it does continue to the point where the similarities between the two sub-types (colour, thickness, roughness and salinity) make it almost impossible to separate polar^2 from winter^2 ice.

Although this situation exists in some areas of the Archipelago such as Hecla and Griper Bay the movements and subsequent ablation and disappearance of these old sub-types considerably reduces the problem of differentiation.

Pictorial Description of Sea Ice Types

The following photographs show the main types of sea ice and some of their associated features.

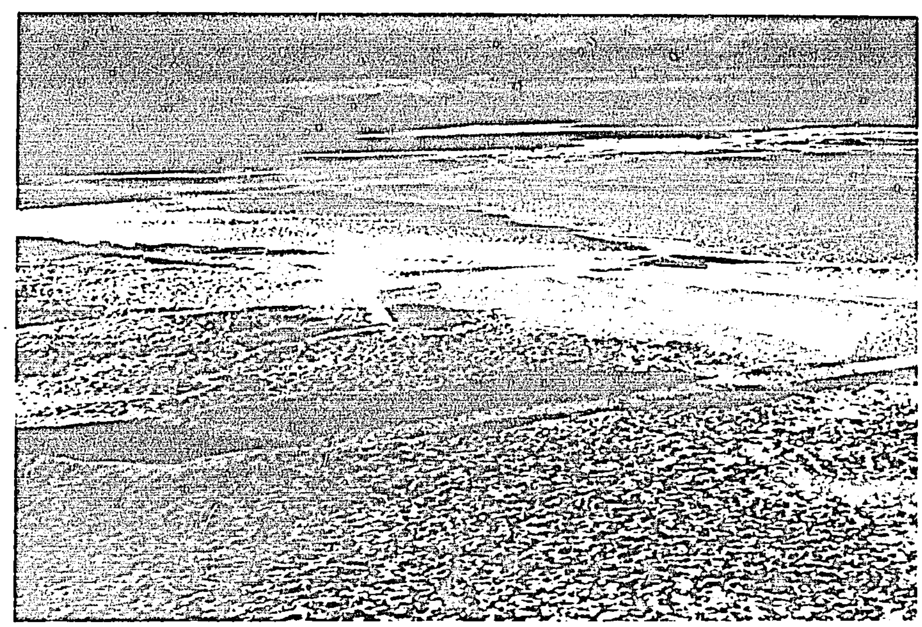


Figure 2 Winter ice and shallow sheet puddling on Viscount Melville Sound. June 27, 1966. Altitude approximately 2000 feet. Winter Harbour is in the background.

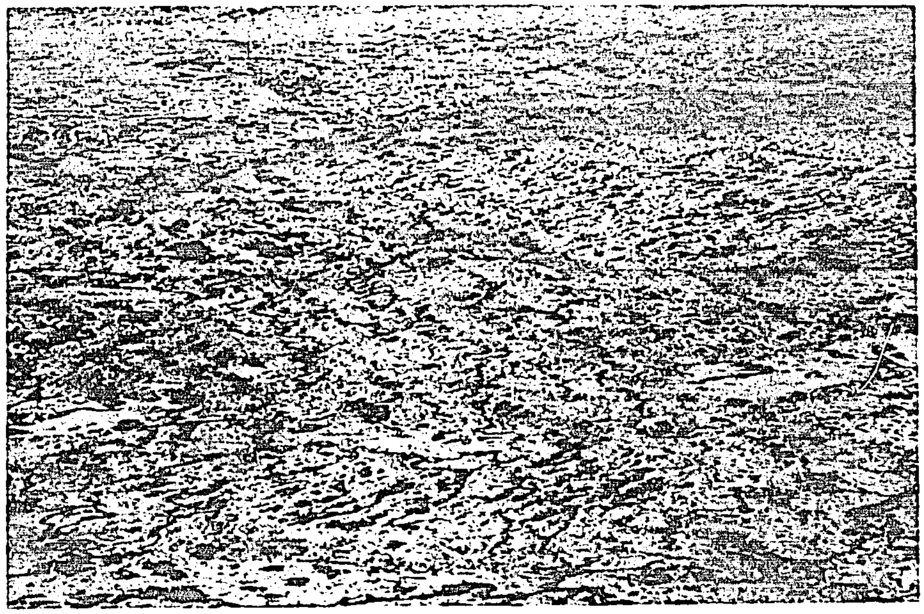


Figure 3 Old sea ice on Hecla and Griper Bay just east of McCormick Inlet. July 24, 1964. Altitude approximately 2000 feet.

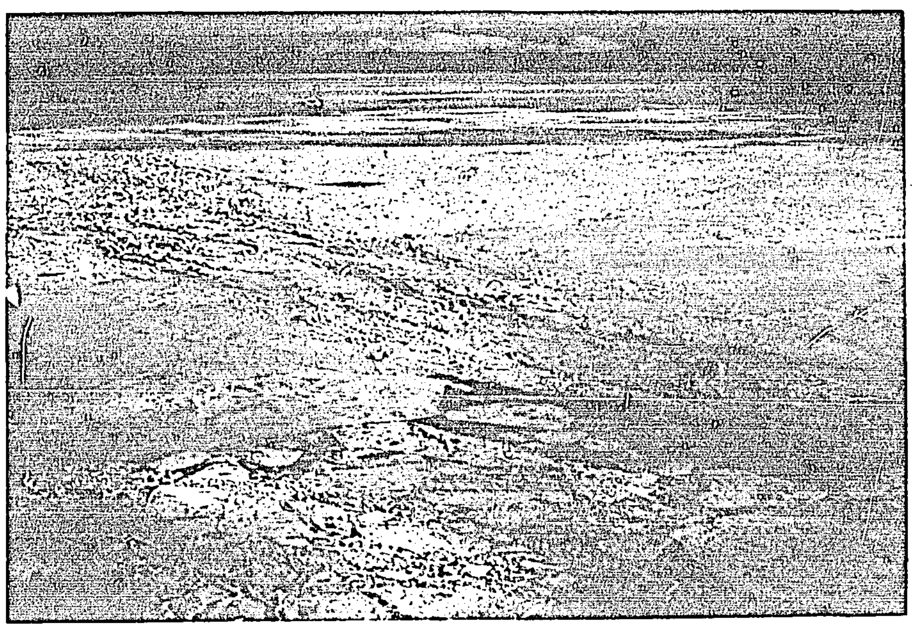


Figure 4 Polar ice front west of Houghton Head, Prince Patrick Island. August 4, 1965. Altitude approximately 1100 feet.

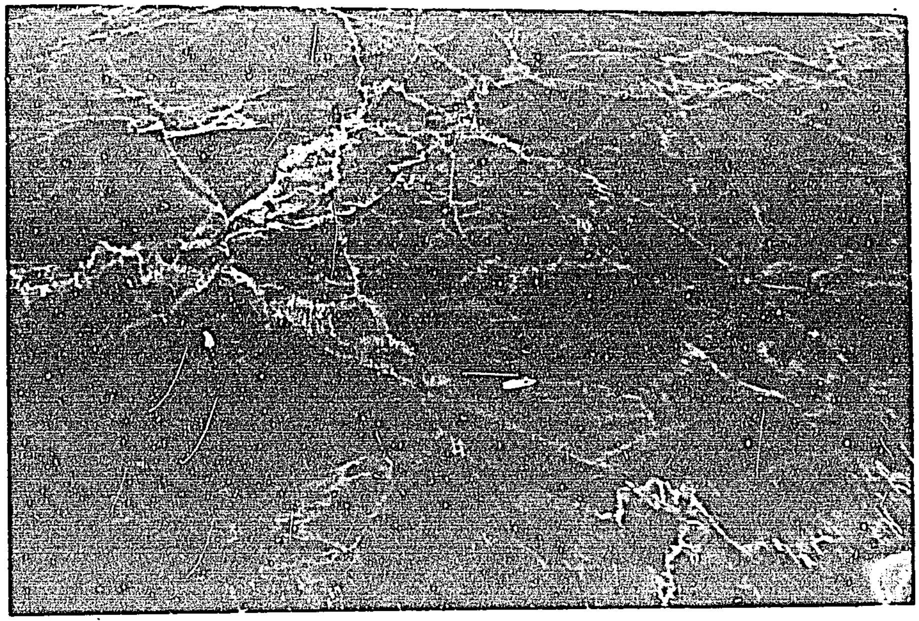


Figure 5 Shelving and young ice in the middle of Crozier Channel. September 28, 1966. Altitude approximately 3000 feet.

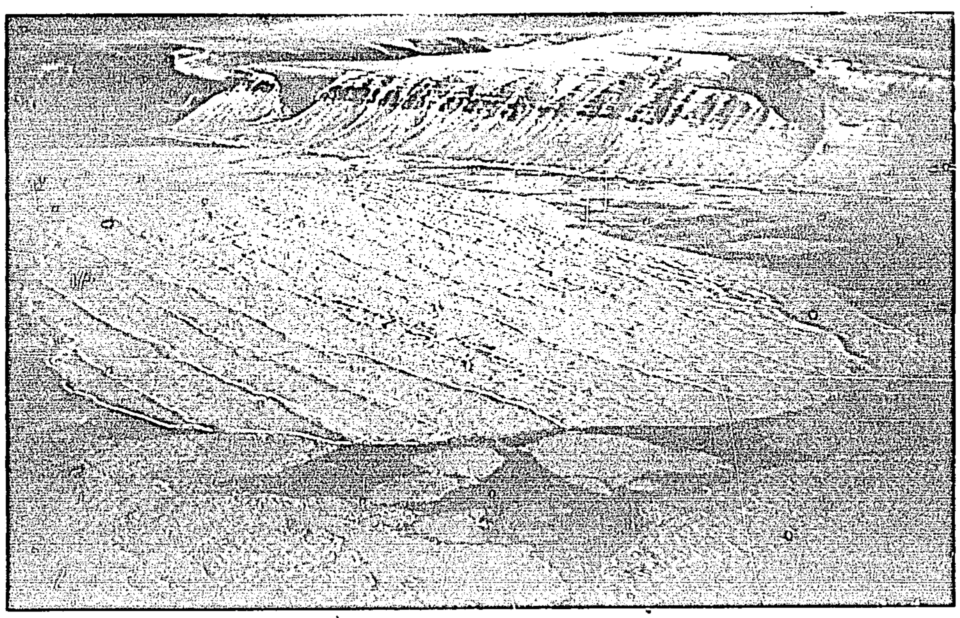


Figure 6 Ice island moving through Hell Gate. October 1, 1965.

Features Common To Sea Ice

There are many features which are common to all types of sea ice and most of these can be identified during aerial surveys of ice conditions.

Puddles

At first puddles are formed on the surface of the ice from melted snow. Later in the season they are supplied with water from the ablation of the ice surface itself. When first formed each puddle may be a separate unit but as the ablation season progresses most become linked in a system which drains toward a crack or some other opening in the ice cover. Generally puddles form in elongated strings between the snow drifts on winter ice. However on winter[2] or polar ice the puddles tend to become wider and more rounded while maintaining their basic elongated shape.

Usually puddles reach their greatest extent, up to 70% of the ice surface in a particular area, during the first quarter of the melt season. This large areal extent is a result of rapid melting which occurs before the water on the surface of the ice has found a drainage channel to the sea. Once this channel is formed the area of the sea ice covered with water suddenly decreases to about 35%. This area is maintained for some time thereafter because the puddles increase their depth as the outlet spillway is eroded.

Toward the latter part of the season the percentage of the area covered by puddles decreases further because less water is provided by ablation to fill the puddles and drainage channels.

Although puddles are generally elongated, sheet puddling is an important exception. As the name implies, a considerable area of the sea ice surface is completely covered by a large usually shallow pool of melt water. A shallow type of sheet puddling may occur on level winter ice which had a uniform snow cover and which had undergone little or no ridging. Shallow sheet puddling may be caused by the rapid melting of the surface snow accompanied by rainfall. The shallow type of sheet puddling seldom remains on the surface for more than a few days. This type of puddle is unique in its rapid formation and equally rapid disappearance. A deeper type of sheet puddling may form on ice which is surrounded by older and rougher sea ice. In this case the melt water formed in situ from the ablation of the snow is augmented by meltwater from the surrounding ice. In Prince Gustaf Adolf Sea this type of puddle may remain for an entire summer season.

Rotten Ice

After a certain amount of insolation a puddle may melt through the ice and merge with the underlying sea water. From the air the puddles which have 'burned' through the ice can be distinguished because they appear black while ordinary puddles maintain a dark blue colour. In order to classify an area of sea ice as rotten a considerable number of puddles must have 'burned' through the ice. Rotten ice indicates a decrease in the thickness of the surrounding ice and reduces the strength of the ice to the point where a relatively small dynamic force will shatter the entire ice field. Although some of the puddles on a consolidated ice cover may have 'burned' through, the sea ice between the puddles is usually more than one meter thick. Rotten ice rarely accounts for more than 20% of the total ice cover of any area.

Brash Ice

Once a consolidated ice cover containing rotten ice has broken up the remaining fragments are difficult to classify because they are so small and featureless. In this instance the pieces of ice may be referred to as brash. This term also applies to small pieces of ice wreckage approximately two meters across which are formed during other physical processes. For example, brash usually occurs after ice floes impinge against one another and particularly when ice floes are jostled together along an ice edge. Periodically strings of brash ice are formed due to wind action.

Glimmer Ice

As its name suggests, this type of ice may reflect light rays like a mirror. Glimmer ice forms on puddles. Usually this fresh-water ice is covered with snow shortly after its formation but its presence may be detected, under a light snow cover, by the dark slush line around the edge of the former puddle.

Sea Ice Forms Resulting From Dynamic Processes

When two ice floes come together, the sea ice in the impact area is usually cracked and crumpled. Most of the relief found on ice covers is a consequence of this process although some relief may result from puddling. The thickness and momentum of the floes involved in a collision determine the height of the ridges both above and below the water level. If two floes of different thickness collide, the thinner or weaker flow will suffer the greatest loss of area. If two floes of similar thickness come together similar areas will be lost and uniform ridges will be formed.

Shelving or Rafting

Shelving or rafting occurs almost without exception on young ice. Shelving is readily identified from the air because the overridden areas appear light grey in contrast to the black appearance of young ice. Two forms of shelving may result from the movements of young ice. The first is the common shelving or rafting where a portion of one young ice floe partially overrides an adjoining floe just as one card lying on a table can be slid over another. The second form termed finger rafting is more spectacular. It occurs as the edge of one floe alternately overrides and dips under the opposing floe.

Ridging

The relief features resulting from the ridging process may form as rapidly as those of shelving but they are larger and remain visible longer than the features caused by shelving. Ridging is usually restricted to winter and polar types of sea ice with periodic appearances in young ice which approaches 30 cm in thickness. Ridging results when ice floes are subjected to pressures greater than the crushing strength of the participating floes. The width, height and length of a ridge depends on the thickness, type and momentum of the colliding floes. There are many historic descriptions of the loud noises accompanying these processes and of the great chunks of ice which may be haphazardly piled on one another during the formation of a pressure ridge. Although pressure ridge formation may be very rapid and noisy, other ridges form slowly with little noise. No matter how a pressure ridge forms it creates a very tortuous surface which greatly hinders surface travel over sea ice. The pieces of ice making up a pressure ridge vary in size from very fine flour-like ice to huge chunks weighing many hundreds of tons.

Immediately after pressure ridges are formed the elevated pieces are not strongly bonded together. If the ice floes which caused the ridge are separated from one another before the ridge can consolidate, the elevated pieces not piled on the adjacent floes may return to the sea to be refrozen into the ice surface.

No average height for pressure ridges can be given because very few have been measured. Probably the first large scale measuring of pressure ridge heights will be made in March 1968 when the 'Bird's Eye' sea ice reconnaissance programme tests a laser profiler.

Bummock

This term was recently introduced (Armstrong, 1966). Bummocks are the subsurface continuation of pressure ridges. Nuclear submarines travelling under the Arctic Ocean ice pack have used a sonar operated 'ice machine' to continuously record these subsurface undulations. Indeed submarines rely on this 'ice machine' to avoid bummocks and to find patches of thin ice or sky lights weak enough for them to break through to the surface.

Hummock

A hummock is a pressure ridge which has undergone at least one complete ablation season. For example a pressure ridge formed in late May which is ablated during June, July, and August may be termed a hummock after continuous freezing conditions prevail in late September. A hummock may have considerable relief after one ablation season but it is more rounded than the pressure ridge from which it formed. The relief of a hummock is gradually reduced during successive ablation seasons until it approximates that formed on winter[2] ice.

Ice Forms: Land Origin

All the forms discussed in this section at one time rested on land or were attached to the shore of some land mass. Generally, with the exception of ice islands, all the forms of floating or drifting ice which can be grouped within these limits are called icebergs.

Icebergs

The members of this group come into existence when chunks of ice calved (broken off) from a glacier or split off from an existing iceberg. The features common to icebergs are well known and need not be repeated at this time but there are two smaller members of the group which will be described.

The smallest member is usually called a growler. This form may be entirely awash. Associated with growlers are bergy bits. These forms are slightly larger than growlers. Usually a bergy bit is less than ten meters across and less than ten meters protrudes above sea level. In most cases it is assumed that both of these forms originated from, or are the remains of, an iceberg. The smaller the bergy bit becomes, the harder it is to determine its origin. For example, growlers and small bergy bits may be the remnants of hummocks or they may be fragments of ice islands. There is no definite method which an airborne observer can use to ascertain the parent of growlers of bergy bits but a good estimate can be made. If these forms are found in an area where icebergs are common it is likely that they were formed from icebergs. If the pieces are found in the proximity of ice islands then these masses were probably the progenitors. On the other hand if growlers and bergy bits appear where no icebergs or ice islands are common it might be correctly concluded that they are the remains of massive hummocks.

Ice Islands

Ice islands are a form of tabular iceberg. They are only found in arctic waters. These masses form as a part of an ice shelf and become ice islands when the shelf breaks and sets them adrift. Ice islands are characterized by their uniform undulating surface and by their thickness. A number of ice islands have been traced during the routine P.C.S.P. sea ice reconnaissance flights. Figure 7 and Table 2 which accompanies the figure show the drift of the Ward Hunt group of ice islands between 1963 and 1967. As revealed by figure 7 the movements of ice islands show the relative drift of sea ice and this property will be referred to in the following chapter.

Description of Cartographic Procedures

Boundaries

Sometimes one type of ice is distinctly separate from another but in most cases there is a zone where the two types merge together. There are four types of boundaries used on the following maps. Only three of these are represented in the legend because the fourth boundary is shown on the map by the limits of certain graphic patterns.

Polar Ice Front

The polar ice front represents the boundary between the moving sea ice of the polar basin and the consolidated or unmoving ice which covers the straits and channels of the Archipelago. Usually this boundary is accentuated by a high concentration of pressure ridges along its length. Usually a solid heavy black line is drawn on the map to show the polar ice front.

Common Boundary Line

This relatively thin solid black line is used on the maps to show the limit of two different types of ice or to show the limits for specific concentrations of the same kind of ice. The thin solid black line is the most common boundary on the maps and it may occur any place in the Archipelago or the Arctic Ocean.

Assumed Boundary Line

The thin broken black line is used on the maps when the observer cannot get an overall view of the ice conditions. The broken line is used to delimit areas where it is assumed that no change has occurred between flights. For instance, the boundary between the winter and polar ice in Hassel Sound remained in the same place for at least four seasons. If this sound were surveyed during flight number one and again during flight number four and the same boundary was observed each time a dotted boundary would be put on the maps representing flights two and three while solid boundary lines would appear

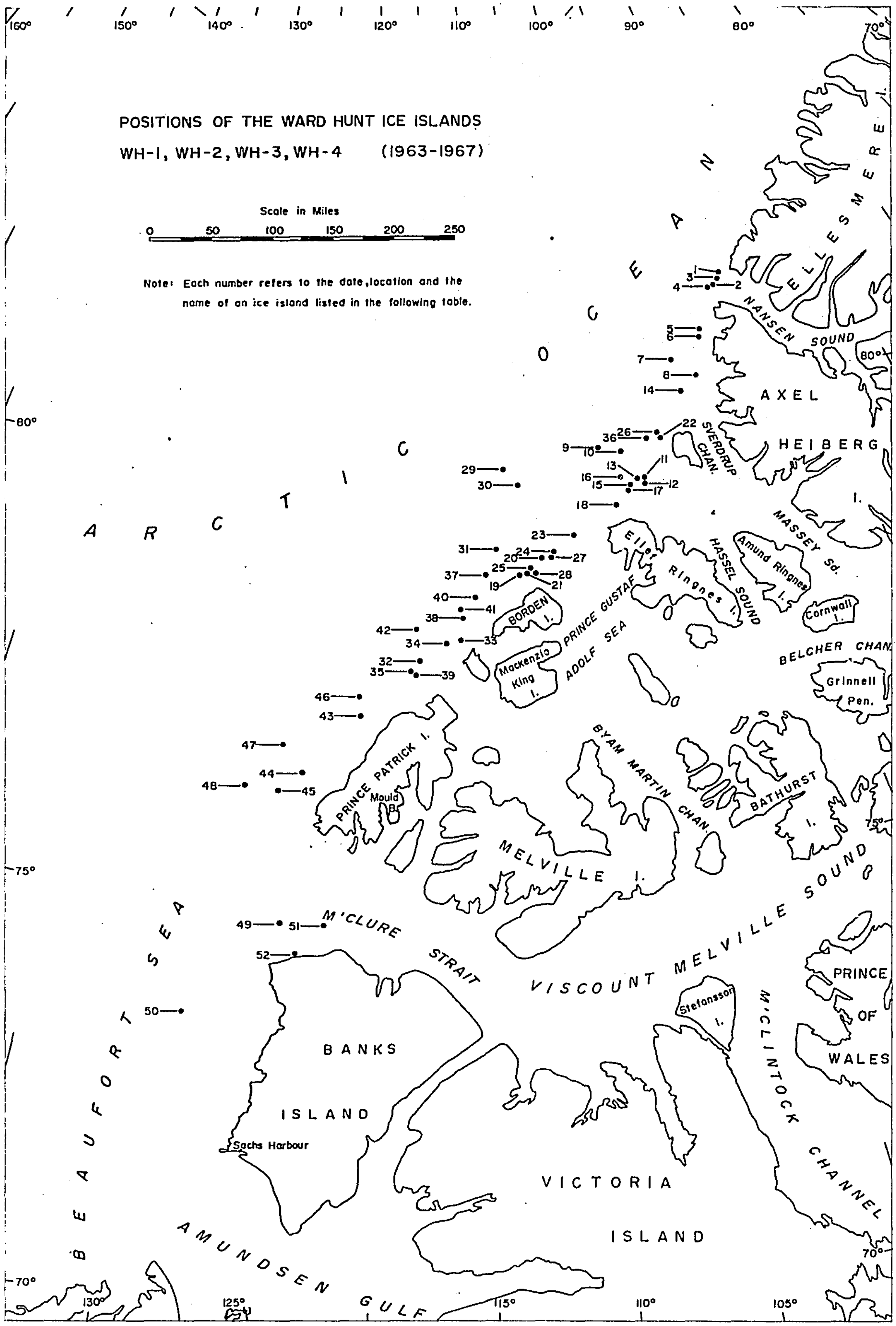

POSITIONS OF THE WARD HUNT ICE ISLANDS
WH-1, WH-2, WH-3, WH-4 (1963-1967)
Scale in Miles
0 50 100 150 200 250
Note: Each number refers to the date, location and the name of an ice island listed in the following table.
160° 150° 140° 130° 120° 110° 100° 90° 80° 70°
80° 75° 70°
130° 125° 115° 110° 105°
ARCTIC OCEAN
ELLESMERE I.
NANSEN SOUND
AXEL HEIBERG I.
SVERDRUP CHAN.
MASSEY Sd.
Amund Ringnes I.
HASSEL SOUND
Ellef Ringnes I.
Cornwall I.
BORDEN I.
PRINCE GUSTAF ADOLF SEA
Mackenzie King I.
BELCHER CHAN.
Grinnell Pen.
PRINCE PATRICK I.
Mould B.
BYAM MARTIN CHAN.
BATHURST I.
MELVILLE I.
VISCOUNT MELVILLE SOUND
M'CLURE STRAIT
PRINCE OF WALES
Stefansson I.
M'CLINTOCK CHANNEL
BANKS ISLAND
Sachs Harbour
BEAUFORT SEA
AMUNDSEN GULF
VICTORIA ISLAND

Figure 7

TABLE 2

WARD HUNT ICE ISLANDS LOCATED DURING P.C.S.P. SEA ICE FLIGHTS*

REFERENCE NUMBER	FLIGHT NO. AND YEAR	DATE AND MONTH	NAME OF ICE ISLAND	LOCATION LATITUDE	LONGITUDE
1	1-63	24/6	"Joan" possibly WH-3	81°40'	92°45'
2	1-63	24/6	"June" possibly WH-4	81°34'	93°20'
3	2-63	4/7	"Joan" possibly WH-3	81°38'	92°55'
4	2-63	4/7	"June" possibly WH-4	81°34'	93°45'
5	3-63	19/7	"Joan" possibly WH-3	81°20'	95°34'
6	3-63	19/7	"June" possibly WH-4	81°12'	95°45'
7	4-63	30/8	"Joan" possibly WH-3	80°52'	98°12'
8	4-63	30/8	"June" possibly WH-4	80°43'	97°00'
9	5-63	10/9	"Joan" possibly WH-3	80°26'	104°40'
10	5-63	10/9	"June" possibly WH-4	80°17'	103°15'
11	1-64	24/6	Possibly WH-4	79°45'	102°15'
12	2-64	13/7	Possibly WH-3	79°43'	102°15'
13	2-64	13/7	Possibly WH-4	79°45'	102°45'
14	5-64	19/8	Possibly WH-2	80°35'	98°20'
15	6-64	5/9	Possibly WH-3	79°43'	103°10'
16	6-64	5/9	Definitely WH-4	79°48'	103°40'
17	8-64	27/9	Possibly WH-3	79°42'	103°15'
18	8-64	27/9	Possibly WH-4	79°30'	104°25'
19	2-65	7/7	Definitely WH-4	78°54'	111°05'
20	3-65	18/7	Definitely WH-3	79°06'	109°45'
21	3-65	18/7	Definitely WH-4	78°54'	110°45'
22	4-65	4/8	Definitely WH-2	80°12'	100°30'
23	4-65	4/8	Definitely WH-1	79°23'	107°20'
24	4-65	4/8	Definitely WH-3	79°10'	108°50'
25	4-65	4/8	Definitely WH-4	78°58'	110°25'
26	6-65	1/9	Possibly WH-2	80°13'	100°30'
27	6-65	1/9	Definitely WH-3	79°07'	108°58'
28	6-65	1/9	Definitely WH-4	78°56'	110°05'
29	7-65	20/9	Definitely WH-2	80°18'	101°18'
30	8-65	4/10	Definitely WH-3	78°55'	110°25'
31	8-65	4/10	Definitely WH-4	78°46'	112°15'
32	-66	19/5	Definitely WH-4	77°57'	117°20'
33	A-66	3/6	Definitely WH-1	78°25'	114°50'
34	A-66	3/6	Definitely WH-3	78°11'	115°55'
35	A-66	3/6	Definitely WH-4	77°49'	117°50'
36	1-66	19/6	Definitely WH-2	80°10'	101°20'
37	1-66	19/6	Definitely WH-1	78°57'	113°05'
38	1-66	19/6	Definitely WH-3	78°28'	114°38'
39	1-66	19/6	Definitely WH-4	77°49'	117°40'
40	4-66	29/7	Definitely WH-1	78°40'	113°50'
41	4-66	29/7	Definitely WH-3	78°36'	114°50'
42	6-66	3/9	Definitely WH-1	77°52'	117°30'
43	6-66	3/9	Definitely WH-3	77°20'	120°40'
44	6-66	3/9	Definitely WH-4	76°39'	123°40'
45	7-66	16/9	Definitely WH-4	76°25'	124°55'
46	7-66	25/9	Definitely WH-1	77°35'	120°55'
47	7-66	25/9	Definitely WH-3	76°59'	124°48'
48	7-66	25/9	Definitely WH-4	76°27'	126°25'
49	A-67	25/3	Definitely WH-1	74°48'	124°15'
50	A-67	25/3	Probably WH-3	73°45'	128°15'
51	-67	12/8	Definitely WH-1	74°55'	122°10'
52	-67	6/10	Definitely WH-1	74°30'	123°35'

* Locations between 24/6/63 and 10/9/63 were recorded by W.A. Black. Locations 24/6/64 to 25/3/67 were recorded by the author except for 19/5/66 when George Burry (a pilot for P.C.S.P.) landed on WH-1 and left ten empty 45 gallon gas drums. Subsequent sightings (after 12/8/67) were made by W.J. Seifert.

on maps one and four. Generally the broken boundary lines are used only when some concrete evidence is available. Periodically a broken line was used to represent the limits of visibility when a track was made over open water.

Limit of Visibility

The last type of boundary (which is not a line) is formed by the edge of a graphic pattern on the map. For example on Flight No. 9, 1961 (Fig. 9) the edges of the graphic patterns show the limit of visibility and suggest that similar sea ice extends beyond this limit.

Graphic Patterns

The concentration or coverage and the three main types of sea ice are represented by twelve different graphic patterns. See Figure 8. This figure or legend is

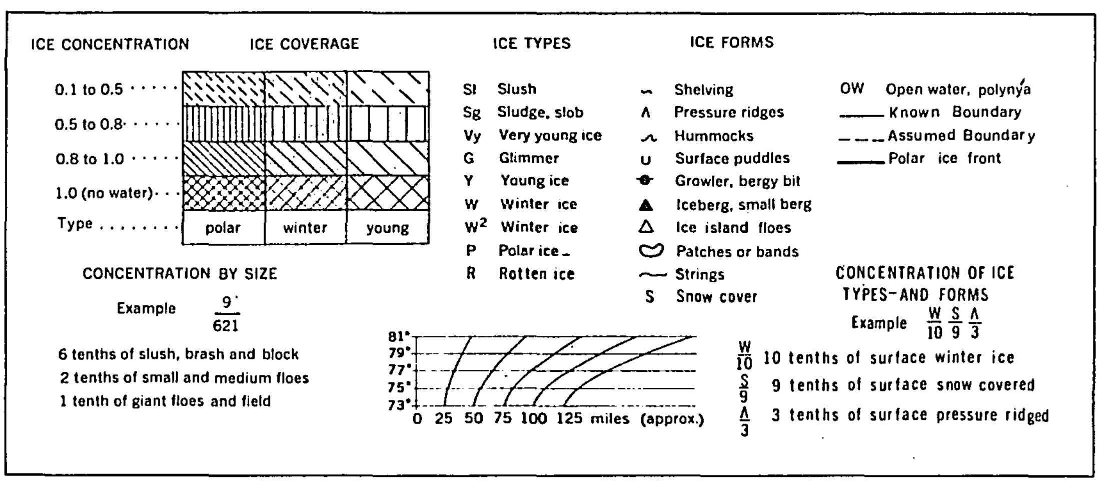


Figure 8 Legend For Sea Ice Maps

found on all the major maps and this same cartographic system is used to represent sea ice conditions on maps too small to have a detailed legend (Appendix II).

Patterns Representing Concentrations

The graphic patterns vary in density from those of a closely spaced type used to represent polar ice, to the wider spaced patterns representing winter ice and finally to the widest pattern which is used to represent young ice. The density of the graphic patterns decreases with a corresponding decrease in the concentration and the patterns have been arranged so that the various concentrations of each of the three types of ice are shown by similar patterns (Fig. 8). For example a crossed line screen is used to show a solid cover of polar, winter, or young ice. The patterns remain the same, only the density of the pattern changes. Thus any area of the map covered with the crossed line screen represents an area where the ice cover was solid or consolidated. Similar patterns are used to show concentrations; from eight to ten tenths (diagonal lines) five to eight tenths (vertical lines) and from one to five tenths (broken diagonal lines).

