Technical Report 46

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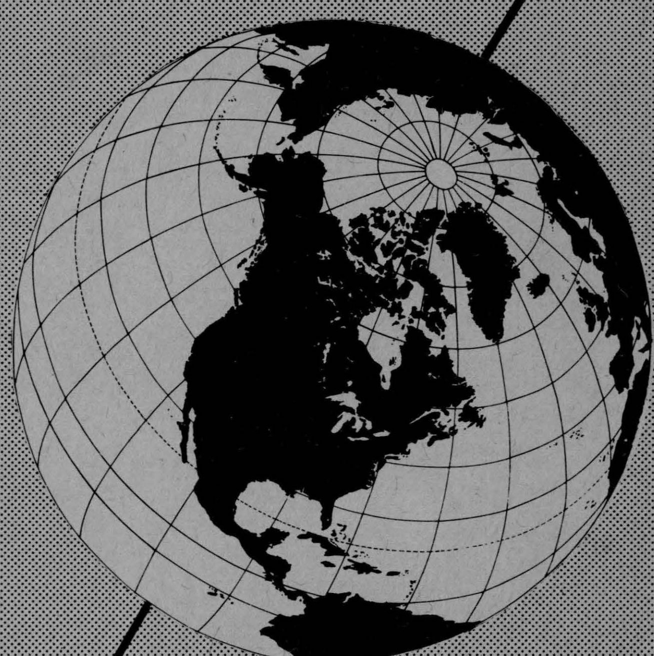

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Wilmette, Illinois

ARMY-MRC VICKSBURG, MISS.

SIPRE Report 46

A RECONNAISSANCE FOR A SOUTHERN GREENLAND ICE-CAP ACCESS FOR MILITARY PURPOSES

by Robert E. Frost

This is a report on a study of southern Greenland for the purpose of locating an area suitable for development of a port, an overland access route, and an ice-cap access route. The report is based on study of maps, airphotos of a limited coverage of a portion of southern Greenland, literature, and a short field reconnaissance trip during the summer of 1956. The report presents the combined views of a study group which consisted of representatives of U. S. Army Engineer Arctic Task Force; Snow Ice and Permafrost Research Establishment; Transportation Arctic Group; Office, Chief of Engineers; and the Danish Government. (Responsibility for report preparation was given to Photographic Interpretation Research Branch of SIPRE, Mr. Robert E. Frost, Branch Chief.) A final and more detailed report of the area selected will be completed as soon as additional maps, literature, and airphotos can be obtained and analyzed.

Department of the Army Project 8-66-02-004

A RECONNAISSANCE FOR A SOUTHERN GREENLAND ICE-CAP ACCESS FOR MILITARY PURPOSES

by
R. E. Frost

SUMMARY

The area under consideration for location of an all-year ice-cap access route includes the far southwest coast of Greenland between Frederikshaabs Isblink on the north and Narsarssuak Air Base (BW-1) on the south. The report also includes a summary of a short survey in the vicinity of Sondrestrom Air Base (BW-8) as it offers potential as a point of seasonal feeder line access to the interior of Greenland.

The most feasible access to the ice cap in southwest Greenland is from the existing port and air base at Narsarssuak. The ice-cap access point is about 27 miles northeast of the air base. In order to facilitate movement of personnel, supplies, and heavy equipment to this access point, it would be necessary to construct a road approximately 40 miles in length. The suggested route generally follows the southern shores of Gannet Bay to its head, then east-northeast along the major base-level stream (which rises in the mountains near the ice-cap access point), and then north across an arm of land which extends well out into the ice cap. The road would have an average over-all grade of about 2%, with local grades greater in many instances but not excessive. A considerable portion of the road construction would be in sidehill cut and fill either in rock, talus, or glacial debris. It is believed that sufficient materials suitable for construction are available. The road at the ice-cap access point in the marginal zone crosses a rather narrow zone with few crevasses, lakes, and an unknown slush condition. The more stable ice-snow condition is found at an elevation of about 6000 ft. An extensive operation will necessitate expansion of the existing Subport Narsarssuak, which can be accomplished without difficulty because both the topographic situation and the engineering materials are satisfactory.

Ivigtut Fjord and Frederikshaab-Kvane areas offer potential sites for location and development of a port, an access route, and ice-cap access, but they are rated as poorer because construction would be difficult and costly. The mountainous topography and great diversity of relief and land forms create severe problems for grade and alignment. Port location and development is believed possible but at great effort and cost, largely because of the rocky nature of the terrain.

Based on a short survey, it is believed that the Sondrestrom area offers a good potential for seasonal access to the ice cap during all but the two- or three-month summer thaw period. If this area were to be used, it would be necessary to construct an access road to the ice cap and major engineering problems are not expected. The suggested location follows a terrace on the north side of the Watson River. Soils and topography are favorable throughout most of the location.

CONTENTS

I. INTRODUCTION

Purpose.

1. The purpose of this survey was to locate an area in southern Greenland which can provide military access to the interior of the ice cap. Reconnaissance was made on several potential areas to determine their suitability for location and development of a port, an overland access route, and an ice-cap access route.

Area of interest.

2. The best area is the southwest coast of Greenland between Narsarssuak and Frederikshaabs Isblink because it is reported to be essentially ice-free throughout most of the year (Victor, 1955). Consideration is given to the vicinity of Sondrestrom Air Base because of the existing installations (see Fig. 1).

Information sources.

3. Literature available in the field consisted of several volumes of Meddelelser om Grønland (Bøggild, 1953; Bøgvad, 1938; Callisen, 1943; Cromelin, 1937; Wegmann, 1938) and a report by the Danish Commission for Geological and Geophysical Investigations (1938). Maps available in the field included WAC Charts (1:1,000,000), AMS Charts Series C501 (1:250,000), and AAC Charts (1:250,000). Aerial photography included miscellaneous trimetrogon strips of the area between Ivigtut and Frederikshaabs Isblink and a few miscellaneous trimetrogon strips in the Sondrestrom area. Aerial photography for the Narsarssuak area was not available to the field party prior to or during the survey.

Procedure.

4. Aerial photography, maps, and literature of the area between Ivigtut and Frederikshaab were studied prior to the field inspection trip. A preliminary report covering sites in these areas was prepared. A briefing on information developed was held on 16 July 1956 at Headquarters, 1st Engineer Arctic Task Force (currently designated United States Army Engineer Arctic Task Force). Participants at the conference included representatives of 1st Engineer Arctic Task Force (1st EATF); Office, Chief of Engineers (OCE); Transportation Arctic Group, Transportation Corps (TRARG, TC); and Denmark. The field reconnaissance was conducted during the period 17 July to 1 August. The field party consisted of: Lt. Col. E. F. Clark, Commanding Officer, USAEATF; Mr. Robert Jackson, OCE; Dr. Henri Bader, Mr. W. K. Boyd, and Mr. R. E. Frost, SIPRE; Lt. P. Eaton, TRARG, TC; W/O S. B. Bowling, 1st EATF; Dr. T. M. Griffiths, University of Denver (SIPRE contract representative); and Dr. A. Norvang, Denmark. Field activity included: one air reconnaissance trip (C-47) and several short field trips in the BW-8 area by the entire group; a few aerial reconnaissance flights (H-19, L-20, and SA-16) and a few short field trips by various members of the group at BW-1; and several aerial reconnaissance flights over the ice cap by Dr. Bader near BW-8 (C-47 of the Hiran Group). Landings on the ice cap were made by Dr. Bader, Dr. Griffiths, and W/O Bowling for purposes of evaluating the surface characteristics. Field inspection over the land provided a means of identifying the rock and soil types as well as evaluating the land area from an engineering standpoint. Aerial reconnaissance provided a means of comparing areas and obtaining low-altitude oblique photos along the routes selected. Information concerning the existing port facilities at BW-1 and BW-8 was made available by Lt. Eaton through his contacts with the Subport Commander at each location.

This report represents the combined views of the field study group.

