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Author(s)	KUSUNOKI, Kou; ONO, Nobuo
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Ice Conditions in Lützow-Holm Bay, Antarctica, 1956-59, Presented on the Basis of Photo-Interpretation*

By

Kou KUSUNOKI and Nobuo ONO

楠 宏 · 小野 延雄

*Oceanography Section, The Institute
of Low Temperature Science*

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Abstract

Based on airphotos taken by Lars Christensen's Expedition (1937) and by the Japanese Antarctic Research Expedition (1957 and 1959), Antarctic ice features on the coastal area of Lützow-Holm Bay, especially in the vicinity of Showa Base, are discussed. Pairs of airphotos covering the same areas in different years are used for a comparative study of the long term changes in ice conditions, such as the flow rate of channel glaciers and the decay of ice tongues. Sea ice conditions in the bay are studied on the basis of shipboard observations and airphotos.

1. Introduction

Lützow-Holm Bay, Queen Maud Land, Antarctica, was first sighted from the air on the 21st of February, 1931, by H. RIISER-LARSEN and NILS LARSEN from the Norwegian expedition led by GUNNAR ISACHSEN aboard the *Norvegia* (G. ISACHSEN 1931). On this occasion the southern extension of the sea was observed in the distance covered with very dense pack-ice, small leads and open water. This ice-covered sea extended between meridians 35 and 40°E. From this flight the eastern shore of the bay, Prince Olav Land, discovered in the previous year, was sighted in the distance. In 1933 RIISER-LARSEN failed in an attempt to land on the northern promontory of an ice-covered peninsula at about 34°E. This peninsula, named after RIISER-LARSEN, forms the western boundary of Lützow-Holm Bay. From the viewpoint of the history

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of Antarctic exploration, it should be noted that Captain COOK made the first crossing of the Antarctic Circle in 1773 north of Lützow-Holm Bay. Since that time several explorers have attempted penetration of this bay.

The coastal area of Lützow-Holm Bay was first photographed from the air by member of LARS CHRISTENSEN's expedition aboard the *Thorshavn*. On February 4, 1937 an air reconnaissance flight was made by LARS CHRISTENSEN over the hitherto unknown land between 34 and 40°E and this land was named Prince Harald Land (Prins Harald Kyst). The following day aviator VIGGO WIDERØE and photographer NILS ROMNAES took oblique photographs of this coast, using an electrically driven RKM P21 Zeiss camera (18 × 18 cm film size, 21 cm focal length), from an altitude of between 1400 and 2000 meters (L. CHRISTENSEN 1938). At this time the *Thorshavn* was hove to at 34°03'E and 67°50'S. In 1946 H. E. HANSEN worked out the first map of this area drawn to a scale of 1:250000 using as its basis the *Thorshavn*'s position and the photographs obtained by WIDERØE and ROMNAES.

In the 1946-47 season the U. S. Naval Task Force 68 executed an intensive photo reconnaissance survey (Operation Highjump) over the Antarctic continent. They made several flights over Prince Olav and Prince Harald Lands at altitudes of about 3000 meters using an aircraft equipped with a K17 camera with a trimetrogon photographic system. One of the most valuable references for photo-interpretation of Antarctic ice features was published following this operation, but no maps have been drawn of this area (U. S. Air Force 1953).

The first landing on Prince Harald Land was made by the Japanese Antarctic Research Expedition (JARE) in January 1957. This expedition was organized to carry out scientific programs during the International Geophysical Year, 1957-58. They established Syowa Station on East Ongul Island, about 5 km from the eastern shore of Lützow-Holm Bay. Representatives from the Geographical Survey Institute of the Ministry of Construction were responsible for the aerial photogrammetry and the terrestrial surveys. During the first mission to the Antarctic in 1956-57 several flights were made for the purpose of photogrammetry and logistics. During the following season of 1957-58 adverse weather and ice conditions and the use of the aircraft for evacuation of the wintering over party from Syowa Station made any further photo survey work impossible even though the plane was equipped with cameras. During the 1958-59 season Syowa Station was reoccupied but only one flight was made for the purpose of aerial photogrammetry. This flight was made on February 5, 1959 starting from the expedition ship *Soya* which was at 40°14'E and 67°41'S and proceeding along the Prince Olav coast.

The authors were members of the expedition as oceanographers and ice observers on board the *Soya*: KUSUNOKI in 1956-57 and ONO in 1958-59. This report is based upon the actual ice conditions as observed from the ship and the aerial photographs taken by T. KAJI in 1957 and by A. YOSHIDA in 1959. These oblique and vertical photographs cover the eastern part of Lützow-Holm Bay, especially in the vicinity of Syowa Station. Since the original purpose of the aerial photographic survey was to aid in the compilation of maps of the land area, there are very few photographs of the sea ice conditions in the central part of Lützow-Holm Bay. Of the many airphotos taken by the Norwegian party in 1937, only twenty were available to the authors during the present study. The airphotos taken by the U.S. Task Force 68 were left on Syowa Station and could not be used at all. The twenty Norwegian airphotos were useful for comparative study of long term changes in the ice conditions, but the primary basis for the following discussions are the data obtained by JARE, and particularly those obtained during the austral summers of 1956-57 and 1958-59 when the authors were members of the expedition.

II. Airphoto Survey of the Japanese Antarctic Research Expedition

A Cessna-180 aircraft equipped with floats or skis was used for airphoto survey in the austral summer of 1956-57. A Fairchild K-17 camera with a lens of 15 cm focal length and a film size of 9×9 inches, was installed for vertical photography. A hand-held Williamson F-24 camera with a focal length of 5 inches and a film size of 5×5 inches, was used for oblique photography. In addition to these, the aircraft was also equipped with a small hand-held camera (Konishiroku, Tokyo). Between January 14 and February 1, 1957, nine airphoto reconnaissance flights were made along the coast of Prince Olav and Prince Harald Lands and a detailed aerial survey was carried out in the vicinity of the Ongul Islands. A total of 750 vertical and 450 oblique airphotos were obtained using Eastman Kodak Super XX Aerographic Film (9.5 inches×150 feet rolls) and Sakura Aero Film (5.5 inches×56 feet rolls). The average exposure for vertical photos was 1/400 second at $f=8$ or 11 with a No. 2 Aero Vignetted Filter. Two maps were drawn as a result of this operation: "Syowa Base, scale 1:1000" and "East Ongul Island, 1:5000". This season's survey was reported by T. KAJI (photographer) and E. IMBE (terrestrial surveyor) (1957). They also determined the position of Syowa Station by sun-shots with a Wild T2 theodolite and established eight ground control points on East Ongul Island. The position of Syowa Station thus

determined was:

Longitude $39^{\circ}35'24'' \pm 12''$ East,
 Latitude $69^{\circ}00'22'' \pm 04''$ South.

The flight routes for this season are shown in Fig. 1, which also includes one route flown in 1959 along the Prince Olav Coast. In February of the 1958-59 season about 190 vertical airphotos were taken from a De Haviland Beaver (DHC-2) which had also been used for airphoto reconnaissance during the previous season. The results were published as two maps entitled "Prince