It is possible to use a greater number of graphic patterns to show the concentrations than the four subdivisions arbitrarily chosen for this study. The concentrations from one to five tenths are brought together to form one pattern because most vessels will attempt to navigate through this amount of sea ice. Of course the type of ice has a bearing on navigability and it is assumed that most captains, if given a choice, would rather contest a five tenths concentration of young ice than a similar amount of polar ice. The second concentration which ranges between five and eight tenths prevents most vessels not escorted or reinforced vessels from moving. However some ice-strengthened vessels which have extra power, are able to penetrate the young and winter concentrations in this range. Ice-breakers can navigate in the five to eight tenths concentration but if the concentration is entirely polar ice they will have difficulty. The third concentration ranges from eight to ten tenths. The most powerful ice-breakers can traverse young ice, winter ice and, with difficulty, polar ice when it is concentrated to this degree. Ordinary vessels cannot navigate through any type of ice when this concentration exists but some specially equipped vessels of the 'Dan' class may be able to force their way through young ice under these conditions. The final concentration pattern representing ten tenths (no water) indicates that the entire ice cover is completely solid or consolidated. Few ships except ice-breakers will attempt to penetrate a solid ice cover. The most powerful can be completely stopped by this amount of polar ice. However the large ice-breakers like the 'John A. MacDonald' will attempt to break through a solid field of winter ice if it has some rotten areas. A solid concentration of young ice usually does not inhibit ice-breakers, but may do so if the young ice freezes to the hull of the vessel.

There is an additional concentration or lack of concentration which ranges from less than one tenth to no ice at all. When this situation occurs the letters OW are inserted on the map to designate areas of open water. Of course all ships will be able to navigate in this concentration but the normal surface vessel will have to reduce speed if pieces of sea ice appear.

Patterns Representing Ice Types

It is difficult to graphically represent the three types of sea ice which exist in one area by one graphic pattern. The graphic pattern to be used is determined by the concentration of the predominant type of ice. If an ice cover is made up of three tenths of polar ice, four tenths of winter ice and three tenths of young ice, the polar type of graphic pattern (closely spaced lines) will be used on the map. In other words, a concentration of three tenths or more of polar ice in an ice field is represented on the map by the polar pattern. A similar situation exists for the graphic representation of winter ice. If an ice cover consists of three tenths winter, five tenths young, and two tenths polar ice the winter pattern is used on the map. Similarly if three tenths is young, two tenths winter, and two tenths polar ice, the young ice pattern is chosen.

Occasionally conditions exist where two tenths of polar, two tenths of winter and two tenths of young sea ice make up the concentration of one ice field. In this case the polar pattern is used. However if there were two tenths of winter ice, one tenth of polar ice and two tenths of young ice mixed together the winter pattern would prevail.

In order to make the graphic patterns representing the various types of sea ice stand out, various colours are used. A red shaded area signifies that more than three tenths of the concentration is polar ice. Similarly a blue colour superimposed on the graphic pattern indicates that at least three tenths of the ice cover is winter ice and less than three tenths is polar ice. A green colour indicates that young ice covers at least three tenths of the sea ice in a particular area while polar and winter ice each have a concentration of two tenths or less.

Fractions

The specific types and concentrations are shown on the map by fractions which interrupt the appropriate graphic pattern. The system used in this case represents floe size by means of the denominator of a fraction.

Floe Size

As indicated by the denominator of the fraction at the bottom left hand corner of the legend, (Fig. 8) the concentration of sea ice by floe size is shown by three separate numbers. This system is independent of ice type. The first number (6) designates the concentration of the smallest floes as brash ice. Most of these masses would fit into an ordinary room. The next range of floe sizes represented by the two in the denominator, includes the small and medium sized chunks of sea ice. This category includes all floes larger than those of the first category up to floes with an area approximating 40 km^2. The final category represented by one in the denominator includes floes larger than 40 km^2. The sizes shown in the denominator are always recorded in the same sequence from left to right. For example, if figures such as 621 occur in the denominator they signify that six tenths of the ice cover are small floes, two tenths are medium floes and one tenth are giant floes. A solid or consolidated ice field is indicated when the denominator reads 0010.

Sample Fraction

The following fraction is only an example because it is very unlikely that all the terms given below could exist in an area at the same time. This fraction represents the order or sequence of fractions which is

$$\frac{P^2}{1}\ \frac{P}{2}\ \frac{W^2}{2}\ \frac{W}{1}\ \frac{Y}{1}\ \frac{Sl}{1}\ \frac{Sg}{1}\quad \frac{9}{621}\ \frac{\Lambda}{2}\ \frac{\sim}{3}\ \frac{\backsim}{2}\ \frac{S}{9}\ \frac{U}{3}\ \frac{R}{2}\ \frac{G}{2}$$

used on all sea ice maps that follow. The letters representing the various ice types making up the first of the fraction are described in the legend (Fig. 8) and the denominators indicate the tenths of the area covered by each type of ice. The second section of the fraction consists of a numerator (9) which gives the overall concentration of sea ice in tenths, and the denominator which has been described in the preceeding paragraph. The significance of the numerators in the third section of the fraction are explained in the legend and the denominators indicate the distribution of each in tenths.

There are a number of additional subtleties which are included in various fractions. For example the numerator of the fraction representing the concentration is the sum of the ice type denominators. If the fraction denoting the concentration has a numerator of 10 and a denominator of 0,19 it indicates that sea ice completely covers the surface and shows that the cover is cracked and probably moving. Occasionally, in order to provide more detailed information, greater or less than signs are used before the numerator of the concentration fraction or with the denominator of the fraction denoting the ice types.

Data Reduction

The original field information is collected and placed on a work or field sheet with a scale 1:1,000,000 or less. It is cartographically impossible from the standpoint of reproduction to produce maps of that size and then reduce them to a legible size which would fit into an ordinary publication. As a result the data on the field sheets is reduced by one third or more and placed on master copies with a scale of approximately 1:4,000,000. These master copies are completed by drafting the various fractions, patterns and symbols and the maps are reduced photographically. The final scale of the Mercator projections showing the sea ice distribution in the Queen Elizabeth Islands approximates 1:12,000,000.

CHAPTER 3

GENERAL PATTERNS AND THE PROGRESSION OF BREAK-UP AND FREEZE-UP

Introduction

The procedures and techniques described in the foregoing chapters were used to collect a considerable amount of sea ice information. Between 1961 and 1966 fourty-eight different maps showing the distribution of sea ice in the Queen Elizabeth Islands were made. The following description is based on the information shown on these maps. Although each of the maps is important only six will be given in this chapter. These maps were selected because they represent the ice variations which may occur in different years just before freeze-up. Twenty-eight additional maps show the ice distribution in the areas of Northern Ellesmere Island, M'Clintock Channel, and the Beaufort Sea. An example of each of these smaller maps as well as a list of all the maps made by the P.C.S.P. is given in Appendix II.

A number of general accounts of the sea ice distribution in the Canadian Arctic have been published in the past. For example, the "Pilot of Arctic Canada" (Hydrographic Service, 1959, 1960 and 1961) describes the ice conditions as they were known in the late fifties. The "Ice Atlas of Arctic Canada" (Swithinbank, 1960) contains the historic data up to 1958 and Black, (1957, 1958, 1959 and 1961a) collected data in the eastern Arctic from an ice-breaker during the summers of 1956, '57, '58 and 1960. Although this information and that collected by the Meteorological Branch is useful practically no regular sea ice reconnaissance surveys were carried out over the Queen Elizabeth Islands until the P.C.S.P. began making observations in 1961. The sea ice data collected by the R.C.S.P. in 1961 (Black, 1961b) was not processed beyond the field map stage until the present author compiled the material. The 1962 sea ice conditions in the Queen Elizabeth Islands were well described, (Black, 1965). Preliminary reports were written to describe the 1963 ice conditions in the area (Black, 1963a and b) but the maps (Black, 1963c) remain to be published. Similarly, unpublished maps describing the summer ice conditions in the Queen Elizabeth Islands are available for 1964, 1965 and 1966 (Lindsay, 1964, 1965 and 1966). In addition to the information collected by the P.C.S.P. the sea ice reconnaissance flights conducted by the Meteorological Branch (Department of Transport, 1960 through 1965) periodically provided additional coverage of some parts of the Queen Elizabeth Islands.

The first portion of this chapter will show the general trends of the sea ice distribution in the Queen Elizabeth Islands during the summers between 1961 and 1966 inclusive. One map for each year will be introduced to portray the annual variations in the ice cover and the type of ice year will be indicated. The remainder of the chapter will describe the usual progression of break-up and freeze-up in the area.

General Patterns

1961

The following account is a summary of unpublished material collected by Black (1961b).

By the end of June 1961 very little ice movement had occurred in the Queen Elizabeth Islands. The polar ice front stretched unbroken from M'Clure Strait along the western coasts of the islands fronting on the Arctic Ocean and passed the entrance to Nansen Sound. The ice on the eastern portion of Lancaster Sound was moving while the western portion remained solid. Open water was present in the southern parts of Penny Strait, and Hell Gate and Cardigan Strait were ice-free. A small amount of open water existed along the southern portion of Hendriksen Strait. The remaining straits and channels of the study area remained solid although puddling was beginning in most areas.

Toward the latter part of July the southern channels had shattered and the ice in these areas was in motion. The northern channels were still supporting a consolidated cover while the polar ice front remained in a position almost the same as in June. The ice cover on Jones Sound had shattered and there was a considerable amount of open water in Hell Gate, Cardigan Strait and that portion of Jones Sound southeast of these straits. All the ice in Lancaster Sound and Wellington Channel had broken by this time and the area up to the northern portion of Penny Strait had shattered. The southern portion of Norwegian Bay between Graham Island and North Kent Island had broken and some areas of open water existed. The central portions of Belcher Channel had broken and the ice in the section of Eureka Sound north of Stor Island was in motion. The ice cover in the northern half of Barrow Strait was composed of relatively small floes while the consolidated cover on the remaining portions of this strait were just beginning to break up. The northern extremeties of Prince Regent Inlet, Peel Sound and M'Clintock Channel still maintained a solid cover. The ice on the western part of M'Clure Strait had broken up and was moving while the eastern portion was solid although cracks were present. The ice in Byam and Austin Channels was solid as was the ice covering the remainder of the straits to the north. Although the eastern and western sections of Parry Channel were broken and moving the central area was unbroken except for a narrow strip of ice. This strip existed along the southern coast of Melville Island and extended eastward south of Byam Martin Island and into Barrow Strait where it continued eastward along the south coast of Bathurst Island. This strip is subsequently referred to as "the Parry strip" because Captain Parry first navigated it in 1819. At the end of July 1961 the concentration of ice in the Parry strip ranged from five to nine tenths while most of the ice immediately north of it remained solid.

A considerable amount of ice had disappeared by the end of August 1961. Open water existed in Lancaster Sound, Jones Sound, Wellington Channel, Barrow Strait and Eureka Sound. The ice on the remaining channels of the area had broken up with the exception of Hazen Strait and the area West of Lougheed Island. In addition, the ice cover remained solid on both sides of Amund Ringnes Island and in Wilkins Strait. The polar ice front had ceased to exist except in the area to the northeast and west of Meighen Island. The ice cover on Ballantyne and Fitzwilliam Straits had shattered. To the south, Prince Regent Inlet was broken and moving, Peel Sound was mainly open water and M'Clintock Channel was shattered and in motion.

The last observations made in the Queen Elizabeth Islands, during 1961 were made in late September. The information shown on figure 9 was collected by Black between September 19 and 23 during flight No. 9. Although the entire area was not covered during the flight, a considerable amount of data can be interpolated on the basis of the previous flights. Young ice began to form during the first week of September but break-up and movement continued. Most of Massey Sound had broken and the only areas of the Queen Elizabeth Islands that remained solid were those around Meighen Island. By mid-September the ice cover in the Queen Elizabeth Islands was beginning to consolidate and figure 9 shows that Prince Gustaf Adolf Sea and the area north of Byam Martin Channel had already stopped moving. It may be assumed that Ballantyne Strait and the areas north and east of Fitzwilliam Strait including Hazen Strait began to solidify at the same time. Although young ice would be present in the remaining channels, no consolidation would occur in these areas until the latter part of September and in the larger areas like Viscount Melville Sound, Jones Sound, M'Clure Strait, M'Clintock Channel and Lancaster Sound consolidation might not occur until late November or early December. Indeed the ice cover in areas such as Lancaster Sound may not be consolidated at any time of the year.

The foregoing summary of the 1961 summer sea ice conditions in the study area is extremely general but it serves to point out the considerable movement of ice which may occur and the amount of open water that may exist. Generally speaking

Figure 9

ICE DISTRIBUTION, QUEEN ELIZABETH ISLANDS
September 19-23
1961

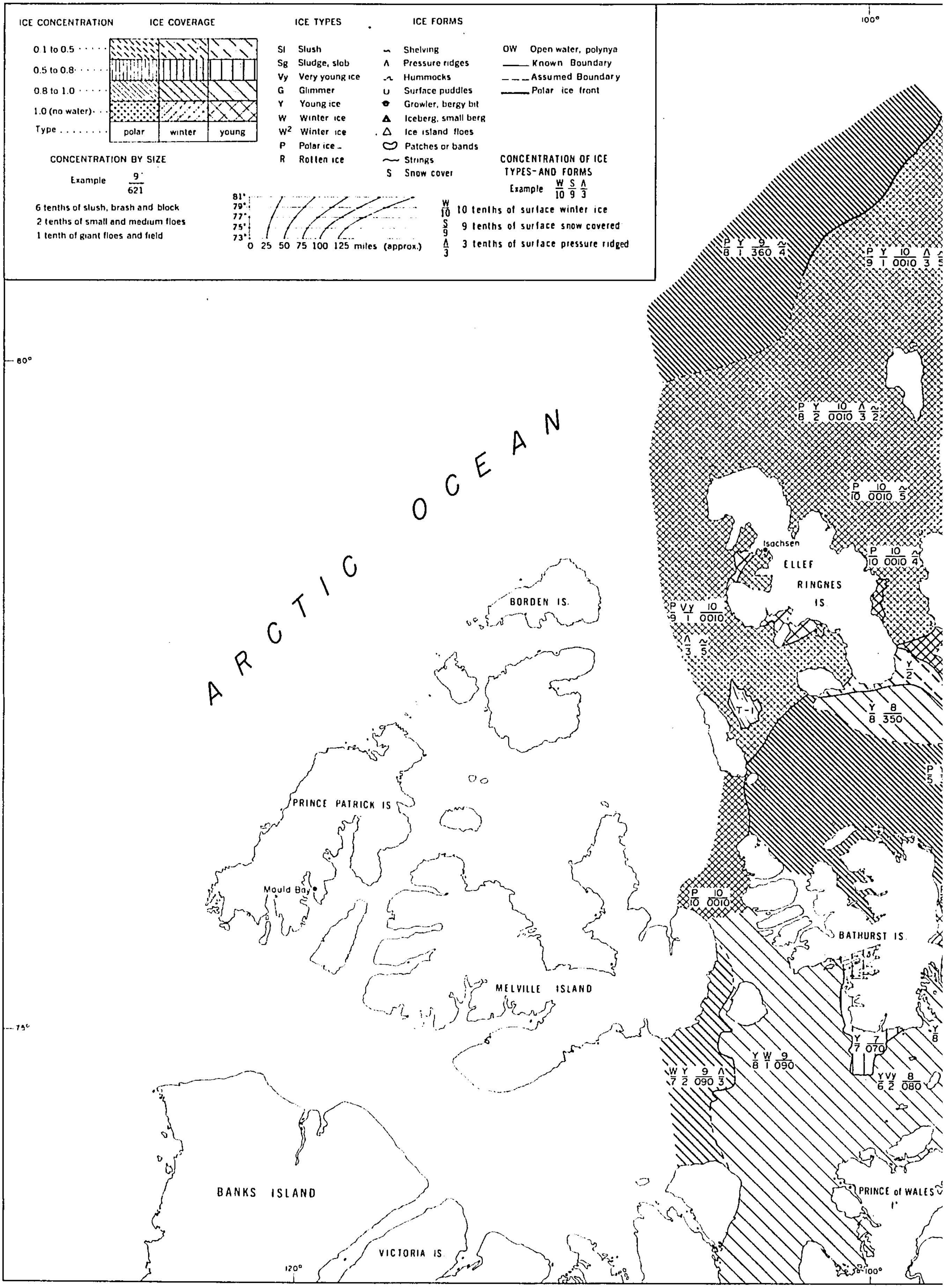
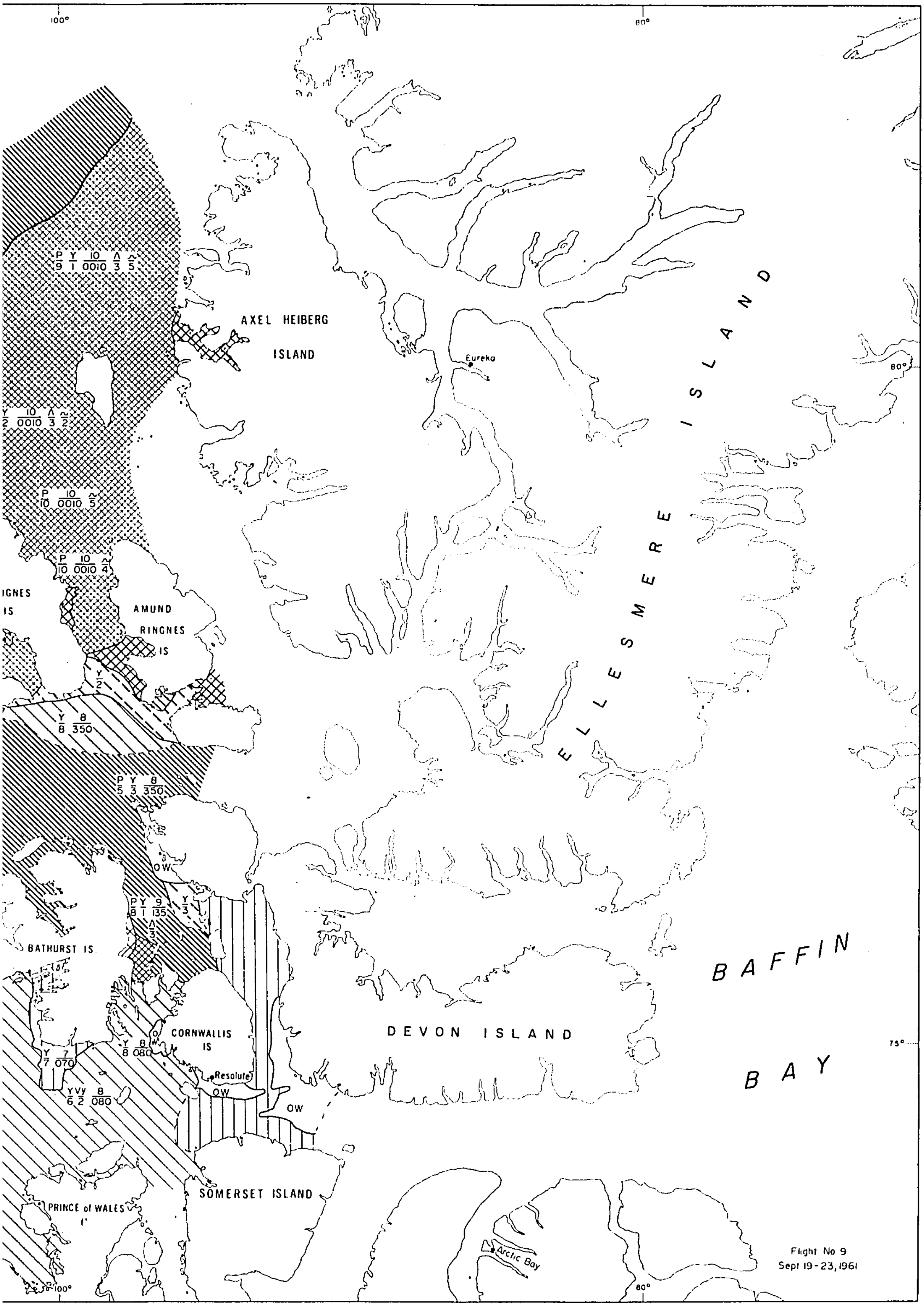


Figure 9 ICE DISTRIBUTION, QUEEN
(from data collected by



ɪTION, QUEEN ELIZABETH ISLANDS
;ollected by Black)

the 1961 summer season could be called a 'good' ice year because the ice cover on most of the channels broke up and moved.

1962

The following description of the ice conditions for the 1962 season in the Queen Elizabeth Islands has been summarized from a detailed report (Black, 1965). By the end of June 1962 the ice cover over the entire area generally resembled that for the same period in the preceding year with the exception of Lancaster Sound and the northern part of Prince Regent Inlet which were almost entirely ice-free. The eastern section of Barrow Strait was mainly open water as was the northern part of Penny Strait and the eastern portion of Queens Channel. Hell Gate and Cardigan Strait were ice-free and the western part of Jones Sound adjacent to these areas was open water. The rest of the channels remained consolidated. The polar ice front was well defined and extended across M'Clure Strait and along the western edge of the Archipelago up to and beyond the entrance to Nansen Sound.

The polar ice front remained in a similar position at the end of July with the exception of the M'Clure Strait area where a considerable amount of fracturing and movement occurred earlier in the month. Nansen Sound remained solid but the entire Eureka Sound system with the exception of the very southern portion had broken up and was moving. Norwegian Bay remained solid in the north while the southern section between Graham Island and North Kent Island had broken up. The fractured ice cover on Belcher Channel was separated from the broken area on Norwegian Bay by a tongue of solid ice extending to Grinnell Peninsula from the channel between Cornwall and Graham Islands. The ice cover on Hendriksen Strait had broken. The ice on Jones Sound was shattered and moving, while Lancaster Sound, Prince Regent Inlet and the eastern part of Barrow Strait remained ice-free. Wellington Channel had shattered while Penny Strait and Queens Channel were almost ice-free. The southern part of unnamed sea north of Bathurst Island between Desbarats Strait and Belcher Channel maintained a solid ice cover while the northern half of this area between Lougheed Island and Hendriksen Strait had shattered. The ice in Byam and Austin Channels remained consolidated. Barrow Strait had shattered but the central portion of Peel Channel remained solid. The central and extreme western parts of Viscount Melville Sound remained solid while the eastern area of M'Clintock Channel had broken up. A considerable amount of open water existed in the eastern part of M'Clure Strait and the ice cover on the western portion had broken and was moving. The southern halves of Crozier Channel and Kellett Strait were broken while their northern areas remained consolidated. The remaining interior area of the Queen Elizabeth Islands including Ballantyne Strait, Hecla and Griper Bay, Hazen Strait, Prince Gustaf Adolf Sea, Peary Channel, Hassel Sound, Sverdrup Channel and Massey Sound were solid up until the latter part of July in 1962.

By August 5th all the straits and channels of the Archipelago had broken except for the areas immediately adjacent to northern Bathurst Island and that part of Peary Channel extending from the northern end of Hassel Sound to the Arctic Ocean. Once the northern channels break up they allow the polar ice to flood into the Archipelago and this invasion was well under way by mid-August in 1962.

The following situation existed at the end of August 1962. Nansen Sound was loosely covered in its southern reaches while the northern portion maintained a seven tenths cover of polar ice. Eureka Sound and all the adjoining fiords were almost entirely ice-free. Norwegian Bay and Belcher Channel except for the extreme southern portions were ice-free. Open water predominated in Jones Sound except for a few tenths of ice in the extreme western portion. Lancaster Sound, Prince Regent Inlet, Peel Sound, Wellington Channel, Queens Channel and Penny Strait were entirely, free of sea ice. Barrow Strait had a few tenths of ice in its central portion while McDougall Sound had a similar concentration along its western part. Austin Channel and the eastern portion of Viscount Melville Sound including northern

M'Clintock Channel were almost completely open water as was M'Clure Strait. Although the ice cover had broken in the remaining areas of the Archipelago the concentration was generally nine tenths with the exception of Ballantyne Strait and Hassel Sound which had about a three tenths cover.

Figure 10 shows the sea ice distribution in the latter part of September 1962. By this time young ice had formed and covered most of the areas of open water present in the Archipelago during late August with the exception of the eastern channels. Jones Sound remained ice-free in its northern, central and eastern portions. Lancaster Sound, Prince Regent Inlet, Wellington Channel, Queens Channel, Penny Strait and much of Barrow Strait remained relatively ice-free. Young ice had formed on Hendriksen Strait and Penny Strait, the western portion of Viscount Melville Sound, the central and eastern portion of M'Clure Strait in addition to Crozier Channel, Kellett Strait and Fitzwilliam Strait. With the exception of the bay adjacent to Isachsen, the bays along the northern part of Bathurst Island and some landfast ice along the western coasts of Prince Patrick Island and Borden Island, the rest of the straits and channels of the Queen Elizabeth Islands were occupied by open water or moving ice. Consolidation probably began by the end of September but the date when the ice cover in the area

Figure 10

ICE DISTRIBUTION, QUEEN ELIZABETH ISLANDS
September 24-29
1962

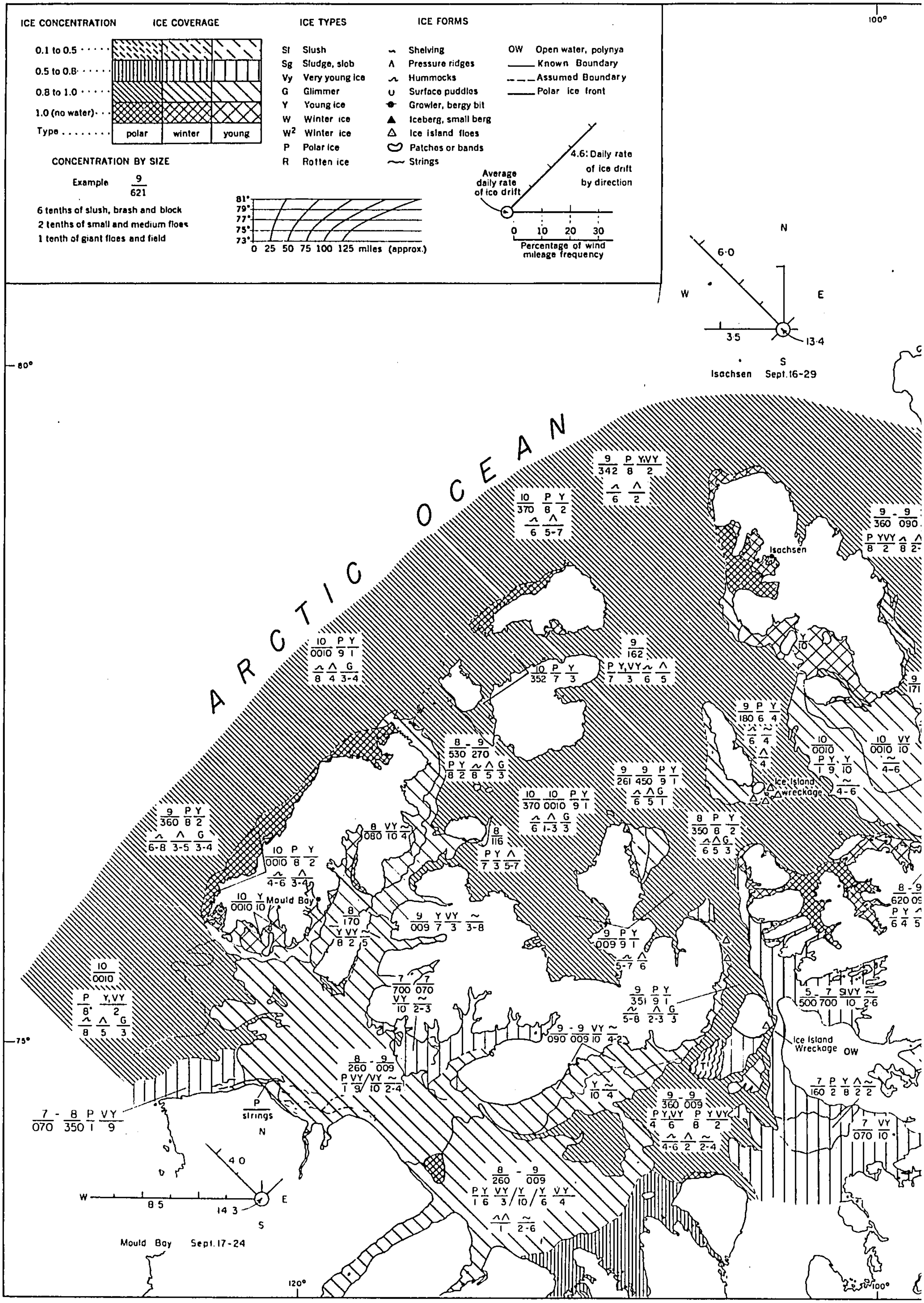
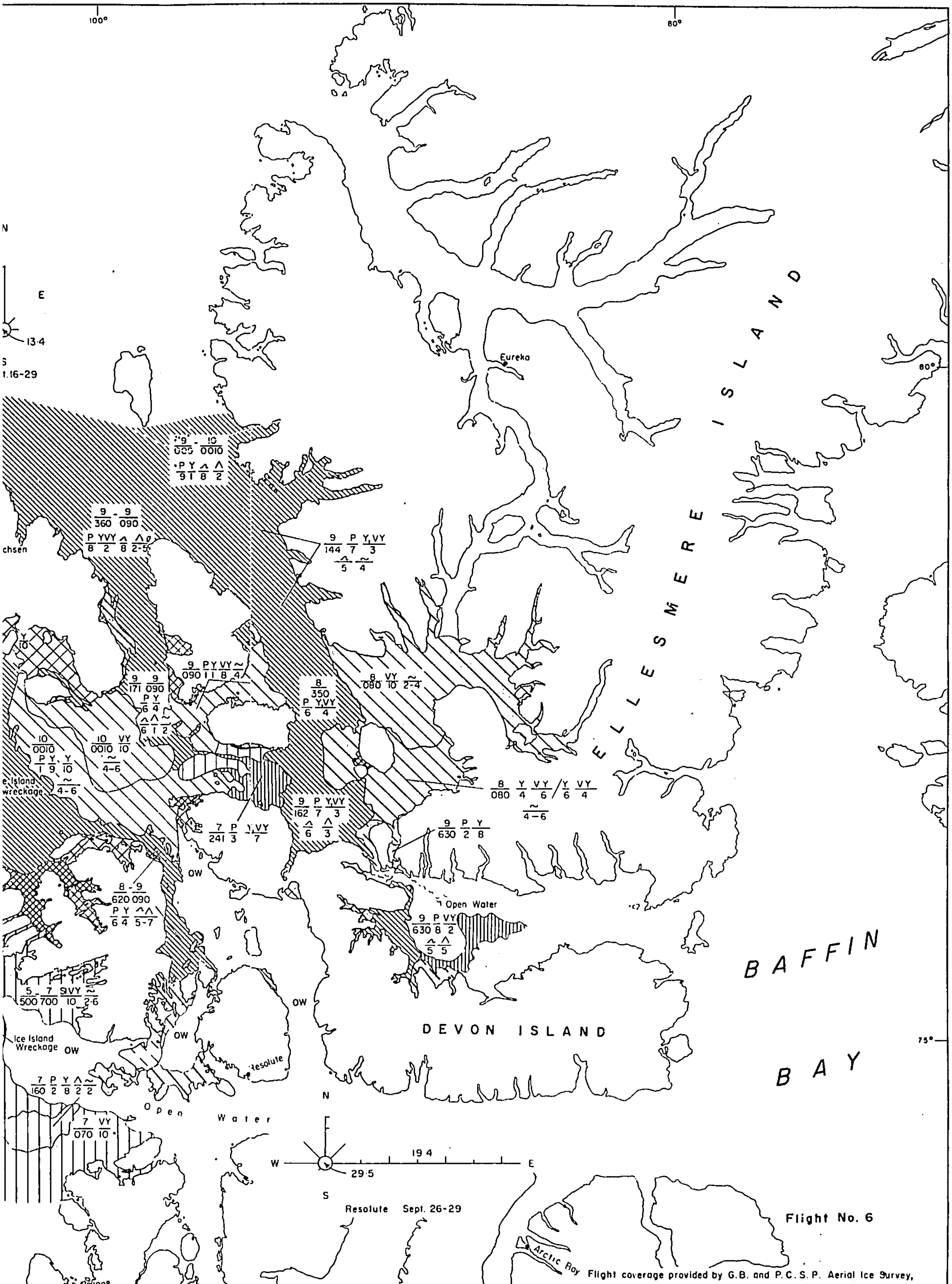


Figure 10 ICE DISTRIBUTION, (

(map from Black,



STRIBUTION, QUEEN ELIZABETH ISLANDS
from Black, 1965)

became completely solid is unknown.