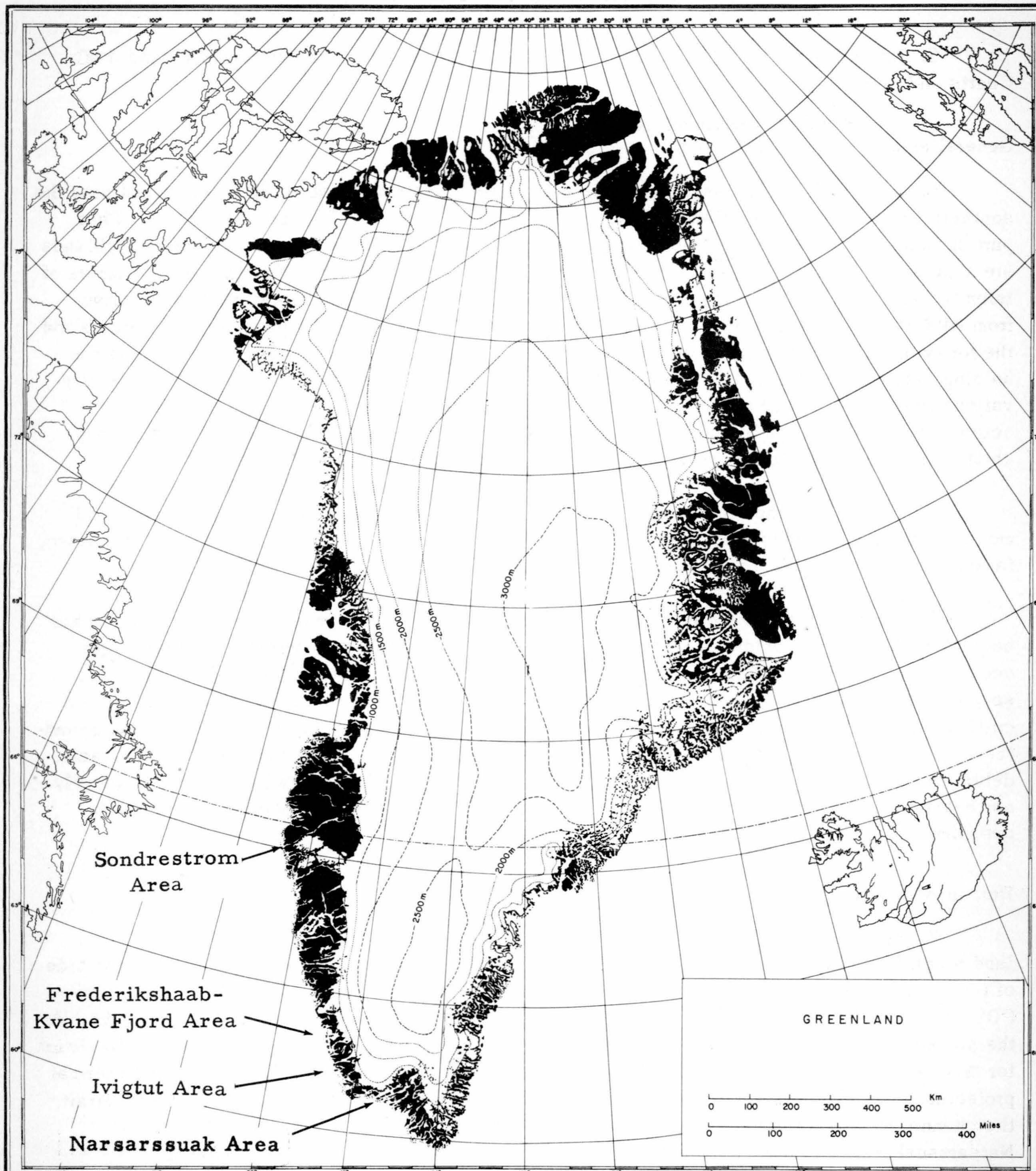

Figure 1. Map of Greenland showing general location of study areas.

II. NARSARSSUAK AIR BASE (BW-1)

5. Information is based on a short field reconnaissance trip and existing WAC and AAC Charts and AMS Series C501 maps.

General area.

6. Narsarssuak Air Base, commonly called BW-1, is situated about 40 miles inland near the southern tip of Greenland on Gannet Bay, the westernmost branch of Tunugdliarfik Fjord. This part of Greenland is rugged and consists of mountains and long fjords. The mountainous highlands are separated by long fjords which trend generally northeast-southwest and terminate in a series of islands, which add to the irregularity and complexity of the coast line. Great mountains, some from 6400 to over 8000 ft high, form the boundary inland between the permanent glacial ice cap and the rocky terrain which fringes most of Greenland. The high mountains appear as a great barrier holding back the ice cap in this area. Within a few miles of this barrier, the ice cap reaches elevations in excess of 8000 ft. There are many valley glaciers, both active and inactive. The active glaciers discharge large icebergs into the fjords. The inactive ones appear to be slowly ablating and receding, leaving debris-filled valleys containing glacially fed streams.

The bedrock of the area in the immediate vicinity of Narsarssuak is largely igneous and metamorphic and includes granite, gneiss, schist, syenite, and pegmatites. The Igaliko sandstone, famous for its unique red and white coloring, is found nearby.

For the most part this area is rocky and has little or no surface mantle, even though it has been glaciated. In the upland areas, scattered boulders and patches of debris of glacial origin occur in depressions and other scattered locations where removal down the slopes has not been severe. The lower slopes of the rocky uplands are mantled in many places with deep deposits of colluvial and/or talus material which has accumulated through the combined action of freezing-and-thawing, running water, and gravity. The fjords containing dead glaciers have deposits of glacial debris in the form of moraines, lake beds, and outwash plains. The fjord which extends generally northeast from BW-1 and contains the dead or stagnant Kiagtut Glacier contains each of these deposits.

Port in Narsarssuak area.

7. Subport Narsarssuak is located on the Narsarssuak Reach approximately 40 miles inland along Tunugdliarfik Fjord and just southeast of Narsarssuak Air Base proper on the east side of the fjord. The port consists of one pier, small closed storage facilities (two buildings), limited POL storage facilities, and adequate anchorage facilities for both deep-water craft and barges. At the present stage of development of Narsarssuak Air Base, the port has adequate terminal facilities for discharging cargo and POL. It is believed that there is access to the port through a somewhat protected channel relatively free from heavy ice during all months of the year. From Davis Strait the channel proceeds through a network of islands into Brady Fjord, thence south around Narsarssuak Reach into Tunugdliarfik Fjord and the port proper. The active glacier in Niaqarnarssuk Korok, which forms the east branch of Tunugdliarfik Fjord, discharges large icebergs into the fjord. The larger bergs become grounded prior to entering the portion of the fjord in which the port is located. During winter months, Tunugdliarfik Fjord is frozen over (10 - 12 in.) and the bergs become ice-locked. During very cold winters the water freezes to greater depths. The tide (mean) in the vicinity of Narsarssuak is 6.6 ft, spring range 8.6 ft. The approach channel up the fjord is adequate for heavy shipping. The waters of the fjord are deep, in excess of 100 fathoms; however, a shelf of widths up to 100 ft fringes the fjord. The side walls are steep

and often precipitous. Shallows are found in the vicinity of Narsarssuak Air Base, just north of the port proper; shallow water also occurs in the upper reaches of Gannet Bay. The area in the vicinity of the port would lend itself well to additional piers and anchorages, and adequate storage facilities could be built for increased activity. The air base contains many unused buildings. The present reservation contains good engineering soils and ample area for expansion of the port and its facilities (construction of open and closed storage and other structures).

Access route.

8. There are no roads in the Narsarssuak area which extend from the air base into the adjacent uplands. The route believed to offer the most favorable grade and alignment is approximately 40 miles long and trends generally north and northeast, rising from sea level at the port to about 4500 ft at the ice-cap access point with an over-all grade of about 2%. Figure 2 shows the general route location. To gain the most favorable grade and alignment for a road in this mountainous area, it is necessary to utilize the not-too-severe gradient of the base-level stream which rises in an elevated, lake-studded upland valley and empties into Gannet Bay.