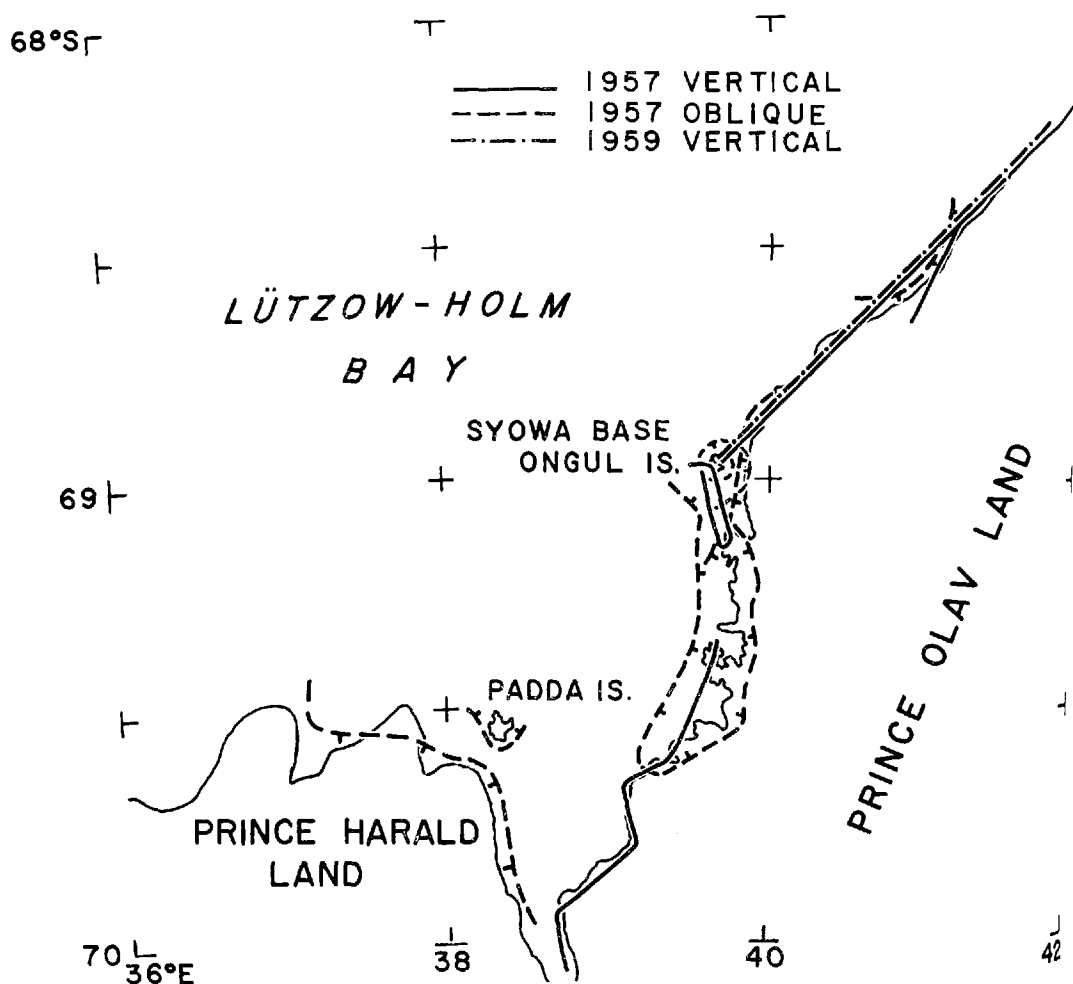


Fig. 1. Flight routes of aerial surveys by the Japanese Antarctic Research Expedition in 1957 and 1959

Olav Land, I and II" with a scale of 1:100,000.

It should be noted that the position of Syowa Station is fixed as 39°45'E and 68°58'S on the map compiled by H. E. HANSEN. While this indicates an error of about 5 minutes in his map, this error is remarkably small when one considers that the map was compiled from oblique photographs without ground controls. It was also found that a narrow channel filled with snow and ice divides Ongul Island into two parts, i.e. East Ongul on which Syowa Station was located and West Ongul, which was not identified in HANSEN'S map.

III. Surface Features of the Littoral Area of Lützow-Holm Bay

During the summer season of 1956-57, the major effort of JARE was the establishment of the Syowa Station, but a few days' field survey of geomorphology and geology was carried out around the Ongul Islands and the Langhovde mountain area about 20 km south of the station. During the winter of 1957, field surveys were carried out in the vicinity of the station, and along the Prince Olav Coast as far east as 42.5°E and in the Skarvsnes and Skallen area to the south of the station. Some members of the party accomplished the first ascent of Mt. Botnnuten whose elevation is given as 1480 meters on HANSEN'S map (T. YOSHIKAWA and H. TOYA 1957; T. TATSUMI, K. KIKUCHI and H. KUNO 1957; T. TATSUMI and T. KIKUCHI 1959a, b). A summarized description of the area covered by these surveys, particularly in the vicinity of Syowa Station, will be given. Fig. 2 is presented as an aid in understanding the descriptions which follow, which were compiled from the photographs and which show the major outlets of land ice and the exposed land areas.

Ice cliffs and exposed rocks form the coast-line of Prince Olav Land that portion of the coast of Queen Maud Land which lies between 40 and 45°E). Prince Harald Land which lies between 34 and 40°E, contains many ice-free areas scattered between 38.5 and 40°E. The Riiser-Larsen Peninsula, a broad ice-covered projection, forms the western portal to Lützow-Holm Bay. In 1934 this bay was named by B. AAGAARD for Cdr. FINN LÜTZOW-HOLM who was a pilot with the Norwegian expedition under RIISER-LARSEN in 1929-30.

Many prominent, exposed areas exist on the eastern coast of Lützow-Holm Bay. Langhovde, with the highest elevation of 510 meters, Skarvsnes (355 m), and Skallen (190 m) are conspicuous rocky headlands bordering this coast. At lower elevations there are many small, bare rocks and glacial deposits.

Ongul Island group and its highest elevation is 255 meters.

These islands and rocky headlands are composed of many kinds of metamorphic rocks probably of pre-Cambrian origin. The characteristic geomorphological features of this area have been attributed to the effects of glaciation by the continental ice sheet. Evidence of such glaciation in the recent past is given by polished surfaces, roche moutonnée, striations, grooves, and the glacial moraines. Small glacier cirques remain near the summit of Langhovde mountain and strong nivation, weathering, and wind erosion are exerting their influence upon the formation of the present glacial topography. Terrace-like elevated surfaces about 15 to 30 meters high found in the Ongul Islands and on Langhovde gave evidence of recent eustatic movement which was further confirmed by the existence at these levels of sand and gravel layers bearing fossil-shells. According to observations made by the above mentioned researchers, the direction of ice movement in the recent past was estimated to be from E to W or ESE to WNW which is approximately normal to the eastern coast-line of Lützow-Holm Bay which lies north and south.

In the late months of 1957 the following two ground controls were determined:

Mount Botnnuten	37°55.1'E, 70°23'S,
Hinode-misaki*	42°37.2'E, 68°08.6'S.
(Cape Sunrise)	

From the shore Mt. Botnnuten is the only nunatak to be seen in Prince Harald Land.** There was not sufficient time to carry out a terrestrial survey in the summer season of 1957-58 and 1958-59, and a more detailed terrestrial survey, including distance measurement by tellurometer, was planned for the summer of 1959-60.

The geomorphology and geology of the shoreline of Prince Olav Land north of Syowa Station has not yet been reported in detail, with the exception of the glaciological observations made by TATSUMI and KIKUCHI (1959 b), despite several trips to the east made during the the winter of 1957.

Several airphotos are included to supplement the above description of the surface features of the littoral area and to aid in visualization of the details. Plate I (A, B) and II (C, D) are shown in order from east to west across Lützow-Holm Bay, passing over Syowa Station on the Ongul Islands.

Plate I-A shows the coast of Prince Olav Land at 41.5°E and 60.5°S.

* Named by JARE I, 1956-57.

** The nunatak area (Yamato Mountains) at 71.5°S, 35.8°E was surveyed by JARE IV in November of 1960. The highest peak of about 2470 meters was named Mt. Fukushima, for Shin Fukushima who was lost in 1960 near Syowa Station.

The surface of the land ice, the major part of which is covered with snow, indicates a featureless topography with very slight undulation. Outlets of ice forming ice streams and many exposed rocks and glacial deposits may be seen along this coastline. In other places on the coastline north of 69°S there are ice cliffs and tongues of ice. The average height of the ice cliffs is about 20–50 meters with a maximum of 100 meters.

Many ice-free, hilly islands and headlands may be seen between 69 and 70°S on the eastern coast of Prince Harald Land. For example, Plate I–B shows the Ongul Islands and the continental ice with almost featureless surfaces. No exposed area is seen on the plateau of Prince Olav Land or in eastern Prince Harald Land, but ablation phenomena are conspicuous on the islands and the sea ice. The slope of the surface near the coast seems steeper than that of the higher inland elevations above 500 meters. Vehicular approach to the continent in this area is severely limited by the ice cliffs, some tens of meters in height, which form the coastline.

Plate II–C shows the unique nunatak, Mt. Botnnuten, about 40 km away. The surface is very even except in the crevassed area near the coast shown at the bottom of this photo, which is the western lateral of crevassed glacier at 38.5°E.* The western part of Prince Harald Land bordering this glacier has a very low elevation and an even surface topography.

Plate II–D shows the northern edge of Riiser-Larsen Peninsula with its low elevation and fringing ice shelf.