Figure 10 shows the conditions which exist in the fall of a 'very good' ice year. This type of year is characterized by large amounts of open water at the height of the summer melt and a greater than normal amount of young ice in the fall as freeze-up begins.

1963

The 1963 summer season resembled that of 1962 with regard to the areas that broke up and moved, but as will be pointed out in the following description the concentrations of sea ice throughout the entire area in 1963 were much greater than those found in 1962. By the end of June 1963 all the waters of the Queen Elizabeth Islands maintained a consolidated cover of sea ice with the exception of a few areas. A small patch of open water existed at the northern end of Penny Strait and the eastern portion of Queens Channel remained ice-free. Hell Gate and Cardigan Strait were also ice-free. Lancaster Sound maintained a solid ice cover which is not the usual case. M'Clure Strait remained solid excepting the southwestern portion which was ice-free. The polar ice front extended some distance off shore along the western coast of the Archipelago.

It is difficult to describe the situation at the end of July 1963. Little sea ice information was collected between the third week in July and the latter part of August because the ice reconnaissance aircraft remained grounded at Isachsen due to a muddy airstrip. By the end of the third week in July most of the ice cover in the Queen Elizabeth Islands was still solid. Exceptions were Lancaster Sound which had broken to support an eight tenths cover and northern Prince Regent Inlet and the eastern part of Barrow Strait where the ice cover had shattered to form a nine tenths concentration. Penny Strait was ice free while Queens Channel and Belcher Channel supported an eight tenths cover. By this time the central portion of the Hendriksen Strait was seven tenths covered. Open water in Hell Gate and Cardigan Strait extended into the western portion of Jones Sound and the area between North Kent Island and Graham Island had broken to support a five tenths cover of ice. The southwestern part of M'Clure Strait was ice-free while the central portion had broken to form a nine tenths cover. The easternmost part of M'Clure Strait remained solid as did the remainder of the straits and channels in the study area.

A major change in the sea ice conditions had occurred by the end of August 1963. With the exception of northern Nansen Sound, Sverdrup Channel, Wilkins Strait, and the bay near Isachsen the total sea ice cover of the Queen Elizabeth Islands had broken up and was in motion. Central and southern Nansen Sound maintained an eight tenths cover while central Eureka Sound and the adjoining fiords were ice-free. The remaining areas in the Eureka Sound system maintained a five tenths cover of sea ice. A band of open water surrounded the western portion of Ellef Ringnes Island while Norwegian Bay was eight tenths covered. Jones Sound was ice-free and Lancaster Sound and Prince Regent Inlet were seven tenths covered by ice. Wellington Channel and Peel Channel were ice-free but Barrow Strait, Penny Strait and Queens Channel were covered with at least eight tenths of ice. The northern portion of M'Clintock Channel, the southern and eastern parts of Viscount Melville Sound supported a nine tenths cover and the remainder of the Sound was open water. M'Clure Strait to the west was five tenths covered while the eastern part adjacent to Viscount Melville Sound was ice-free. Crozier Channel, Kellett Strait and Fitzwilliam Strait were mainly ice-free. The remaining waters in the study area supported a broken and moving ice cover with a concentration of between nine and ten tenths.

In order to describe the situation which existed at the end of September the information shown on figure 11 has been augmented by data collected during an uncompleted flight made at the end of the month. By the end of September 1963 the young ice was nearly consolidated in Eureka Sound and Nansen Sound. The ice cover on Norwegian Bay was beginning to consolidate while Jones Sound remained mainly open water. Young ice had begun to form in Lancaster Sound and Prince Regent Inlet although the ice in these channels and in Wellington Channel and Penny Strait continued to move.

Barrow Strait had a moving cover of mainly young ice while eastern Viscount Melville Sound and northern M'Clintock Channel supported a moving cover of mainly polar and winter ice. The remainder of Viscount Melville Sound was nine to ten tenths covered with moving young ice. The eastern portions of M'Clure Strait as well as Crozier Channel, Kellett Strait and Fitzwilliam Strait also maintained a nine to ten tenths cover of young ice. The western half of M'Clure Strait supported an eight to nine tenths cover of mainly polar ice. At this time a solid unmoving ice sheet covered Hecla and Griper Bay, Wilkins Strait, and the northern coast of Bathurst Island. The remainder of the channels had a moving ice cover between nine and ten tenths which soon consolidated.

The 1963 summer season may be classed as a 'good' ice year as far as the break-up was concerned. However, most ship captains might not agree because the ice in the southern channels did not have time to melt or disperse before the northern channels opened and allowed more ice to pour in to augment the ice cover already present in the usual shipping lanes of the Queen Elizabeth Islands.

1964

The sea ice conditions which existed during the 1964 summer season were nearly reverse of those observed in 1962 and 1963. By the end of June in 1964, all the northern and most of the southern channels maintained a solid cover of ice.

Figure 11

ICE DISTRIBUTION, QUEEN ELIZABETH ISLANDS
September 10-14
1963

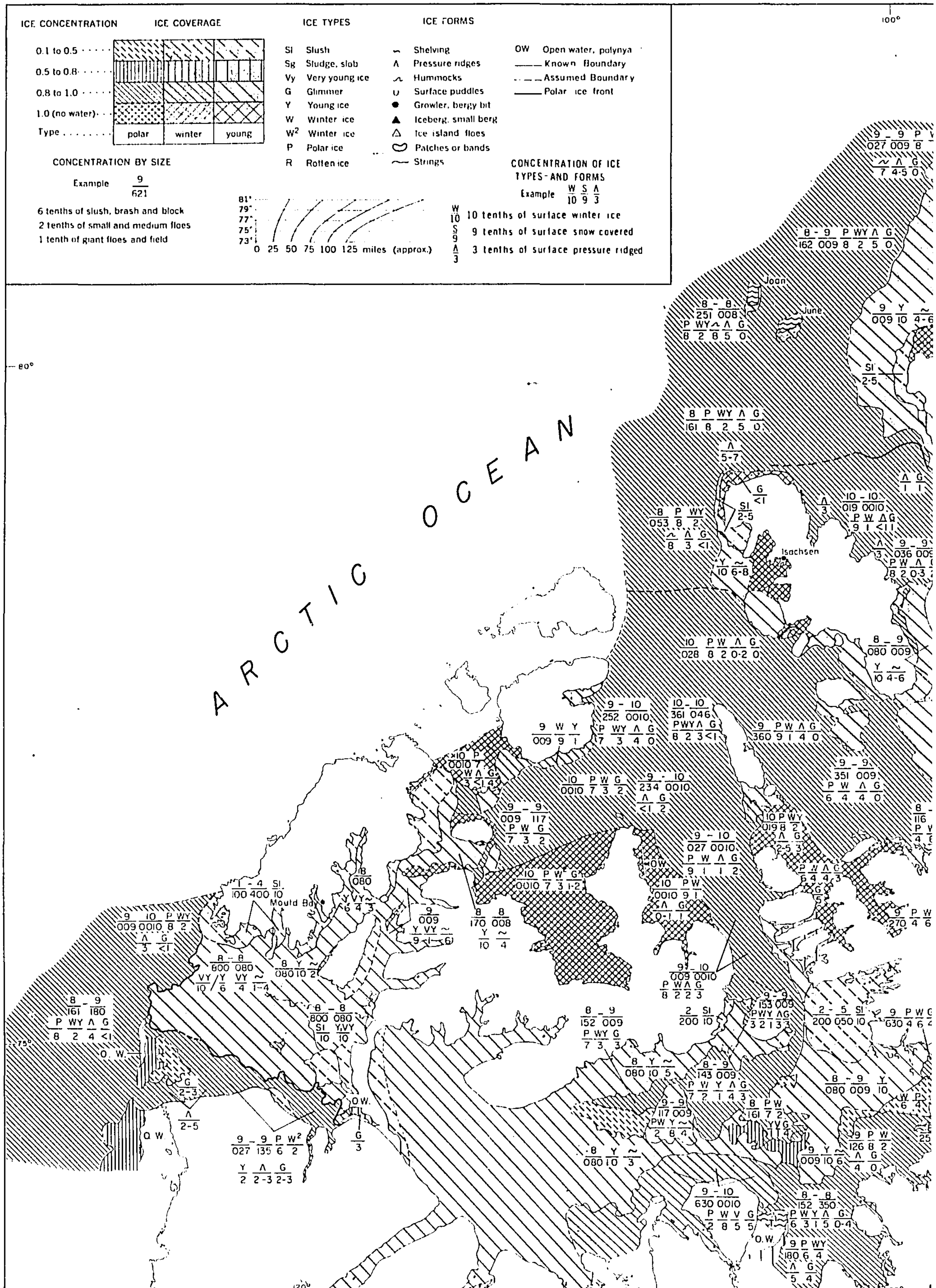


Figure 11 ICE DISTRIBUTION,

(map by Black,

ꟾTRIBUTION, QUEEN ELIZABETH ISLANDS
ap by Black, 1963)

The polar ice front was well defined and it extended from Banks Island along the western edge of the Queen Elizabeth Islands and continued past the northern entrance to Nansen Sound. Hell Gate, Cardigan Strait and a small portion of Jones Sound near the southern entrance to these straits were ice-free. The eastern portion of Jones Sound was ice-free and so was Lancaster Sound. Open water in Lancaster Sound extended westward into Barrow Strait to the meridian passing through Resolute. The ice cover on the northern section of Prince Regent Inlet had broken. A small patch of open water existed in mid-Penny Strait while a larger ice-free area appeared on the eastern portion of Queens Channel.

With the following exceptions the situation at the end of July was similar to the one at the end of the preceeding month. That portion of Eureka Sound north of Stor Island had broken up as had the section of Norwegian Bay between Graham Island and Hell Gate. The ice cover on Jones Sound had fractured and the eastern half was ice-free. Lancaster Sound was entirely ice-free as were Queens Channel and Penny Strait. Wellington Channel had broken up while the ice cover on Prince Regent Inlet remained unbroken. Belcher Channel had shattered and open water existed in the middle of Hendriksen Strait. The western part of Barrow

Strait remained solid while the portion east of Lowther Island contained no ice. The remainder of the area studied maintained a solid ice cover.

The changes which had occurred by the end of August 1964 were slight but nevertheless the southern half of Nansen Sound had broken and was beginning to support a young ice cover. Eureka Sound with the exception of its southermost section was mainly ice-free. The northeastern portion of Norwegian Bay had recently fractured and the moving ice in the southern portion of this bay was separated from the open water in Belcher Channel by a solid tongue of sea ice. Hell Gate and Cardigan Strait were covered with a few tenths of ice while Jones Sound was mainly ice-free. Lancaster Sound, the northern portion of Prince Regent Inlet and Peel Sound were all ice-free and a similar condition existed on Wellington Channel, Queens Channel, Penny Strait and Hendriksen Strait. The eastern portion of Barrow Strait was ice-free while the western section supported a five tenths cover. The Parry strip had broken earlier in the month but by the end of the month the sea ice on the remaining portions of Viscount Melville Sound was just beginning to fracture. The broken cover on M'Clure Strait extended about half way up Crozier Channel while Kellett Strait remained consolidated. The polar ice front had maintained its position and the rest of the channels in the study are not described above, supported a solid ice cover.

Generally the pattern of break-up and movement progressed very slowly during September 1964. Figure 12 outlines the situation for the middle of the month while the following description is based on data collected during a later flight, between September 26 and 29. By the end of September, Nansen Sound and Eureka Sound had a solid ice cover except in the vicinity of Stor Island. The northwestern part of Norwegian Bay remained solid and the eastern and southern portions were beginning to freeze. A few floes were scattered in Hell Gate and Jones Sound while Lancaster Sound, Wellington Channel, Queens Channel and Penny Strait were ice-free. Although young ice had formed in Belcher Channel and Hendriksen Strait movement was still possible. McDougall Sound, Peel Sound and Barrow Strait also supported a moving cover of young ice. By the end of the month the southern portion of Viscount Melville Sound and the northern section of M'Clintock Channel which had broken during the middle part of September began to consolidate. By the latter part of the month the Parry strip was covered with young ice as was Byam Channel. The young ice on the eastern portion of M'Clure Strait and the southern sections of Crozier Channel and Kellett Strait had formed

Figure 12

ICE DISTRIBUTION, QUEEN ELIZABETH ISLANDS
September 15-24
1964

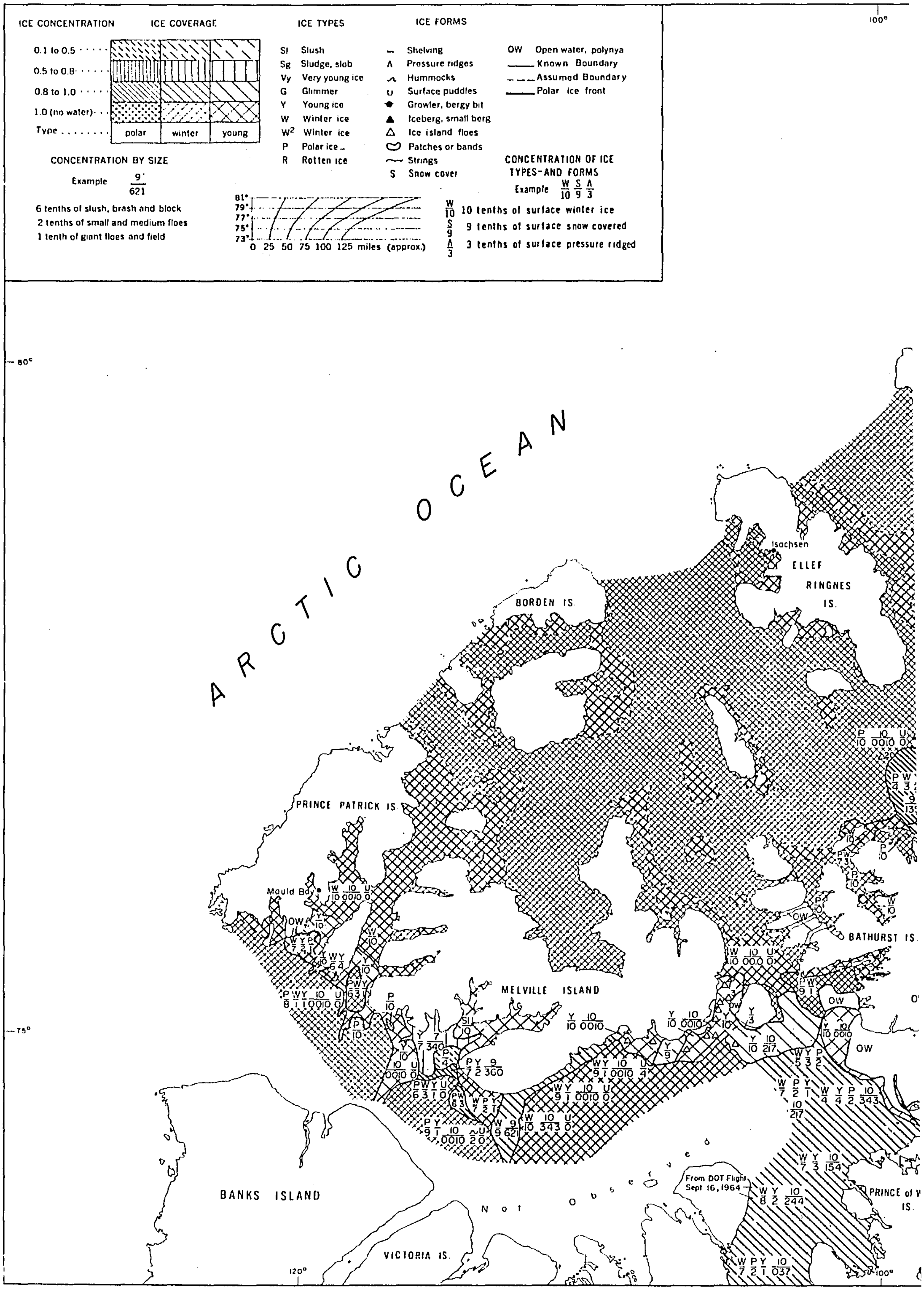
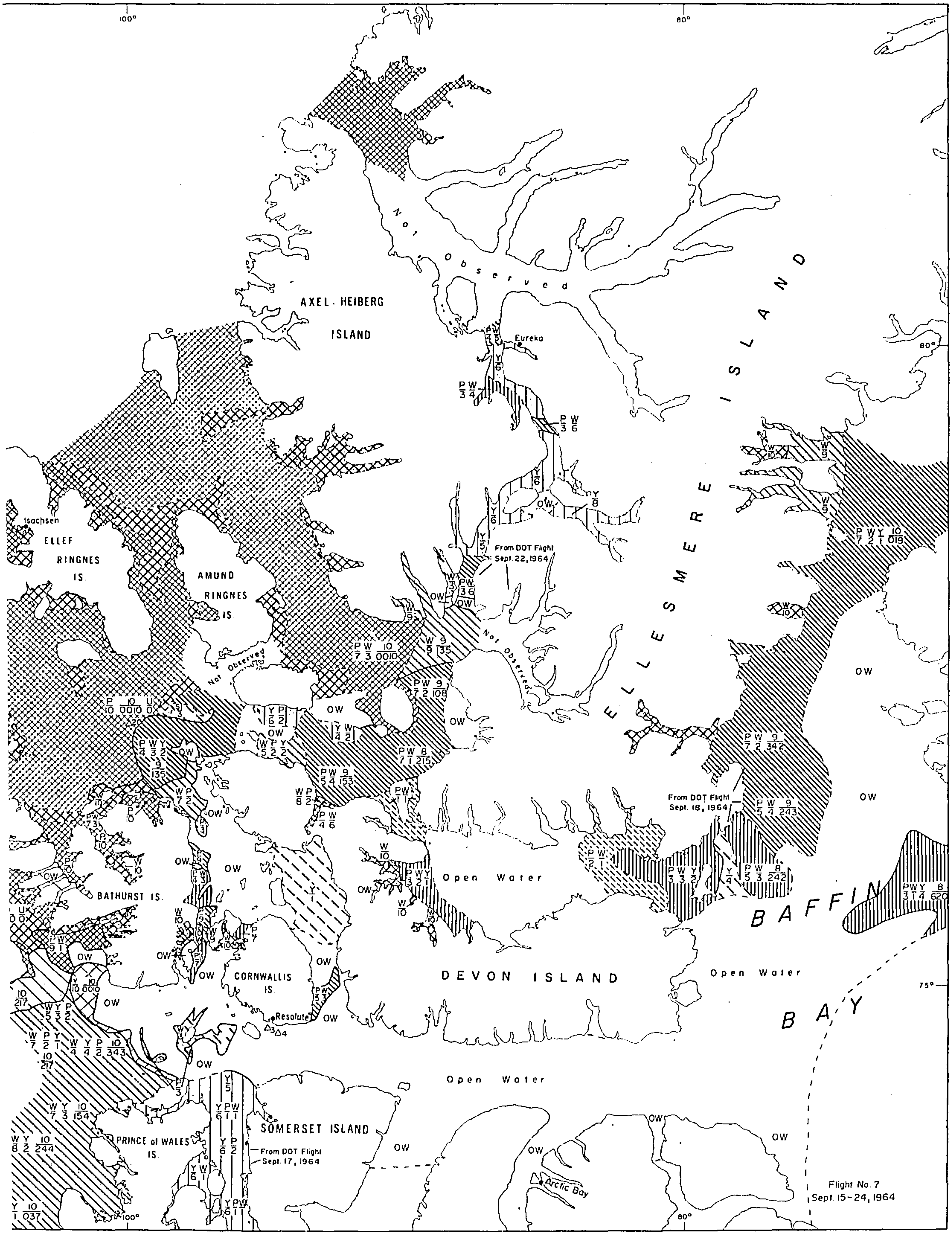


Figure 12 ICE DISTRIBUTION, QU
(map by Lindsay, 196



STRIBUTION, QUEEN ELIZABETH ISLANDS
y Lindsay, 1964)

a solid cover while the remainder of M'Clure Strait remained in motion. By the end of September the polar ice front had retreated somewhat closer to the coast of the Archipelago and dipped into the northern entrances to Prince Gustaf Adolf Sea and Peary Channel.

With the exception of parts of Eureka Sound, Norwegian Bay, Belcher Channel and Hendriksen Strait there was no movement of the sea ice covering the areas of the Queen Elizabeth Islands to the north of Parry Channel during the 1964 season. For this reason the summer of 1964 was considered a very 'bad' ice year.

<u>1965</u>

The distribution of sea ice in the Queen Elizabeth Islands at the end of June 1965 was very similar to the same period in 1964. That is the majority of the channels remained solid. Exceptions to this general observation were the ice-free area of Hell Gate, Cardigan Strait and the eastern entrance to Jones Sound. The portion of Lancaster Sound east of Prince Leopold Island was ice-free while the cover on the northern part of Prince Regent Inlet was in motion. The middle of Penny Strait was ice-free and so was the eastern half of Queens Channel. The polar ice front was well defined across the entrance of M'Clure Strait and as usual it extended along the western coast of the Queen Elizabeth Islands past Nansen Sound.

Though a few areas had begun to break-up by the end of July 1965 the majority of the channels remained solid. Eureka Sound had broken up and maintained a three tenths ice cover. That part of Norwegian Bay north of Hell Gate had broken, while the central portions of Jones Sound were beginning to fracture. The easternmost portion of Jones Sound was ice-free as was Lancaster Sound and the northern section of Prince Regent Inlet. The ice cover on Wellington Channel and eastern Barrow Strait had broken and by the end of the month the concentration in these areas was five tenths. Northern Peel Sound remained consolidated. Queens Channel and Penny Strait were mostly open water as was the middle portion of Hendriksen Strait but the ice cover on Belcher Channel had just begun to move. Even though the western half of M'Clure Strait had broken, the concentration was at least nine tenths. The polar ice front appeared to be closer to shore than when previously observed.

By the end of August 1965 the progression of break-up had almost reached its maximum extent for the season. Nansen Sound remained solid except for the southernmost part where young ice was beginning to form. Eureka Sound was mostly open water. The eastern and southern portions of Norwegian Bay had broken so that a moving ice cover existed over the areas east and south of the eastern entrance to Belcher Channel. The central portion of Hendriksen Strait remained open while the ice north of Penny Strait had begun to break up. Penny Strait maintained a five tenths cover and so did the eastern portion of Queens Channel. However, the eastern part of this channel, Wellington Channel, northern Prince Regent Inlet and Lancaster Sound were free of ice. McDougall Sound and the eastern half of Barrow Strait were ice-free but Barrow Strait to the west was nine tenths covered. By the end of August the Parry strip was moving but the ice cover on the remainder of Viscount Melville Sound as well as the northern part of M'Clintock Channel was solid. M'Clure Strait, the southern portions of Kellett Strait and Crozier Channel had broken. The ice cover on the rest of the straits and channels remained solid and the polar ice front remained in a position similar to that at the end of July.

Figure 13 shows the distribution of sea ice in the middle of September when most of the break-up had ceased. However, by the end of September more young ice had formed. For example, southern Nansen Sound and the main portions of Eureka Sound were solidly covered with young ice. Although the whole cover on Norwegian Bay had broken up earlier, by the end of the month the young ice had knitted the floes together and the ice cover was solid. Hell Gate, Cardigan

Strait and Jones Sound were mainly ice-free except for a few floes of young ice. Most of Lancaster Sound was ice-free while Prince Regent Inlet, Barrow Strait, Wellington Channel, Queens Channel and Penny Strait supported various concentrations of young ice. Like Norwegian Bay, the area between Penny Strait and southern Ellef Ringnes Island broke up during the first part of September but was consolidated again by the latter part of the month. The Parry strip was covered with young ice while the remainder of Viscount Melville Sound was solidly covered by mainly winter ice. Viscount Melville was solid at the end of September but the northern portion of M'Clintock Channel was still in motion. Ice on the extreme western section of M'Clure Strait was moving though the remainder of the strait and the southern portions of Crozier Channel and Kellett Strait were consolidated for the winter. Although only a few areas of the polar ice front were seen during the last flight in 1965, its position had remained relatively stationary since the end of August.

The ice conditions during the 1965 summer season cannot be classed as 'good' or 'bad' nor can the conditions be termed 'average' because the progression and extent of break-up was less than average. Hence the season was designated as a 'fair' ice year.

Figure 13

ICE DISTRIBUTION, QUEEN ELIZABETH ISLANDS
September 13-22
1965

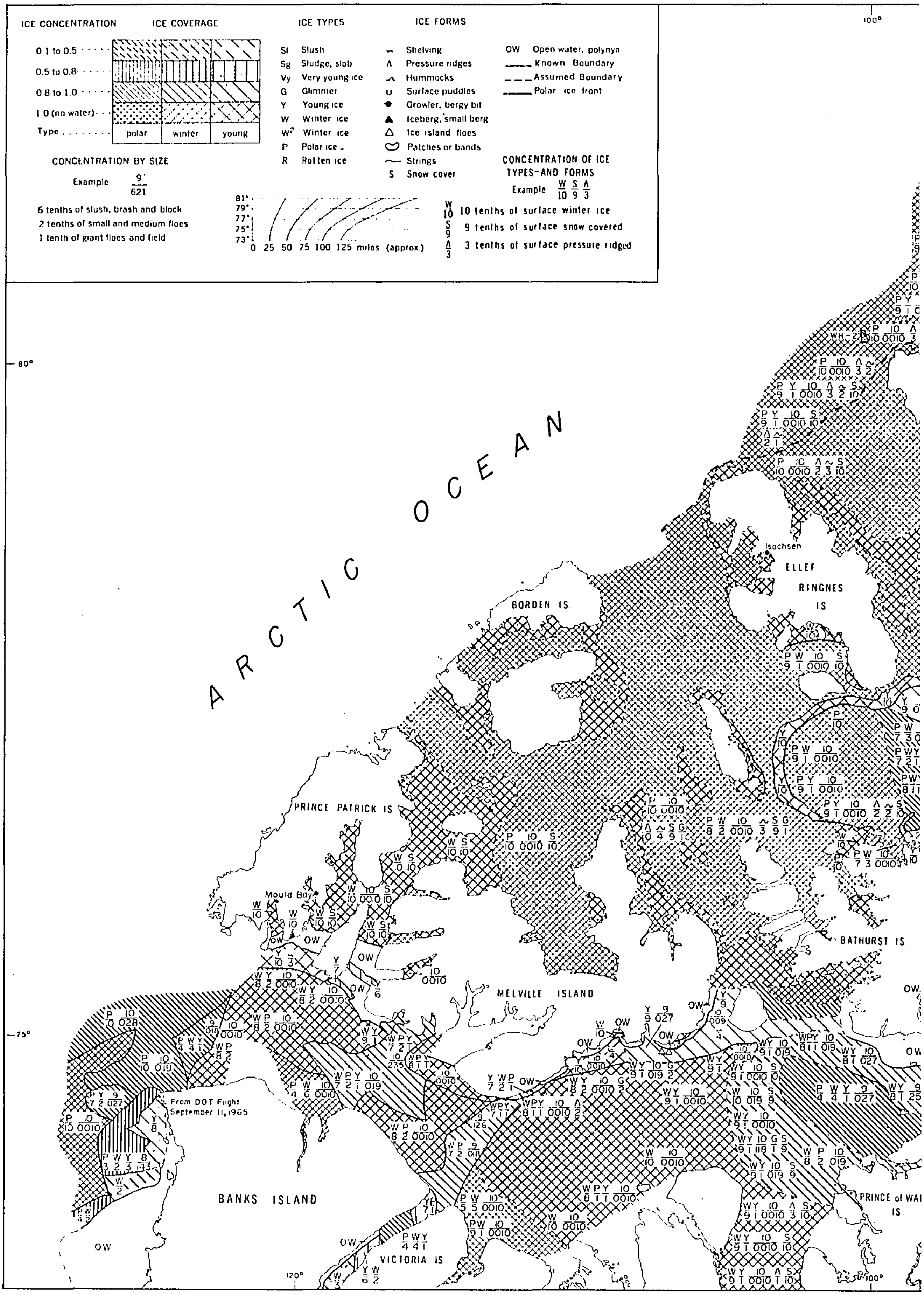
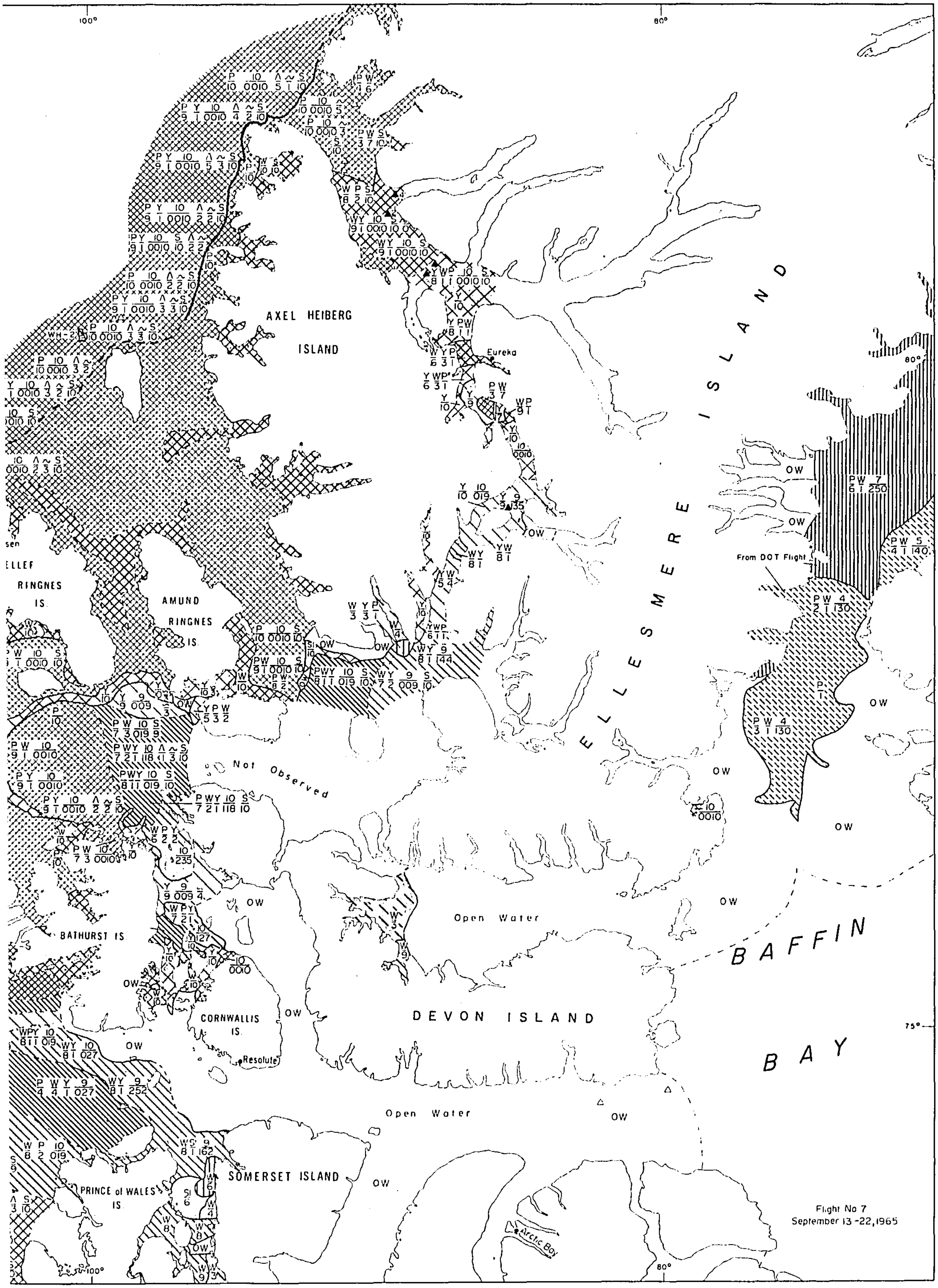


Figure 13 ICE DISTRIBUTION, Q
(map by Lindsay, 19



TRIBUTION, QUEEN ELIZABETH ISLANDS
Lindsay, 1965)

<u>1966</u>

At the end of June 1966, as in previous years, most of the channels maintained a solid ice cover. Open water occurred in Hell Gate, Cardigan Strait and the westernmost portion of Jones Sound. Lancaster Sound was mostly open water as far west as the solid edge which extended northward from Prince Leopold Island to Deven Island. Northern Prince Regent Inlet was broken and maintained about a five tenths cover. Queens Channel and Penny Strait were covered with moving ice. All other areas were solidly covered except the western half of M'Clure Strait. The polar ice front extended northeast along the western coast of the Queen Elizabeth group from the southern tip of Prince Patrick Island past the entrance to Nansen Sound.