The road can be divided into sections related to the local physiography. Because the only map available to the field party had a 1000-ft contour interval, only approximations can be given in this report. For about 11 miles, from the port area to the 2000-ft contour, the route follows a generally northward course along the east side of Gannet Bay and along the stream emptying into the bay, with an average grade of about 3-1/2%. Most of this part of the road is in rock and will require sidehill cut-and-fill sections. The side slopes of the valley are not too steep and the rock is igneous and metamorphic. Excellent granular material sources occur in the large outwash plain at BW-1, in a large alluvial fan about 4 miles from BW-1, along the road location, and in the stream valley near the end of this portion of the route. These deposits could provide considerable granular material for base course and surface course use.

Between the 2000- and 3000-ft contours, the route trends generally east-northeast for about 17 miles with an average grade of slightly over 1%. This section crosses rock, colluvial and/or talus material, glacial till, glacial outwash, and possibly lacustrine deposits. Granular materials suitable for base course and surface can be found in areas of glacial outwash and alluvial fans at discharge points of lateral streams along the thread of the main valley. It will be necessary to bridge some of the more active lateral streams. A large, spectacular waterfall occurs in the main stream.

Between the 3000-ft contour and the ice-cap access (about 4500-ft elevation), the route trends northward for 11 miles, rising about 1500 ft with an average grade of about 2-1/2%. Except for an outwash plain remnant at the lower end, the road would require considerable sidehill cut-fill section in rock. The streams at the lower end are in deep canyons and at least two bridges would be required. Granular materials can be found in the dissected outwash plain remnants; because of their high elevation, however, they may be frozen.

Ice-cap access.

9. The ice-cap access point is located at grid coordinate MJ 9719 (see Fig. 2). This spot is on a rocky, peninsulalike point of land which extends out onto the ice cap. It is flanked on the west by a large glacier which is considerably crevassed and on the east by a smaller glacier. The ice cap at the access point appears to have few crevasses. The general route location beyond this access point is governed by the fact that very intense crevassing prohibits any access to the high snow region lying generally west of two very large nunataks, with centers at grid coordinates NJ 1849 and NJ 2030. The suggested route from the access point trends east-northeast in a great

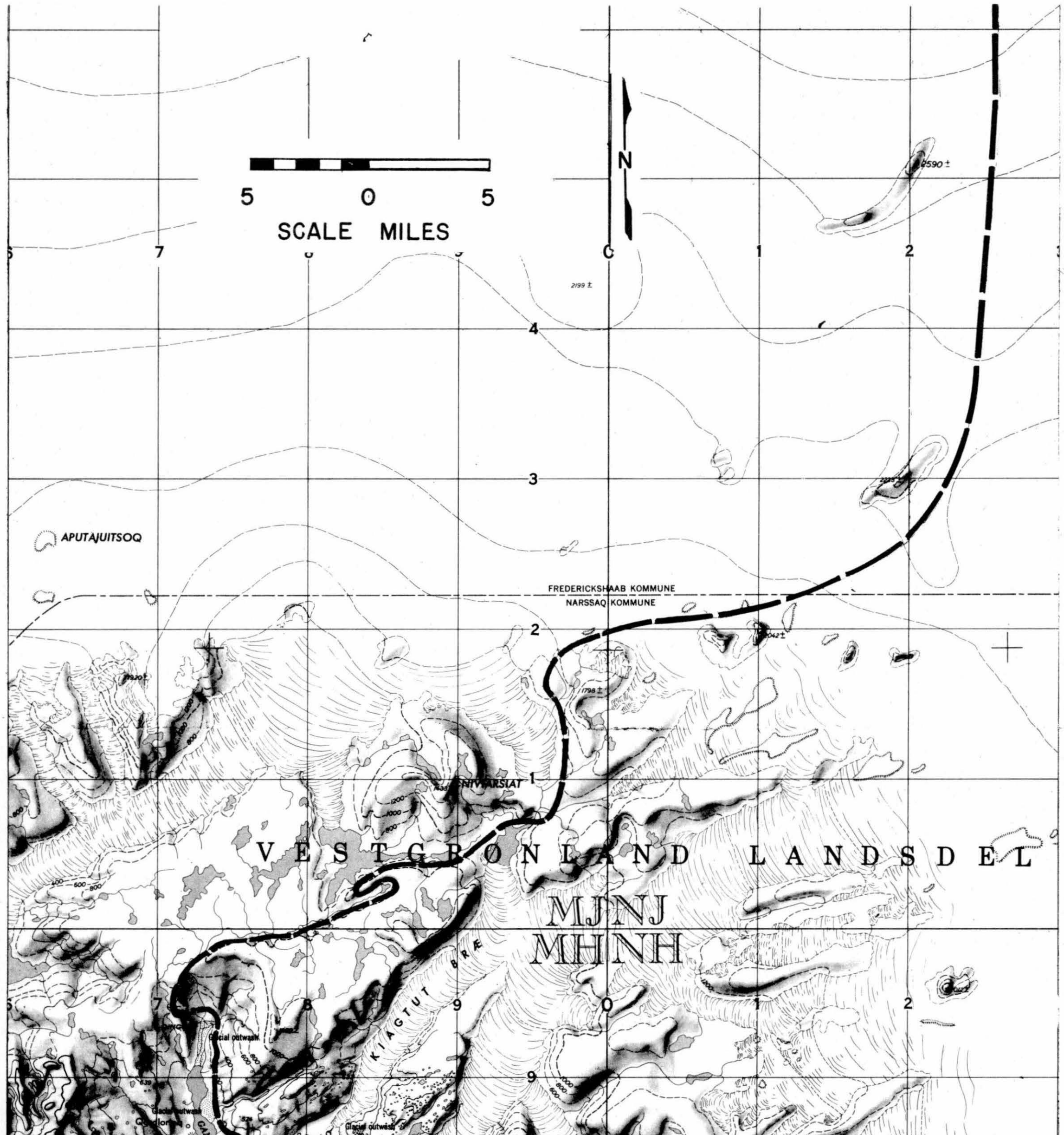

Figure 2. Preliminary access BW-1 to ice cap.

curve to the southernmost of these two nunataks, thence northward along their east side. Directly east of the northern nunatak there are a few crevasses. The route to the north of these two nunataks was not explored but the even slope is not likely to be badly crevassed.

The 19 or 20 miles of road from the ice-cap access point to the southernmost nunatak must remain close to the outer edge of the ice cap, where it will cross some crevasses but probably not a large number. In this lower region there is believed to be a pressure regime where the ice cap pushes against the higher land. Surface transportation over this section would be possible, but a decision on the feasibility of subsurface transportation must await careful survey by field parties.

III. SONDRESTROM AIR BASE (BW-8)

10. Information was obtained from a short field reconnaissance survey and from existing WAC, AAC, and AMS C501 maps.

General area.

11. Sondrestrom Air Base, commonly called BW-8, is situated at the head of Sondre Stromfjord about 105 miles northeast of Simiutak Island, which is at the mouth of the fjord on Davis Strait. The air base lies about 80 statute miles east of Holsteinsborg, which is also on Davis Strait. This portion of the west coast of Greenland is a relatively ice-free, mountainous area several hundred miles in length and varying in width from about 50 to over 100 miles. A few of the higher areas in this rather narrow band of mountains are mantled with permanent ice fields, such as Sukkertoppen Isflade southwest of BW-8 (elevation 7000 ft). The eastern border of the ice-free area at the contact with the permanent ice cap rises to elevations varying from 1000 to nearly 4000 ft with the majority of the area between 500 and 2000 ft. On a regional basis the relief is not excessive. It has been described as a low highland consisting of generally low, softly rounded forms, some nearly level plains, and a few scattered mountains. This upland surface is broken by a series of long fjords extending from the permanent ice cap to Davis Strait and trending generally northeast-southwest. The upland surface is dotted with lakes, many with no outlet.

The greater part of the bedrock surface consists of gneiss, schist, and some scattered intrusives of granite, pegmatite, and similar rocks. The entire area shows evidences of glaciation, but the mantle of glacial debris is generally rather thin. Mechanical weathering is severe and the products of disintegration occur in great talus piles on the lower slopes. Many of the valleys and fjords contain considerable accumulation of glacial debris in the form of moraines and outwash plains. Some deltas and alluvial fans also occur. The lower slopes of hills and mountains which border stream valleys are mantled in places with deposits of sand believed to be aeolian in origin. A few eskers and drumlinlike hills are reported in the Holsteinsborg-Sukkertoppen District.