These oblique photographs are too small and usually taken from too great a distance to show any of the surface details, but additional details are available thanks to the observations made by the wintering party of 1956–58 (T. TATSUMI and T. KIKUCHI 1959a). In April 1957 a trip was made from Syowa Station to the east side of Langhovde on the continental ice at an elevation of about 500 meters. This route is pictured in Plate I–B. Another trip was made to Mt. Botnnuten during September–October 1957, crossing the sea ice from the station to Padda Island in Havsbotn. The surface condition of the continental ice along this route may be seen in Plate II–C. TATSUMI and KIKUCHI (1959a) reported that the eastern part of Prince Harald Land may be characterized as a wastage zone in contrast to the western part which is bordered by the Shirase Glacier centered at 38.8°E. These surface traverses were, of course, limited to the littoral area, so that the extension of this wastage zone onto the higher plateau has not yet been confirmed. Their conjecture was based on the fact that the depth of the snow cover in eastern Prince Harald Land was 10–30 cm, while much deeper snow cover was observed

* The Shirase Glacier (named in 1961 by JARE for Lieut. Nobu Shirase).

en route to Mt. Botnnuten. Also, many meltwater pools and streams were found on the continental ice on the eastern coast; in some places exposed blue ice (superimposed ice) which was believed to have been formed from meltwater, was observed. The deteriorated ice surface of the eastern coast of Prince Harald Land is evident in Plate III. Well-developed streams on the ice surface, many meltwater pools (tarn) on the rock surface,* and ice morass in sea ice, indicate how intensively ablation takes place in the land area.

Skavler on the eastern coast of Prince Harald Land are 10–20 cm high and develop ENE along the direction of the prevailing winds. In the vicinity of Padda Island, the direction of the skavler on the sea ice was SES and their height attained 30–70 cm. The direction of the huge snow drifts on the leeside of Mt. Botnnuten was WNW, while the skavler of this area were oriented in the north-south direction. The crevasses with undulated surfaces, some of them snow-filled or bridged, are found in the higher elevations and their outlets are in the vicinity of Syowa Station. The vast continental ice sheet covers this land mass where there are no mountains, no rugged terrain or ice capped islands. No highland, cirque or avalanche ice was observed, just small scale, snowdrift ice lying in the lee of the rocky coastline of Prince Olav Land.

Glaciers: Most of the outlets of land ice are channel glaciers in this region, as there is no evident upheaval of sub-glacial topography. Most of the outlets shown in Fig. 2 may be classified as channel glaciers, and Plate I-A also shows an example of this type of glacier. As mentioned before, the ice sheet covers Riiser-Larsen Peninsula and forms an ice shelf with a gentle surface gradient at the littoral sector. In contrast to this, a fairly rugged sub-glacial topography of the coast along Prince Olav Land and eastern Prince Harald Land may be deduced from the surface features. No ice shelf may be seen along Prince Olav Land between 39 and 42°E.

The Shirase Glacier, whose tongue floats into Havsbotn, is in the boundary region between the ice-covered Riiser-Larsen Peninsula and the east coast of Prince Harald Land. The east side of this glacier is shown in Plate IV, where its width is about 10 km there are many ice pinnacles and seracs along the side of the glacier and streams and melt water lakes, some of them a few hundred meters in diameter and partly frozen, on its surface. Drifted snow makes the crevassed surface indistinct. It is estimated that the length of the

* TATSUMI and KIKUCHI (1959 a) noted that some pools in the Langhovde area would presumably not freeze down to the bottom. They estimated the depth to be exceeded 3 to 4 meters. Though they did not measure the salinity of the pools, it is probable that some of them are saline as others found in Antarctic coast have been and that lake ice will not form down to the bottom.

main body of the floating tongue of Shirase Glacier extends about 40 km into Havsbotn.

Another example of a channel glacier is shown in Plate V-A and B (east side) and Plate VI-A and B (west side). This glacier is located in Prince Olav Land at 41.3°E and 68.5°S. The flow rate of this glacier was estimated from a comparison of the airphotos taken of it in 1957 and 1959. This rate was estimated to be 300 m/year in the case of airphotos V-A and B and 400 m/year for airphotos VI-A and B.* Such pairs of airphotos were unfortunately unavailable for any other site or year but from the movement of stakes set on the ice slope at an elevation of 150 m, about 11 km from Syowa Station, it was estimated that the flow rate was an order of one meter in the direction of WNW within 8 months in 1957 and 1958 (T. TATSUMI and T. KIKUCHI 1959 b). This rate is very small in comparison with the rate estimated from the airphotos, however they reported that many cracks and hummocks in the sea ice presumably caused by glacier flow, suggested active movement of the outlets.

Changes in glacial morphology may be seen in Plate VII-A and B, the most striking of which is the disappearance of the Honnörbrygga Ice Tongue which may be seen extending about 5 km from the shore in Plate VII-A, taken by the Norwegians in 1937. Plate VII-B, taken in 1957, shows the remnants of the calved ice tongue represented by tabular icebergs in Byvägen Inlet south of Honnörbrygga. This strongly suggests that the decay of the ice tongue took place in recent years, at least within the last twenty years. Similar calving of an ice tongue was observed at Kjukevågssodden (Kjukevåg Ice Tongue), located between Skarvsnes and Skallen, but airphoto surveys in 1957 and 1959 show no remarkable calving along the Prince Olav Coast during this period. Meteorological observations made at Syowa Station since 1957 suggest that gale winds with velocities in excess of 80 knots rarely occur more than once in several years. In March of 1957 a maximum wind velocity of 32.9 m/sec (64 knots) was recorded and the fast ice covering Ongul strait between the continent and Ongul Island was broken and drifted southward. Breaking of the ice in the channel was not again reported until February 1962. It is worthy of note that the outburst of Greenland icebergs into Baffin Bay occurs at intervals of 20 to 25 years (ZUBOV 1945) and also that there were 13 severe iceberg seasons off Newfoundland during the period from 1900 to 1961 (I. I. SCHELL 1962). It is therefore conjectured that the remarkable calving of ice tongues and the breaking of fast ice in the Lützow-Holm Bay area may take

* An estimation of the flow rate of this glacier was reported by NAKANO, KAJI and HARADA (1960), as 832 to 1208 meters in two years.

place under extreme climatic conditions which usually occur only once in every several years.

In general, the surface of the continental ice along the coast of Lützow-Holm Bay is considerably influenced by intensive solar radiation and high air temperatures in the summer season. The air temperatures in summer rise above zero and the mean temperature of the coldest month (August) in 1958 was -20.4°C (N. MURAKOSHI 1958), which suggests that the climate of this area is mild in comparison with other inland station areas.

IV. Sea Ice Conditions in Lützow-Holm Bay

Before discussing the conditions in Lützow-Holm Bay based on the air-photos, ice conditions observed by the expedition ship *Soya* will be given. These are valuable since such intrinsic characters of ice such as thickness, density, structure, etc. can hardly be deciphered from airphotos. Aboard the ship observations were carried out by radar, optical instruments and naked-eyes. Ice type, size, thickness, concentration, age and surface topography are reported, as is its stage of decay and the amount and condition of its snow cover. Related meteorological observations and information obtained by ice reconnaissance flights are also included. Since these flights were made by plane and helicopters whose primary purpose was to assist the *Soya* in navigating through the ice, the observations from the aircraft and from the ship are limited to Lützow-Holm Bay and especially to those areas most favorable to navigation.

1956-57 season

On January 4, 1957 the first iceberg was encountered at $35^{\circ}00'\text{E}$ and $53^{\circ}55'\text{S}$, and the *Soya* reached the edge of the ice off Cape Close in Enderby Land, on January 7. The ship navigated along the edge of the open pack-ice from about 54°E and 65°S to 33°E and 67.5°S , off Riiser-Larsen Peninsula. She then returned to about 40°E where she entered the pack-ice on January 16th and on January 24th she finally moored at the edge of fast ice at $39^{\circ}09'\text{E}$ and $69^{\circ}00'\text{S}$. Fast ice about 2 meters thick developed for about 20 km between the ship and Ongul Island. Fig. 3 shows the northern fringe of the pack-ice of this season and of the 1959 season.