By the end of July 1966 Eureka Sound was beginning to break up. Although most of Norwegian Bay remained solidly covered that portion between Hell Gate and Graham Island had recently broken. Hell Gate, Cardigan Strait and the westernmost portion of Jones Sound were ice-free. The eastern end of Jones Sound was also ice-free while the central portion remained solid. That part of Lancaster Sound east of Prince Leopold Island was entirely ice-free. Prince Regent Inlet in the northern reaches maintained a six tenths ice cover while the eastern section of Barrow Strait was five tenths covered. The ice cover on Wellington Channel had just broken up. Queens Channel and Penny Strait were ice-free. The ice cover on Belcher Channel had cracked and was moving and the central portion of Hendriksen Strait was open water. Viscount Melville Sound maintained a solid central area while the northern and eastern portions had begun to move. The ice cover on M'Clure Strait was moving but Kellett Strait, Crozier Channel and the remaining channels in the study area supported a solid ice cover. The polar ice front remained in a position similar to that at the end of June.

By the end of August the break-up had advanced considerably. Although the main portion of Nansen Sound remained solid, the southernmost part was ice-free. Eureka Sound was ice-free. The ice cover on Norwegian Bay had completely shattered but Massey Sound remained consolidated. The ice on Belcher Channel was moving. Hendriksen Strait, Hell Gate, Cardigan Strait, Jones Sound, Lancaster Sound and the northern part of Prince Regent Inlet were ice-free. Wellington Channel and eastern Barrow Strait were almost ice-free while Queens Channel was completely ice-free. Penny Strait was covered with broken and moving ice and the area north of it was broken. Meanwhile Hassel Sound remained solid. The ice cover on McDougall Sound, western Barrow Strait, Viscount Melville Sound and northern

M'Clintock Channel was moving. The Parry strip was beginning to develop and the ice cover on Austin Channel and Byam Channel had broken. The southern part of M'Clure Strait was covered with at least nine tenths of ice while the northern section together with Crozier Channel and Kellett Strait was ice-free. The remaining areas investigated supported a solid cover and the polar ice front appeared to have moved closer to shore along its entire length.

The situation at the end of September can be generally determined from the distributions shown on Figure 14. However the conditions described below differ from those shown on Figure 14 because they are summarized from a flight made toward the end of September. By this time northern Nansen Sound was still solidly covered, with young ice forming in the southern portion of the sound. Eureka Sound supported a complete cover of young ice except in the vicinity of Stor Island. The ice cover on Norwegian Bay and Belcher Channel had consolidated. Massey Sound and the channels to the north of it remained solid during the 1966 season. Hell Gate, Cardigan Strait and Jones Sound were ice-free. Lancaster Sound, northern Prince Regent Inlet, eastern Barrow Strait, Wellington Channel, Queens Channel and Penny Strait were mostly ice-free near the end of September although some young ice floes were present in these channels. Most of

Figure 14

ICE DISTRIBUTION, QUEEN ELIZABETH ISLANDS
September 16-25
1966

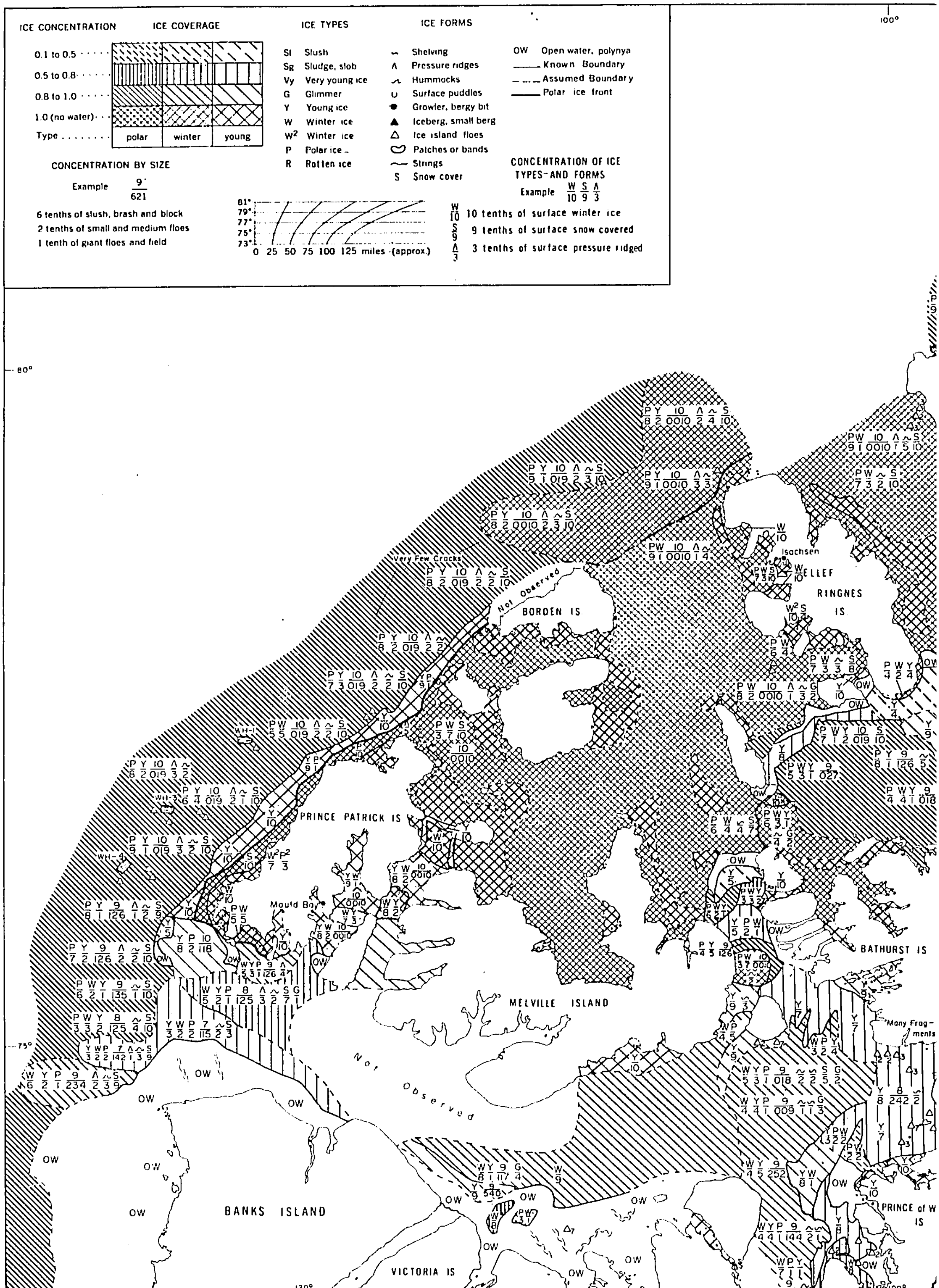
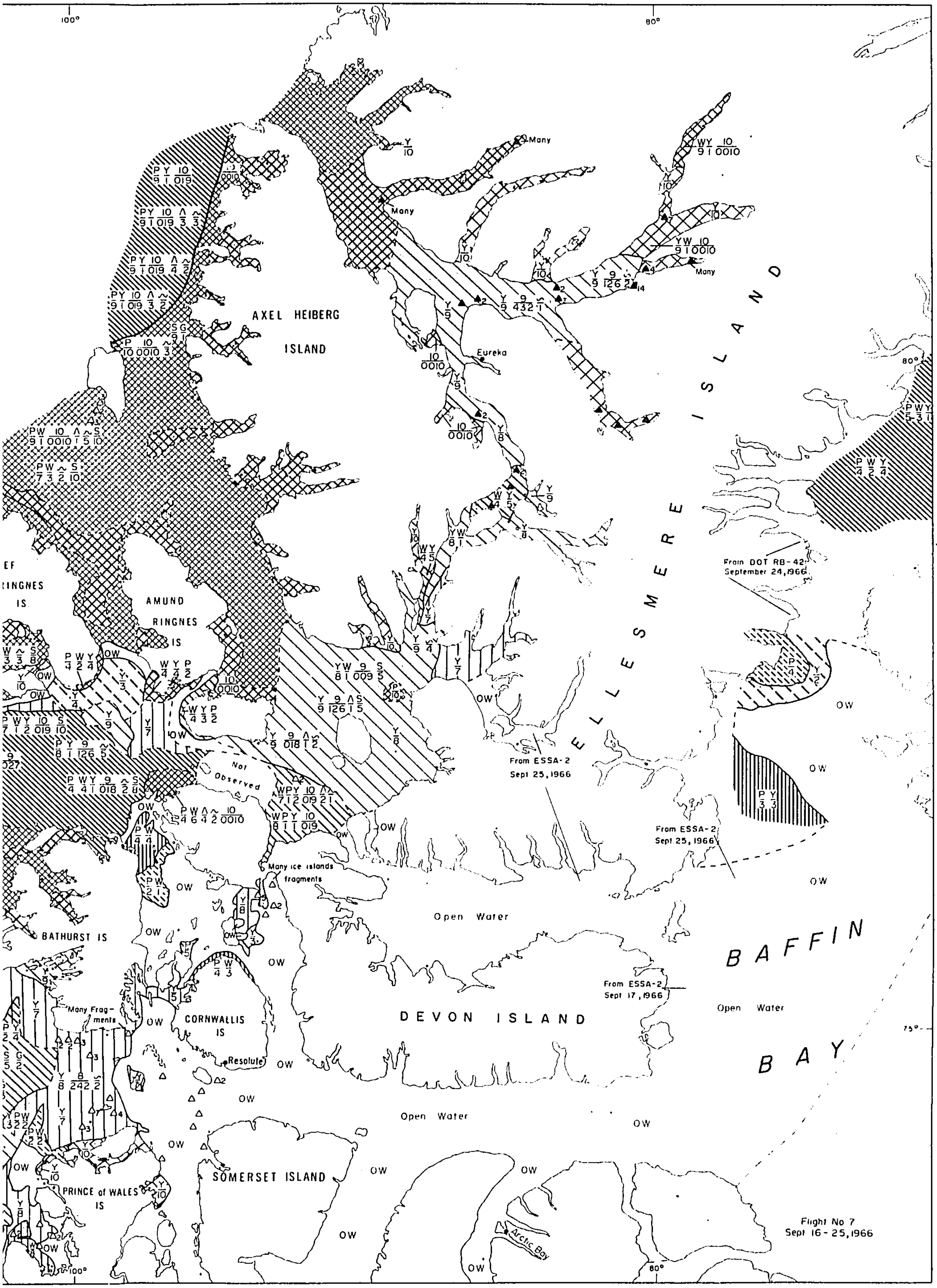


Figure 14 ICE DISTRIBUTION,
(map by Lindsay, 1



RIBUTION, QUEEN ELIZABETH ISLANDS
Lindsay, 1966)

the area north of Penny Strait had consolidated while McDougall Sound, western Barrow Strait, Byam Channel, Austin Channel and Byam Martin Channel supported a partially consolidated cover of mainly young ice. The Parry strip was covered with young ice and some movement was possible. Most of the ice cover on Viscount Melville Sound had consolidated but some movement was possible on northern M'Clintock Channel. The central and eastern portions of M'Clure Strait were solidifying while Fitzwilliam Strait, Kellett Strait and Crozier Channel were solidly covered with mainly young ice.

Generally the break-up and movement in the study area during the 1966 summer season extended further than was the case in 1964 or 1965 but to a lesser extent than in 1962 or 1963. As a result the 1966 summer season is classified as an 'average' ice year.

Forecasting the Type of Ice Year

The descriptions given above show that a considerable fluctuation in the sea ice conditions may occur from year to year. It might be assumed that the type of year could be forecast by comparing the conditions in a specific or indicator area with those noted at the same time during a previous year. It is possible to forecast the type of ice year but the forecast cannot be made until the end of July. By this time it is too late for the ships and the shippers to modify their plans or adjust their loads to take advantage of the forecast. As a result the indicator area type of forecast is of little practical value.

Progression of Break-Up

Even though it is not possible to forecast the type of ice year that will occur it is possible to accurately forecast the break-up patterns which will occur in any given year. But it remains impossible to give specific dates for the various steps in the progression of break-up. The following descriptions are based on the data which has been summarized above especially that collected by the author during 1964, 1965 and 1966.

Before describing in detail the break-up patterns for specific areas the general patterns will be given as they are likely to exist at the end of each month during any year. By the end of June, although most of the channels of the study area are solidly covered with sea ice some areas of open water always exist. For example portions of the channels on either side of North Kent Island remain entirely ice-free or lightly covered with ice throughout the winter. By the end of June these channels (Hell Gate and Cardigan Strait) are entirely ice-free. Two other areas, Penny Strait and Queens Channel, exhibit similar characteristics. Although both Queens Channel and Penny Strait may freeze over during the winter it is usually the case that the easternmost part of Queens Channel remains ice-free. There is an additional section of the study area

(Lancaster Sound) which may have a considerable amount of ice-free water during the winter and by the end of June. Nothing definite can be said about the ice conditions in Lancaster Sound during the winter months except that a solid cover is not likely to exist for very long. That portion of Lancaster Sound east of Prince Leopold Island may be completely ice-free in mid-March. Although it is possible for the open water in Lancaster Sound to extend close to Resolute Bay by the end of June, it is more likely that only the portion of the Sound east of Prince Leopold Island will be ice-free.

The patterns which develop in July are not radically different from those of mid-June. Open water still remains in Hell Gate and Cardigan Strait and the open portions of Penny Strait and Queens Channel usually combine to form one ice-free area. Lancaster Sound may have a few floes. However Eureka Sound, Jones Sound, Wellington Channel, M'Clure Strait and Belcher Channel break up by the end of July. The middle portion of Hendriksen Strait has usually become ice-free by the end of July and the ice cover between Hell Gate and Graham Island has shattered. The remaining channels studied here support a solid ice cover.

The situation at the end of August cannot be described with the same accuracy as June and July.

However by the end of August in an average year Eureka Sound, Jones Sound, Lancaster Sound, Wellington Channel, Queens Channel, Penny Strait and the eastern portion of Barrow Strait have become ice-free. Open water probably exists in Hendriksen Strait, Belcher Channel and the southern portions of Crozier Channel and Kellett Strait. The ice cover on the southern portion of Nansen Sound, the eastern section of Norwegian Bay and the northern part of Viscount Melville Sound will have broken up by this time. In some years the remaining channels have also broken while in other years these channels are still solid at the end of August.

There may be considerable year to year variations in the sea ice pattern on the straits and channels of the study area by the end of September but the variations are not as formative as those which may occur in August. Usually in late September the sea ice over the main part of the Queen Elizabeth Islands is in the process of consolidation. However Jones Sound, Lancaster Sound, Wellington Channel, Queens Channel and Penny Strait with the exception of a few patches of young ice are usually relatively ice-free at this time. Although the young ice cover has begun to form and helps to solidify the existing ice fields some movement can and does occur in many of the larger channels well on into October and November and possibly later. Only in 1967 have sea ice reconnaissance aircraft remained in the Queen Elizabeth Islands long enough to make surveys in November. It is hoped that these observations will be extended so that some coverage is gained during each of the winter months. Until such time as these surveys are carried out only general statements like the ones given above can be made concerning the final dates of consolidation of the sea ice cover in the various channels of the study area.

Specific Break-Up Patterns

The general progression of the break-up for each summer month has been described in the foregoing paragraphs. This section will deal with the specific break-up patterns which are unique to each area of the Queen Elizabeth Islands. No effort will be made to state the exact time for each stage of break-up because the yearly variations are too great. However it is possible to describe chronologically the progression of break-up in the various water bodies of the area because a recognizable step by step progression usually occurs. Proof for this statement is given below.

Lancaster Sound

Usually the portion of Lancaster Sound east of an arcuate ice edge extending northward from Prince Leopold Island to the southern coast of Devon Island is ice-free before any other channel in the study area. The area west of the Prince Leopold boundary is one consolidated ice cover and may remain so for a number of weeks. Suddenly the western portion of the sound breaks up and the edge between solid ice and moving ice moves westward to a line approximating the meridian through Resolute Bay. This boundary may remain in the same position for another two weeks before the portions west of it begin to shatter.

Prince Regent Inlet

The ice cover on Prince Regent Inlet does not exhibit any step by step progression of break-up. It is usually the case in this inlet that if one portion is solid the whole of it is solid but once the break-up starts the entire inlet becomes a moving mass almost at the same time. The ice cover or the amount of open water in Prince Regent Inlet seems to depend on the predominant wind direction in the early summer. For example, a steady south wind for a few days may drive the shattered ice fields out of the inlet and into Lancaster Sound where the floes are ablated. If these winds do not occur, then the inlet may support a fairly concentrated ice cover until the ice is ablated in situ.

Jones Sound

Jones Sound has a characteristic progression of break-up. There are areas of open water which form early in the season at each end of the sound. The central portions remain consolidated while the area of open water at each end grows larger. Usually the ice-free area at the eastern end of the sound expands faster than that at the western end. Once the eastern area has opened as far west as a meridian passing through Cape Sparbo the northernmost portion of the sound begins to shatter. As a result a band of moving ice is formed along the southern coast of Ellesmere Island between the open water areas at either end of the sound. Three or four days after this condition has established itself the remainder of the sound fractures into quite large floes with the exception of Bear Bay and portions of West Fiord which remain solid for at least two more weeks in the case of Bear Bay and for a considerably longer period for West Fiord. Most of Jones Sound may be ice-free before the ice cover on West Fiord disappears.

Hell Gate and Cardigan Strait

During the winter months the waters of Hell Gate and Cardigan Strait may freeze until there are only small areas of open water on either side of the southern portion of North Kent Island. As the season progresses these areas of open water expand northward along either side of this island until a boundary is formed at the entrance to Norwegian Bay. The edge between open water and solid ice usually remains in this position for a considerable length of time. Similarly the open water in these channels extends southward to the entrance of Jones Sound where a definite boundary between ice and water exists for some weeks. This ice edge may retreat slowly eastward into Jones Sound.

Eureka and Nansen Sounds

The break-up and disintegration of the ice cover on Eureka Sound proceeds northward and southward from the area around the northern end of Stor Island. The ice cover north of Stor Island breaks up and disintegrates before the southern portion. Usually an ice edge exists for a week or more across the part of the sound just north of Eureka. In the south the boundary between the open or moving ice and the solid ice establishes itself for some time where Eureka Sound enters Norwegian Bay. While this boundary remains stationary the ice edge at the northern end of the Sound extends itself into the southernmost part of Nansen Sound where the boundary between the solid ice and the open water tends to form at right angles to the walls of this sound. Usually the ice edge remains near Hare Fiord for a period of time and may suddenly move north to the vicinity of Otto Fiord where the boundary between solid and moving ice remains until the sound freezes over again. Of course the entire surface of Nansen Sound may shatter in 'good' years but the whole of Eureka Sound will become ice-free even in the worst ice years.

Penny Strait and Queens Channel

The progression of break-up in the Penny Strait, Queens Channel area is relatively straight forward. The open water in Penny Strait extends northward to the ice boundary across the northern portion of the strait between Grinnell Peninsula and the north eastern part of Bathurst Island. The edge remains stationary here for some time. Queens Channel establishes its eastern limits of open water along the eastern parts of the islands between Grinnell Peninsula and the northern part of Cornwallis Island. The southern part of Penny Strait and the northern part of Queens Channel join to form an ice-free area while land-fast ice extends along the eastern coast of Bathurst Island.

Wellington Channel

At approximately the time when Queens Channel and Penny Strait become ice-free the entire cover on Wellington Channel suddenly fractures and large floes are expelled into the open water of Lancaster Sound. These floes seldom move very far in this sound before they are completely ablated and open water prevails. It is possible for Wellington Channel to support a completely solid ice cover at the beginning of a week and be entirely ice-free at the end of the week.

Belcher Channel

The first signs of break-up in Belcher Channel appear as elongated and curved areas of open water extending along a line between the northeastern part of Grinnell Peninsula to the central southern coast of Cornwall Island. Next, areas of open water appear to the southeast of Table Island. The ice cover between these areas shatters and then extends itself until the entire channel consists of moving ice. The boundaries at either end of the channel may exist for some time because the adjacent areas do not usually fracture until the latter part of the season.

Hendriksen Strait

The little patch of open water or the polynya which occurs in the middle of Hendriksen Strait gradually expands until the western half of the strait is ice-free. The eastern and western parts of the strait do not break up until the ice in the adjacent channels begins to disintegrate.

Norwegian Bay

The break-up of Norwegian Bay may be divided into five separate steps. The relative location of the boundaries formed during each of these steps are readily forecast but it is difficult to state the time at which they will occur. Initial break-up begins in a triangular area with the apex at the south of Graham Island and the sides extend to the northwestern side of the entrance to Cardigan Strait and to the northeastern side of the entrance to Hell Gate. These boundaries remain until the second step proceeds to form a curved boundary extending from the southern tip of Graham Island to the point on Ellesmere Island mid-way between Hell Gate and Blue Fiord. Shortly after this boundary between solid ice to the north and the moving ice to the south has been established the third step occurs and the area of Norwegian Bay northeast of Graham Island breaks up. The western boundary of this area is formed by an uncommonly straight line between the northern tip of Graham Island and the southernmost tip of Axel Heiberg Island. Almost immediately after the break-up of the northeastern area the southwestern portion gives way and begins to move. This is the fourth step. The northern boundary formed in this area extends in a curved line between the central eastern part of Cornwall Island to a similar position on Graham Island. Within a few days a considerable expanse of open water may exist to the south of this boundary as the ice tends to concentrate along the northern coast of Grinnell Peninsula. The break-up of the ice cover on the north west section of Norwegian Bay constitutes the fifth and final step. First to break-up in this area is the ice along the southern coast of Axel Heiberg Island. Then a very distinct boundary appears between the north east corner of Cornwall Island and the south western tip of Axel Heiberg Island. Usually this boundary will remain until freeze-up even though further fracturing occurs in the eastern parts of Norwegian Bay.

Unnamed Region North of Penny Strait

At approximately the same time that step four occurs on Norwegian Bay the ice cover in the area north of Penny Strait begins to break-up. Basically three main steps occur in the break-up of this unnamed region. First the ice due north of Penny Strait breaks up and extends eastward to the entrance to Belcher Channel and Hendriksen Strait. At the same time a boundary between the moving cover on the eastern part of the unnamed area and the consolidated cover on Hassel Sound is formed across the southern entrance of this sound. The second step sets the western boundaries for the break-up in this region. This boundary forms part of a large circle which extends from the southern coast of Ellef Ringnes Island, along the southern coast of King Christian Island. It curves within a few miles of the island southeast of Lougheed Island, continues curving past Seymour Island and extends along the northern coast of Bathurst Island to the mouth of Penny Strait. The entire ice-field within the confines of this boundary usually moves a few miles to the south and east during which time the ice cover continues to break-up from east to west. Later in the season the northwestern boundary of this region may extend across Maclean Strait from the northwestern tip of King Christian Island to the mid-eastern portion of Lougheed Island.

Barrow Strait

While the channels in the central and eastern parts of the study area are breaking up a similar situation occurs in Parry Channel. The boundary between solid and moving ice extending south from Resolute moves westward and forms a line joining Cape Cockburn to Lowther Island and the central northern coast of Russell Island. Although most of the ice east of this line is moving, the cover on McDougall Sound remains solid to the north of an east-west boundary joining the southeastern tip of Bathurst Island and the south-western part of Cornwallis Island.

M'Clure Strait

The break-up on M'Clure Strait progresses eastward from a boundary between Cape Manning and Cape Prince Alfred. There is no step-like development for the break-up pattern on this channel because no boundary remains stationary for an extended period of time.

Viscount Melville Sound

The break-up occurs in four successive stages. The first part to break-up is the Parry strip. As previously stated in this case the ice cover immediately south of Melville Island from Winter Harbour to the eastern tip of the island fractures and rapidly disintegrates to form an area of open water along the coast. This strip of open water soon extends eastward across the southern entrances to Byam Channel and Austin Channel to link-up with the moving ice cover on Barrow

Strait. The southern boundary of the Parry strip remains relatively stationary while the second step progresses. During this phase the ice cover begins to break-up at the lateral extremities of Viscount Melville Sound and this break-up progresses toward the center until the solid area in the middle is bounded by the meridians running through Stefansson Island and Peel Point. Shortly after this the third step begins. During this stage the ice cover on that portion of Viscount Melville Sound south of a line between Elvira Island and Peel Point breaks up and the bays along the northern coast of Victoria Island become ice-free at the same time. The final step is completed when the central portion of the sound breaks into large floes and begins to move.

Secondary Channels

While the break-up was progressing on Viscount Melville Sound, the cover on Austin Channel remains solid but at least half of the ice cover on Byam Channel, Kellett Strait and Crozier Channel breaks up. Soon after this the ice cover on Austin Channel shatters and the northern boundary extends along a parallel from Melville Island to northern Byam Martin Island and across to Bathurst Island. This boundary may remain for only a brief period before the rest of Byam Martin Channel breaks up. A new boundary between solid and moving ice is formed by the intersection of a line running along the meridian from the northeast coast of Melville Island and a line approximating a parallel extending westward from the tip of Cameron Island. At approximately the same time the ice cover on Fitzwilliam Strait and the area south of Emerald Island breaks up and begins to move.

Depending on the type of ice year the patterns described above may be realized to a greater or lesser extent. In exceptional years the channels to the north of those described above such as Prince Gustaf Adolf Sea and Peary Channel may also break up to some extent.

Progression of Freeze-Up

Up until the fall of 1967 very few sea ice reconnaissance flights were carried out over the Queen Elizabeth Islands after the middle of October. As a result there is very little information available concerning the progression of freeze-up in this region. Because of this lack of data the following description of the freeze-up patterns is highly generalized.

General Indications of Freeze-Up

In the past it has been assumed that most of the sea ice movements cease fairly early in the autumn. Although some areas do comply with this idea and are consolidated by the middle of October there are quite a number of areas which do not consolidate until the first part of November and there are other areas which may remain in motion for the entire year.

The first indication that the sea ice cover on certain areas is beginning to consolidate is the formation of glimmer ice and young ice. The formation of glimmer ice depends on local freezing conditions. As a result there seems to be no specific pattern for the formation of ice of this type in the study area except for a general progression from north to south. Glimmer ice does little to supplement consolidation.

The second indicator of impending solidification is the appearance of young ice. The formation of a young ice cover does not mean that further movement is impossible because the primary forms of this type of ice are relatively thin and weak.

Specific Progressions

The progression of freeze-up described below is that which may be expected when the progression of break-up advances as outlined above.

Nansen Sound and Eureka Sound

Young ice begins to form on the southern portions of Nansen Sound during the first weeks in September. By mid-September the area supports a complete cover but some ice movement is still possible. By the end of September the southern part of Nansen Sound is solidly covered with young ice and very little further movement is likely to occur. Also by the end of September most of Eureka Sound with the exception of the channels on either side of Stor

Island is completely covered with young ice but final consolidation does not occur until the first week in October.

Secondary Channels

By the beginning of October young ice forms have begun to appear in all the areas of the Queen Elizabeth Islands which were ice-free during the summer season. As young ice forms, the movement in the areas north of Eglinton Island, Byam Martin Island and Penny Strait is considerably reduced. These areas as well as those to the north of them will become completely consolidated by mid-October.

Norwegian Bay and Belcher Channel and the Western Channels

Norwegian Bay and Belcher Channel support a moving ice cover up until the latter part of October. By this time only the central portions of Belcher Channel and that part of Norwegian Bay between Hell Gate and the southern part of Graham Island remain in motion. These areas likely become consolidated after the first week in November. In addition, Crozier Channel, Kellett Strait, Byam Channel, Austin Channel and McDougall Sound have all consolidated by the first week in November if not earlier.

Jones Sound

Jones Sound exhibits a freeze-up pattern that is almost the reverse of its break-up pattern. By the beginning of November the central portions of this Sound are likely to be solidly covered with young ice while the eastern half and a small part of the western portion remain in motion. Probably the remainder of Jones Sound consolidates during the latter part of November. At this time open water still exists in Hell Gate and Cardigan Strait at the western entrance to the sound and a similar condition exists on Lady Ann Strait at the eastern end of Jones Sound.

Viscount Melville Sound

The general progression of freeze-up on Parry Channel proceeds to the east and west from a central area in Viscount Melville Sound. The movement in the central portions of this sound is restricted by the latter part of October and probably consolidation is the rule by the middle part of November. The ice cover on the western part of the sound and the eastern half of M'Clure Strait will probably consolidate at the same time or shortly after mid-November.

The freeze-up patterns for the above areas are relatively clear cut and straight forward. However the sequence of freeze-up becomes increasingly difficult to forecast as the remaining channels are considered. From the least difficult to the most difficult to forecast, these channels are western M'Clure Strait, Barrow Strait, Penny Strait, Queens Channel, Wellington Channel and finally Lancaster Sound.

M'Clure Strait

The freeze-up on the western portion of M'Clure

Strait occurs between November and the end of February. The latter date is suggested on the basis of the drift of an ice island called 'WH-1' (Fig. 7). This ice island drifted into the western portion of the strait during the first months of 1967 where it was subsequently located in March 1967. In addition 'Station Charlie' probably entered M'Clure Strait in the late fall of 1963. Admittedly this evidence is rather scanty but it does suggest that the western part of M'Clure Strait remains in motion until the first months of the new year.

Barrow Strait

The date of final freeze-up on Barrow Strait can only be guessed. It seems likely that movement on the western half of the strait will cease near the middle part of November. The eastern portion (east of the Meridian through Resolute) may remain in motion till the end of November and it is possible that during some winters the ice in this area will remain in motion for the entire year. There are a number of indirect sources which support this assumption. In 1850 De Haven's ship drifted through Barrow Strait at the end of November (Kane, 1854). Reports from residents at Resolute suggest a water sky exists in the area during some winters and at least one of the Eskimo hunters at Resolute does not like to hunt in the area during the winter because the ice might drift away with him. This evidence plus the fact that the eastern portion of the strait can be ice-free in the early spring (Lindsay, 1964), suggests that consolidation may not occur during some seasons or if it does, it is during the first three months of the new year.

Wellington Channel

The average date for final freeze-up on Wellington Channel cannot be definitely stated. During November 1850 De Haven drifted up and down the channel until the end of the month. It is probable that the ice cover on this channel becomes consolidated by the middle of December. However, there is very little evidence to support this statement.

Queens Channel and Penny Strait

A similar situation exists when an attempt is made to suggest dates for consolidation of the ice cover on Queens Channel and Penny Strait. As suggested above it is likely that a polynya exists throughout the winter on the eastern part of Queens Channel. Also an ice free area may exist in the centre of Penny Strait until February when it freezes over. Although there is no proof, it is possible that the sea ice consolidates around these areas of open water by late November and continues to encroach on the so formed polynya until a consolidated cover occurs or until the ice begins to feel the effect of the approaching summer.