The upper reaches of Sondre Stromfjord and Bowdoin Bay, a branching fjord, both contain considerable accumulations of alluvial silt and clay (possibly preglacial marine sediments), glacial outwash, glacial till, stream alluvium, and deltaic deposits. The marine (?) sediments and the outwash materials form terraces in the upper part of these two fjords. Moraine deposits of glacial till occur along the sides of the fjords, often forming the transition between the terrace and the rocky upland slopes. Watson River (also named Wilson River on some maps) discharges great quantities of silt and fine sand into the fjord at Sondrestrom, which has resulted in a generally shallow water condition between the air base and the confluence of Bowdoin Bay and Sondre Stromfjord.

Port in Sondrestrom area.

12. Subport Sondrestrom, also known as Camp Lloyd, is located at the northern end of

North Fork, the northernmost branch of Sondre Stromfjord, nine miles west of the base. The port is limited to lighterage cargo discharge, accomplished by using a dredged channel from the anchorage to the quay. A mooring buoy a few hundred feet due east of the anchorage is used for discharge of POL. At present there are no closed storage facilities available and the open storage is limited to a small area in the vicinity of the quay. The subport is capable of discharging the current flow of cargo but not without a great deal of effort.

Access to the port during the shipping season, which is 1 June through 15 November, is up Sondre Stromfjord to Camp Lloyd. The channel from the anchorage to the quay appears to be silting up at a rate of about 1 ft per yr (oral communication). The fjord does not contain icebergs other than those which may drift in from Davis Strait. During the coldest part of the winter, the ice attains a thickness of 60 to 72 in. in the fjord. Most of the fjord between Davis Strait and Bowdoin Bay reaches depths of 100 fathoms. This depth decreases to about 5 fathoms in the vicinity of Camp Lloyd. Inland from this point tidal flats occur. The side slopes of the fjord are for the most part rocky and steep but not precipitous. Several major streams enter the fjord from the south banks. Small, rather insignificant streams enter the fjord from the area to the north.

Increased activity at the port would necessitate an extensive dredging operation to provide an adequate channel in the Camp Lloyd area. Also it would require the construction of closed storage facilities and additional open storage facilities. The latter would cause considerable problems because of topography, soils, and rocks. Point Hancock, about five miles southwest of Camp Lloyd and across the fjord from the mouth of Bowdoin Bay, has more desirable characteristics for port development and expansion than does the Camp Lloyd area.

Access route.

13. The suggested route between Sondrestrom (BW-8) and the ice-cap access point trends generally east-northeast along the north bank of Watson River (Fig. 3). The route is about 22 statute miles long and rises about 1000 ft between the air base and the ice-cap access. The road could utilize about 4 miles of an existing road which runs east-northeast from the air base to a series of borrow pits, but improvement of grade and alignment would be necessary.

For the most part, the area immediately adjacent to the north shore of the Watson River is suitable for road construction. Between the air base and Russell Glacier, the route follows a series of elevated terraces and terracelike land forms which are composed of granular materials and glacial till. Just beyond the end of the present road, sidehill cut-and-fill sections would be necessary—partly in hard gneiss bedrock and partly in talus material—at the point where Watson River flows through a narrow, rocky defile, creating a few hundred yards of rapids. Beyond this point and extending nearly to Russell Glacier, the suggested route follows a series of terraces. Wherever possible, the road would be on the outer portion of terraces and terracelike land forms in order to avoid the poor drainage and adverse permafrost conditions of the mid-portions to the inner portions of these land forms. Occasionally, the stream valley crowds the northern valley sides where the terraces are very narrow or are replaced, and in some instances covered, by talus materials. Here, to avoid severe landslides, it is suggested that the talus be avoided and the road placed on a fill section. Scattered patches of aeolian sand occur throughout the valley, some on the terraces.

It is necessary to skirt the north side of Russell Glacier, its moraine, and a chain of lakes which are lateral to its north side. It is believed that this could be done without excessive earthwork or rockwork. There may be some steep grades over short distances. There is another possible route generally north of and parallel to the Watson River route, skirting just north of Sugar Loaf Mountain and passing through a series of troughs. However, because of adverse soil and permafrost

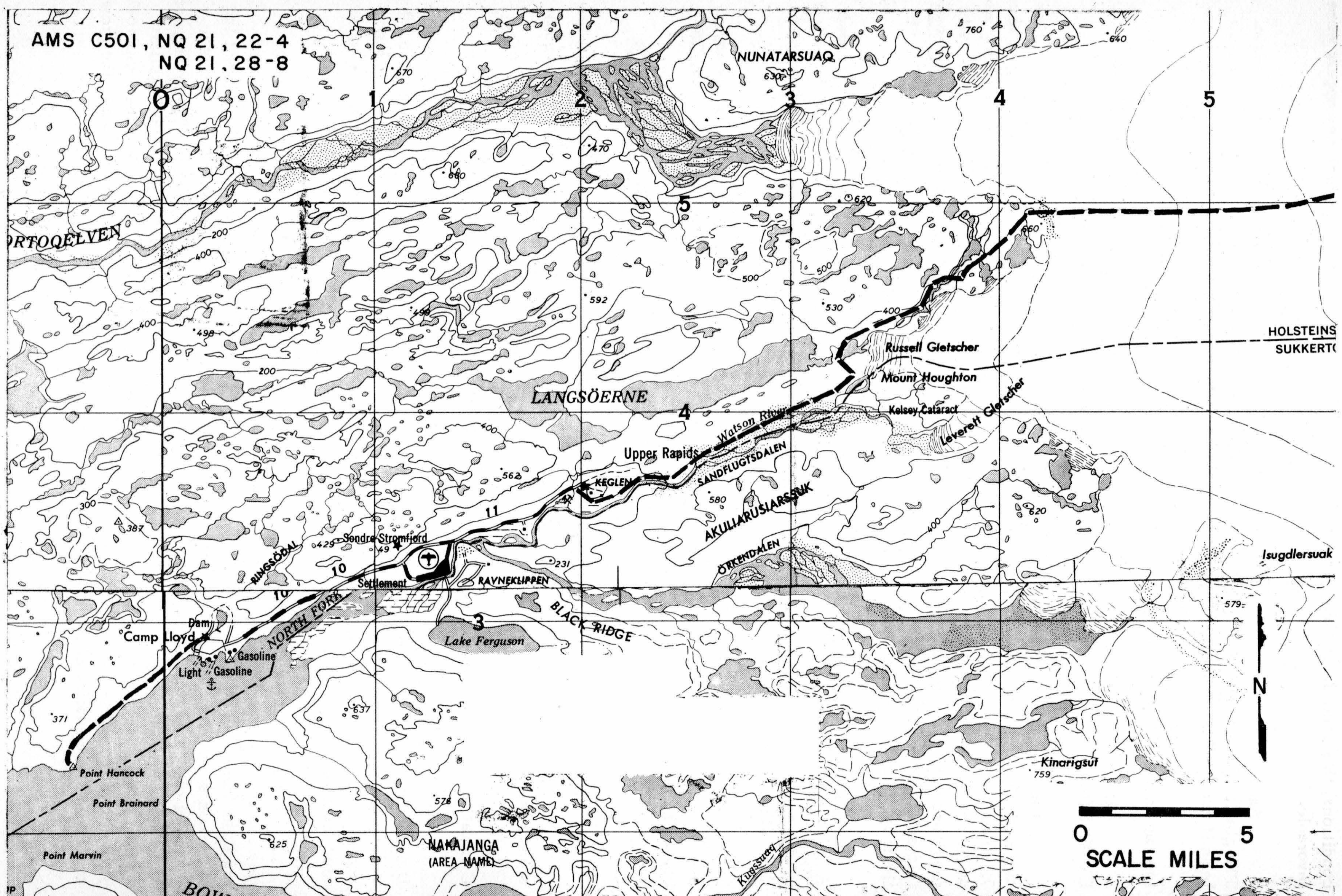

Figure 3. Preliminary access BW-8 to ice cap.

conditions, this route is probably a poor one even though the grade and alignment may appear more favorable.