The concentration along the ship's southbound course sometimes exceeded 8/10th. The dominant ice type was hummocked winter ice about 1 meter thick in floes ranging from a few meters to several hundred meters in diameter. The major part of the ice surface was covered with snow up to 50 cm in depth and few meltwater pools were seen. The average thickness of the rafted

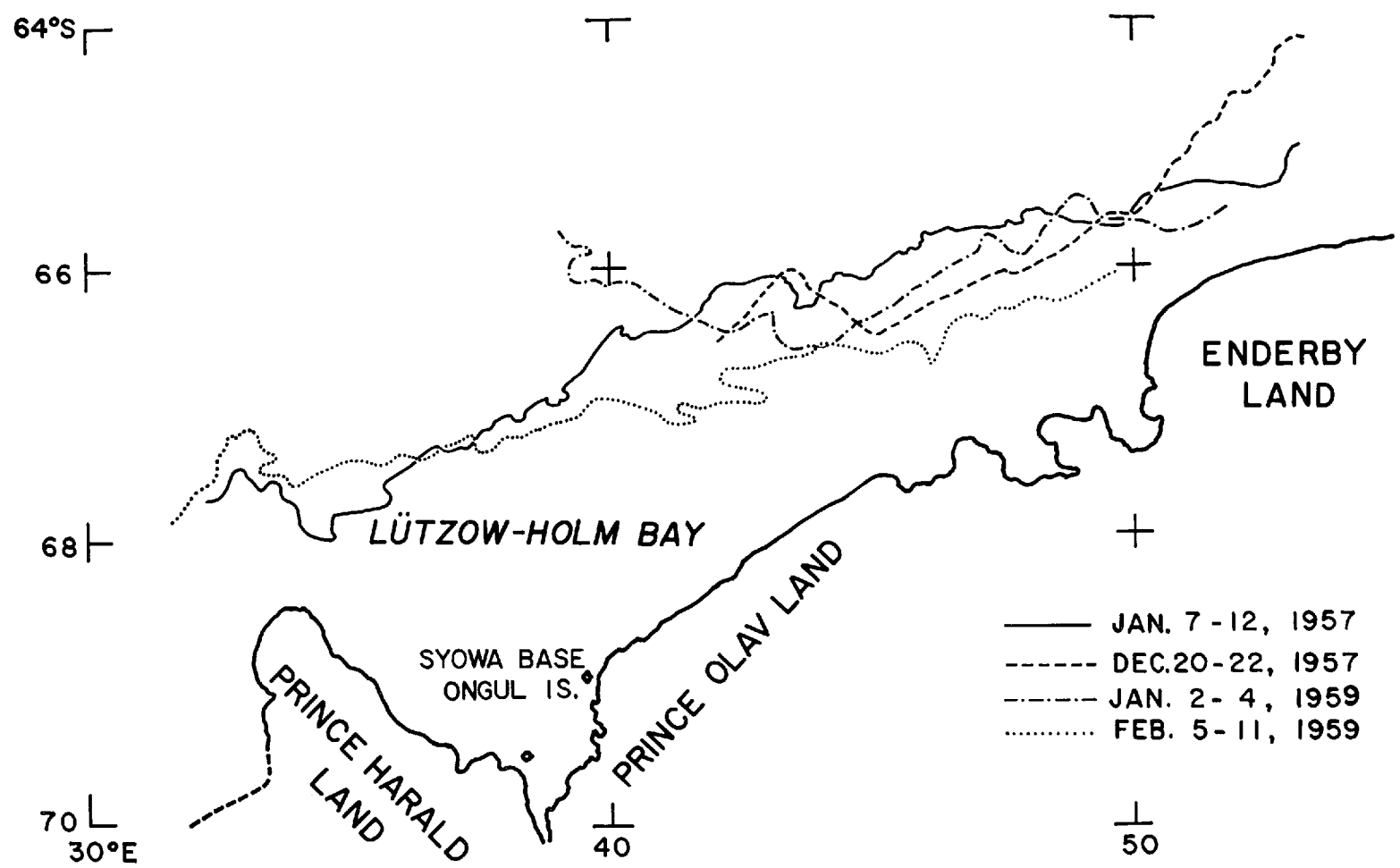


Fig. 3. Observed positions of the edge of the pack-ice in the summer months of 1957 and 1959 in the Lützow-Holm Bay area

ice was about 1 meter.

The ship's southward journey through the pack-ice was facilitated by an open lead about 35 km off the coast of Prince Olav Land and running parallel to it but on the return voyage the ship was beset with consolidated pack-ice. At one time during a storm she drifted westward maintaining an average speed of 0.6 knots, but she finally escaped from the ice at about 35°E and 68°S, northeast of the Riiser-Larsen Peninsula. The ice conditions of this season were summarized in ice charts compiled by KUSUNOKI (1958).

The *Soya* was accompanied on this operation by the *Umitaka Maru* from Tokyo University of Fisheries which cruised along the outer edge of the pack making observations of the ice drift, icebergs and the drift of the icebound *Soya* (T. KUMAGORI, II. HOTANI and S. YANAGAWA 1958).

1957-58 season

In the 1957-58 season the *Soya* was icebound in Lützow-Holm Bay for 40 days because of adverse weather and ice conditions. The rescue of the wintering-over party on Syowa Station was effected by Beaver aircraft in cooperation with the USN ice-breaker, *Burton Island*. Plans for reoccupation of the station were abandoned because of the lateness of the season and, as was mentioned before, it was impossible to conduct any airphoto survey flights.

The first iceberg of the season was sighted at 39°00'E and 53°48'S on December 17, 1957 and the ship reached the edge of the pack-ice at 53°00'E and 62°50'S on the 20th, off Cape Close, Enderby Land. Between December 23, 1957 and January 31, 1958 the icebound ship drifted west-southwest until she worked free at the northwest of Riiser-Larsen Peninsula, at which time the relief operation was commenced.

During February the following ice edges were observed: February 6, 1958; 31°22'E, 67°46'S; 8th, 39°18'E, 67°43'S; 23rd, 29°32'E, 67°53'S. The dominant ice type was hummocked winter ice about 1-2 m thick intermingled with weathered floes which were believed to be two years old or more. Many icebergs and bergy-bits were found off western Prince Olav Land and north of the Riiser-Larsen Peninsula. Stranded icebergs were also found in the Gunnerus Bank area off this peninsula. The surface of the ice was usually covered with snow about 30-50 cm deep and meltwater pools were occasionally observed on the surface. When the ship was beset, the ice drift rate was observed to be 0.1 to 0.9 knots, with an average angle of deflection of 17°. The *Soya* began her return trip on February 24. (S. MURAUCHI and Y. YOSHIDA 1959).

1958-59 season

In this season the first iceberg was encountered at 33°26'E and 50°10'S

on December 29, 1958 and the *Soya* reached the edge of the pack-ice off Cape Close, Enderby Land on January 2, 1959, at $50^{\circ}01'E$ and $64^{\circ}59'S$. Between January 14 ($40^{\circ}27'E$, $67^{\circ}33'S$) and February 1 ($37^{\circ}18'E$, $67^{\circ}49'S$) the ship drifted with the pack-ice. During this period the reoccupation of Syowa Station and the air lift of the cargo was executed. The ice surrounding the ship was composed of small ice floes of thick winter ice and brash ice and snow slush cemented the floes. In the latter period of the drift the floes were rafted with the height of the raft ice reaching 2–3 meters above the level surface of the ice. The snow-cover observed in this season was much deeper than that of the previous two seasons. Airphoto reconnaissance was carried out on February 5 along the Prince Olav Coast and vertical photographs were taken of the pack-ice near the ship moored to the ice edge. On February 12 the ship set sail for the north and the last iceberg was seen on February 18 at $23^{\circ}20'E$ and $48^{\circ}03'S$. The ice conditions observed on board the ship, especially the drift of the pack-ice field and its compaction and rarefaction were reported by ONO (1959, 1960).

An outline of the conditions of sea ice and icebergs observed from the *Soya* is given in brief. It should again be noted that the routes of the photo reconnaissance flights are limited to the littoral area in Prince Olav, Prince Harald, and Lützow-Holm Bay (see Fig. 1), therefore, there are no photos which indicate the surface features of the sea ice in the central part of the bay. Prior to the description of the sea ice along the coast covered by air reconnaissance, a supplemental figure relating to the mean position of the edge of the pack-ice off Syowa Station is given (Fig. 4). The position of the edge of the pack-ice at $40^{\circ}E$, roughly that of Syowa at $39.6^{\circ}E$, was read for each month from the charts of MACKINTOSH and HERDMAN (1940) and "Oceanographic Atlas of the Polar Seas, Antarctica" (U.S. Navy Hydrographic Office 1957). On the latter chart, the northernmost position of ice with greater than 5/10th concentration was adopted. Those positions were plotted in Fig. 4 with the data of JARE.