Lancaster Sound

It is almost certain that in some years the sea ice cover on Lancaster Sound remains in motion throughout the entire winter. The part of this sound to the west of a meridian through the northeastern tip of Somerset Island probably maintains an ice cover similar to that on eastern Barrow Strait. The assumption that the portion of the sound to the east of this meridian remains in motion is based on rather indirect evidence. However if all the pieces of evidence are considered the assumption is tenable. The fact that De Haven drifted in Lancaster Sound all through December is evidence for the fact that this area is one of the last to freeze-up. The Eskimos from Admiralty Inlet area do not cross to Devon Island during the winter because the ice is 'bad'. Bad ice to an Eskimo is that type which breaks up under him or drifts away with him. Moreover, early spring reconnaissance flights have shown that the area can be entirely ice-free in March and April. If Lancaster Sound does support a solid cover it probably occurs on the western half for a brief period during the months of April, May or early June.

The writer is aware that many of the statements regarding the progression of freeze-up suggested in the above paragraphs are not heavily supported by evidence. The required evidence will probably become available within the next few years from Meteorological Branch or other mid-winter reconnaissance flights. If this type of information is not collected during those flights, it will probably become available from the more sophisticated sensing systems which will likely be employed in polar orbiting satellites. Probably within the next two or three years the information collected by these satellites will be able to replace that collected during the airborne sea-ice reconnaissance flights presently conducted over the Canadian Arctic Archipelago.

CHAPTER 4

"MASS BALANCE" OF SEA ICE IN THE QUEEN ELIZABETH ISLANDS

Introduction

The mass balance of certain glaciers has been studied for a number of decades but it is only recently that research work relating to the mass balance of sea ice has been started. These studies have dealt mainly with the sea ice cover on the Arctic Ocean and the results indicate that minor increases in the mean annual air temperature would be sufficient to melt all the ice within a few years (Fletcher, 1966). If the Arctic Ocean does become ice free major and world-wide climatic changes would occur. Presently no definite conclusions concerning the fate of the sea ice on the Arctic Ocean have been given because of the lack of detailed mass balance measurements.

A mass balance study of the sea ice cover in the straits and channels of the Queen Elizabeth Islands should be more accurate than a similar study conducted on the Arctic Ocean because there is more detailed data available relating to the concentration and the distribution of various types of ice. However in both areas very few thickness measurements have been made and subsequent volume calculations are not much more than "educated guesses". As a result of the lack of thickness information the "mass balance" pilot study described below is based entirely on areal data.

In order to present this type of "mass balance" study it is necessary to have a knowledge of the amount of ice which may drift from one area to another. This information will be summarized in the following text. Then the general "mass balance" during three types of ablation seasons will be compared and a specific study of the sea ice "mass balance" during an 'average' ice year will be described and analysed.

Drift Patterns

General

Generally the sea ice in the study area moves from the north and west to the south and east. The drifts are controlled mainly by the winds but currents are effective in some areas. General wind patterns may be deduced from the surface weather charts but very little is known about the currents except that they are assumed to be weak in most of the channels (Collin, 1962).

The following descriptions are based on historic and recent drift data. In addition drift patterns have been inferred from the distribution and movement of ice islands, icebergs and specific ice-floes found in the study area.

Historic Drifts

Although a number of vessels have drifted with the ice in the study area for various lengths of time only two of the longer drifts will be described. Both of these historic drifts indicate the west to east movement in

Parry Channel.

The U.S.S. ships 'Advance' and 'Rescue' commanded by Captain De Haven were caught in the young ice near the south eastern tip of Cornwallis Island in September 1850 (Kane, 1854). By the end of the month the wind had driven both vessels to the northern part of Wellington Channel. From here the ships drifted south and reached Lancaster Sound by November. By the end of the year they had drifted to the eastern entrance of the sound.

In May 1854 Captain Belcher, who commanded a number of ships attempting to rescue Sir John Franklin ordered Captain Henry Kellett to abandon his ship (McDougall, 1857). The H.M.S. 'Resolute' was abandoned just south of Cape Cockburn on Bathurst Island. After having drifted eastward through Barrow Strait and Lancaster Sound the ship was recovered some 16 months later in Davis Strait along the eastern coast of Baffin Island near the entrance to Cumberland Sound.

Recent Drifts

The known and deduced movements of ice islands, icebergs and ice-floes helps to augment the relatively meager supply of information on drifts available for the study area. It is believed that most of the ice islands and ice island fragments found in the study area originated from the Ward Hunt Ice Shelf and entered the Archipelago through one of its northern channels.

There are usually a few small icebergs drifting in the waters of the study area. The scarcity of icebergs stems from the fact that there are relatively few tidewater glaciers entering the waters of the study area.

Ice-floes are ubiquitous in the study area and it is impossible to identify and trace the drift of a specific floe unless it has a characteristic mark on its surface. The drift of two identifiable floes will be discussed below.

Ice Islands

Ice islands and ice island fragments are found in the majority of the channels in the study area. The distribution of these features gives more meaningful drift data than that provided by icebergs because the origin of ice island is known and because they all enter the Archipelago through one of the northern channels. Usually they enter through Peary Channel or Prince Gustaf Adolf Sea although a few may come through Nansen Sound, Sverdrup Channel, Ballantyne Strait or possibly M'Clure Strait.

As a result of this rather selective system of entering the Archipelago no ice islands are found in Hazen Strait, Hecla and Griper Bay, Fitzwilliam Strait or Crozier Channel and Kellett Strait. Usually M'Clure Strait is free of ice islands but WH-1 did enter the westernmost part of this area early in 1967.

Some basic drift information was obtained by observing the movements of an ice island called T-1. This island drifted into Prince Gustaf Adolf Sea and was located by the P.C.S.P. some 60 km. north of Lougheed Island in September 1959. From here it drifted along the eastern coast of Lougheed Island, through Desbarats Strait, Byam Martin Channel and into Viscount Melville Sound. T-1 drifted west to the meridian through Winter Harbour and then moved eastward in the sound until it began to drift south through M'Clintock Channel. The movements of other ice islands in the same area have indicated a similar drift pattern (Black, 1965).

Icebergs

There are a number of small icebergs distributed in the study area. Up to the present time no specific drift information has been obtained from tracing the drift of a specific iceberg. However it is possible to infer the drift of these features by noting their position and estimating their place of origin. In the following description of the drifts in specific areas the presence or absence of icebergs will be used to help support the observations given.

Ice-Floes

The drift of two specific ice-floes, one carrying an abandoned helicopter and the second called Station Charlie, indicates the general drift patterns in two separate parts of the study area.

During the summer, 1963, a helicopter was abandoned on a polar ice-floe in Prince Gustaf Adolf Sea mid-way between Isachsen and the northern part of Borden Island. This floe began to move south around August 20 and had reached the middle portion of Byam Martin Channel before freeze-up stopped the ice from moving in 1963.

Station Charlie sometimes called ALPHA II was the second U.S. ice-floe station set out on the Arctic Ocean. It was set up on a polar ice-floe approximately 460 km. NNW of Point Barrow on April 29, 1959. After a brief drift the station was abandoned on January 7, 1960 at 76°55'N, 169°04'W because of hazardous ice conditions. Russian observers claimed that Station Charlie was located at 79°N, 177°W in April 1960 and at 83°N, 155°W in April 1961. The R.C.A.F. located the remains of the station at 82°28'N, 130°00'W in May 1962. The floe was not seen again until June 22, 1964 when the P.C.S.P. located it in M'Clure Strait at 74°39'N, 121°35'W or 10 miles north of Cape Wrottesley on Banks Island.

Although the P.C.S.P. did not locate Station Charlie during 1963 it is likely that it entered M'Clure Strait in the fall of that year. Station Charlie was located one more time during the summer of 1964 but it has not been sighted since although pieces of ice similar to those accompanying the station have been found further east in M'Clure Strait as well as along the western coast of Banks Island.

Movements in Specific Areas

The movements unique to this strait are probably the least well known of any in the study area. Even though Station Charlie moved into the western part of the strait for a few months little information was gained concerning the overall drift patterns. Similarly the ice island WH-1 moved into the strait early in 1967 but little drift information resulted because the island remained almost stationary close to the north coast of Banks Island for the duration of the 1967 observation period.

The winds seem to be the main controlling factor of ice drift or movement on M'Clure Strait. In some years the strait becomes relatively ice-free at the end of the ablation season only to be filled up with polar ice driven in by westerly winds. In other years practically no polar ice penetrates more than a few miles into the strait.

Crozier Channel, Kellett Strait and Fitzwilliam Strait

The straits separating Prince Patrick Island from Melville Island show a weak southerly drift. When the ice cover in these areas shatters the floes move south into M'Clure Strait. The weak surface drift in these areas is shown by the fact that a moderate southerly wind lasting a few hours will reverse the drift pattern and send the floes against the water movement.

Prince Gustaf Adolf Sea and Byam Martin Channel

From the drift of T-1 and the ice island fragments distributed along the western coast of Ellef Ringnes Island, it is assumed that a southerly ice drift is the norm for Prince Gustaf Adolf Sea. Since ice island fragments can be located on either side of Lougheed Island the southerly drift extends to Byam Martin Channel and and proceeds through Austin and Byam Channel into Viscount Melville Sound. Although T-1 drifted westward through Desbarats Strait before turning south this drift is considered to have been a result of the winds. Indeed all the movements in this area are likely to be wind induced because no surface currents have been described. There are a number of fragments of ice islands strung out along the eastern coast of Melville Island in Byam Martin Channel and Byam Channel. Few ice islands exist along the eastern side of Byam Martin Channel but both the eastern and western coasts of Byam Martin Island have a number of grounded fragments. These fragments indicate that, if the ice concentration permits, the floes will drift south into Viscount Melville Sound on either side of Byam Martin Island.

Viscount Melville Sound

The ice island fragments on Viscount Melville Sound are concentrated in specific areas. The northern portion of the sound is one of these areas and particularly in the region previously described as the Parry strip. A number of fragments are usually found between Cape Cockburn and Byam Martin Island and this string extends along the southern coast of Byam Martin Island and across the southern entrance of Byam Channel to the southeastern tip of Melville Island.

From this tip numerous fragments of ice islands may be located a few miles from the southern shore of Melville Island all the way to the latitude of Winter Harbour. The distribution of these fragments is not a unique occurrence because Lieutenant W. E. Parry (Parry, 1821) noted similar objects in 1819 and so did Captain Bernier almost 100 years later (Bernier, 1910). These masses were of very great assistance to Parry as his ships could navigate between the fragment and the shore thus allowing the fragment to bear the brunt of the floes which otherwise would have cracked his ship. Lieutenant Parry was very careful to note that one must not jump to conclusions concerning the direction of the drift in the Parry strip area because he believed that the wind had a considerable influence. However Captain Bernier believed that the general drift in Viscount

Melville Sound was easterly especially in the area south of Dundas Peninsula. This may be the case for drifting ice in the western part of Viscount Melville Sound but the distribution of ice islands along the northern portion of the sound as far as the latitude of Winter Harbour and the drift of T-1 indicates that there is a westerly drift from the vicinity of Cape Cockburn on Bathurst Island as far as Winter Harbour. It might be stated here that it is assumed that no ice islands reach Winter Harbour from the west because up until the present time no ice islands or ice island fragments have been located in eastern M'Clure Strait. After an ice island reaches the area to the south of Winter Harbour there is a question as to whether it changes its course like T-1 and drifts south and then east or drifts south and then west. Although T-1 drifted east it appears that at least two fragments are tending to drift to the west from the center of Viscount Melville Sound. These fragments were located in the late fall of 1965 and again before break-up began in the following season. During the freeze-up period they moved from the western portion of Viscount Melville Sound into the eastern portion of M'Clure Strait.

There are very few if any ice island fragments in southern portion of Viscount Melville Sound. A few fragments are strung out from east to west in the center of the sound mid-way between Stefansson Island and Byam Martin Island.

To summarize the general statements made above it appears that the ice in Viscount Melville Sound tends to move to the west in the northern and western portions of the sound. However, from the distribution of ice island fragments it appears likely that ice in the central and eastern portions drifts southeast from the area south of Winter Harbour across the entrance to M'Clintock Channel and into the southern portion of Barrow Strait. It is likely that the winds are the main causes of drift in this area.

M'Clintock Channel

The distribution of ice island fragments in M'Clintock Channel indicates that the overall movement of sea ice proceeds in a southerly direction. Although there are a few fragments in the central portion of the channel the majority are located along or close to the eastern coast of Victoria Island. While T-1 remains relatively stationary at 71°17'N, 104°W the fragments pass it by and continue to drift through Victoria Strait. Once a fragment has passed through this strait it will soon ablate and disappear.

Northern Channels

For an ice island fragment to enter one of the northern channels of the Queen Elizabeth Islands it must be present at the northern entrance to these channels when they begin to break-up and move. These channels do not break-up every year. For example no polar ice or ice island fragments were allowed to enter the study area from the late fall of 1963 up until the summer of 1968 because the northern channels such as Nansen Sound, Sverdrup Channel, Peary Channel, Prince Gustaf Adolf Sea or Ballantyne Strait did not break up. There was a large southerly movement of polar ice through these channels in 1961 and 1962. At that time many ice islands were swept into the Archipelago. The fragments first to enter the Archipelago drifted into the more southern areas while the last fragments to enter have been trapped in the same position for at least four years. There are a few chunks in the northern central part of Peary Channel and in the lee of Meighen Island while the middle and southern parts are almost free of ice islands. Hassel Sound, like Sverdrup Channel, has a few fragments trapped in its ice cover but it is likely that most of the fragments drifted out of these areas during the 1963 break-up season. Massey Sound hosts a number of fragments in its northern section and like the fragments in Hassel Sound they will move to the south when the break-up season allows.

The general trend of the surface drift in Nansen

Sound and Eureka Sound is from north to south. This observation is confirmed by surface current measurements (Collin, 1962). The drift of a number of icebergs also substantiates this observation.

Norwegian Bay

It might be assumed that fragments entering Norwegian Bay from Massey Sound would drift directly south between Graham Island and Cornwall Island. In reality the fragments appear to move along the northern part of Norwegian Bay before moving south betweenGraham Island and the southwestern part of Ellesmere Island.

Unnamed Region North of Penny Strait

Ice island fragments entering the large unnamed body of water north of Penny Strait from either Maclean or Hassel Sound to move toward the northern entrance of Penny Strait. From Hassel Sound the ice islands appear to drift almost directly south to Penny Strait. No fragments have been recorded in Belcher Channel proper but there are a number of fragments (at least two dozen) to the north of Crescent Island. It might seem that these fragments would enter Belcher Channel as they are closer to it but they will probably move south through Penny Strait as numerous others have done.

Hell Gate and Cardigan Strait

If a fragment manages to drift across Norwegian Bay to the entrance to Hell Gate or Cardigan Strait it has a good chance of moving into Jones Sound provided that the fragment is small enough to pass through these narrow channels. During the 1965 break-up season a fairly large fragment was observed in Norwegian Bay between Hell Gate and Graham Island. By mid-September this island had moved across the southern part of Norwegian Bay and at least half way through Hell Gate. See Figure 6. By the spring of 1966 it had moved into Jones Sound where it remained trapped in the consolidated cover just east of the entrance to Cardigan Strait. During its trip through Hell Gate the ice island maintained its shape. However it was severely reduced in thickness by the currents during its trip through Hell Gate and during its stay at the mouth of Cardigan Strait. As a result of this ablation the island was in an advanced state of decay early in the 1966 season and subsequently disappeared before its movements on Jones Sound could be traced. Although a certain amount of sea ice passes through Hell Gate and Cardigan Strait during the year it is the exception rather than the rule to find ice islands in Jones Sound which have passed through the narrow channels at its western end.

Penny Strait and Queens Channel

Once an ice island fragment or an ice floe enters the northern part of Penny Strait it drifts very rapidly through the remainder of the strait and moves into the southern portion of Queens Channel. A few fragments drift along the eastern coast of Bathurst Island but they do not remain in the south western part of Queens Channel. Very few fragments move into McDougall Sound and few escape through the northern channels leading from Queens Channel into Wellington Channel. The majority of the fragments entering Queens Channel accumulate in large numbers just west of the entrance to Maury Channel. This channel is the main exit for fragments from Queens Channel.

Wellington Channel

Once an ice island has passed through Maury Channel it drifts south in Wellington Channel along the eastern coast of Cornwallis Island. A few fragments and bergs have been located along the northeastern coast of Wellington Channel but these pieces were probably moved by a northerly drift along the eastern side of the channel.

Barrow Strait

As the fragments move out of Wellington Channel into Barrow Strait they drift around the southeast corner of Cornwallis Island. Here they may be joined by small icebergs. Both the fragments and the bergs continue moving west along the southern coast of Cornwallis Island. Usually two or three of these ice masses are present off Resolute Bay.

During attempts to mark one of these fragments with concentrated sea marker dye a rock sample was recovered. This sample was reported to have originated from the northern coast of Ellesmere Island in the vicinity of Ward Hunt Island (R. Christie, personal communication).

The ice island fragments continue moving west in Barrow Strait between Griffith Island and Cornwallis Island and usually a number of them become grounded in the bays along the southwestern coast of Cornwallis Island. From the southwestern tip of Cornwallis to the southeast part of Bathurst Island the fragments seem to move in a westerly direction. As was the case with Cornwallis Island a number of fragments are located in Barrow Strait along the southern coast of Bathurst Island. These fragments seem to concentrate in the vicinity of Cape Cockburn. From here the pieces of ice islands may continue to drift westward when the conditions are appropriate or begin to drift to the south. The H.M.S. 'Resolute' referred to earlier probably followed the latter course.

Fragments which drift south in the western portion of Barrow Strait begin to drift eastward when they reach the area north of Prince of Wales Island. They continue drifting eastward between Russell and Lowther Islands. Once a fragment has passed through the channel between Russell and Lowther Island it will probably move across the northern entrance to Peel Sound but occasionally some fragments move south into Peel Channel. By the time the smaller ice island fragments reach that portion of Barrow Strait north of Sommerset Island they have been considerably ablated and only a few of them move eastward out of Barrow Strait.

Lancaster Sound

As indicated by the drifts of the U.S.S. 'Advance' and 'Rescue' and the H.M.S. 'Resolute' there is a general easterly movement through Lancaster Sound. However the appearance of icebergs along the southern coast of Devon Island indicates a westerly drift in this area.

"Mass Balance"

Area Investigated

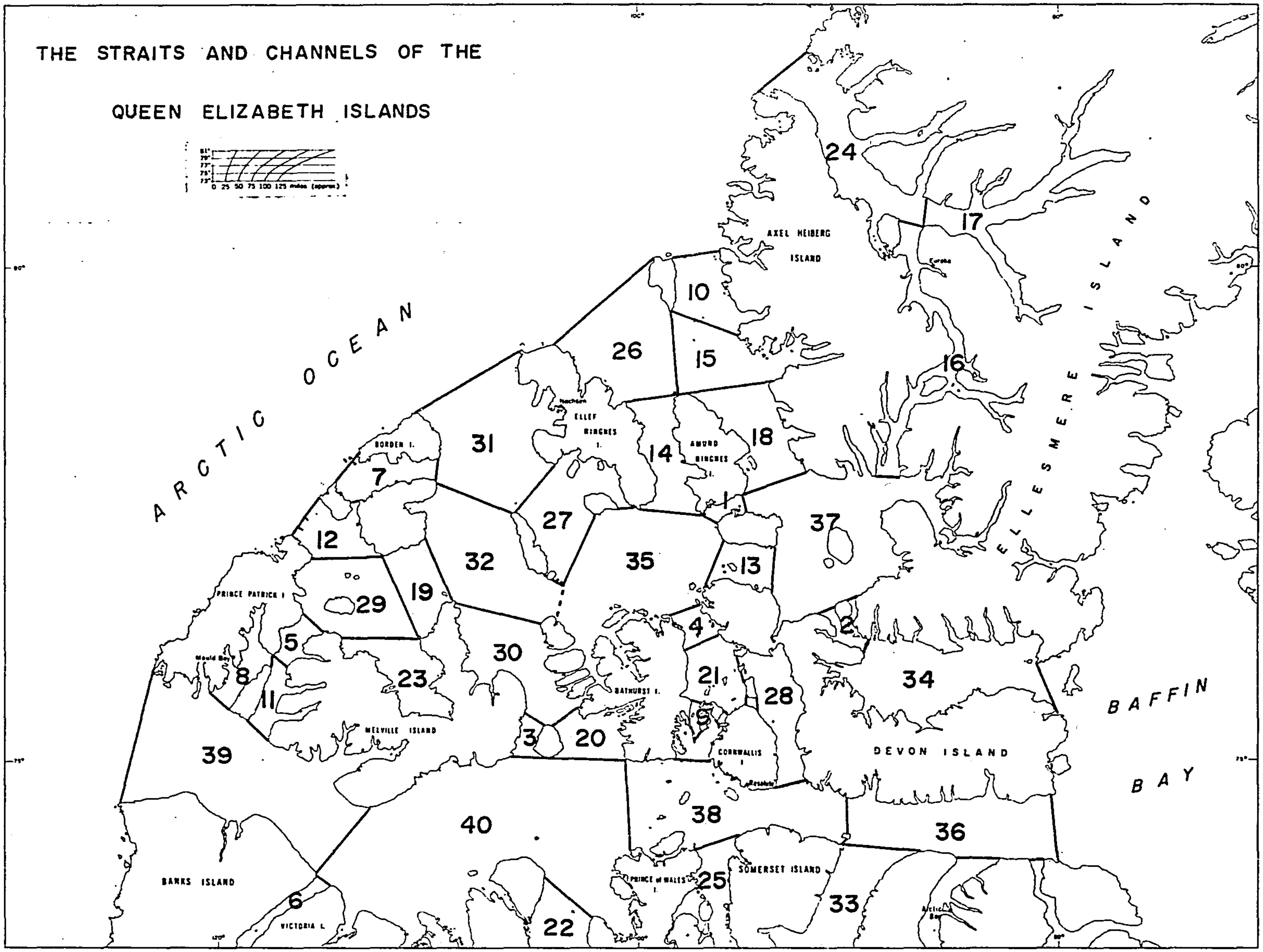
In order to calculate the area of sea ice in the study area it was necessary to break the region down into a number of subsections. This was accomplished by using the channels and straits as subdivisions. The boundaries of these bodies of water have been described in the "Pilot of Arctic Canada". These boundaries were plotted on a 1:4,000,000 Lambert Conical Projection map with standard parallels at 64° and 68°. Figure 15 shows the areas considered and Table 3 gives the key for the numbers on the figure as well as some of the basic relationships among the areas. The area of each channel was derived by counting the squares on gridded paper and then converting these areas to square kilometers. The accuracy of this method may vary from that of the average of many planimeter readings for each area. However it was felt that this type of accuracy was not justifiable because the areas were measured from a relatively small scale map and the resulting figures were to be rounded off the nearest 10.

Most of the subsections chosen represent one specific body of water but some of the smaller areas were grouped together. The asterisks after certain entries in Table 3 indicate partial areas, unnamed areas, and areas which were grouped together. For example area number nine includes Crozier Strait, Pullen Strait, and McDougall Sound. Also, Maury Channel has been grouped with Queens Channel to form the area numbered 21. Together Hell Gate and Cardigan Strait form area number two. The areas numbered 6,22,25,33 and 40 represent only a part of each channel. The unnamed areas are numbered 15,29,32 and 35. The boundary between areas 32 and 35 has been arbitrarily chosen because Desbarats Strait was not described in the "Pilot of Arctic Canada".

Comparative "Mass Balance" 1962, 1964, and 1966

Considerable fluctuations in the areal extend of the ice cover on the straits and channels of the Queen Elizabeth Islands may occur from year to year. Evidence of these fluctuations are presented in Table 4.

Figure 15



THE STRAITS AND CHANNELS OF THE QUEEN ELIZABETH ISLANDS

TABLE 3

AREAS SURVEYED

AREA	NAME	MILES^2	KILOMETERS^2	% OF TOTAL AREA
1.	Hendriksen Strait	320	830	.2
2.	Hell Gate*	600	1550	.4
3.	Byam Channel	640	1650	.4
4.	Penny Strait	680	1750	.4
5.	Fitzwilliam Strait	720	1860	.4
6.	Prince of Wales Strait*	880	2280	.5
7.	Wilkins Strait	1000	2580	.6
8.	Crozier Channel	1040	2680	.6
9.	McDougall Sound*	1080	2790	.6
10.	Sverdrup Channel	1240	3200	.7
11.	Kellett Strait	1280	3300	.8
12.	Ballantyne Strait	1280	3300	.8
13.	Belcher Channel	1320	3400	.8
14.	Hassel Sound	1630	4230	.9
15.	Unnamed area*	1880	4850	1.1
16.	Eureka Sound	1880	4850	1.1
17.	Greely Fiord system	2030	5260	1.2
18.	Massey Sound	2030	5260	1.2
19.	Hazen Strait	2110	5470	1.2
20.	Austin Channel	2190	5680	1.3
21.	Queens Channel*	2230	5780	1.3
22.	M'Clintock Channel*	2750	7120	1.6
23.	Hecla and Griper Bay	2830	7330	1.6
24.	Nansen Sound	2870	7430	1.7
25.	Peel Sound*	2870	7430	1.7
26.	Peary Channel	3070	7960	1.8
27.	Maclean Strait	3150	8160	1.8
28.	Wellington Channel	3150	8160	1.8
29.	Unnamed area*	4070	10530	2.4
30.	Byam Martin Channel	4460	11560	2.6
31.	Prince Gustaf Adolf Sea	5220	13530	3.0
32.	Unnamed area*	5780	14970	3.3
33.	Prince Regent Inlet*	8090	20960	4.7
34.	Jones Sound	8250	21370	4.8
35.	Unnamed area*	8730	22610	5.0
36.	Lancaster Sound	9330	24160	5.4
37.	Norwegian Bay	9680	25090	5.6
38.	Barrow Strait	9960	25810	5.8
39.	M'Clure Strait	17340	44910	10.0
40.	Viscount Melville Sound	32440	84040	18.9
	TOTALS	172057	445741	100.0

TABLE 4

SUMMARY: ✯ AREA OF ICE AT THE END OF EACH SUMMER MONTH 1962, 1964, 1966.

	June	%	July	%	Aug.	%	Sept.	%
1962	386840	87	208600	48	141490	32	290490	65
1964	399380	90	378480	85	321570	72	352600	79
1966	410860	92	356650	80	299540	67	365080	82

✯ Summarized from Appendix III, Tables, i, ii and iii.

The values in per cent given above and in the following tables represent the ratio of existing ice cover to the total possible area which could be ice covered.

The differences between the 1966 season and that of 1964 as shown in Table 4 are not very large but the variation between 1962 and 1964 certainly shows that the former was a 'good' ice year while the latter was a 'poor' year.

If it were possible to calculate the volume instead of the area the data would be of more use. Hopefully sea ice thickness data will soon be recorded during airborne ice reconnaissance flights. Until that time basic studies such as this one will be limited to the consideration of areas rather than volumes. The export, import and ablation values presented below are limited in the same way. However, it is hoped that the data given here will be useful in laying the ground work for future and more detailed studies of the "mass balance" of sea ice in the Queen Elizabeth Islands.

"Mass Balance 1966"

The 1966 summer season was selected for this "mass balance" study because it represents patterns of ice distribution and movement which appear in the Queen Elizabeth Islands during an 'average' ice year.

It is difficult to base the measurements of import, export, and ablation on specific facts because the knowledge of the rates and patterns of movement in the area is limited. The following description of the 1966 "mass balance" is based on the foregoing outline of the various drift patterns and the distribution of ice in 1966 plus a considerable amount of subjective judgement.

Methods Uded

A number of tables will be given to help describe the general "mass balance" of ice the various parts of the study area for the four summer months in 1966. The basic data is presented by the last four tables (iv to vii) in Appendix III. This information is summarized in the text by tables five and six.

Tables iv to vii give a very detailed breakdown of the import, export, ablation or formation of ice by area. A number of steps were taken to determine the various areas represented in the tables. The main steps are outlined below.

The total area of open water present at the end of the month (column four) in any one of the forty areas studied was determined by subtracting the total area of ice (column three) from the total area of the water body given in column one. To calculate the total expansion (+) or contraction (-) of open water (column five) in any specific area during the month the amount of open water at the end of the previous month (column two) was subtracted from column four or the area of open water at the end of the present month. During this procedure it was necessary to keep track of the sign (+) or (-) in order to show whether or not the area of open water had expanded or contracted during the month.

It was more difficult to calculate the figures in the remaining columns and a considerable amount of subjective judgement and interpolation was necessary. Generally the area of ice ablated (column eight) plus the area of ice exported (column seven) minus column six or the amount of ice imported results in the total expansion or contration shown in column five.

Possible Sources of Error

In most cases the area of sea ice either exported was negligible (nil) and the amonnt ablated could be readily calculated. However in areas where ice was simultaneously imported, exported, ablated or formed the accuracy of the figures in columns six, seven and eight may be considerably below 70%.

Additional errors result from the fact that the areas were calculated on the basis of one month intervals. If each area could be surveyed every two days or once a week the movements, formation or ablation of the ice cover could be calculated more accurately. Another type of error that will be quite obvious to the reader stems from the nil statements given in column eight. It is impossible to believe that no ablation occurs in these areas during the summer months. The nil term is used in column eight to express the fact that the area of ice did not change due to ablation but this must not be construed to mean that the volume of the ice cover remained the same.

Although errors may occur in some of the data presented in the tables there are a certain periods when the results are quite accurate. For example Hendriksen Strait was solidly covered during June. By the end of July at least 580 square kilometers of open water existed in the central part of this strait. At that time the ice at either end of the strait remained solid and it can be assumed that 580 square kilometers of sea ice ablated because no ice could be exported or imported. On the other hand areas like Viscount Melville Sound may import sea ice from M'Clure Strait, Austin Channel, Byam Channel, Barrow Strait, or M'Clintock Channel. In addition it may be able to export sea ice into a few or all of these areas depending on the prevailing wind. Once the cover on all these channels has shattered and is in motion it is extremely difficult to determine whether Viscount Melville Sound exports or imports sea ice from M'Clure Strait, M'Clintock Channel or Barrow Strait.

General Trends

Even though the accuracy of the figures showing the area of sea ice ablated, exported or imported in specific areas may vary considerably from the real situation the results presented in the following table show that the over all trend is what one might expect. For example

TABLE 5

SUMMARY:[*] AREA (km^2) EXPORTED IMPORTED ABLATED OR FORMED - SUMMER 1966

	Exported	Imported	Ablated	Formed
June	4640	4480	5590	-
July	12970	13850	49030	-
August	21190	22460	59330	-
September	9840	8840	-	78100
	48640	49630	113950	78100

Leaf 123 omitted in page numbering.

* Areas are the sums of columns six, seven and eight, Appendix III, Tables iv, v, vi and vii.
The figures for export and import given in this table show that there is relatively little movement in June with increasing movement in July and maximum movement in August followed by a reduction in September. The ablation begins in June but is concentrated in July and August and little occurs in September. In addition, the figures showing formation conform with the general trend because sea ice does not begin to form until September. It should be noted that the 78100 square kilometers of sea ice formed during September take in all types of young ice.

If, as suggested above, the ice conditions in the Queen Elizabeth Islands in during the summer of 1966 represent those of an average ice year then the figures in Table 6 represent the average areas of sea ice exported, imported, ablated and formed between June 1 and September 30 of that year. About 40% of the entries in this table are shown as Nil. About 70% of these nil readings are a result of areas like Wilkins Strait and ten others where no ice was imported or exported nor was the area reduced by ablation or increased by formation. The remaining 30% of the nil readings result from areas such as Massey Sound which did not import or ablate any ice during the season although some ice was exported.

In this table (6) the percentages indicate the total area of sea ice which was exported, imported, ablated or formed during the entire summer for each of the forty straits and channels. Although it is not shown in Table 6 it is certain that export, import and formation continue in some areas during October and even later in other areas. The information summarized in this table is the key for the following generalizations describing the main areas where sea ice may be exported, imported or ablated. Although the information given in Table 6 relates to the conditions in a specific year (1966) the description below will interpret the data to show the main areas of sea ice export, import or ablation during any type of ice year.