Ample materials are believed to be available in the granular terraces and the flood plain. The glacial till contains a considerable amount of silt and may result in severe frost-heave problems if used without corrective measures.

Ice-cap access.

14. The ice-cap access point is situated just north of Russell Glacier at coordinate EV 4248 (see Fig. 3). The elevation at this spot is approximately 2000 ft.

From the access point, the route over the ice cap progresses a little north of east and then due east. The marginal zone between the land and about the 5000-ft contour on the ice cap is about 75 miles and is characterized in general by many thaw lakes and many rather large and winding melt-water streams. Immediately adjacent to the land there is a belt about 5 miles wide which is quite rough and contains many pinnaclelike ice forms. Crevasses are numerous and severe over most of this area. The two big obstacles to surface or subsurface transportation in the marginal zone are the rough pinnaclelike topography and the slush and lake belt.

The route over the ice was selected from observations made during aerial reconnaissance flights. It was the opinion of the observers that the crevasses along this route would not create a severe problem and that the majority of the lakes and surface streams appeared to lie in a zone to the north and a similar zone to the south of the selected location.

Because of the severe summer slush condition (resulting from the generally low elevation) and the band of hummocky and pinnaclelike ice topography, it is the general consensus that BW-8 cannot be included in any summer transportation system.

IV. IVIGTUT AREA

15. A detailed study of trimetrogon aerial photography of the Ivigtut area was followed by a short aerial reconnaissance flight.

General area.

16. The Ivigtut area is situated on the southwest coast of Greenland in the Frederikshaab District about 80 miles west of Narsarssuak and about 65 miles east-northeast of Julianehaab. The village of Ivigtut is situated on the southern side of Arsuk Fjord, or Ivigtut Fjord as it is more commonly called. The region under consideration flanks the fjord for about 5 to 10 miles on either side, extending from Davis Strait to the permanent ice cap—a distance of 15 to 20 miles.

The Ivigtut area is situated in a very narrow band of generally ice-free land between the sea and the permanent ice cap. This portion of Greenland is intersected by deep fjords which mark the troughs once filled by ice. The fjords generally trend northeast-southwest. Some of the longer ones are 35 to 40 miles long. The land between the fjords, on a regional basis, forms a series of elongated and generally parallel, but often irregularly shaped, highlands. These are, for the most part, quite rugged throughout most of their length. The side slopes of the estuarylike fjords are very steep and rise to great heights in a short distance. The hardness of the rocks together with the activity of the glacier and the present-day severe climate has resulted in the great topographic irregularity of the uplands between the fjords.

The Ivigtut area can be classed as mountainous. There are no areas anywhere in the region which approach a plain or any other generally level form. Some sharp escarpments occur along areas which appear to be block-faulted. The general land elevation is about 1500 ft but rises to about 2500 ft at the ice-cap edge. Mt. Kunait, west of Ivigtut, is the highest peak. It rises to an elevation of 4200 ft. Other peaks rise to 2500 and 3000 ft.

The Ivigtut region is composed chiefly of metamorphic rocks with intruded dikes and sills. Some batholiths of granite occur. Old sedimentary rocks have not been found. A few scattered patches of glacial debris occur as a mantle on the rocks. The glacial debris appears to be quite bouldery and notably lacking in fine-grained soils. In places the contact between ice cap and land is marked by moraines, which appear to consist of coarse debris on ice.

Many of the steep, rocky slopes are marked by colluvial materials, and extensive talus occurs at the base of some of the more rugged hills. A few of the major stream valleys appear to contain alluvial-colluvial deposits which are local in occurrence. A few small deltalike deposits are to be found in the fjord at the discharge points of streams.

Fine-grained soils are scarce. Those which do occur are in areas of former upland lakes, some of the upland valleys which appear to have been blocked or partially blocked, deltas, and in a few areas of glacial till.

Port sites.

17. Several port possibilities exist in the Ivigtut littoral, most of them in broad and rather low defiles in the otherwise rocky walls of the fjord. These locations are (see Fig. 4): Inugsuk

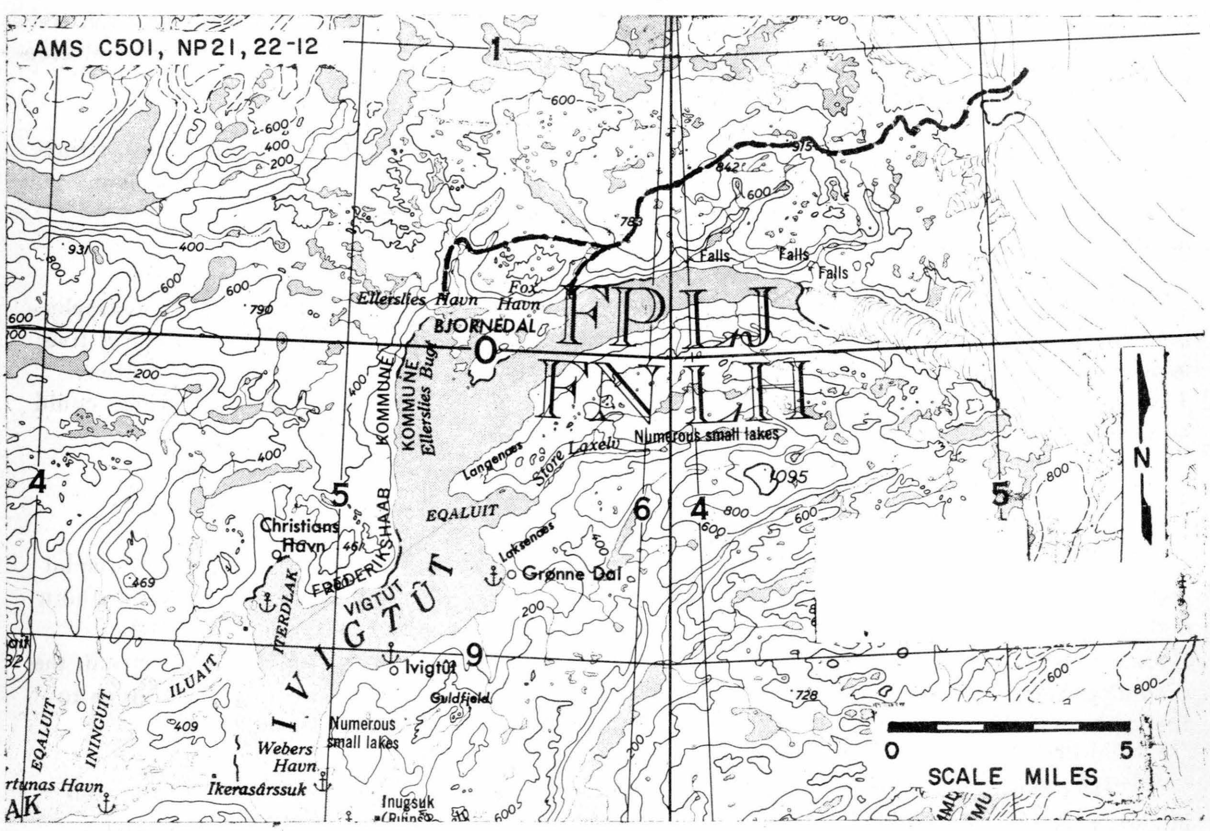

Figure 4. Preliminary access Ivigtut Fjord area.

(FN 5285); Ivigtut (FN 5289); Grønne Dal (FN 5693); Eqaluit Inlet (FN 5795); Christians Havn (FN 4892); an unnamed spot at FN 5297; and Bjornedal (FP 5302). All but the one at Bjornedal have been ruled out because of the excessive grades required to gain access to the uplands. The east side of the fjord provides very poor access to the inland ice, even though Grønne Dal and Eqaluit may provide a reasonable port site. The Grønne Dal offers easy grade for a short distance only. It is believed that Bjornedal peninsula, flanked by Ellerslies Havn and Fox Havn, offers the most feasible site for port and harbor development. From all indications, the bay, Ellerslies Bugt, provides a natural harbor. The topography of the peninsula, islands, and mainland shore line is rugged but to a lesser degree than that along the coast in either direction. The peninsula is of ample size for port facility development. Access to the upland may be provided by road from either end of the base of the peninsula, but the grade from Fox Havn would be severe.