Fig. 4 indicates that the edge of the pack-ice off Syowa Station is to be found at about $67^{\circ}S$, which is more than 200 km from the coast. It is therefore deduced that the variation in the position of the pack-ice in summer months is within a range of 60 miles (Fig. 3 and 4). The ice inside the edge of the pack is fairly well consolidated and in almost every season of the year, the shore is fringed with fast ice so that navigation of the Lützow-Holm Bay area is very difficult even for icebreakers of the *Wind* and *Ob* classes. In *Soya's* (4200 ton displ., 4800 H.P.) experience with JARE her closest approach

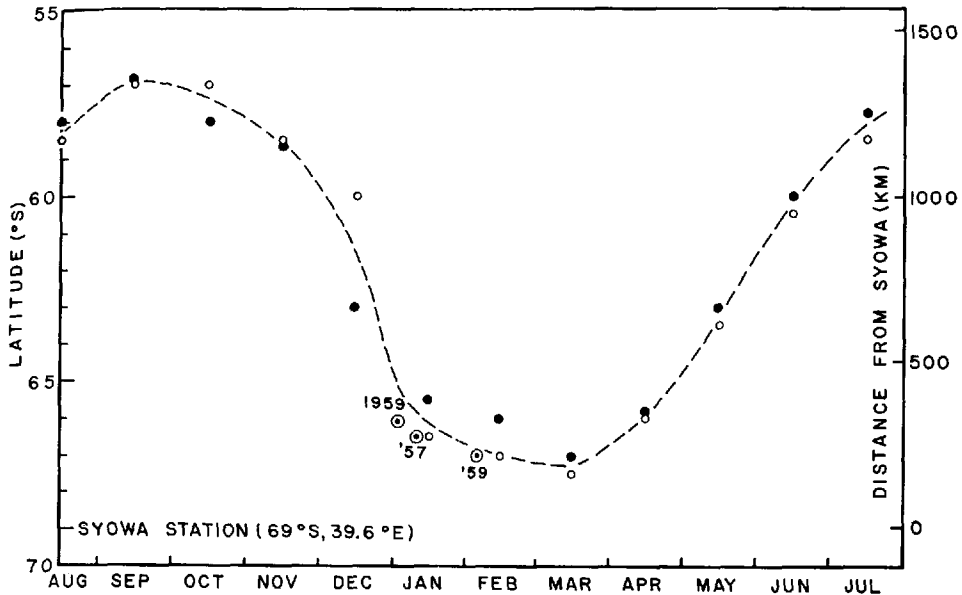


Fig. 4. Monthly position of the edge of the pack-ice on the meridian 40°E .
 Open circles: MACKINTOSH and HERDMAN (1940); Closed circles: Oceanographic Atlas of the Polar Seas, Antarctica (1957); Circles with dot: JARE in 1957 and 59

to the shore was in February, 1957 when she reached the shore fast ice extending about 25 km from the shore of Ongul Island. In other operational seasons, the width of the polar fast ice did not differ very much from the above figure, but navigation was very difficult because of dense pack-ice which extended more than 100 km from the shore. Supply and relief operations were inevitably executed by helicopters and light airplanes with the exception of the 1957 season when surface transportation was used. As is shown in Fig. 3 and 4, the width of pack ice along the coast of Prince Olav Land usually exceeds 50 miles in normal summer months. Navigation is, of course, largely dependent upon the winds and seas which recess the pack-ice. As the direction of the prevailing wind in this area is NE, favorable off-shore winds are rarely experienced in normal years. These unfavorable natural conditions forced JARE to remodel the *Soya* into a type of aircraft carrier.

Mention should be made of the noticeable surface features of the sea ice which are discernible in the vertical airphotos of the littoral area. Plate VIII shows the level sea ice floating in the upper left and the polar fast ice in the right. Many puddles may be seen on the surface of the sea ice. These puddles averaged 50 cm in depth. As the thickness of the fast ice at the

mooring site was 2.4 meters, it was deduced that this ice was several years old. In order to verify this conjecture, the maximum thickness of winter fast ice at the shore of Antarctica was estimated by the use of the following formulas ;

$$I^2 + 50I = 8R \quad \text{ZUBOV (1945)}$$

$$I = (2.1 \sim 2.7) \sqrt{R} \quad \text{FUKUTOMI, KUSUNOKI and TABATA (1950)}$$

where I is the maximum thickness in cm and R is the degree-days of frost. The results are shown in Table 1.

Table 1. Computed maximum thickness of the winter ice of the Antarctic coast

Location	Year	R (deg.-days)	Maximum thickness (cm)		
			(ZUBOV)	(FUKUTOMI et al.)	
Syowa	1957-58	3660	148	127	163
Mawson	1957	3595	146	125	161

Computed values of the maximum thickness of the winter ice are in a range of 125-163 cm. This supports the conclusion that the fast ice shown in Plate VIII which is 2.4 meters thick should be classified as several years old. If one assumes that 2.5 meters is the maximum thickness of polar fast ice in this area and that the number of degree-days of frost is 3700, then the mean annual ablation of the ice is probably about 50 cm using ZUBOV's estimation of maximum thickness and mean annual ablation.

The air reconnaissance flights of 1957 and 59 showed almost universal ablation phenomena of the ice surface. For example, Plate IX shows puddles on the sea ice and frozen meltwater pools and meltwater streams on the top of an iceberg. The open water on one side of the iceberg and the sea ice jammed around the other side suggests the presence of relative motion between the iceberg and the surrounding sea ice along a N-S direction. Note the concentric ablation pattern around the iceberg in the left center. Plate IX was taken south-west of Skarvsnes mountain, so that the thermal effect of exposed land is more pronounced on the surface of the sea ice. Plate X shows a typical example of the final stage of ice deterioration in the proximity of exposed land and many meltwater pools (tarn) on the lower elevations of the land and completely melted puddles.

A description of the calving of the Honnörbrygga Ice Tongue which probably occurred within the past twenty years, has already been given. Plate XI-A and B are the unique pair which covered the same area for the two

years, 1957 and 1959, and they were used to study the movement of the icebergs and the water-borne ice tongue fragments. During these two years there was no perceptible change in the position of the iceberg groups "A" and "B" as shown in these photos and because of this and their height above the sea ice, they were presumed to be grounded. It was reported that Ongul Strait between Ongul Islands and the continent was opened by a strong blizzard in the austral fall of 1957. It is unlikely that transposition of these icebergs could take place under such severe conditions. There has been no further report of breaking of the sea ice shown in Plate XI-A and B despite the remarkable deterioration of the sea ice in the summer months.

Plate XII-A and B are presented for comparison of the ice conditions around Syowa Station in 1937 (A) and 1959 (B). There is no perceptible change in the general ice condition or in the land morphology, except for the appearance of the iceberg group "Λ" shown in Plate XII-B which is the same group shown in Plate XI-A, B and previously discussed. Plate XII-A and B contain no decipherable guidance of advance or retreat of the continental ice.

These comparative studies suggest that marked change in the ice conditions such as the grounding of the iceberg groups are rare, probably occurring only once in several, possibly a dozen, years.

V. Concluding Remarks

The major part of the descriptions given in this paper concerns the physiographic nature of the surface of the continental and sea ice and the features of the exposed rock in the littoral area of Lützow-Holm Bay area in the Antarctic. Results of field observations carried out by geologists, geomorphologists, surveyors, and oceanographers of JARE are summarized to supplement the report. The airphotos taken by JARE did not cover the greater portion of the central part of the bay, so that the descriptions of ice conditions are restricted to the littoral area of Prince Olav and Prince Harald Lands, and especially the vicinity of the Ongul Island group on which Syowa Station was established in 1957.

The area subjected to the present discussions may be classified as a so-called Antarctic "Oasis". Airphotos of both the land and sea areas are included, which show ablation phenomena resulting upon the intensive solar radiation and relatively high air temperature of this region. Despite this ablation, these airphotos also give evidence of continued active glacial flow and the existence of many coastal outlets. Paired airphotos are used to estimate the average flow rate of a glacier in Prince Olav Land and to illustrate the

calving of ice tongues south of Syowa Station.