Area of Ice Exported

Theoretically every strait, channel or sound in the study area is capable of exporting some area of sea ice at different times of the year. However only the sea ice exported during the summer months of an average ice year is considered here. Within these limits certain areas export a considerable amount while other areas export practically none at all. It might be expected that Lancaster Sound and Jones Sound export the largest areas of sea ice. This idea is not borne out by the field investigations nor in the data presented in Table 6 (see area 34 and 36). Since these channels export very

TABLE 6

TOTAL AREA (km^2) EXPORTED, IMPORTED, ABLATED OR FORMED - SUMMER 1966

AREA	NAME	EXPORT	%	IMPORT	%	ABLATE	%	FORM	%
1.	Hendriksen Str.	Nil	Nil	530	64	780	94	170	20
2.	Hell Gate*	Nil	Nil	580	37	580	37	Nil	Nil
3.	Byam Channel	1790	108	200	12	60	4	1650	100
4.	Penny Strait	2910	166	1930	110	510	29	920	53
5.	Fitzwilliam Str.	1770	95	Nil	Nil	90	5	1860	100
6.	Prince of Wales Str.*	100	4	Nil	Nil	700	31	570	25
7.	Wilkins Strait	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
8.	Crozier Channel	1900	70	900	34	240	9	1240	46
9.	McDougall Sound	2140	77	Nil	Nil	650	23	2650	95
10.	Sverdrup Channel	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
11.	Kellet Strait	860	26	870	26	200	6	190	6
12.	Ballantyne Strait	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
13.	Belcher Channel	Nil	Nil	Nil	Nil	300	9	Nil	Nil
14.	Hassel Sound	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
15.	Unnamed Area*	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
16.	Eureka Sound	Nil	Nil	300	6	3460	71	3110	64
17.	Greely Fiord System	Nil	Nil	200	4	3350	64	3150	60
18.	Massey Sound	160	3	Nil	Nil	Nil	Nil	Nil	Nil
19.	Hazen Strait	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
20.	Austin Channel	5960	105	400	7	120	2	5110	90
21.	Queens Channel*	200	3	2910	50	6880	119	1850	32
22.	M'Clintock Channel*	1920	27	1500	21	1420	20	1130	19
23.	Hecal and Griper B.	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
24.	Nansen Sound	500	7	Nil	Nil	250	3	750	10
25.	Peel Sound*	1100	15	Nil	Nil	6330	85	6690	90
26.	Peary Channel	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
27.	Maclean Strait	200	2	Nil	Nil	Nil	Nil	200	2
28.	Wellington Channel	2420	30	200	2	5940	73	4960	61
29.	Unnamed Area*	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
30.	Byam Martin Channel	600	5	Nil	Nil	170	1	190	2
31.	Pr. Gustaf Adolf Sea	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
32.	Unnamed Area*	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
33.	Prince Regent Inlet*	11510	54	500	2	1710	8	2050	10
34.	Jones Sound	Nil	Nil	Nil	Nil	21270	99	Nil	Nil
35.	Unnamed Area*	2460	11	200	1	Nil	Nil	2260	10
36.	Lancaster Sound	Nil	Nil	11710	48	13740	57	2250	9
37.	Norwegian Bay	580	2	160	1	4340	17	12250	49
38.	Barrow Strait	1000	4	10360	40	31900	123	17630	68
39.	M'Clure Strait	860	2	8430	19	3660	8	2280	5
40.	Vis. Melville Sound	7700	9	7750	9	5300	6	2990	4
	TOTALS	48640		49630		113950		78100	

little sea ice into the seas surrounding the Archipelago and very little if any sea ice is exported from the northernmost channels into the Arctic Ocean there are only four other areas where ice may be exported from the study area. However the surface drift in Prince of Wales Strait precludes any export and the trends in Prince Regent Inlet seem to indicate that ice is exported from this inlet to Lancaster Sound rather than through Fury and Hecla Strait. The amount of ice exported fromthe study area through Peel Sound seems to be almost nil. There remains one main avenue into which large areas of sea ice may be exported. This avenue is M'Clintock Channel.

Within the area certain channels export a considerable amount of ice in relation to the total amount of sea ice available. For example, Byam Channel and Austin Channel each export more than 100% of their total area. However Penny Strait exports at least one and a half times its total area. These three channels with the addition of Fitzwilliam Strait are the main routes through which sea ice is exported from the more central parts of the study area because Hell Gate exports very little.

Although export occurs in the above mentioned and other channels (see Table 6) it is likely that the total area of sea ice exported from the study area during the four summer months of an 'average' ice year amounts to less than 3000 square kilometers. This is not very large when it is compared with the total possible area, 445,740 km^2, of ice which could be exported nor is it very large when it is compared with the total of 48,640 km^2 which moves from one channel to another within the study area during an average year.

Area of Ice Imported

There are a number of areas through which sea ice may be imported into the region. However during 1966 the most important areas for imports namely Nansen Sound, Sverdrup Channel, Peary Channel, Prince Gustaf Adolf Sea, and Ballantyne Strait did not break up. As a result no sea ice was imported into the study area through these channels. If Jones Sound or Lancaster Sound received any imports the total area was almost negligible. One area, M'Clure Strait, remains. Probably some sea ice was imported into this area from the Beaufort Sea, but it is unlikely that the total area exceeded 9,000 km^2 or approximately 20% of the total area of M'Clure Strait.

As was the case with the exports, certain straits and channels in the study area imported a greater amount than others. With the exception of M'Clure Strait, the main areas which received imports of sea ice were Lancaster Sound, Barrow Strait and Viscount Melville Sound. Each of these areas was augmented by approximately

10,000 km^2 of ice during the season. In addition, approximately 12,000 km^2 of ice were imported by Queens Channel, Penny Strait and slightly less than 1,500 km^2 by M'Clintock Channel.

Area of Ice Ablated

The approximate areas of ice imported into, 9,000 km^2, and exported from 3,000 km^2, the study area suggests that there would be a net gain of 6,000 km^2 of sea ice if there was no ablation or melting during the season. There was a considerable amount of ablation during the summer season of 1966. An area at least 18 times that of the net gain or approximately 114,000 km^2 (see Table 6) of sea ice were ablated from the waters of the straits and channels in the study area.

As stated earlier it is likely that all of the 40 straits and channels in the area lost some of their volume through ablation even though some of these areas are represented by Nil in Table 6. However this table shows the area, not the volume, of sea ice which was ablated. Although ablation reduced the area of sea ice in 65% of the channels by 113,950 km^2 there were seven main areas which accounted for 80% of the total area ablated. The greatest ablation occurred in Barrow Strait where 31900 km^2 or 30% of the total ice cover ablated in the study area disappeared. Second was Jones Sound which ablated 18% or 21,270 km^2. The remaining areas were Lancaster Sound 12%, Queens Channel 6%, Peel and Wellington Channels with 5% each and Viscount Melville Sound which ablated 4% of the total area of sea ice ablated in the study area. All these channels with the exception of Jones Sound and Lancaster Sound exported some area of sea ice. This would suggest that the maximum area they could ablate is shown in the ablation column of Table 6. The fact that Jones and Lancaster Sound did not export large amounts suggests that they have the potential to ablate a greater area of sea ice than they did in 1966. The maximum area that either of these two sounds may ablate remains unknown.

Summary

The various summaries given in this chapter show the amount of sea ice which is likely to exist in a particular part of the Canadian Arctic Archipelago during 'good', 'bad' and 'average' ice years. One year, 1966, was chosen to represent the normal condition and the amounts of sea ice exported, imported ablated and formed in the study area were considered for each of four summer months in that year. The methods used to determine the area of sea ice were extremely crude and unsophisticated but this system was chosen because the number of observations were few and did not merit a detailed analysis. As a result much of the data presented was highly generalized and some of it was interpolated on the basis of three summers during which the ice conditions in this area were observed.

It is quite likely that a more detailed analysis of the same basic data would result in figures somewhat different from those presented in the tables. Even though this situation might exist the basic trends will be the same. No attempt was made to balance the various figures but the overall results do correlate with the movement patterns and the usual ice distribution patterns which exist in the study area during each ablation season.

This chapter represents the first step or pilot study in a series of studies which will be gradually developed to provide a more detailed description of the "mass balance" of sea ice in the Canadian Arctic. Although only four months of one summer season were outlined above the next effort will include the "mass balance" for all the summers during which sea ice data has been recorded in the study area. While these investigations are being conducted a concentrated effort will be made to develop some system that can be used to give the thickness of the ice which exists in the area.

If an acceptable system can be developed to give the thickness then the "mass balance" studies can be converted from the basic areal approach into the more meaningful volume approach. There are a number of methods which are presently available to guess at the thicknesses of the various types of sea ice. What is needed is something on which to base these guesses. A programme will likely be conducted in the summer of 1968 to accurately describe the variations in thickness as the ablation season progresses. This information will at least give some basis of guessing at the sea ice thicknesses in other parts of the study area. Of course the final solution to the thickness and thus the volume problem can only be resolved with the perfection of an airborne sensing device which records ice thickness. Although many attempts have been made to perfect such an instrument at the present none have been successful. Hopefully this gadget will be available within one or two years but until it is, the volume, which is possibly the most important part of sea ice mass balance studies will remain unknown.

Although this problem remains to be resolved there can be no doubt that some of the straits and channels of the study area play a larger part in importing, exporting and ablating sea ice than other areas. Lancaster Sound and Barrow Strait import the greatest area of sea ice. Prince Regent Inlet and Viscount Melville Sound export more square kilometers of sea ice than any of the other areas while Barrow Strait, Jones Sound and Lancaster Sound are the most important areas for the ablation of sea ice. The final and possibly most important observation of the sea ice "mass balance" in the study area during an average ice year is the relatively small area of ice which is exported. During the 1966 season more than 25% of the total ice cover was ablated within the area while less than 1% of the total cover was exported from the study area.

CHAPTER 5

CONCLUSION

General Synopsis

It would be repetitive at this stage to attempt to summarize the foregoing chapters as each chapter itself contained a summary of the procedures used to collect, map, and present the sea ice data. The type of operation, the various types of ice, the system used to record the data and the methods of cartographic representation were the basic factors described in the first two chapters. The next chapter presented the general patterns of break-up, freeze-up and movement of sea ice in the Queen Elizabeth Islands region. These three chapters formed the basis for the inferences and conclusions stated in chapter four which described the general "mass balance" of sea ice conditions in the region. The "mass balance" study was curtailed by the lack of ice thickness data. However the import, export and ablation was shown by means of area rather than volume. It appears that only a small area of sea ice is exported from the region during an average year and that only small quantities of sea ice are imported. The largest amounts of ice were ablated in Jones Sound, Lancaster Sound and Barrow Strait.

Sea ice information has been collected for a number of years. With this background of information future investigations must concentrate on specific factors which influence and control the conditions that have been previously described. Of course the regular ice surveys must be continued. There are a large number of specific studies which may be conducted from the geographical point of view but these studies would be much more meaningful if they could be tied in with associated studies in other disciplines. For example a detailed study of the mass balance of sea ice in the waters of the Canadian Arctic Archipelago would require the combined efforts of Glaciologists, Oceanographers, Meteorologists, Physicists and Geographers. If an interdisciplinary plan could be evolved with specific aims and tasks allocated for the group as well as individual investigators many of the unknown factors related to the mass balance of sea ice could be described in the detail which is necessary.

It is quite likely that the mass balance of certain glaciers may be related to the mass balance of sea ice in adjacent areas and vice versa. Oceanographic data have been collected in specific channels in the

Queen Elizabeth Islands. However many of the channels have not even been sounded let alone investigated for temperature profiles and currents. In addition, little data has been collected to describe the conditions which exist in, on, over and under the sea ice during the winter months. Although the physical properties of sea ice have been described in some detail and a considerable amount of geographical information relating to types and distributions has been described many factors require further investigation.

Recommendations For Future Investigations

More Objective Techniques

Aside from the need for interdisciplinary sea ice investigations there are a number of other studies which should be carried out to add to the general knowledge as well as to modify and perfect present techniques. The techniques of recording and presenting the data now in use could be modified so that more information could be collected in the same time. A system should be developed to record this basic data in a form which is easily converted into graphic patterns. For example, punched cards and computers have been used to print sea ice information on maps and possibly this system merits more investigation.

Remote Sensing

Before too much time is spent perfecting such a programme some method must be developed to reduce the relatively large amount of subjective judgement used to collect the original data. There are a few methods presently available which make it possible to record the data more objectively. Airborne infra-red photography can be used to show the different types of sea ice. The exposures resulting from this system show the thinner ice darker on the grey scale than the thicker portions. The draw back of course is that the photographs must be interpreted in order to reduce the data to map or tabular form. Radar can be used to show ice boundaries when visibility does not permit the observer to see the ice, in this case radar does not identify the type of ice.

Satellite photography helps reduce the subjective nature of sea ice surveys by presenting a real time picture of the ice conditions. However the interpretation of these photographs is subjective because at the present time the scale of the exposures relayed to the read-out stations does not allow specific types of ice or concentrations to be identified. Future satellites will include more sophisticated sensing devices but these satellites are seldom put in polar orbits until they have been used for some time in a more equatorial orbit. No matter how sophisticated the videcon sensing system of a polar orbiting satellite may be, the images of the sea ice distribution cannot be seen through a cloud layer nor can they be seen during the period of darkness which covers the arctic areas for a portion of the year.

Modifications and refinements to the remote sensing systems presently used will increase the objectiveness of sea ice studies but will not entirely eliminate subjective judgement. It is possible to envisage a completely objective system to record the sea ice distribution. This statement rests on the belief that a device will be invented to measure the thickness of sea ice through cloud and in darkness. This device may be carried in an airborne or orbiting object as long as the exact geographical coordinates of the aircraft or satellite are known. Both the thickness measurements and the position would be continuously recorded on magnetic tape or paper tape. These tapes could then be fed through a computer which would reduce the mass of data into a form suitable for a particular user. Continuous positioning systems such as DECCA have been set up in the Arctic and these systems have been adapted to present a continuous log of positions punched (in digital form) on paper tape. The main problem is centered around the present lack of any airborne device that will accurately record the thickness of sea ice above and below the water level. This device must be invented before any major break-through in sea ice reconnaissance techniques can be accomplished. Objectivity could be increased if airborne instruments are developed which could continuously record the temperature at various levels in the ice, the temperature of the air above and the water below the ice, as well as the radiation balance.

Since many of these instruments have not been perfected at the present time a considerable amount of subjectivity still remains with sea ice reconnaissance programmes. Admittedly the U.S. 'Bird's Eye' flights attempt to become more objective by counting the number of ridges, cracks and the concentration of ice during specific time intervals but still the observer uses some personal judgement and this judgement varies from observer to observer.

Subjective Investigations

There are certain relatively subjective investigations which must be carried out in the near future in order to lay the ground work to interpret the mass of objective data which will be collected in the future. Specific efforts should be made to describe in detail the topography of the upper and lower surface of the sea ice cover for the different types of ice. These investigations should be coupled with a macroscopic description of the evolution of pressure ridges and hummocks and the ablation at the upper and lower interfaces of the sea ice cover. Also, descriptions of the currents in the area as well as preliminary hypotheses relating to the various factors which cause the yearly fluctuations in the areal extent of the ice cover should be attempted.

Topography

A small scale or local study of the topography or relief of the upper and lower surfaces of the different types of sea ice would include the causes of the features, their seasonal fluctuations with the net result being a roughness key. This key could be used in conjunction with present and future systems of airborne sensing in order to produce a better evaluation of the roughness parameters that exist over and under different types of ice at different times of the year. This type of study would include the yearly fluctuations in thickness as well as the description of the formation of keel ice and the description and life history of underwater relief features in relation to those seen on the surface. Detailed topographic profiles approximately 50 meters long set up on floes carefully selected to represent the average conditions would provide the type of information required.

The description of the life history, including the formation, structure and decay of a pressure ridge, closely parallels the topographic study suggested above. Generally very little data is available pertaining to the displacement caused by pressure ridges and relatively little is known of the changes which take place inside the ridge after it forms. A pilot study to investigate this problem should consider at least one ridge formed from polar ice and one from winter ice. Of course it would be by chance that an observer was present during the formation of a ridge but investigations should be commenced very shortly after the ridge began to form. General topics to be considered would be the time dependent extent of the surface relief as well as similar measurements of the underwater relief. The effect of the ridge on the sea ice in the immediate vicinity should be noted as well as the structure and density of the interior part during formation, or shortly after and at different times during its lifetime in order give a chronologic and meaningful summary of the evolution of the ridge. Theoretically the same ridge should be studied after it has undergone an ablation season and is classed as a hummock.

In order to give a general yet realistic description of a pressure ridge from the time of its formation and through the hummock stage at least three years of periodic observations would be necessary. Aside from the basic difficulties inherent in measuring the various parameters, the three year time span would impose additional logistic, location and identification problems even if only two ridges were initially chosen for investigation. Of course one assumes that the ridges or hummock will not disappear due to ice movement or ablation during the period of investigation.

Ablation

To a certain degree the ablation of the surfaces of the ice sheet in contact with the atmosphere and with the water is related to the topography study and the investigation of the ablation of sea ice should be combined with the study of ridges and general topography. There have been a few attempts to measure the ablation from the upper surfaces of an ice sheet, but almost no efforts have been made to measure the ablation from the lower surface. For these reasons basic studies to measure surface and sub-surface ablation should be conducted in various latitudes in order to produce a general description of the trends.

The study of the formation, growth and decay of puddles is closely associated with the ablation investigation and might be included as a part of these studies. It is generally concluded that puddles begin to form from melted snow and once they have become established they remain in place even though all the surrounding snow has melted. A study of the evolution of puddles would consider these features at various latitudes and on various types of sea ice. Information should be gathered on the physical development of the puddle such as its depth, slope of its sides, the time and cause of its largest areal extent, the time of its greatest volume as well as the temperatures at various levels and the salinity changes throughout the ablation season. Since it is apparent that most of the water of the puddles drains from the ice surface via cracks, seal holes and by other means some effort should be made to describe the development of the area which may be drained by a specific sink.

Forecasting

Most of the proposed studies suggested above deal with the evolution of the ice cover but the basic ablation studies outlined would provide needed and easily collected information which could be used to forecast the type of ice year. It is certain that the weather causes the large fluctuations of the ice cover from year to year. Since it is not possible to accurately forecast the meteorological conditions that will exist over an area a year in advance it is almost impossible to forecast the types of ice year which will occur. However by studying the basic characteristics of the sea ice and the underlying water masses it may be possible to recognize key factors that will serve as reliable indicators for the next season. There is a whole system of factors which determines the yearly fluctuation but the main factor is insolation. It is not yet feasible to install automatic stations to record and transmit the insolation values over the entire area but it might be possible to estimate the insolation if a suitable empirical key could be developed to describe the ice surface on the basis of the puddle type and distribution. The ideal method would use an airborne ice thickness sensor to measure the amount of ice ablated at specific times during the year. Then on the basis of previous observations related to the present situation it would be possible to accurately forecast the ice conditions.

Resumé

The basic descriptions of the methods of collecting, representing and interpreting sea ice information have been given in the foregoing text. This information may be used in a number of ways ranging from such diversified ends as forecasting for surface transportation to heat

balance studies. The general trends and basic patterns have been described and additional specific and detailed studies of a geographical nature have been suggested and outlined. It is hoped that the geographic observations given above will complement the existing information and will facilitate a correlation including the parameters of meteorology, oceanography and ice physics and their relationship with the dynamics of sea ice in the Canadian Arctic.

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APPENDIX 1

TABLE i

P.C.S.P. SEA ICE RECONNAISSANCE FLIGHTS

1961	W.A. Black	(Observer)	
	Flight No. 1	June 18	ICE-RB; Via Borden Is, Fitzwilliam Str, Byam Martin Chan. (2.3 hours) RB-IC; Via Penny Str, Hassel Snd, Meighen Is. (2.3 hours)
	Flight No. 2	June 26	IC-RB; Via Lougheed Is, Penny Str, McDougall Snd. (2.7 hours) RB-IC; Via Wellington Chan, Belcher Chan, Hassel Snd. (2.7 hours)
		June 27	IC-RB; Via Middle Fd, Eureka Snd, Jones Snd. (4.7 hours)
		June 30	RB-RB; Via Lancaster Sound. (1.9 hours) RB-MD; Via Barrow Str, Byam Martin Chan, Hecla and Griper Bay (3.1 hours) MD-IC; Via Borden Is. (3.0 hours)
	Flight No. 3	July 25	IC-IC; Via Hassel Snd, Hendriksen Str, Belcher Chan, Maclean Str. (4.2 hours) IC-EU; Via Meighen Is, Nansen Snd. (2.1 hrs) EU-RB; Via Eureka Snd, Jones Snd, Lancaster Snd. (4.2 hours)
		July 26	RB-RB; Via Wellington Chan, Penny Str, Byam Martin Chan. (3.6 hours)
		July 28	RB-MD; Via Viscount Melville Snd. (4.8 hrs) MD-MD; Via Borden Is, Lougheed Is.(4.7 hrs)
	Flight No. 4	July 30	MD-RB; Via northern Viscount Melville Snd. (3.6 hrs) RB-IC; Via Wellington Chan, Penny Str. King Christian Is. (2.3 hours)
	Flight No. 5	Aug. 3	IC-IC; Via Meighen Is, Nansen Snd, Eureka Snd, Norwegian Bay, Hendriksen Str, Hassel Snd. (5.0 hours)
		Aug. 5	IC-RB; Via Belcher Chan, Jones Snd, Lancaster Snd. (3.5 hours) RB-IC; Via Barrow Str, Byam Martin Chan, Lougheed Is. (3.3 hours)
	Flight No. 6	Aug. 11	IC-MD; Via Borden Is, M'Clure Str.(4.6 hrs) MD-RB; Viscount Melville Snd, Byam Chan, Barrow Str. (4.1 hours) RB-IC; Via Penny Str, Danish Str. (2.0 hrs)
		Aug. 12	IC-IC; Via Norwegian B., Jones Snd, Belcher Chan. (3.3 hours)

	Flight No. 7	Aug. 27	IC-RB; Via Byam Martin Chan, Viscount Melville Snd. (3.9 hours)
	Flight No. 8	Sept. 6	IC-MD; Via Borden Is, M'Clure Str. (3.0 hrs)
		Sept. 7	MD-RB; Via Emerald Is, Desbarats Str, Penny Str. (4.0 hours).
		Sept. 8	RB-MD; Via northern Viscount Melville Snd. (3.6 hours) MD-RB; Via southern Viscount Melville Snd. (4.8 hours)
	Flight No. 9	Sept.19	IC-IC; Via Prince Gustaf Adolf Sea, Meighen Is, Hassel Snd, Danish Str. (5.5 hours)
		Sept.23	RB-RB; Via Penny Str, Byam Martin Chan, Barrow Strait. (3.2 hours)
1962	W.A. Black	(Observer)	
	Flight No. 1	June 21	IC-RB; Via Byam Martin Chan, Barrow Str. (5.0 hours) RB-MD; Via Viscount Melville Snd.(5.2 hrs) MD-IC; Via Borden Is. (4.6 hours)
		June 23	IC-IC; Via Meighen Is, Nansen Snd, Eureka Snd, Norwegian Bay. (4.8 hours) IC-RB; Via Belcher Chan, Jones Snd, Lancaster Snd. (3.5 hours) RB-IC; Via Penny Str, Lougheed Is.(2.3 hrs)
	Flight No. 2	July 5	IC-RB; Via Belcher Chan, Jones Snd, Lancaster Snd. (6.7 hours) RB-MD; Via Viscount Melville Snd. (5.3 hrs) MD-IC; Via M'Clure Strait, Borden Is.(4 hrs)
		July 6	IC-RB; Via Penny Str, Wellington Chan(4 hrs) RB-IC; Via Byam Martin Chan, Lougheed Is. (4.9 hours)
	Flight No. 3	July 17	IC-RB; Via Belcher Chan, Jones Snd, Lancaster Snd. (5.0 hours) RB-IC; Via Wellington Chan, Penny Str, (4.5 hours) Danish Str.
		July 18	IC-EU; Via Meighen Is, Nansen Snd. (3.0 hrs) EU-IC; Via Eureka Snd, Norwegian B., (3.5 hours) Hendriksen Str.
		July 20	IC-MD; Via Borden Is, M'Clure Str. (5.2 hrs)
		July 21	MD-IC; Via Viscount Melville Snd, Byam Martin Chan. (5.5 hours)

	Flight No. 4	Aug. 4	IC-RB; Via Hecla and Griper B, Viscount Melville Snd. (3.7 hours) RB-RB; Via Wellington Chan, Belcher Chan. Penny Str. (3.3 hours) RB-IC; Via Barrow Str, Byam Martin Chan, Lougheed Is. (2.5 hours)
		Aug. 5	IC-IC; Via Meighen Is, Nansen Snd, Eureka Snd. (5.2 hours) IC-MD; Via Wilkins Str, Fitzwilliam Str. (3.8 hours) MD-IC; Via M'Clure Str, Borden Is. (4.0 hrs)
	Flight No. 5	Aug.26	IC-RB; Via Danish Str, Belcher Chan, Jones Snd, Wellington Chan. (3.7 hours) RB-MD; Via Barrow Str, Byam Martin Chan, Emerald Is. (3.4 hours) MD-IC; Via M'Clure Str, Borden Is.(3.5 hrs)
		Aug.28	IC-IC; Via Meighen Is, Nansen Snd, Eureka Snd. (5.5 hours)
		Sept. 2	IC-IC; Via Hassel Snd, Hendriksen Str, Lougheed Is. (4.3 hours)
		Sept. 3	IC-RB; Via Bathurst Is, Penny Str, McDougall Snd. (3.6 hours)
		Sept. 5	RB-MD; Via northern Viscount Melville Snd. (4.7 hours) MD-RB; Via southern Viscount Melville Snd. (5.5 hours)
	Flight No. 6	Sept.24	RB-MD; Via mid Vsicount Melville Snd.(5.3hrs)
		Sept.25	MD-MD; Via M'Clure Strait. (5.5 hours) MD-MD; Via Hecla and Griper B., Byam Chan. Liddon Gulf. (4.4 hours)
		Sept.26	MD-IC; Via Borden Is. (3.4 hours)
		Sept.27	IC-IC; Via Massey Sound, Hendriksen Str, Danish Str. (4.5 hours)
		Sept.29	IC-RB; Via Lougheed Is, Belcher Chan, Jones Snd, Wellington Chan. (4.3 hours)
1963	W.A. Black	(Observer)	
	Flight No. 1	June 21	IC-RB; Via Lougheed Is, Penny Str, McDougall Snd. (4.2 hours) RB-RB; Via Wellington Chan, Belcher Chan, Jones Snd, Lancaster Snd. (5.4 hours)

	June 22	RB-MD; Via mid Viscount Melville Snd. (5.5 hours) MD-IC; Via M'Clure Str, Borden Is. (5.5hrs)
	June 23	IC-MD; Via Wilkins Str. (3.2 hours) MD-IC; Via Emerald Is, Lougheed Is.(3.4hrs)
	June 24	IC-EU; Via Meighen Is, Nansen Snd. (3.6hrs) EU-IC; Via Eureka Snd, Norwegian Bay, Massey Snd. (3.9 hours)
Flight No. 2	July 4	IC-EU; Via Meighen Is, Ward Hunt Is, Nansen Snd. (5.1 hours) EU-IC; Eureka Snd, Norwegian B., Massey Snd. (3.3 hours)
	July 5	IC-RB; Via Hassel Snd, Hendriksen Str, Jones Snd, Lancaster Snd. (5.2 hours) RB-MD; Via mid Viscount Melville Snd. (4.5 hours) MD-IC; Via M'Clure Str, Borden Is. (3.8 hrs)
	July 9	IC-RB; Via Maclean Str, Penny Str, Wellington Chan. (5.0 hours) RB-IC; Via Barrow Str, Byam Martin Chan, Hazen Str. (6.8 hours)
Flight No. 3	July 18	IC-RB; Via Welkins Str, Hecla and Griper B, Austin Chan. (3.0 hours) RB-MD; Via mid Viscount Melville Snd. (3.4 hours) MD-IC; Via M'Clure Str, Borden Is. (3.2 hrs)
	July 19	IC-EU; Via Meighen Is, Nansen Snd. (4.3 hrs) EU-RB; Via Eureka Snd, Norwegian Bay, Jones Snd, Lancaster Snd. (11.7 hours)
	July 20	IC-IC; Via Maclean Str, Penny Str, Belcher Chan, Hendriksen Str. (6.6 hours)
Flight No. 4	Aug. 23	RB-RB; Via Lancaster Snd, Jones Snd, Wellington Chan. (4.1 hours) RB-RB; Via McDougall Snd, Penny Str, Austin Chan, Barrow Str. (3.6 hours)
	Aug. 26	RB-RB; Via Barrow Str, Byam Martin Is, Barrow Str. (4.7 hours) RB-MD; Via Viscount Melville Snd, M'Clure Str. (4.9 hours)
	Aug. 27	MD-IC; Via Borden Is. (4.1 hours)

		Aug. 30	IC-EU; Via Meighen Is, Nansen Snd.(3.4hrs) EU-IC; Via Eureka Snd, Norwegian B, Massey Snd. (3.6 hours)
		Aug. 31	IC-RB; Via Hendriksen Str, Belcher Chan, Wellington Chan. (3.5 hours)
		Sept. 1	RB-IC; Via McDougall Snd, Austin Chan, Hazen Str, Wilkins Str. (6.9 hours)
		Sept. 2	IC-RB; Via Maclean Str, Penny Str. (2.5hrs)
	Flight No. 5	Sept.10	RB-IC; Via Lancaster Snd, Jones Snd, Norwegian B, Hendriksen Str. (5.6 hours) IC-RB; Via Meighen Is, Hassel Snd, Penny Str. Wellington Chan. (5.5 hours)
		Sept.11	RB-MD; Via Viscount Melville Snd. (6.4 hrs)
		Sept.14	MD-MD; Via M'Clure Strait. (3.8 hours)
		Sept.15	MD-RB; Via Crozier Chan, Hazen Str, Desbarats Str, Barrow Str. (5.2 hours)
	Flight No. 6	Sept.28	RB-RB; Via Lancaster Snd, Wellington Chan, Belcher Chan, Massey Snd, Hendriksen Str. (4.3 hours) RB-MD; Via Viscount Melville Snd. (4.1 hrs)
		Sept.29	MD-IC; Via Borden Is. (2.5 hours) IC-MD; Via Wilkins Str, Ballantyne Str. (2.4 hours) MD-MD; Via M'Clure Str. (3.7 hours)
		Sept.30	MD-IC; Via Fitzwilliam Str, Hazen Str. (3.1 hours) IC-RB; Via Penny Str, McDougall Snd. (4.9 hours)
1964	D.G. Lindsay	(Observer)	
	Flight No. 1	June 21	MD-RB; Via Viscount Melville Snd, Byam Martin Is, Barrow Str. (4.1 hours)
		June 22	RB-RB; Via Lancaster Snd, Jones Snd, Wellington Chan. (4.7 hours) RB-MD; Via southern Viscount Melville Snd. (4.5 hours)
		June 24	RB-EU; Via McDougall Snd, Penny Str, Norwegian B, Eureka Snd. (4.4 hours) EU-MD; Via Nansen Snd, Meighen Is, Borden Is. (4.1 hours)