According to AAC Chart 109DII, the fjord is about 100 fathoms deep between the mouth and Grønne Dal. Inland beyond Grønne Dal, depths are not shown on the map, but there are sufficient evidences on the photographs to indicate that the great depths continue inland for considerable distance. Depths in Davis Strait beyond the fjord and around the islands vary between 20 and 100 fathoms. For the most part the fjord appears to be free from submerged obstructions and shoal conditions. A few small islands occur off the tip of the peninsula at Bjornedal (FN 5598).

The entire Bjornedal area is composed of rocks, believed to be gneiss intruded with granite and/or syenite. The rugged nature of the area suggests rather hard and durable rock. Loose material in the form of bouldery talus occurs in the major valley at Ellerslies Havn. There are no evidences of sorted materials in the port area. If an extensive port is contemplated, one requiring considerable storage area, rock excavation would be large. Masonry-type construction should be considered for some of the buildings and for facing some of the large fills which may be required. Because of the diversity of relief it may be necessary to consider a layout which utilizes several levels in order to minimize rock excavation. Consideration should be given to partial sidehill excavation for building location as well as tunnel-type excavations.

Frost action will not be a problem in the port at Bjornedal because of the absence of fine-textured soils. Ice can be expected in some of the joints and cracks of the rock, which means that tunnels and sidehill excavations intended for use as storage or as portions of buildings would have to be lined or grouted.

The potential port area appears to be relatively free of snowdrift in the April photographs—probably because of its sheltered position and its proximity to the axis of the fjord. Four or five scattered lakes occur on the Bjornedal peninsula. The smaller ones may freeze to the bottom. The large one in the east center of the peninsula may be a permanent source of water which could be used all year.

Access route.

18. Figures 4 and 5 show the approximate location of the access road between Bjornedal and the ice cap. Two port access routes are shown (Fig. 5). The two routes join at the southern end of a long lake at FP 5703. The access route leaves the rock at a moraine at LJ 5108. Because of the diversity of topographic forms and the rather rugged nature of the local terrain, the road alignment must vary considerably. As the ice cap is approached, consideration is given to the grade and alignment which would minimize maintenance problems due to snowdrift.

Rockwork would predominate throughout the entire length. Bulk fill of coarse talus and boulders may be satisfactory, but consideration must be given to design of base course and surface course gradations to provide stability as well as reduce maintenance of the road surface

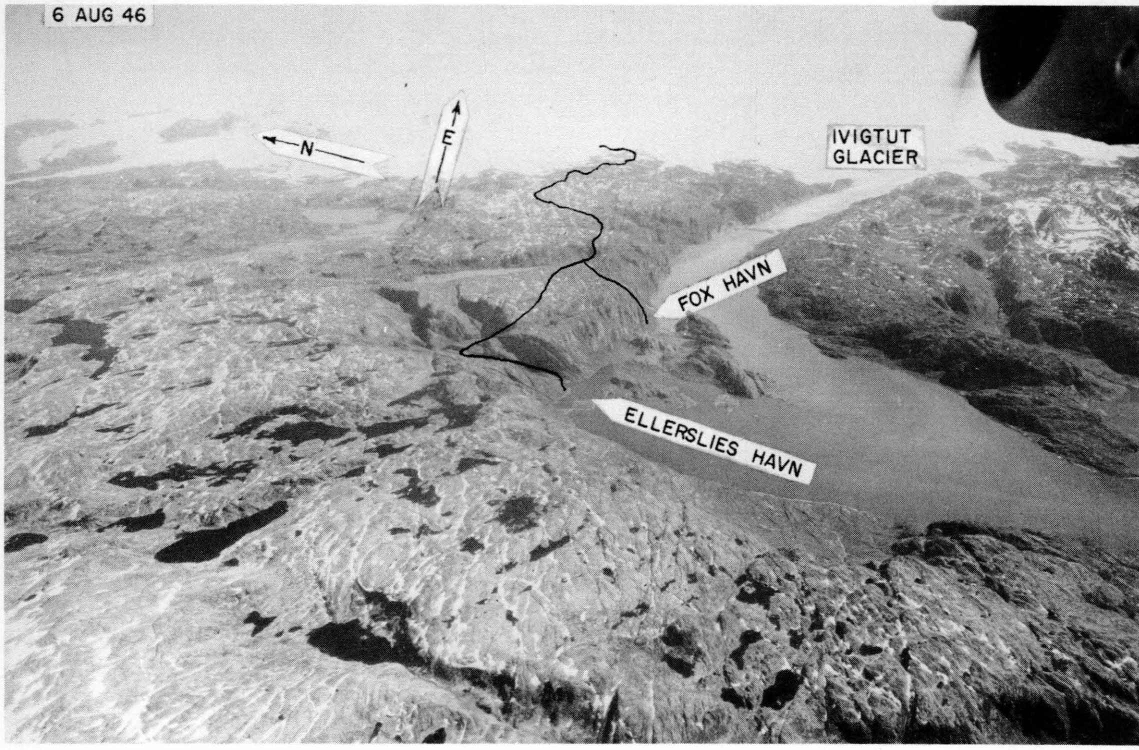

Figure 5. Ivigtut Fjord area, showing preliminary access routes and ice-cap access.

and the equipment using the road. Where it is necessary to cross areas subjected to severe snowdrifting, it is suggested that railroad-type snowsheds be used. Whenever possible, east-facing slopes should be utilized in order to lessen the drift problem.

There are no sources of unconsolidated loose materials other than local talus. Materials for bulk fill and for base course and surface course would have to be excavated from bedrock. Crusher plants should be set up in the dikes, particularly dikes which have weathered below the general surrounding elevation. These materials are believed to be coarse crystalline. Thus, they should crush easily and also continue to break up under the action of traffic, providing a surface which can be maintained easily.

Snowdrifting would be a problem of considerable magnitude. On upland areas, the location should avoid the wind shadow of adjacent rises. The use of rock snow fences may be considered in areas of generally level topography. When wind shadow cannot be avoided, the use of snowsheds is advised. Permafrost is of no concern in the road location because of the absence of fine-textured material. Icing may occur during spring melt periods if runoff from higher areas having considerable snow cover is not diverted.

Ice-cap access.

19. The following is based on study of aerial photography (limited coverage) dated August 1946, April 1947, and one row of vertical photographs, July 1942. One short aerial reconnaissance flight over the area in July 1956 provided an indication of the present condition of the ice-cap access and its utility for overland transport.

The prospects for a route over the marginal ice in the Ivigtut area are not good. Two prominent lobes of rock extend out into the ice cap in the area immediately north of Ivigtut Glacier. Well-developed shear moraines (ice-cored) form the transition between the rock and the ice cap. In the contact zone the moraine elevation is between that of the high rocks on one side and the lower ice-cap surface on the other. The local relief of the rocks in the access zone is quite rugged with escarpments, spires, pinnacles, and other rugged forms everywhere present. A zone of glacial ice mantled with seasonal snow separates the moraine from the rock of the mainland. This zone is generally flat, sloping downward from the moraine to the rock, forming a highly asymmetrical trough. The moraine is part of a continuous ridge which marks the contact zone for several miles in this vicinity. In general, its crest is sharply rounded and it has long, rather steep slopes throughout most of its length. The north end flares out and exhibits a minute ridgelike appearance. These secondary ridges are believed to be related to different upper surface levels of the ice cap as its elevation changed, probably during recession. The moraine contains a few well-developed cracks which are transverse and believed to be related to shear activity in the ice cap. At one spot it appears as though ice calving was under way at the time of photography. The permanent ice exhibits shear-type markings in the transition zone. The winter photographs (obliques) show much drifting between the moraine and the rock and behind the prominent rises on the rock. In this zone the problem of snowdrift would be of considerable magnitude. Drifts appear to be quite deep on the lee of all prominent rises, including the entire length of the moraine. It is again stressed that consideration be given to the use of snowsheds at critical places where location cannot be on the windward side. Permafrost would not be a problem in this area. Poor quality of the photographs precluded crevasse detection on the initial photostudy. Aerial inspection in July 1956 determined the presence of intensive crevassing, which would limit operations.