Sea ice conditions are unfavorable for navigation despite the warm climate of the Lützow-Holm Bay area. The ice which clogs the central portion of the bay under the influence of the prevailing winds from the north or northeast along the coast of Prince Olav Land and currents setting SE at velocities of 0.2 to 0.3 knots, is prevented from further movement by the shallow Gunnerus Bank off the Riiser-Larsen Peninsula and by the peninsula itself which forms the western shore-line of the bay. Conditions are also unfavorable for surface transportation in this area because of pressure ridges in the pack ice and meltwater pools on the fast ice which effectively prevented vehicular use except in the 1956-57 season.

Though the present report is largely concerned with ice conditions in the littoral area, much information such as morphological analysis of the land area may be gained by detailed photo-interpretation. The airphotos taken by JARE are too large in scale (1:10,000) to be useful in any study of the flora or fauna of the area and airphotos of smaller scale should be planned. Preplanned air reconnaissance survey is also badly needed for such specific subjects as photogrammetry, surface physiography of land, snow and ice, glacier flow, ice cliff variation, calving of ice tongues, compaction, rarefaction and drift of sea ice, iceberg drift, and so forth. The importance of glaciological observations in the vicinity of Syowa Station emphasizes the necessity for yearly airphoto flights during the summer season to record glaciers, ice cliffs, and glacier tongues in relation to the ice budget of Antarctica. Even though the meteorological satellites which are currently orbited for sea ice reconnaissance are making great contributions, airphoto flights over the pack ice area are still necessary to obtain more detailed information about Lützow-Holm Bay. The use of color and infrared film has proved most valuable in ice photo-interpretation. Unfortunately these special techniques were not adopted by JARE, but the authors believe that they will doubtless be used in the future when scientific activities are resumed in connection with the reopening of Syowa Station.