	June 25	MD-MD; Via M'Clure Str. (2.8 hours)
Flight No. 2	July 7	CB-MD; Via Viscount Melville Snd.(4.5 hrs)
	July 8	MD-RB; Via Emerald Is, Desbarats Str, (4.0 hours) Penny Str. RB-MD; Via northern Viscount Melville Snd. (5.0 hours)
	July 9	MD-MD; Via Brock Is. (5.0 hours)
	July 13	MD-EU; Via Fitzwilliam Str, Mackenzie King Is, Meighen Is, Nansen Snd. (4.3 hours) EU-RB; Via Eureka Snd, Norwegian B, Jones Snd, Wellington Chan. (4.5 hours)
	July 15	RB-RB; Via Wellington Chan, Belcher Chan, Massey Snd, Hassel Snd, Penny Str. (5.0hrs) RB-MD; Via Viscount Melville Snd, Kellet Str. (4.5 hours)
Flight No. 3	July 24	RB-MD; Via Byam Martin Is, Hecla and Griper Bay. (2.6 hours)
	Aug. 2	MD-RB; Via Hazen Str, Bathurst Is.(3.0hrs) RB-MD; Via Byam Martin Chan, Fitzwilliam Str. (3.0 hours) MD-SY; Via M'Clure Str, Beaufort Sea. (2.3 hours)
	Aug. 7	CB-MD; Via M'Clintock Chan, Viscount Melville Snd. (4.5 hours)
	Aug. 8	MD-IC; Via Borden Is. (4.0 hours) IC-MD; Via Wilkins Str, Fitzwilliam Chan. (1.8 hours)
Flight No. 4	Aug. 10	MD-RB; Via Byam Martin Is, McDougall Snd. (3.7 hours) RB-IC; Via Penny Str, Maclean Str. (2.6hrs) IC-MD; Via Borden Is, Wilkins Str. (2.2hrs)
	Aug. 11	MD-EU; Via Hazen Str, Cape Isachsen, Nansen Snd. (4.1 hours) EU-RB; Via Eureka Snd, Norwegian Bay Belcher Chan. (3.1 hours)
	Aug. 12	RB-MD; Via mid Viscount Melville Snd.(5.5hrs)
	Aug. 13	MD-IC; Via Hazen Strait (3.1 hours) IC-MD; Hassel Snd, Massey Snd, Fitzwilliam Str. (5.7 hours)

Flight No. 5	Aug. 18	MD-RB; Via Hecla and Griper B, Byam Martin Is, McDougall Snd. (3.7 hours) RB-EU; Via Wellington Chan, Jones Snd, Norwegian B, Eureka Snd. (4.5 hours)
	Aug. 19	EU-MD; Via Nansen Snd, Meighen Is, Wilkins Str. (4.5 hours)
	Aug. 23	MD-IC; Via M'Clure Strait, Borden Is, Peary Chan, Massey Snd, Belcher Chan, Hassel Snd. (5.4 hours) IC-MD; Via Hazen Str, Fitzwilliam Str. (2.1 hours)
Flight No. 6	Sept. 2	MD-MD; Via M'Clure Str. (2.0 hours)
	Sept. 3	MD-MD; Via Kellet Str, Liddon Gulf, northern Viscount Melville Snd. (3.5 hours)
	Sept. 4	MD-RB; Via mid Viscount Melville Snd. (3.0 hours) RB-EU; Via Wellington Chan, Jones Snd, Belcher Chan, Norwegian B, Eureka Snd. (4.0 hours)
	Sept. 5	EU-IC; Via Nansen Snd, Meighen Is, (3.3hrs) IC-MD; Via Prince Gustaf Adolf Sea, Hazen Str, Fitzwilliam Str. (2.0 hours)
Flight No. 7	Sept. 15	MD-RB; Via northern Viscount Melville Snd. (4.0 hours)
	Sept. 23	RB-RB; Via Wellington Chan, Jones Snd, Belcher Chan, Penny Str. (4.6 hours)
	Sept. 24	RB-RB; Via Barrow Str. (1.4 hours)
Flight No. 8	Sept. 26	RB-RB; Via Prince Regent Inlet, Admiralty Inlet, northern Lancaster Snd. (2.1 hours) RB-IC; Via Penny Str, Belcher Chan, Hendriksen Str, Hassel Snd. (4.0 hours)
	Sept. 27	IC-EU; Via C. Isachsen, Meighen Is, Nansen Snd. (3.0 hours)
	Sept. 28	EU-RB; Via Eureka Snd, Norwegian B, Jones Snd, Wellington Chan. (3.0 hours)
	Sept. 29	RB-MD; Via mid Viscount Melville Snd, Kellet Str. (3.5 hours) MD-CB; Via Crozier Str, Viscount Melville Snd, Wynniatt B. (3.2 hours)

1965	D.G. Lindsay	(Observer)	
	Flight No. 1	June 23	CB-MD; Via M'Clintock Chan, Viscount Melville Snd, Kellet Str. (4.3 hours)
		June 24	MD-RB; Via Hecla and Griper B, Byam Martin Is. (2.9 hours)
		June 25	RB-MD; Via southern Viscount Melville Snd, M'Clure Str. (5.0 hours)
		June 26	MD-IC; Via west Prince Patrick Is. (2.6hrs) IC-EU; Via Meighen Is, Nansen Snd. (2.7hrs) EU-RB; Via Eureka Snd, Norwegian B, Jones Snd, Lancaster Snd. (3.4 hours)
		June 28	RB-MD; Via Wellington Chan, Penny Str, Desbarats Str, Hazen Str. (3.8 hours)
	Flight No. 2	July 5	MD-RB; Via mid Viscount Melville Snd. (5.3 hours)
		July 6	RB-RB; Via mid Lancaster Snd, Jones Snd, Wellington Chan. (4.5 hours) RB-RB; Via Peel Snd, Ommanney B, M'Clintock Chan, Barrow Str. (2.7 hours)
		July 7	RB-EU; Via McDougall Snd, Penny Str, Norwegian B, Eureka Snd. (3.0 hours) EU-IC; Via Nansen Snd, Meighen Is. (3.0hrs) IC-MD; Via Borden Is, Ballantyne Str. (2.6 hours)
	Flight No. 3	July 16	RB-MD; Via mid Viscount Melville Snd. (3.7 hours)
		July 18	MD-IC; Via Borden Is. (3.6 hours)
		July 19	IC-RB; Via Maclean Str, Penny Str, Barrow Str. (3.0 hours)
		July 20	RB-RB Via Wellington Chan, Massey Snd, Strand B, Hell Gate. (7.0 hours) RB-EU; Via Lancaster Snd, Jones Snd, Norwegian B, Eureka Snd. (4.0 hours)
		July 21	EU-IC; Via Hassel Snd. (2.5 hours) IC-MD; Via Wilkins Str, Ballantyne Str. (2.4 hours)
		July 22	MD-CB; Via southern Viscount Melville Snd. (3.7 hours)

Flight No. 4	Aug. 3	CB-MD; Via M'Clintock Chan, Viscount Melville Snd. (4.1 hours)
	Aug. 4	MD-MD; Via M'Clure Str. (2.7 hours) MD-IC; Via Borden Is. (3.0 hours) IC-EU; Via Meighen Is, Nansen Snd. (2.3hrs)
	Aug. 6	EU-RB; Via Eureka Snd, Norwegian B, Jones Snd, Lancaster Snd. (5.0 hours)
	Aug. 7	RB-RB; Via Wellington Chan, Belcher Chan, Penny Str, McDougall Snd. (2.5 hours)
	Aug.10	RB-EU; Via Norwegian B, Eureka Snd. (2.7hrs) EU-LT; Via Nansen Snd, Ward Hunt Ic. (3 hrs)
	Aug.11	LT-EU; Via Lincoln Sea, Robeson Chan, Hall Basin, Greely Fd. (2.7 hours) EU-MD; Via Strand B, Massey Snd. Hendriksen Str. Desbarats Str, Hazen Str, Fitzwilliam Str. (3.7 hours)
	Aug.12	MD-MD; Via M'Clure Str, Prince of Wales Strait, Minto Inlet. (3.3 hours)
Flight No. 5	Aug.14	MD-IC; Via Fitzwilliam Str, Hazen Str, Prince Gustaf Adolf Sea (2.0 hours) IC-MD; Via Borden Is, M'Clure Str. (2.0hrs)
	Aug.15	MD-RB; Via Hecla and Griper B, Byam Martin Is, McDougall Snd. (2.5 hours) RB-MD; Via Erskine Inlet, Byam Martin Chan. Hazen Str. (2.6 hours)
	Aug.16	MD-RB; Via southern Viscount Melville Snd. (3.5 hours)
	Aug.17	RB-MD; Via Barrow Str, Byam Chan. (2.5hrs)
	Aug.18	MD-IC; Via Borden Is. (3.1 hours) IC-RB; Via Hassel Snd, Hendriksen Str, Belcher Chan, Penny Str, McDougall Snd. (3.0 hours)
	Aug.19	RB-CB; Via Barrow Str, M'Clintock Chan. Victoria Str. (4.2 hours)
	Aug.20	CB-SY; Via Prince Albert Snd, Amundsen Gulf Thesiger B. (3.4 hours) SY-MD; Via western Banks Is, M'Clure Str. (2.2 hours)

	Aug. 22	MD-RB; Via Hecla and Griper B. (2.6 hrs) RB-EU; Via Wellington Chan, Jones Snd. Norwegian B, Eureka Snd. (3.2 hrs)
	Aug. 23	EU-LT; Via Greely Fd. (2.5 hrs) LT-EU; Via Tanquary Fd, Canon Fd. (2.2 hrs) EU-RB; Via Eureka Snd, Norwegian Bay. (2.3 hrs)
Flight No. 6	Aug. 28	MD-RB; Via northern Viscount Melville Snd. (4.0 hrs)
	Sept. 1	RB-EU; Via Penny Str, Belcher Chan, Norwegian B, Eureka Snd. (4.0 hrs) EU-IC; Via Nansen Snd, Meighen Is. (2.5 hrs) IC-MD; Via Borden Is. (3.2 hrs)
	Sept. 3	MD-RB; Via Hecla and Griper B, Byam Chan. (2.6 hrs) RB-CB; Via Barrow Str, M'Clintock Chan. (3.2 hrs)
Flight No. 7	Sept.13	CB-MD; Via M'Clintock Chan, northern Viscount Melville Snd. (4.5 hrs)
	Sept.15	MD-RB; Via Fitzwilliam Str, Hazen Str. Desbarats Str, Penny Str, McDougall Snd. (3.2 hrs)
	Sept.18	RB-EU; Via Wellington Chan, Penny Str, Hendriksen Str, Norwegian B, Eureka Snd. (4.0 hrs)
	Sept.20	EU-IC; Via Nansen Snd, Meighen Is.(3.0 hrs) IC-RB; Via Maclean Str, Penny Str.(3.0 hrs)
	Sept.22	RB-MD; Via Barrow Str, northern Viscount Melville Snd. (3.7 hrs)
Flight No. 8	Sept.28	MD-MD; Via M'Clure Str. (3.0 hrs)
	Sept.30	MD-RB; Via northern Viscount Melville Snd, Byam Martin Is. (3.8 hrs)
	Oct. 1	RB-RB; Via Barrow Str, Prince Regent Inlet Lancaster Snd. (2.5 hrs) RB-RB; Via McDougall Snd, Penny Str, Hendriksen Str, Belcher Chan. (4.3 hrs)
	Oct. 2	RB-EU; Via Wellington Chan, Jones Snd, Norwegian B, Eureka Snd. (3.6 hrs)
	Oct. 3	EU-IC; Via Middle Fd, Meighen Is. (2.5 hrs)

		Oct. 4	IC-MD; Via Borden Is. (2.1 hrs) MD-CB; Via Viscount Melville Snd, M'Clintock Chan. (4.1 hrs)
1966	D.G. Lindsay	(Observer)	
	Flight No. A	June 2	MD-MD; Via Brock Is. (4.2 hrs)
		June 3	MD-EU; Via Borden Is, Peary Chan, Sverdrup Chan. (3.0 hrs) EU-LT; Via Greely Fd, Tanquary Fd. (2.2 hrs) LT-LT; Via Lincoln Sea, Robeson Chan. Archer Fd. (2.0 hrs) LT-RB; Via Eureka Snd, Norwegian B, Jones Snd, Wellington Chan. (4.1 hrs)
		June 4	RB-MD; Via Barrow Str, Byam Martin Is, Hecla and Griper B. (3.1 hrs)
		June 10	MD-MD; Via M'Clure Str, western Banks Is. (3.6 hrs) MD-MD; Via Lands End, west of Prince Patrick Is. (6.0 hrs)
	Flight No. 1	June 19	MD-IC; Via Borden Is. (2.5 hrs) IC-EU; Via Meighen Is, Nansen Snd. (2.1 hrs)
		June 20	EU-LT; Via Canon Fd, Nares Chan. (3.1 hrs) LT-EU; Via Ward Hunt Is, Emma Fd, Otto Fd. Hare Fd. (2.8 hrs)
		June 21	EU-RB; Via Eureka Snd, Norwegian B, Jones Snd, Wellington Chan. (3.2 hrs) RB-MD; Via Byam Martin Is, Hecla and Griper B. (2.6 hrs)
		June 22	MD-RB; Via southern Viscount Melville Snd. (4.0 hrs)
		June 25	RB-RB; Via Barrow Str, Prince Regent Inlet, Admiralty Inlet, Lancaster Snd. (4.6 hrs)
		June 27	RB-RB; Via Wellington Chan, Belcher Chan, Penny Str, McDougall Snd. (3.6 hrs) RB-MD; Via northern Viscount Melville Snd. (3.7 hrs)
		June 28	MD-CB; Via Viscount Melville Snd. (3.1 hrs)
		June 30	CB-MD; Via M'Clintock Chan, Viscount Melville Snd. Liddon Gulf. (4.0 hrs)

Flight No. 2	July 4	MD-RB; Via Emerald Is, Hazen Str, Desbarats Str, Penny Str, McDougall Snd. (3.0 hrs)
	July 5	RB-MD; Via Byam Martin Is, Hecla and Griper B. (3.2 hrs) MD-RB; Via mid Viscount Melville Snd. (3.3 hrs)
	July 6	RB-RB; Via Lancaster Snd, Prince Regent Inlet, Peel Snd, Barrow Str. (4.3 hrs)
	July 8	RB-EU; Via Wellington Chan, Jones Snd, Norwegian Bay, Eureka Snd. (3.2 hrs)
	July 9	EU-LT; Via Nansen Snd, Ward Hunt Is.(2.9 hrs) LT-LT; Via Lincoln Sea. (1.2 hrs) LT-EU; Via Robeson Chan, Hall Basin, Kennedy Chan. (2.0 hrs)
	July 10	EU-MD; Via Strand Bay, Prince Gustaf Adolf Sea, Emerald Is. (3.7 hrs)
Flight No. 3	July 17	MD-RB; Via Emerald Is, Lougheed Is, Penny Str. (3.5 hrs)
	July 18	RB-EU; Via Wellington Chan, Jones Snd, Makinson Inlet, Smith Snd, Bache Pen. (4.4 hrs) EU-LT; Via Nansen Snd, Ward Hunt Is.(2.8 hrs) LT-EU; Via Nares Chan. (2.2 hrs)
	July 19	EU-RB; Via Eureka Snd, Arthur Fd, Wellington Chan. (2.8 hrs)
	July 21	RB-MD; Via Byam Martin Is, Hecla and Griper By. (3.0 hrs)
	July 22	MD-RB; Via mid Viscount Melville Snd. (3.8 hrs) RB-MD; Via Penny Str, Maclean Str, Hazen Str, Fitzwilliam Str. (3.1 hrs)
	July 23	MD-EV; Via M'Clures Str, western Banks Is, Beaufort Sea. (4.1 hrs) EV-MD; Via Amundsen Gulf, M'Clure Str. (3.5 hrs)
Flight No. 4	July 29	MD-IC; Via Borden Is. (3.4 hrs)
	July 30	IC-EU; Via Hassel Snd, Hendriksen Str, Massey Snd, Norwegian B, Eureka Snd.(3.4 hrs) EU-LT; Via Otto Fd, Nansen Snd, Yelverton B, Ward Hunt Is. (3.6 hrs)

	July 31	LT-EU; Via Lincoln Sea, Robeson Chan, Hall Basin, Kennedy Chan, Greely Fd. (2.1 hrs)
	Aug. 2	EU-MD; Via Strand Bay, Fitzwilliam Str. (3.8 hrs)
	Aug. 3	MD-IC; Via Borden Is. (2.6 hrs) IC-LT; Via Meighen Is, Ward Hunt Is.(3.5 hrs) LT-EU; Via Nares Chan, Bache Pen, Canon Fd. (2.6 hrs)
	Aug. 5	EU-RB; Via Eureka Snd, Norwegian B, Wellington Chan. (3.2 hrs)
	Aug. 11	RB-MD; Via Byam Martin Is, Hecla and Griper B. (3.0 hrs)
Flight No. 5	Aug. 15	MD-MD; Via M'Clure Str. (3.8 hrs) MD-IC; Via Borden Is. (3.0 hrs) IC-MD; Via Prince Gustaf Adolf Sea, Emerald Is, Fitzwilliam Str. (2.0 hrs)
	Aug. 16	MD-EV; Via M'Clure Str, Beaufort Sea. (4.0 hrs) EV-MD; Via western Banks Is, M'Clure Str. (4.0 hrs)
	Aug. 19	MD-RB; Via mid Viscount Melville Snd. (3.3 hrs)
	Aug. 20	RB-MD; Via northern Viscount Melville Snd. (3.0 hrs)
	Aug. 21	MD-RB; Via Byam Martin Is. (2.8 hrs) RB-MD; Via McDougall Snd, Penny Str, Desbarats Str, Hazen Str. Fitzwilliam Str. (3.0 hrs)
	Aug. 23	MD-RB; Via Byam Martin Is. (2.5 hrs) RB-EU; Via Wellington Chan, Jones Snd, Norwegian B, Eureka Snd. (3.1 hrs)
	Aug. 27	EU-LT; Via Cannon Fd, Nares Chan. (3.2 hrs) LT-EU; Via Tanquary Fd, Greely Fd,(2.1 hrs)
	Aug. 28	EU-IC; Via Nansen Snd, Meighen Is.(2.5 hrs) IC-RB; Via Maclean Str, Danish Str, Penny Str, McDougall Snd. (3.8 hrs)
	Aug. 30	RB-MD; Via Byam Martin Is, Hecla and Griper B. (2.5 hrs)
	Aug. 31	MD-MD; Via M'Clure Str. (3.6 hrs)

Flight No. 6	Sept. 3	MD-MD; Via Borden Is, Wilkins Str, Ballantyne Str, Fitzwilliam Str. (4.6 hrs)
	Sept. 5	MD-RB; Via southern Viscount Melville Snd. (3.6 hrs) RB-EU; Via Wellington Chan, Jones Snd, Makinson Inlet. (3.6 hrs)
	Sept. 6	EU-EU; Via Greely Fd, Tanquary Fd, Otto Fd, Hare Fd, Nansen Snd. (2.8 hrs) EU-RB; Via Eureka Snd, Norwegian B, Wellington Chan. (3.6 hrs)
	Sept. 7	RB-RB; Via Barrow Str, Byam Martin Chan, Desbarats Str, Maclean Str, Hassel Snd, Belcher Chan, Penny Str. (3.8 hrs)
Flight No. 7	Sept.16	MD-MD; Via M'Clure Str, Beaufort Sea. (3.9 hrs)
	Sept.18	MD-CB; Via Viscount Melville Snd, Hadley B. (3.8 hrs) CB-RB; Via M'Clintock Chan, Barrow Str. (4.1 hrs)
	Sept.21	RB-IC; Via Barrow Str, Byam Martin Chan, Desbarats St, Maclean Str. (3.6 hrs) IC-RB; Via Danish Str, Hassel Snd, Hendriksen Str, Belcher Chan, Penny Str, McDougall Snd. (2.8 hrs)
	Sept.22	RB-RB; Via Barrow Str, Byam Martin Is, Viscount Melville Snd, M'Clintock Chan, Barrow Str. (3.6 hrs)
	Sept.23	RB-EU; Via Wellington Chan, Norwegian B, Eureka Snd. (3.2 hrs)
	Sept.24	EU-LT; Via Greely Fd, Lake Hazen. (2.6 hrs) LT-IC; Via Ward Hunt Is, Meighen Is. (3.8 hrs)
	Sept.25	IC-MD; Via Borden Is, M'Clure Str. (4.3 hrs)
Flight No. 8	Sept.27	MD-EV; Via M'Clure Str, Beaufort Sea. (3.8 hrs)
	Sept.28	EV-MD; Via Amundsen Gulf, western Banks Is, M'Clure Str. (4.0 hrs)
	Sept.30	MD-RB; Via northern Viscount Melville Snd. (3.8 hrs)

	Oct. 3	RB-CB; Via Barrow Str, M'Clintock Chan. (3.0 hrs)
	Oct. 4	CB-MD; Via M'Clintock Chan, Viscount Melville Snd. (4.6 hrs)
Flight No. 9	Oct. 6	MD-EV; Via M'Clure Str, Beaufort Sea. (4.0 hrs)
	Oct. 7	EV-MD; Via Amundsen Gulf, western Banks Is. (4.2 hrs)
	Oct. 9	MD-RB; Via mid Viscount Melville Snd. (4.8 hrs)
	Oct. 10	RB-IC; Via Barrow Str, Byam Martin Chan, Maclean Str. (3.3 hrs) IC-RB; Via Hassel Snd, Penny Str, McDougall Snd. (2.2 hrs)

MD-Mould Bay	LT-Alert	SY-Sachs Harbour
IC-Isachson	RB-Resolute Bay	EV-Inuvik
EU-Eureka	CB-Cambridge Bay	

APPENDIX 11

TABLE i

LIST OF SEA ICE MAPS OF THE QUEEN ELIZABETH ISLANDS

FIG. NOS.		FLIGHT NO.	DATE
1	Queen Elizabeth Islands	1, 1961	June 18
2	Queen Elizabeth Islands	2, 1961	June 26-30
3	Queen Elizabeth Islands	3, 1961	July 25-28
4	Queen Elizabeth Islands	4, 1961	July 30
5	Queen Elizabeth Islands	5, 1961	Aug. 3-5
6	Queen Elizabeth Islands	6, 1961	Aug. 11-12
7	Queen Elizabeth Islands	7, 1961	Aug. 27
8	Queen Elizabeth Islands	8, 1961	Sept. 6-8
9	Queen Elizabeth Islands	9, 1961	Sept. 19-23
10	Queen Elizabeth Islands	1, 1962	June 21-23
11	Queen Elizabeth Islands	2, 1962	July 5-6
12	Queen Elizabeth Islands	3, 1962	July 17-21
13	Queen Elizabeth Islands	4, 1962	Aug. 4-5
14	Queen Elizabeth Islands	5, 1962	Aug. 26-Sept.5
15	Queen Elizabeth Islands	6, 1962	Sept. 24-29
16	Queen Elizabeth Islands	1, 1963	June 21-24
17	Queen Elizabeth Islands	2, 1963	July 4-9
18	Queen Elizabeth Islands	3, 1963	July 18-20
19	Queen Elizabeth Islands	4, 1963	Aug. 23-Sept.2
20	Queen Elizabeth Islands	5, 1963	Sept. 10-15
21	Queen Elizabeth Islands	6, 1963	Sept. 28-30
22	Queen Elizabeth Islands	1, 1964	June 21-25
23	Queen Elizabeth Islands	2, 1964	July 7-15
24	Queen Elizabeth Islands	3, 1964	July 24-Aug. 8
25	Beaufort Sea Area	3, 1964	Aug. 2
26	M'Clintock Channel	3, 1964	Aug. 7
27	Queen Elizabeth Islands	4, 1964	Aug. 10-13

28	Queen Elizabeth Islands	5, 1964	Aug. 18-23
29	Queen Elizabeth Islands	6, 1964	Sept. 2-5
30	Queen Elizabeth Islands	7, 1964	Sept.15-24
31	Queen Elizabeth Islands	8, 1964	Sept.26-29
32	Queen Elizabeth Islands	1, 1965	June 23-28
33	M'Clintock Channel	1, 1965	June 23
34	Queen Elizabeth Islands	2, 1965	July 5-7
35	Queen Elizabeth Islands	3, 1965	July 16-22
36	M'Clintock Channel	3, 1965	July 22
37	Queen Elizabeth Islands	4, 1965	Aug. 3-12
38	M'Clintock Channel	4, 1965	Aug. 3
39	Northern Ellesmere Island	4, 1965	Aug. 10-11
40	Queen Elizabeth Islands	5, 1965	Aug. 14-23
41	M'Clintock Channel*	5, 1965	Aug. 19
42	Amundsen Gulf Region	5, 1965	Aug. 20
43	Beaufort Sea Area	5, 1965	Aug. 20
44	Queen Elizabeth Islands	6, 1965	Aug. 28-Sept.3
45	M'Clintock Channel	6, 1965	Sept. 3
46	Queen Elizabeth Islands	7, 1965	Sept. 13-22
47	M'Clintock Channel	7, 1965	Sept. 13
48	Queen Elizabeth Islands	8, 1965	Sept. 28-Oct.4
49	M'Clintock Channel	8, 1965	Oct. 4
50	Queen Elizabeth Islands	A, 1966	June 2-10
51	Northern Ellesmere Island	A, 1966	June 3
52	Queen Elizabeth Islands	1, 1966	June 19-30
53	Northern Ellesmere Island*	1, 1966	June 19-21
54	M'Clintock Channel	1, 1966	June 30
55	Queen Elizabeth Islands	2, 1966	July 4-10
56	Gulf of Boothia	2, 1966	July 6
57	Northern Ellesmere Island	2, 1966	July 9
58	Queen Elizabeth Islands	3, 1966	July 17-23

59	Northern Ellesmere Island	3, 1966	July 18
60	Beaufort Sea Area	3, 1966	July 23
61	Queen Elizabeth Islands	4, 1966	July 29-Aug.11
62	Northern Ellesmere Island	4, 1966	July 30-Aug. 5
63	Queen Elizabeth Islands	5, 1966	Aug. 15-31
64	Beaufort Sea Area*	5, 1966	Aug. 15
65	Northern Ellesmere Island	5, 1966	Aug. 27-28
66	Queen Elizabeth Islands	6, 1966	Sept. 3-7
67	Queen Elizabeth Islands	7, 1966	Sept.16-25
68	M'Clintock Channel	7, 1966	Sept.18
69	Northern Ellesmere Island	7, 1966	Sept.23-24
70	Queen Elizabeth Islands	8, 1966	Sept.27-Oct. 4
71	Beaufort Sea Area	8, 1966	Sept.27-28
72	M'Clintock Channel	8, 1966	Oct. 3-4
73	Queen Elizabeth Islands	9, 1966	Oct. 6-10
74	Beaufort Sea Area	9, 1966	Oct. 6-7
75	Queen Elizabeth Islands	A, 1967	March 16-29
76	Northern Ellesmere Island	A, 1967	March 18