Based on the July 1956 reconnaissance flight, the slush belt appears to be about 8 to 15 miles wide. This, together with the evidence of crevassing, probably eliminates tunneling from consideration. The slush belt would interrupt any surface transportation during a period of two to three months each year. It is believed that the cut-and-cover trench could be used beyond 15 to 30 miles from the edge of the ice cap.

V. FREDERIKSHAAB-KVANE AREA

20. A detailed study was made of trimetrogon strips of photography of the area between the ice cap and Davis Strait, and between the north border of Frederikshaabs Isblink and Sermilik Fjord. The photostudy was followed by a short aerial reconnaissance over part of the area in July 1956.

General area.

21. This area is situated about 125 miles west-northwest of Narsarssuak. It is about 60 miles long and about 25 miles wide and includes land flanking Kvane Fjord, Nerutussoq Fjord, Qagssit Bay, Kuolinik Fjord, and Frederikshaabs Isblink.

With the exception of Frederikshaabs Isblink, the area is a part of the generally ice-free margin of land which bounds most of the west coast of Greenland. The rocky, barren, and extremely rugged highland is crossed by many steep-sided fjords trending generally northeast-southwest. Some of these contain active glaciers which discharge great bergs into the fjords. Smaller ones extend to the ice cap but contain considerable glacial debris throughout much of their length and stagnant and/or ablating glaciers in their upper portion. Frederikshaabs Isblink is a huge ice lobe extending outward from the inland ice proper. It is almost 15 miles wide at its outward part and is separated from Davis Strait by a long, narrow band of glacial and fluvioglacial material varying from two to five miles in width.

This portion of the southwest contains some of the most rugged topography to be found in

Greenland. Along many of the fjords, the clifflike sides rise almost vertically out of the water. In general, from the coast to about the middle of the area, maximum elevations are from 600 to 1800 ft. Inland elevations rise to 3000 to 3500 ft with the terrain increasing in roughness. The most rugged mountain masses occur nearest the ice cap.

The area is composed chiefly of igneous and metamorphic rocks. The igneous rocks are in the form of batholiths, dikes, and possibly sills. Some appear to be composed of coarse-grained igneous materials, as they reflect low and subdued relief. The great diversity of relief which seems to prevail is believed to be associated with the variability of rock types (gneiss which is harder and more resistant to erosion than the schist) and with large faults. The entire area has been glaciated and there are scattered deposits of glacial debris throughout. The flanking lowland on the west side of Frederikshaabs Isblink is composed of moraine and outwash materials which have contributed sediment to the vast tidal flat (deltaic action). Some of the steep side slopes of the fjords appear to be mantled with loose talus, suggesting that landslides could become quite a problem.

Port sites.

22. Access from the ocean in this area is extremely difficult as two generally opposite conditions occur in the fjords. Some fjords appear to be very shallow and contain deltalike deposits, creating a shoal condition that would require extensive dredging operations. Usually these fjords offer easy grades to the ice cap proper or at least to within easy access. Other fjords are bounded by cliffs which rise almost vertically out of the water, thus precluding consideration throughout most of their length. Two possibilities exist in areas where lateral gulleying and stream activity have produced sizeable defiles in the otherwise precipitous side walls. One suggested port location (Port I) is on Nigerdleq Fjord at FP 0884; Port II is on Nerutussoq Fjord at EP 7292 (see Figs. 6-8).

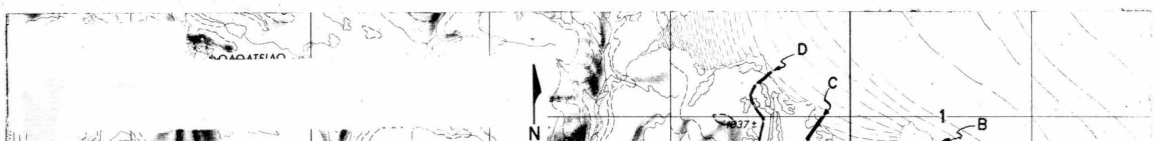

Figure 6. Preliminary access, Frederikshaab-Kvane Fjord area.

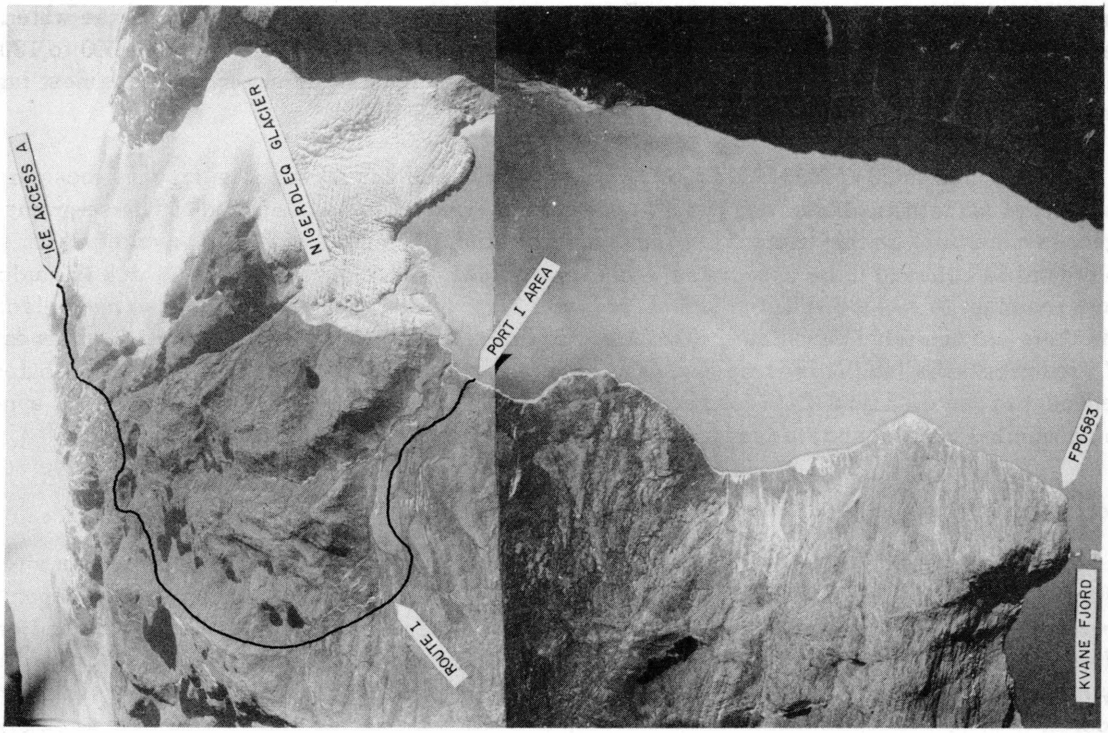

Figure 7. Route I to ice cap, Frederikshaab-Kvane Fjord area.