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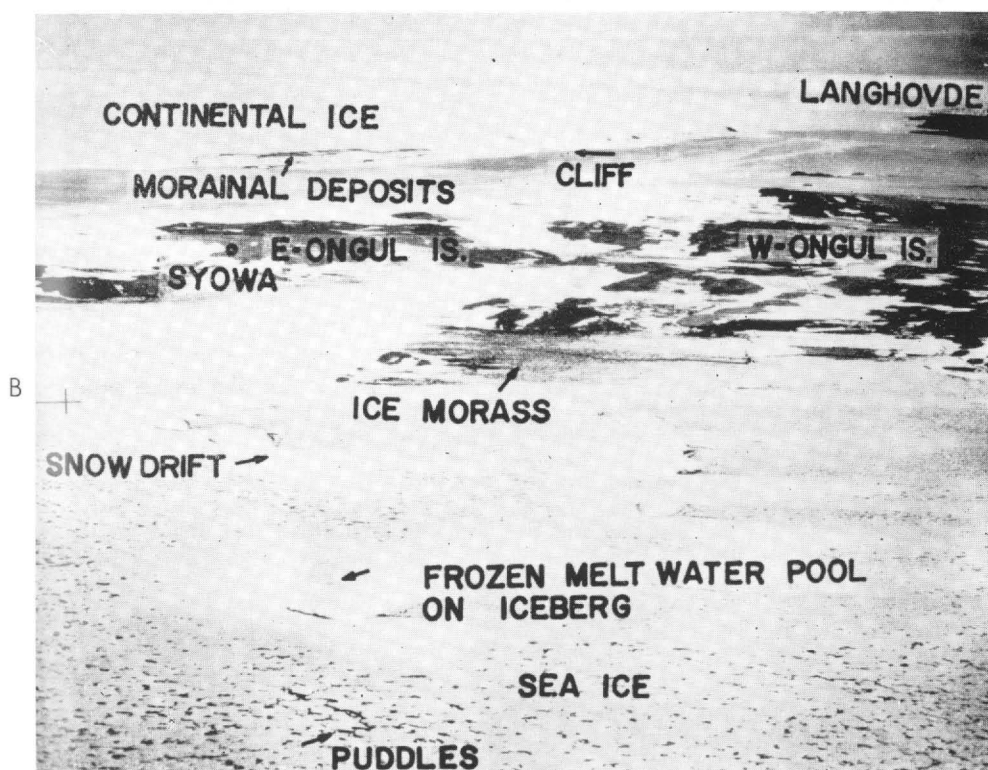
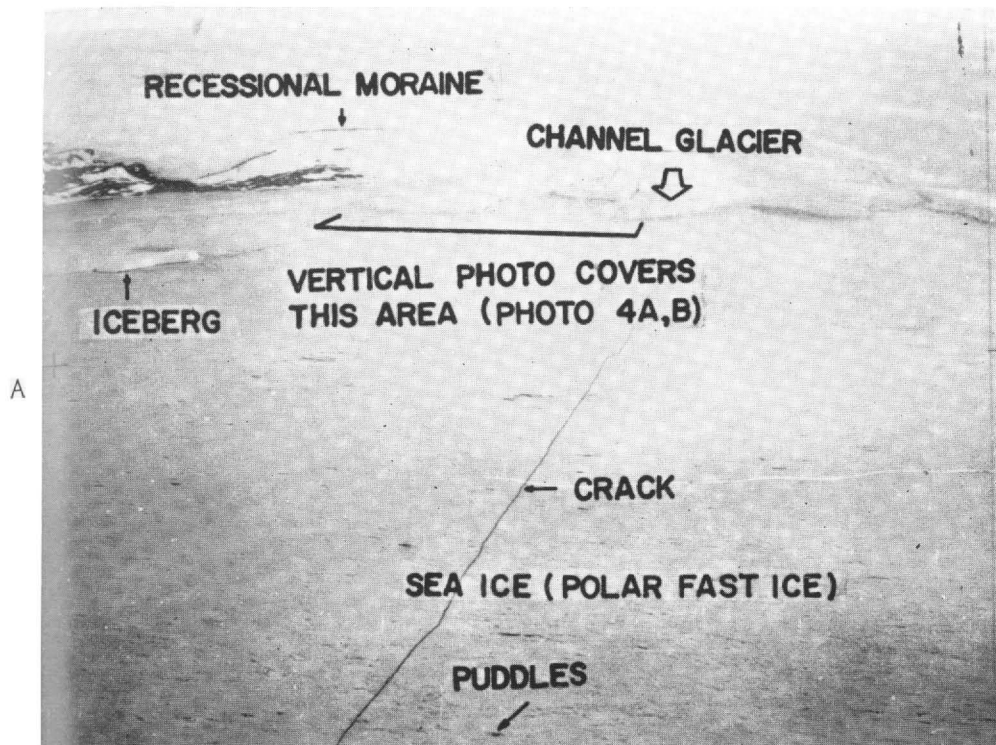
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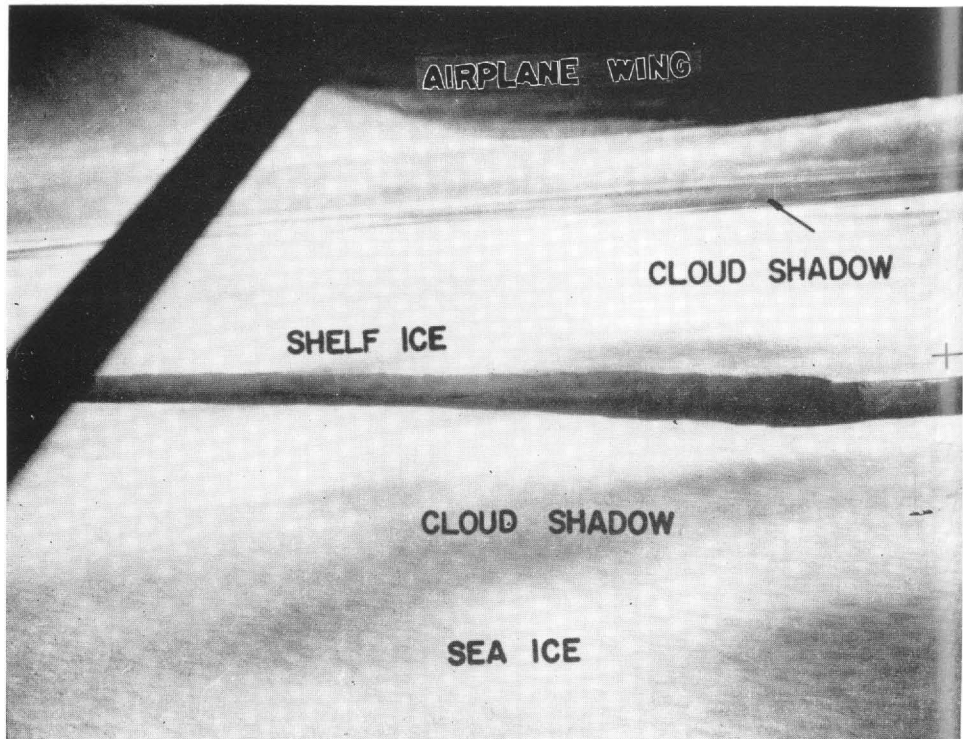
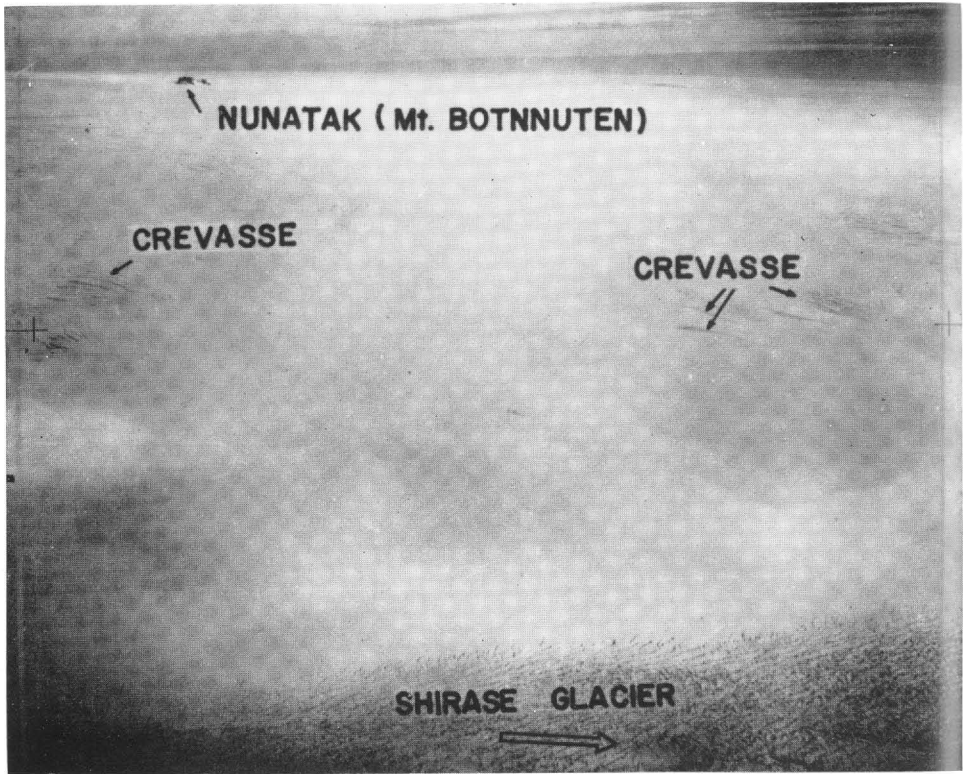
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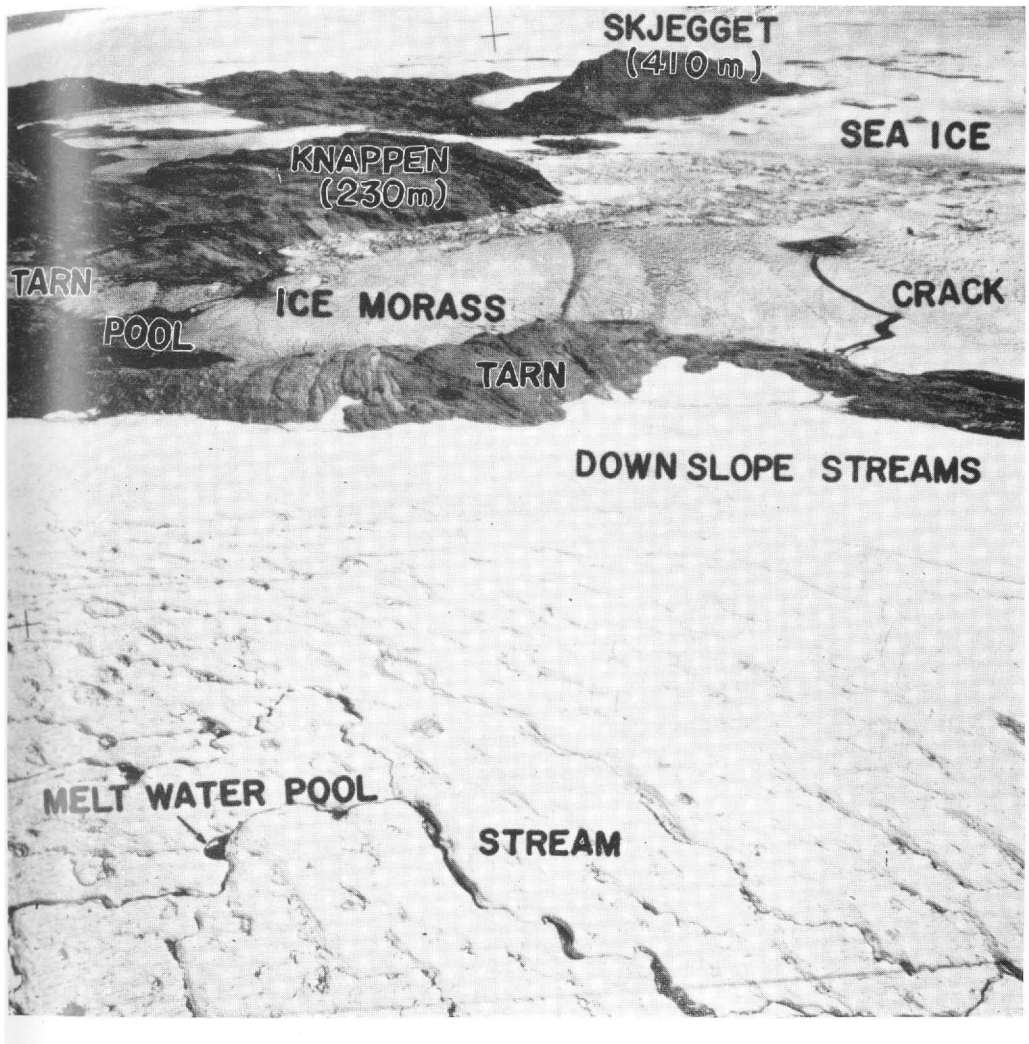
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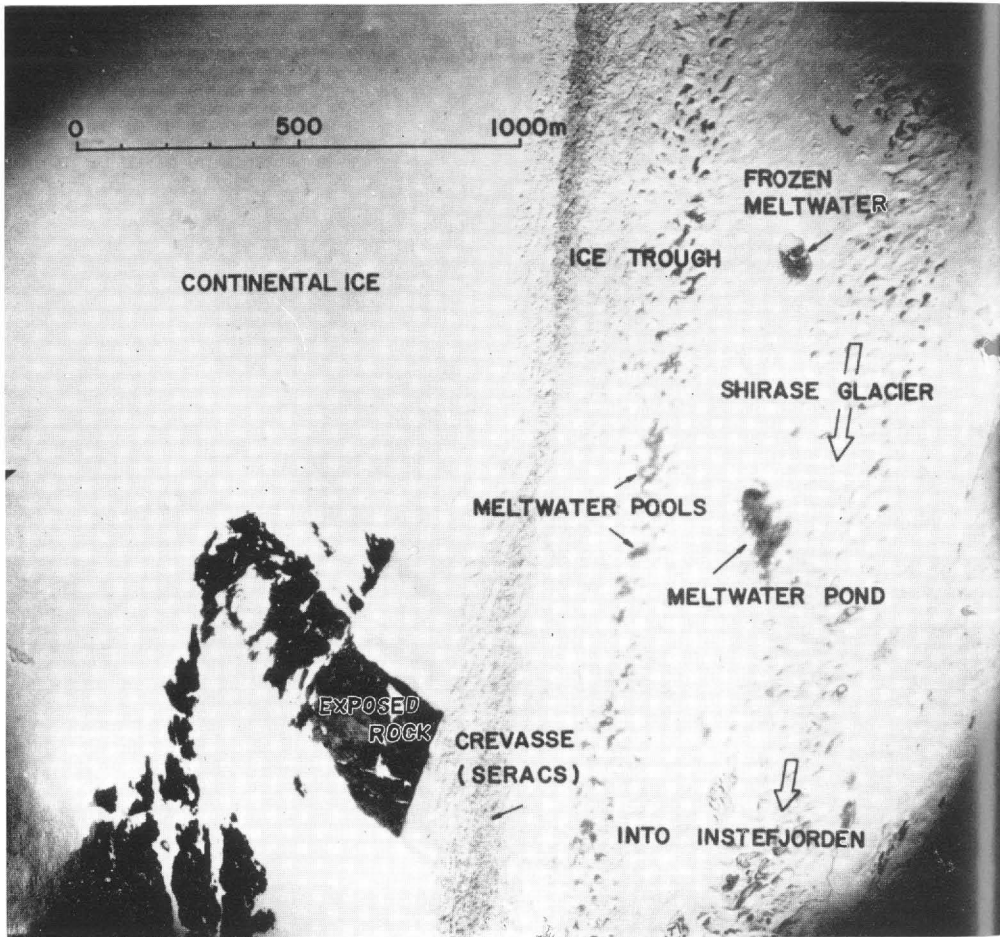
Caption of photographs