* Denotes maps shown following this table

APPENDIX II

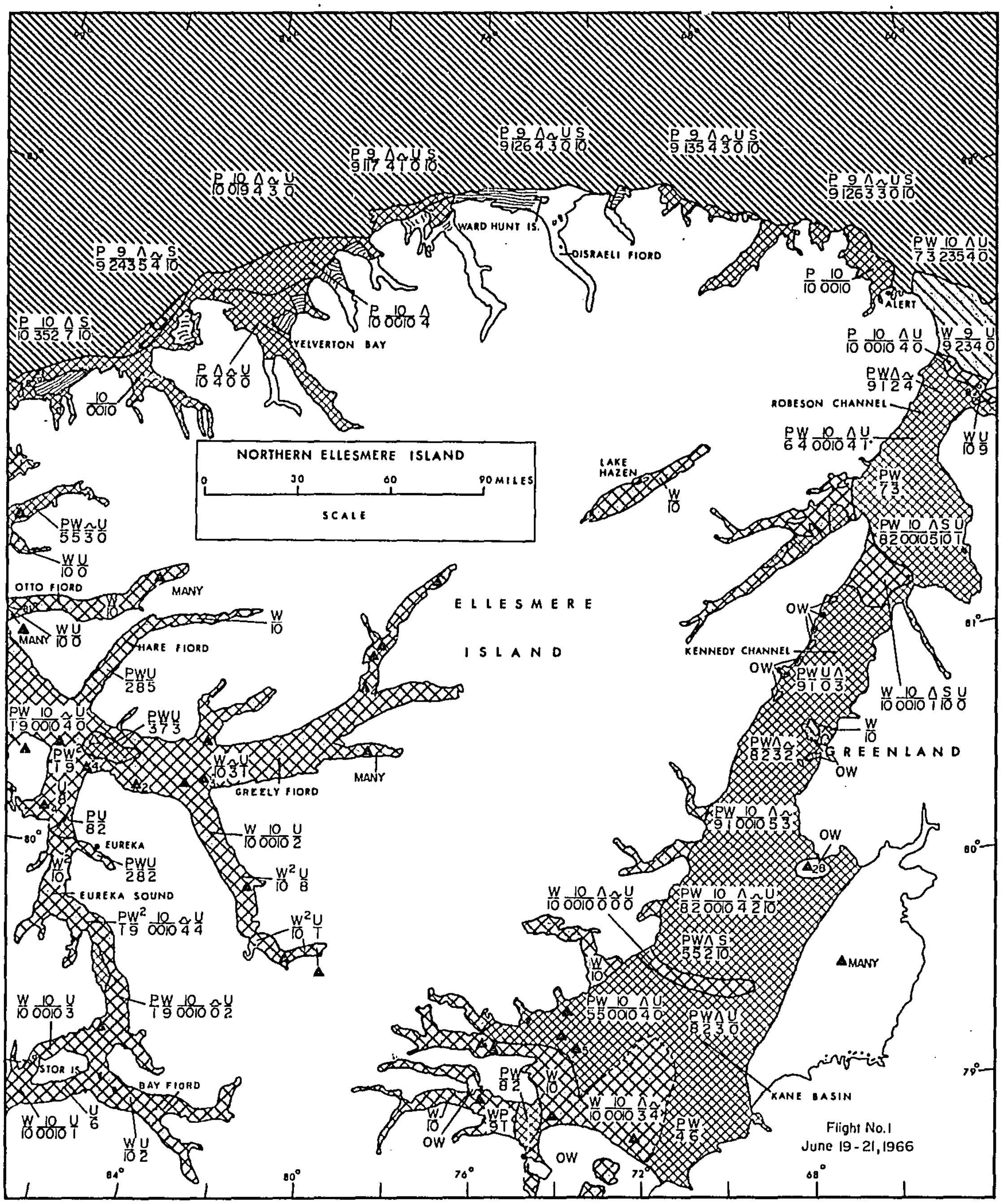

Figure i

APPENDIX II

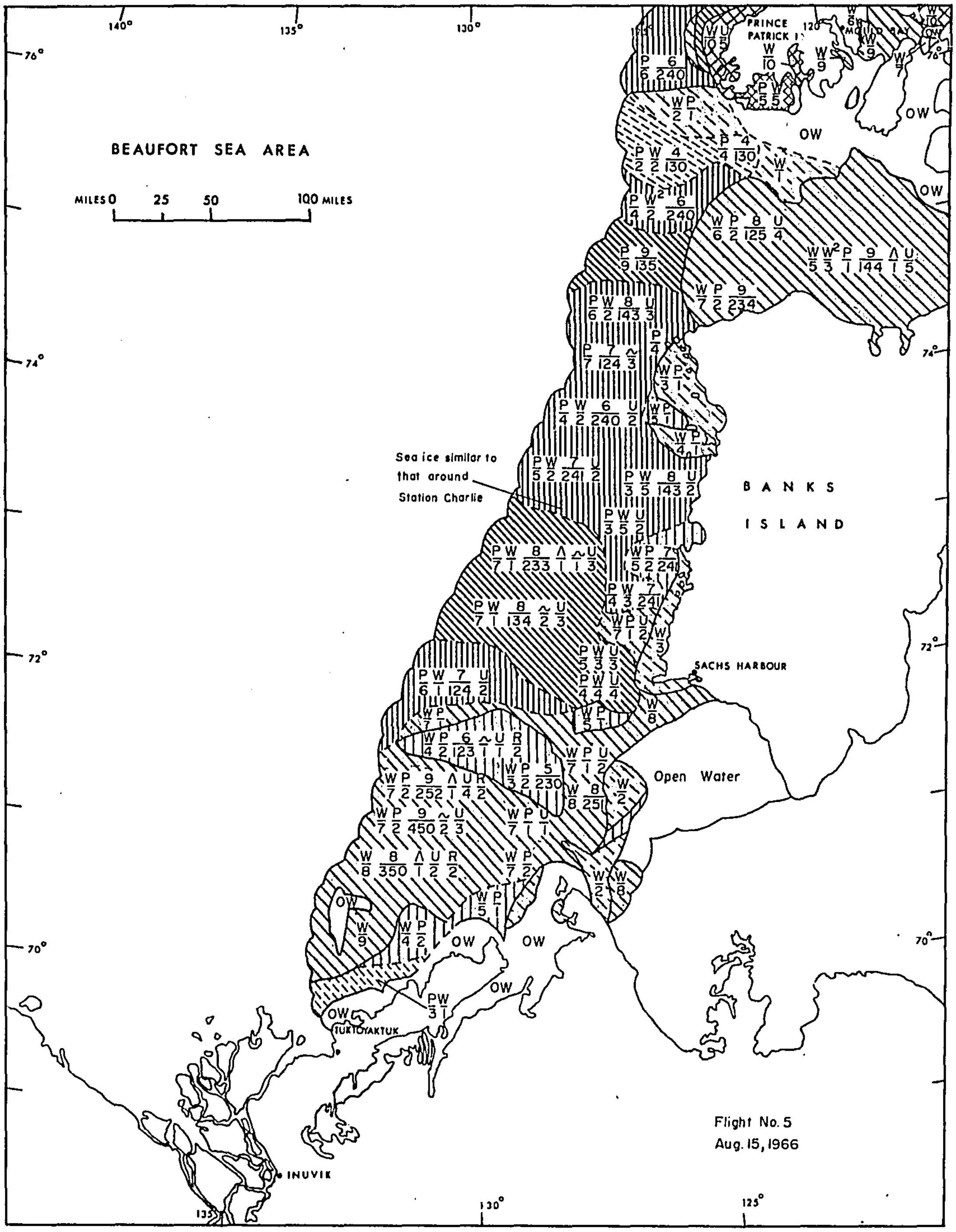

Figure ii

APPENDIX II

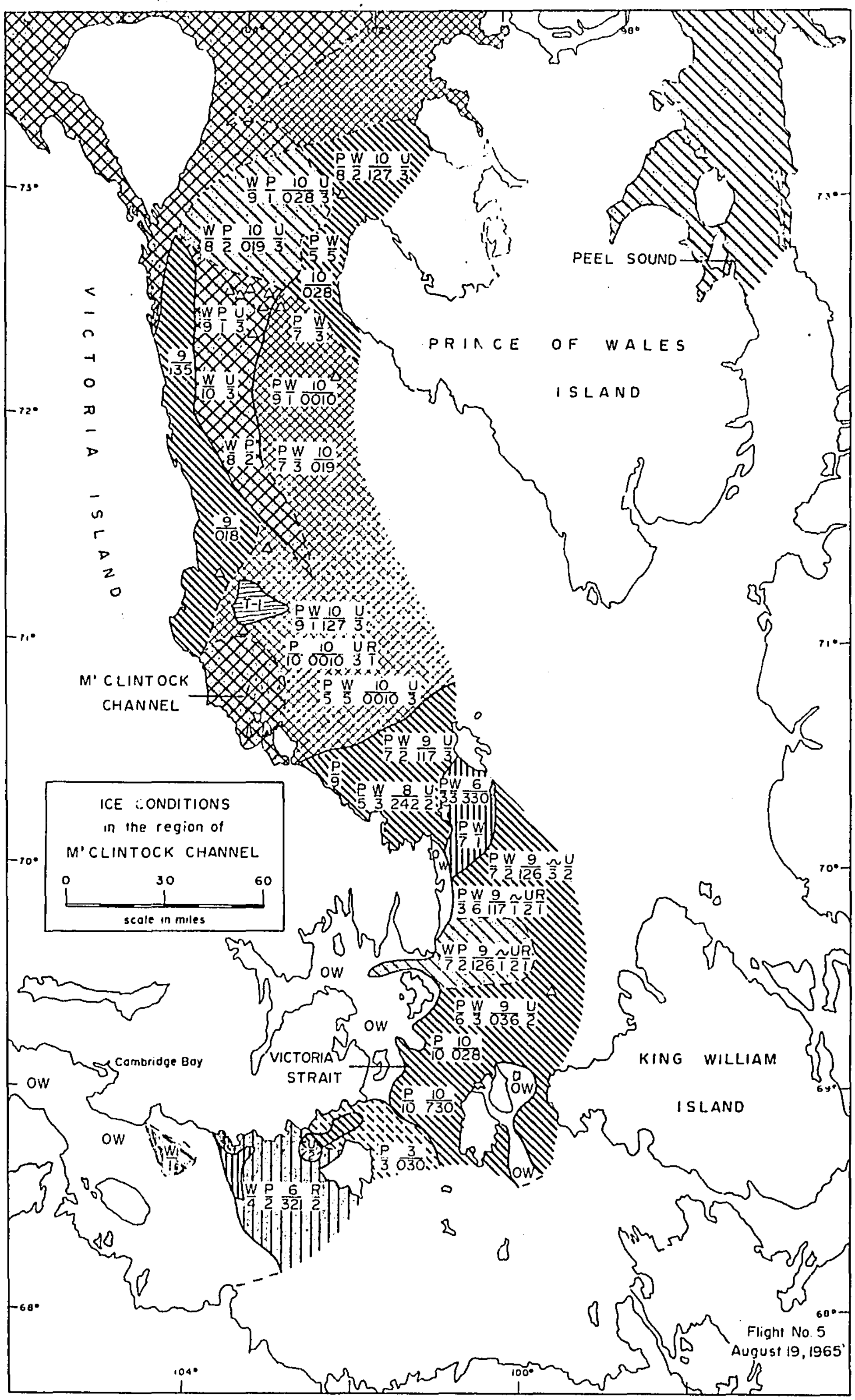

Figure iii

APPENDIX III

TABLE i

AREA (km^2) OF ICE AT THE END OF THE MONTH - SUMMER 1962

AREA	NAME	JUNE	%	JULY	%	AUG.	%	SEPT.	%
1.	Hendriksen Str.	830	100	-	-	250	30	750	90
2.	Hell Gate*	-	-	1460	94	600	39	470	30
3.	Byam Channel	1650	100	1400	84	1490	90	1490	90
4.	Penny Strait	-	-	875	50	-	-	1195	68
5.	Fitzwilliam Str.	1860	100	1000	53	360	19	1674	90
6.	Prince of Wales Str.*	2280	100	1830	80	-	-	2052	90
7.	Wilkins Strait	2580	100	2320	90	1452	56	2322	90
8.	Crozier Channel	2680	100	540	20	260	97	2144	80
9.	McDougall Sound	2790	100	840	30	170	6	990	35
10.	Sverdrup Channel	3200	100	2900	90	2880	90	2880	90
11.	Kellet Strait	3300	100	-	-	190	6	2640	80
12.	Ballantyne Strait	3300	100	2310	70	990	30	2810	66
13.	Belcher Channel	3400	100	2380	70	550	16	2380	70
14.	Hassel Sound	4230	100	1690	40	850	20	3810	75
15.	Unnamed Area*	4850	100	3400	70	3640	75	4370	90
16.	Eureka Sound	4850	100	-	-	480	10	4850	100
17.	Greely Fiord System	5260	100	200	4	-	-	5265	100
18.	Massey Sound	5260	100	4210	80	3950	75	4730	90
19.	Hazen Strait	5470	100	4930	90	4920	90	5470	100
20.	Austin Channel	5680	100	-	-	120	2	3070	54
21.	Queens Channel*	1860	32	840	15	-	-	2820	49
22.	M'Clintock Channel*	7120	100	5680	80	720	10	4984	70
23.	Hecla and Griper B.	7330	100	6960	95	5860	77	6590	90
24.	Nansen Sound	7430	100	500	7	2230	30	7430	100
25.	Peel Sound*	7430	100	430	6	-	-	-	-
26.	Peary Channel	7960	100	7562	95	6760	85	7160	90
27.	Maclean Strait	8160	100	4930	60	3260	40	7750	95
28.	Wellington Channel	7950	97	-	-	-	-	-	-
29.	Unnamed Area*	10530	100	9480	90	7890	75	8950	85
30.	Byam Martin Channel	11560	100	8670	75	9250	80	10410	90
31.	Pr. Gustaf Adolf Sea	13530	100	12217	90	12217	90	12180	90
32.	Unnamed Area*	14970	100	13470	90	13470	90	13470	90
33.	Pr. Regent Inlet*	-	-	-	-	-	-	-	-
34.	Jones Sound	19920	93	-	-	1200	6	2000	9
35.	Unnamed Area*	22300	98	9900	43	7900	35	20350	
36.	Lancaster Sound	2270	9	-	-	-	-	-	-
37.	Norwegian Bay	25090	100	6800	27	2000	8	20070	90
38.	Barrow Strait	19410	75	3880	15	990	4	1350	5
39.	M'Clure Strait	44500	99	23800	53	3590	8	38170	71
40.	Vis. Melville Sound	84040	100	61200	73	41000	48	71430	85
		386840	87	208604	48	141489	32	290486	65

APPENDIX III

TABLE ii

AREA (km²) OF ICE AT THE END OF THE MONTH - SUMMER 1964

AREA	NAME	JUNE	%	JULY	%	AUG.	%	SEPT.	%
1.	Hendriksen Str.	830	100	620	75	-	-	520	63
2.	Hell Gate*	-	-	290	19	310	20	150	10
3.	Byam Channel	1650	100	1650	100	1320	80	1650	100
4.	Penny Strait	820	46	-	-	-	-	-	-
5.	Fitzwilliam Str.	1860	100	1860	100	1860	100	1860	100
6.	Prince of Wales Str.*	2280	100	2280	100	950	42	2280	100
7.	Wilkins Strait	2580	100	2580	100	2580	100	2580	100
8.	Crozier Channel	2680	100	2680	100	2260	84	2480	93
9.	McDougall Sound	2790	100	2170	78	560	20	2790	100
10.	Sverdrup Channel	3200	100	3200	100	3200	100	3200	100
11.	Kellet Strait	3300	100	3300	100	2310	70	3300	100
12.	Ballantyne Strait	3300	100	3300	100	3300	100	3300	100
13.	Belcher Channel	3400	100	2720	80	400	12	3060	90
14.	Hassel Sound	4230	100	4230	100	4230	100	4230	100
15.	Unnamed Area*	4850	100	4850	100	4850	100	4850	100
16.	Eureka Sound	4850	100	4010	83	1210	25	4600	95
17.	Greely Fiord System	5260	100	5260	100	3340	63	5260	100
18.	Massey Sound	5260	100	5260	100	5260	100	5260	100
19.	Hazen Strait	5470	100	5470	100	5470	100	5470	100
20.	Austin Channel	5680	100	5680	100	5480	97	5680	100
21.	Queens Channel*	3470	60	-	-	520	9	320	6
22.	M'Clintock Channel*	7120	100	7120	100	6410	90	7120	100
23.	Hecla and Griper B.	7330	100	7330	100	7330	100	7330	100
24.	Nansen Sound	7430	100	7430	100	6290	85	7430	100
25.	Peel Sound*	7430	100	7430	100	200	3	7430	100
26.	Peary Channel	7960	100	7960	100	7960	100	7960	100
27.	Macelan Strait	8160	100	8160	100	8160	100	8160	100
28.	Wellington Channel	7990	98	5340	65	2860	35	2600	32
29.	Unnamed Area*	10530	100	10530	100	10530	100	10530	100
30.	Byam Martin Channel	11560	100	11560	100	11560	100	11560	100
31.	Prince Gustaf Ad. Sea	13530	100	13530	100	13530	100	13530	100
32.	Unnamed Area*	14970	100	14970	100	14970	100	14970	100
33.	Prince Regent Inlet*	17320	85	10480	50	6580	31	-	-
34.	Jones Sound	17440	82	15790	74	2570	12	240	1
35.	Unnamed Area*	22610	100	22610	100	22110	98	22610	100
36.	Lancaster Sound	-	-	-	-	-	-	-	-
37.	Norwegian Bay	25090	100	23640	94	22580	90	23830	95
38.	Barrow Strait	15700	61	14240	55	8260	32	17760	69
39.	M'Clure Strait	44910	100	44910	100	40420	90	42660	95
40.	Vis. Melville Sound	84040	100	84040	100	79840	95	84040	100
		399380	90	378480	85	321570	72	352600	79

APPENDIX III

TABLE iii

AREA (km^2) OF ICE AT THE END OF THE MONTH - SUMMER 1966

AREA	NAME	JUNE	%	JULY	%	AUG.	%	SEPT.	%
1.	Hendriksen Str.	830	100	250	30	580	70	750	90
2.	Hell Gate*	-	-	280	18	-	-	-	-
3.	Byam Channel	1650	100	1460	88	1480	90	1650	100
4.	Penny Strait	1260	72	-	-	1220	70	1140	65
5.	Fitzwilliam Str.	1860	100	1860	100	1670	90	1860	100
6.	Prince of Wales Str.*	2280	100	2050	90	1480	65	2050	90
7.	Wilkins Strait	2580	100	2580	100	2580	100	2580	100
8.	Crozier Channel	2680	100	2280	85	570	21	2680	100
9.	McDougall Sound	2790	100	2650	95	-	-	2650	95
10.	Sverdrup Channel	3200	100	3200	100	3200	100	3200	100
11.	Kellet Strait	3300	100	3000	91	2310	70	3300	100
12.	Ballantyne Strait	3300	100	3300	100	3300	100	3300	100
13.	Belcher Channel	3200	94	3060	90	3060	90	3060	90
14.	Hassel Sound	4230	100	4230	100	4120	97	4120	97
15.	Unnamed Area*	4850	100	4850	100	4850	100	4850	100
16.	Eureka Sound	4850	100	3390	70	1690	35	4800	99
17.	Greely Fiord System	5260	100	5260	100	2110	40	5260	100
18.	Massey Sound	5260	100	5260	100	5100	97	5100	97
19.	Hazen Strait	5470	100	5470	100	5470	100	5470	100
20.	Austin Channel	5680	100	5540	97	1990	35	5110	90
21.	Queens Channel*	4680	84	-	-	610	11	3460	60
22.	M'Clintock Channel*	7120	100	6400	90	4980	70	6410	90
23.	Hecla and Griper B.	7330	100	7300	98	7330	100	7330	100
24.	Nansen Sound	7430	100	7430	100	6680	90	7430	100
25.	Peel Sound*	7430	100	4460	60	-	-	6690	90
26.	Peary Channel	7960	100	7960	100	7960	100	7960	100
27.	Maclean Strait	8160	100	8160	100	7960	97	8160	100
28.	Wellington Channel	8000	98	5510	68	-	-	4900	60
29.	Unnamed Area*	10530	100	10530	100	10530	100	10530	100
30.	Byam Martin Channel	11560	100	11560	100	10790	93	10980	95
31.	Pr. Gustaf Adolf Sea	13530	100	13530	100	13530	100	13530	100
32.	Unnamed Area*	14970	100	14970	100	14970	100	14970	100
33.	Prince Regent Inlet*	12580	60	12570	60	5240	25	6290	30
34.	Jones Sound	20850	93	9600	45	-	-	-	-
35.	Unnamed Area*	22610	100	22610	100	20350	90	22610	100
36.	Lancaster Sound	3300	14	-	-	430	2	3380	14
37.	Norwegian Bay	24990	99	24510	98	20330	81	22580	90
38.	Barrow Strait	25810	100	14960	58	2270	8	20900	81
39.	M'Clure Strait	43450	97	37270	83	41320	92	43600	97
40.	Vis. Melville Sound	84040	100	77320	92	77480	92	81940	48
		410860	92	356650	80	299540	67	365080	82

APPENDIX III

TABLE iv

ESTIMATED EXPORT, IMPORT, ABLATION DURING JUNE 1966

AREA	NAME	#1	#2	#3	#4	#5	#6	#7	#8
1.	Hndrks	830	Nil	830	Nil	Nil	Nil	Nil	Nil
2.	HellGt	1550	1550	-	1550	Nil	Nil	Nil	Nil
3.	ByamCh	1650	Nil	1650	Nil	Nil	Nil	Nil	Nil
4.	Penny	1750	40	1260	490	+450	Nil	300	A150
5.	Fitzwm	1860	Nil	1860	Nil	Nil	Nil	Nil	Nil
6.	PWales	2280	Nil	2280°	Nil	Nil	Nil	Nil	Nil
7.	Wilkns	2580	Nil	2580	Nil	Nil	Nil	Nil	Nil
8.	Crozir	2680	Nil	2680	Nil	Nil	Nil	Nil	Nil
9.	McDoug	2790	Nil	2790	Nil	Nil	Nil	Nil	Nil
10.	Svrdrp	3200	Nil	3200	Nil	Nil	Nil	Nil	Nil
11.	Kellet	3300	Nil	3300	Nil	Nil	Nil	Nil	Nil
12.	Baltin	3300	Nil	3300	Nil	Nil	Nil	Nil	Nil
13.	Belchr	3400	40	3200	200	+160	Nil	Nil	A160
14.	Hassel	4230	Nil	4230	Nil	Nil	Nil	Nil	Nil
15.	UnName	4850	Nil	4850	Nil	Nil	Nil	Nil	Nil
16.	Eu Snd	4850	Nil	4850	Nil	Nil	Nil	Nil	Nil
17.	Greely	5260	Nil	5260	Nil	Nil	Nil	Nil	Nil
18.	Massey	5260	Nil	5260	Nil	Nil	Nil	Nil	Nil
19.	Hazen	5470	Nil	5470	Nil	Nil	Nil	Nil	Nil
20.	Austin	5680	Nil	5680	Nil	Nil	Nil	Nil	Nil
21.	Queens	5780	200	4680	100	-100	300	Nil	A200
22.	MClint	7120	Nil	7120	Nil	Nil	Nil	Nil	Nil
23.	HecGrp	7330	Nil	7320	Nil	Nil	Nil	Nil	Nil
24.	Nansen	7430	Nil	7430	Nil	Nil	Nil	Nil	Nil
25.	PeelSd	7430	Nil	7430	Nil	Nil	Nil	Nil	Nil
26.	Peary	7960	Nil	7960	Nil	Nil	Nil	Nil	Nil
27.	Mcelan	8160	Nil	8160	Nil	Nil	Nil	Nil	Nil
28.	Welhtn	8160	Nil	8000	160	+160	Nil	Nil	A160
29.	UnName	10530	Nil	10530	Nil	Nil	Nil	Nil	Nil
30.	BymMar	11560	Nil	11560	Nil	Nil	Nil	Nil	Nil
31.	PGusAd	13530	Nil	13530	Nil	Nil	Nil	Nil	Nil
32.	UnName	14970	Nil	14970	Nil	Nil	Nil	Nil	Nil
33.	PRegnt	20960	4000	12580	8380	+4380	Nil	4180	A200
34.	Jones	21370	100	20850	520	+420	Nil	Nil	A420
35.	UnName	22610	Nil	22610	Nil	Nil	Nil	Nil	Nil
36.	Lancst	24160	2100	3300	20860	-140	4180	Nil	A4040
37.	Lorweg	25090	Nil	24990	100	+100	Nil	Nil	A100
38.	Barrow	25810	Nil	25810	Nil	Nil	Nil	Nil	Nil
39.	MClure	44910	1300	43450	1460	+160	Nil	160	A160
40.	VisMel	84040	Nil	84040	Nil	Nil	Nil	Nil	Nil
	TOTALS	445741		410850					

#1 Total area of Strait or Channel (km^2)
#2 Total area of open water at the end of the previous month (km^2)
#3 Total area of sea ice at the end of the present month (km^2)
#4 Total area of open water at the end of the present month (km^2)
#5 Total expansion(+) or contraction(-) of open water during the present month (km^2)
#6 Total imported during present month (km^2)
#7 Total exported during present month (km^2)
#8 Total area ablated(A), formed(F) during present month (km^2)
\- Open water; ice free

APPENDIX III

TABLE v

ESTIMATED EXPORT, IMPORT, ABLATION DURING JULY 1966

AREA	NAME	#1	#2	#3	#4	#5	#6	#7	#8
1.	Hndrks	830	Nil	250	580	+580	Nil	Nil	A580
2.	HellGt	1550	1550	280	1270	-280	280	Nil	Nil
3.	ByamCh	1650	Nil	1460	190	+190	Nil	190	Nil
4.	Penny	1750	490	-	1750	+1260	Nil	900	A360
5.	Fitzwm	1860	Nil	1860	Nil	Nil	Nil	Nil	Nil
6.	PWales	2280	Nil	2050	230	+230	Nil	Nil	A230
7.	Wilkns	2580	Nil	2580	Nil	Nil	Nil	Nil	Nil
8.	Crozir	2680	Nil	2280	400	+400	Nil	400	Nil
9.	McDoug	2790	Nil	2650	140	+140	Nil	140	Nil
10.	Svrdrp	3200	Nil	3200	Nil	Nil	Nil	Nil	Nil
11.	Kellet	3300	Nil	3000	300	+300	Nil	300	Nil
12.	Baltin	3300	Nil	3300	Nil	Nil	Nil	Nil	Nil
13.	Belchr	3400	200	3060	340	+140	Nil	Nil	A140
14.	Hassel	4230	Nil	4230	Nil	Nil	Nil	Nil	Nil
15.	UnName	4850	Nil	4850	Nil	Nil	Nil	Nil	Nil
16.	Eu Snd	4850	Nil	3390	1460	+1460	Nil	Nil	A1460
17.	Greely	5260	Nil	5260	Nil	Nil	Nil	Nil	Nil
18.	Massey	5260	Nil	5260	Nil	Nil	Nil	Nil	Nil
19.	Hazen	5470	Nil	5470	Nil	Nil	Nil	Nil	Nil
20.	Austin	5680	Nil	5540	140	+140	Nil	140	Nil
21.	Queens	5780	100	-	5780	+5680	900	200	A6580
22.	MClint	7120	Nil	6400	720	+720	Nil	500	A220
23.	HecGrp	7330	Nil	7300	Nil	Nil	Nil	Nil	Nil
24.	Hansen	7430	Nil	7430	Nil	Nil	Nil	Nil	Nil
25.	PeelSd	7430	Nil	4460	2970	+2970	Nil	1100	A1870
26.	Peary	7960	Nil	7960	Nil	Nil	Nil	Nil	Nil
27.	Mcelan	8160	Nil	8160	Nil	Nil	Nil	Nil	Nil
28.	Welntn	8160	160	5510	2650	+2490	200	2420	A270
29.	UnName	10530	Nil	10530	Nil	Nil	Nil	Nil	Nil
30.	BymMar	11560	Nil	11560	Nil	Nil	Nil	Nil	Nil
31.	PGusAd	13530	Nil	13530	Nil	Nil	Nil	Nil	Nil
32.	UnName	14970	Nil	14970	Nil	Nil	Nil	Nil	Nil
33.	PRegnt	20960	8380	12570	8390	+10	500	Nil	A510
34.	Jones	21370	520	9600	11770	+11250	Nil	Nil	A11250
35.	UnName	22610	Nil	22610	Nil	Nil	Nil	Nil	Nil
36.	Lancst	24160	20860	-	24160	+3300	500	Nil	A3800
37.	Norweg	25090	100	24510	580	+480	Nil	280	A200
38.	Barrow	25810	Nil	14960	10850	+10850	6860	1000	A16710
39.	MClure	44910	1460	37270	7640	+6180	4280	700	A2500
40.	VisMel	84040	Nil	77320	6720	+6720	330	4700	A2350
	TOTALS	445741	33820	356520	89030	+55210	13850	12970	A49030

#1 Total area of Strait or Channel (km^2)
#2 Total area of open water at the end of the previous month (km^2)
#3 Total area at sea ice at the end af the present month (km^2)
#4 Total area of open water at the end of the present month (km^2)
#5 Total expansion(+) or contraction(-) of open water during the present month (km^2)
#6 Total imported during present month (km^2)
#7 Total exported during present month (km^2)
#8 Total area ablated(A), or formed(F) during present month (km^2)
\- Open water; ice free

TABLE vi

ESTIMATED EXPORT, IMPORT, ABLATION DURING AUGUST 1966

AREA	NAME	#1	#2	#3	#4	#5	#6	#7	#8
1.	Hndrks	830	580	580	250	-330	530	Nil	A200
2.	HellGt	1550	1270	-	1550	+280	300	Nil	A590
3.	ByamCh	1650	190	1480	170	-20	200	120	A60
4.	Penny	1750	1750	1220	530	-1220	1930	710	Nil
5.	Fitzwm	1860	Nil	1670	190	+190	Nil	100	A90
6.	PWales	2280	230	1480	800	+570	Nil	100	A470
7.	Wilkns	2580	Nil	2580	Nil	Nil	Nil	Nil	Nil
8.	Crozir	2680	400	570	2110	+1710	30	1500	A240
9.	McDoug	2790	140	-	2790	+2650	Nil	2000	A650
10.	Svrdrp	3200	Nil	3200	Nil	Nil	Nil	Nil	Nil
11.	Kellet	3300	300	2310	990	+690	70	560	A200
12.	Baltin	3300	Nil	3300	Nil	Nil	Nil	Nil	Nil
13.	Belchr	3400	340	3060	340	Nil	Nil	Nil	Nil
14.	Hassel	4230	Nil	4120	Nil	Nil	Nil	Nil	Nil
15.	UnName	4850	Nil	4850	Nil	Nil	Nil	Nil	Nil
16.	Eu Snd	4850	1460	1690	3160	+1700	300	Nil	A2000
17.	Greely	5260	Nil	2110	3150	+3150	200	Nil	A3350
18.	Massey	5260	Nil	5100	160	+160	Nil	160	Nil
19.	Hazen	5470	Nil	5470	Nil	Nil	Nil	Nil	Nil
20.	Austin	5680	140	1990	3690	+3550	400	3830	A120
21.	Queens	5780	5780	610	5170	-610	710	Nil	A100
22.	MClint	7120	720	4930	2140	+1420	500	720	A1200
23.	HecGrp	7330	Nil	7330	Nil	Nil	Nil	Nil	Nil
24.	Nansen	7430	Nil	6680	750	+750	Nil	500	A250
25.	PeelSd	7430	2970	-	7430	+4460	Nil	Nil	A4460
26.	Peary	7960	Nil	7960	Nil	Nil	Nil	Nil	Nil
27.	Mcelan	8160	Nil	7960	200	+200	Nil	200	Nil
28.	Welntn	8160	2650	-	8160	+5510	Nil	Nil	A5510
29.	UnName	10530	Nil	10530	Nil	Nil	Nil	Nil	Nil
30.	BymMar	11560	Nil	10790	770	+770	Nil	600	A170
31.	PGusAd	13530	Nil	13530	Nil	Nil	Nil	Nil	Nil
32.	UnName	14970	Nil	14970	Nil	Nil	Nil	Nil	Nil
33.	PRegnt	20960	8390	5240	15720	+7330	Nil	6330	A1000
34.	Jones	21370	11770	-	21370	+9606	Nil	Nil	A9600
35.	UnName	22610	Nil	20350	2260	+2260	200	2460	Nil
36.	Lancst	24160	24160	430	23730	-430	6330	Nil	A5900
37.	Norweg	25090	580	20330	4760	+4180	160	300	A4040
38.	Barrow	25810	10850	2270	23540	+12690	2500	Nil	A15190
39.	MClure	44910	7640	41320	3590	-4050	4150	Nil	A1000
40.	VisMel	84040	6720	77480	6560	-160	3950	1000	A2950
	TOTALS	445741	89030	299540	145780	+57000	22460	21190	A59330

#1 Total area of Strait or Channel (km^2)
#2 Total area of open water at the end of the previous month (km^2)
#3 Total area of sea ice at the end of the present month (km^2)
#4 Total area of open water at the end of the present month (km^2)
#5 Total expansion(+) or contraction(-) of open water during the present month (km^2)
#6 Total imported, during present month (km^2)
#7 Total exported during present month (km^2)
#8 Total area ablated(A), or formed(F) during present month (km^2)
\- Open water; ice free

APPENDIX III

TABLE vii

ESTIMATED EXPORT, IMPORT, ABLATION DURING SEPTEMBER 1966

AREA	NAME	#1	#2	#3	#4	#5	#6	#7	#8
1.	Hndrks	830	250	750	80	-170	Nil	Nil	F170
2.	HellGt	1550	1550	-	1550	Nil	Nil	Nil	Nil
3.	ByamCh	1650	170	1650	Nil	-170	Nil	1480	F1650
4.	Penny	1750	530	1140	610	+80	Nil	1000	F920
5.	Fitzwm	1860	190	1860	Nil	-190	Nil	1670	F1860
6.	PWales	2280	800	2050	230	-570	Nil	Nil	F570
7.	Wilkns	2580	Nil	2580	Nil	Nil	Nil	Nil	Nil
8.	Crozir	2680	2110	2680	Nil	-2110	870	Nil	F1240
9.	McDoug	2790	2790	2650	140	-2650	Nil	Nil	F2650
10.	Svrdrp	3200	Nil	3200	Nil	Nil	Nil	Nil	Nil
11.	Kellet	3300	990	3300	Nil	-990	800	Nil	F190
12.	Baltin	3300	Nil	3300	Nil	Nil	Nil	Nil	Nil
13.	Belchr	3400	340	3060	340	Nil	Nil	Nil	Nil
14.	Hassel	4230	Nil	4120	Nil	Nil	Nil	Nil	Nil
15.	UnName	4850	Nil	4850	Nil	Nil	Nil	Nil	Nil
16.	Eu Snd	4850	3160	4800	50	-3110	Nil	Nil	F3110
17.	Greely	5260	3150	5260	Nil	-3150	Nil	Nil	F3150
18.	Massey	5260	160	5100	160	Nil	Nil	Nil	Nil
19.	Hazen	5470	Nil	5470	Nil	Nil	Nil	Nil	Nil
20.	Austin	5680	3690	5110	570	-3120	Nil	1990	F5110
21.	Queens	5780	5170	3460	2320	-2850	1000	Nil	F1850
22.	MClint	7120	2140	6410	710	-1430	1000	700	F1130
23.	HecGrp	7330	Nil	7330	Nil	Nil	Nil	Nil	Nil
24.	Nansen	7430	750	7430	Nil	-750	Nil	Nil	F750
25.	PeelSd	7430	7430	6690	740	-6690	Nil	Nil	F6690
26.	Peary	7960	Nil	7960	Nil	Nil	Nil	Nil	Nil
27.	Mcelan	8160	200	8160	Nil	-200	Nil	Nil	F200
28.	Welntn	8160	8160	4900	3200	-4960	Nil	Nil	F4960
29.	UnName	10530	Nil	10530	Nil	Nil	Nil	Nil	Nil
30.	BymMar	11560	770	10980	580	-190	Nil	Nil	F190
31.	PGusAd	13530	Nil	13530	Nil	Nil	Nil	Nil	Nil
32.	UnName	14970	Nil	14970	Nil	Nil	Nil	Nil	Nil
33.	PRegnt	20960	15720	6290	14670	-1050	Nil	1000	F2050
34.	Jones	21370	-	21370	Nil	Nil	Nil	Nil	Nil
35.	UnName	22610	2260	22610	Nil	-2260	Nil	Nil	F2260
36.	Lancst	24160	23730	3380	20780	-2950	700	Nil	F2250
37.	Norweg	25090	14760	22580	2510	-12250	Nil	Nil	F12250
38.	Barrow	25810	23540	20800	4910	-18630	1000	Nil	F17630
39.	MClure	44910	3590	43600	1310	-2280	Nil	Nil	F2280
40.	VisMel	84040	6560	81940	2100	-4460	3470	2000	F2990
	TOTALS	445741	156030	365080	78930	-77100	8840	9840	F78100

#1 Total area of Strait or Channel (km^2)
#2 Total area of open water at the end of the previous month (km^2)
#3 Total area of sea ice at the end of the present month (km^2)
#4 Total area of open water at the end of the present month (km^2)
#5 Total expansion(+) or contraction(-) of open water during the present month (km^2)
#6 Total imported during present month (km^2)
#7 Total exported during present month (km^2)
#8 Total area ablated(A), or formed(F) during present month (km^2)
\- Open water; ice free