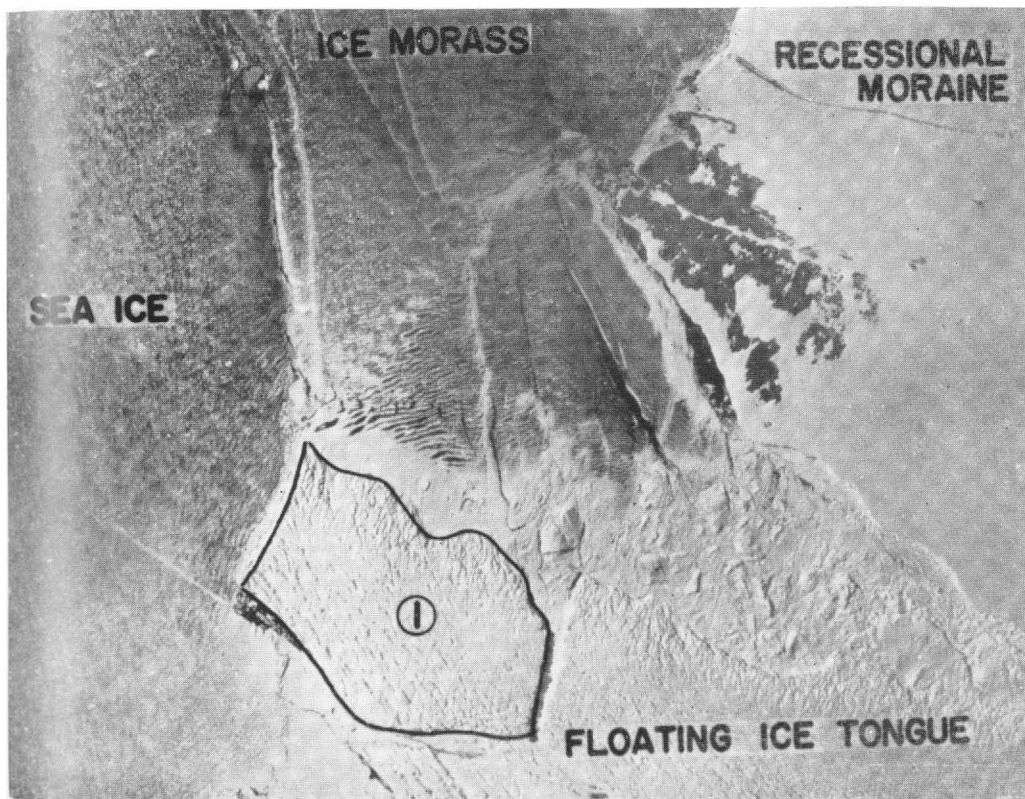
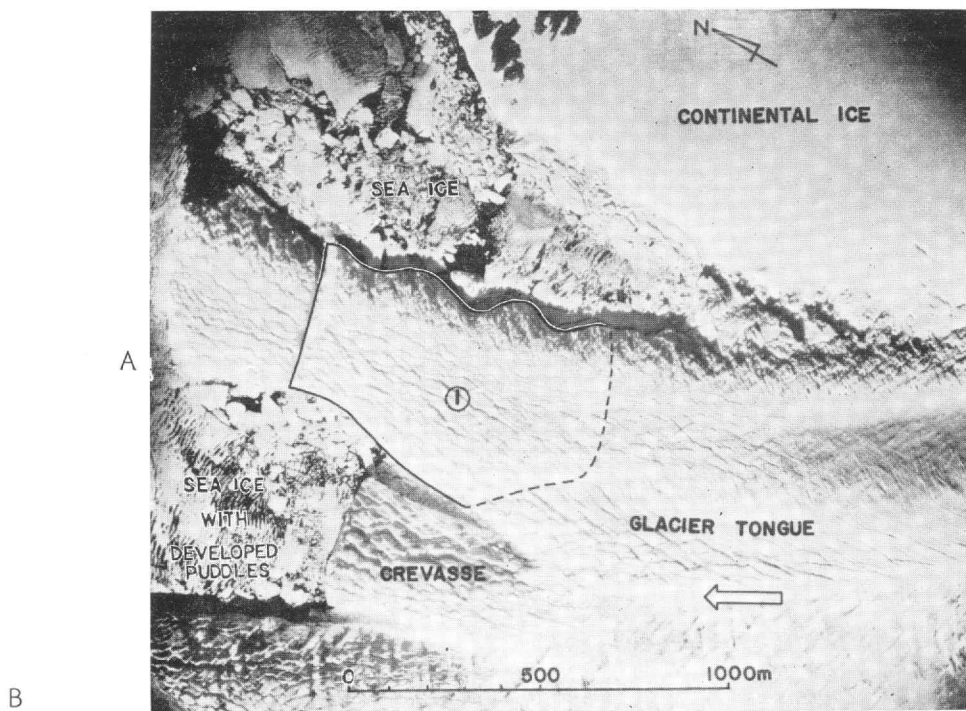
- Plate I- A Continental and fast ice features at 41.5° E, 68.5° S, Prince Olav Land. (JARE 1957)
- Plate I- B Aerial view of Ongul Island group at 39.6° E, 69° S, Prince Harald Land. (JARE 1957)
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- (B) Ditto. (JARE 1957)

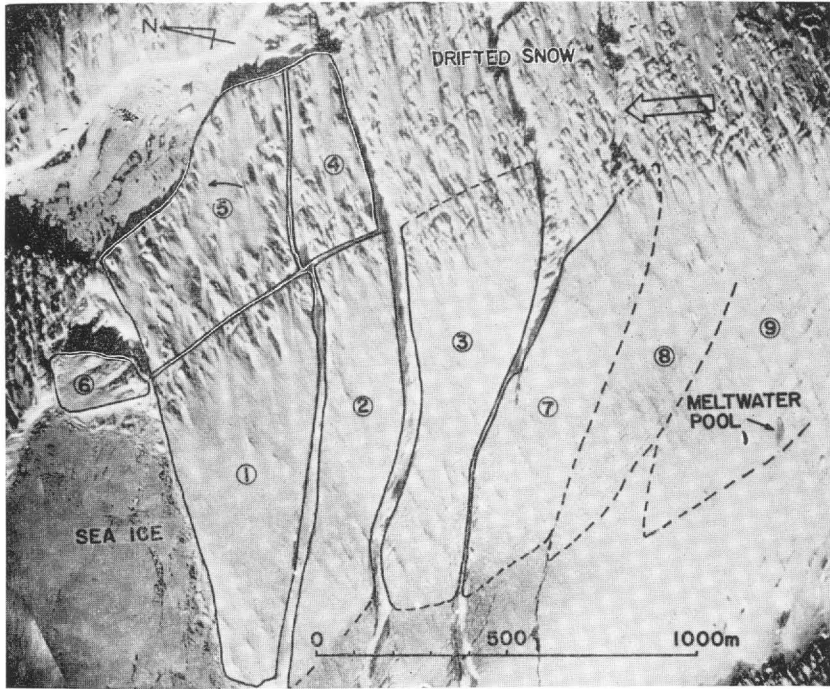












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