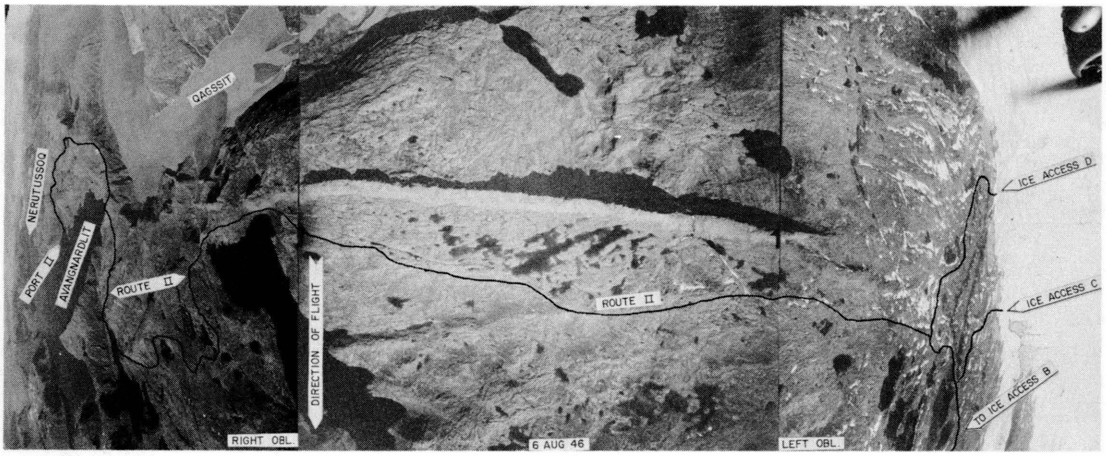

Figure 8. Route II to ice cap, Frederikshaab-Kvane Fjord area.

Specific tide information for this area was not available at the time of the survey but earlier literature sources report tides of 10 to 12 ft. The fjords for the two suggested port areas are reported to be deep. Nothing is now known of ice conditions in these two fjords.

Port I (potential) is in a valley containing rather broad and long terrace remnants which offer considerable surface for development. It is believed that the soils at Port I may be suitable for port development. However, it is also believed that they contain some silt, which may cause frost damage.

Port II would require considerably more rock excavation, as it is situated in a generally rocky valley. Icebergs may be of some concern in the fjord in the vicinity of Port I because of the close proximity to the front of the Nigerdleq Glacier.

Access routes.

23. Two general access routes extending to the ice cap are considered in this study. Access Route I (Fig. 7) extends 5 miles from Port I to the ice cap at Ice Access A. Access Route II (Fig. 8) extends 20 miles from Port II to junctions of Routes B, C, and D. Both Routes I and II cross very rugged and rocky terrain. Access Route I would necessitate a grade which is somewhat steep until the upland is gained. Considerable excavation in rock would be necessary over nearly the entire length of this route.

Route II passes over much less rugged terrain, but it is considerably longer. Initial access to the upland is via a valley which is rather short and steep. For the most part, Route II is situated on a generally rounded elevated surface which is marked by numerous dikes, valleys, glacial basins, and large lakes. Locally, the topography is somewhat rugged. The route parallels a very large dike for several miles. The major part of Route II is confined to rock areas; hence, a great amount of rock excavation could be expected. Local upland patches of glacial debris and local areas of talus on the hillsides would be encountered.

Ice-cap access.

24. Marginal ice conditions all along the 60-mile study area are very poor. The slush condition and the severe crevassing which was visible from aerial reconnaissance observations (but not apparent on aerial photographs of 1946-1947) may eliminate this entire area for consideration. A few general details have been obtained from study of the trimetrogon photographs, but field inspection is needed should the Kvane-Frederikshaab area be further considered.

VI. CRITERIA FOR SOUTH GREENLAND ICE-CAP ACCESS

25. The following criteria have been established for purposes of assisting in preparation of the preliminary investigation. Normal engineering practices common to more temperate climates cannot in many instances be followed because of the influence of the unique environmental stresses in Greenland. Final field survey of the area and evaluation of performance of existing structures of a similar nature based on construction techniques and the environmental aspects will make it possible to develop rigid criteria for use in planning and constructing the final project.

Criteria for ice-cap access.

26. *Minimum snow melt during summer months.* Access to the ice cap at high altitudes is necessary in order to avoid zones of excessive melt. At high altitudes, the melt zone is relatively narrow and melting is not as severe as in lower areas. Excess melt produces saturated snow or slush, many lakes in depressions, considerable gulleying, and development of many runoff streams. Such conditions will seriously impede or prevent over-ice transport in many instances. The danger of flooding is great for tunneling operations in the lower areas during the summer months.

Low degree of motion. Ice in relatively rapid motion is undesirable because of the development of crevasses which become a serious obstacle to overland (ice) transport. Serious damage may result to structures (tunnels, pipelines, rail lines, etc.) from ice which is in motion either from deformation of the ice mass or from the activity of crevasse development.

Few crevasses. Small crevasses can be filled with snow or they can be traversed by tunneling under them. Neither of these can be accomplished if the surface contains considerable slush and/or melt water which may be tapped. For the most part, the greatest number of crevasses, the greatest movement, and greatest amount of slush are in the marginal zone.

Low mean annual temperature. A low mean annual temperature is more favorable because melting is retarded and the rate of deformation decreases.

Criteria for overland route location.

27. *Location.* Consideration should be given to such items as direction of potential snowdrifts and location of the road with respect to windward slopes or crest-line areas in order to minimize the danger from snowdrift accumulation. In glaciated areas, locations of excessive silt content should be avoided because of the possibility of severe frost-heaving problems. Sidehill areas which are mantled with silty material in motion (solifluction lobes) should be avoided because of the icing potential in winter and general instability in summer. In permafrost areas, locations containing considerable ground ice accumulations should be avoided or appropriate construction and design steps should be taken to preserve the thermal regime.

Grade and alignment. These two items should be adjusted to the terrain as much as possible in order to minimize excessive rockwork, much of which will be in very hard rock. Grades should not be over 4% for any great distance. Steep grades up to 7 or 8% can be utilized for very short distances.

Materials. Since rockwork will be considerable in most areas of southern Greenland, it will be necessary to allow bulk fill obtained directly from the pit or quarry or from cut sections without processing. However, materials used for base course and surface course should be relatively free from silt to minimize frost damage.

VII. SITE SELECTION ANALYSIS

28. There are many areas of relatively easy access to the ice cap by use of light equipment, such as dog sleds, and possibly weasels. However, the need to have year-round access to the open sea, to haul heavy equipment and supplies, and to be supported by air precludes further consideration of many site areas.

Narsarssuak—first priority.

29. Even though this location is at the southern tip of Greenland, it offers many possibilities for development not found in the other two areas under consideration. The ice-cap access point is believed to offer the best possibilities in the entire area because of the generally high altitude, narrow slush zone, and relatively few crevasses. It is believed that a pressure regime exists at the ice-cap access point. Subport Narsarssuak, even though at present small, is situated so that it can be expanded with additional pier, open and closed storage, and anchorages to accommodate both deep and shallow draft vessels. The fjord is reported to freeze during the coldest months to depths of 12 in. (greater during extremely cold winters). This precludes its use by all but ice-breaker-type vessels. Ample area, favorable from soils and topography standpoints, is available in the air base area for enlarging the present installation. The air base at BW-1 is now capable of accommodating heavy aircraft. Ample area and good materials are available for its expansion, should it be necessary. An overland access road of approximately 40 miles can be constructed without too great difficulty. A shorter, more direct route can be located, but excessive earthwork in rock and excessive

grades would be necessary. The suggested location follows the main base-level stream from its mouth in Gannet Bay to its headwaters at the foot of an upland glacier. In general, grades are favorable. A few bridges will have to be constructed along the route. From limited data available at this time it is not possible to evaluate snowdrift at spots along the location. Even though the grade and alignment are satisfactory, excavation in rock will be considerable over the 40-mile length. Ample quantities of granular materials occur at many places along the route.

Ivigtut Fjord—second priority.

30. Ice-cap access in the area generally north of Ivigtut Fjord is not good but could possibly be utilized with great expense and effort. The crevasse and slush zone is wider than that at BW-1. Furthermore, access to more stable, higher-altitude snow and ice is quite long. There is no port on the north side of Ivigtut Fjord. Consideration for utilization of Grønne Dal and/or Ivigtut was dropped because the ice-cap access points are very poor for the area on the south side of the fjord. The peninsula called Bjornedal, which extends out from the north side of Ivigtut Fjord, provides some potential shelter and harbor, and also room for port development. The peninsula is rocky but generally low in elevation. There are indications that a limited beach is in existence for initial landing operations. The overland access route between Bjornedal and the ice-cap access will require a rather steep initial access grade from the port area. Considerable rock-work will be encountered throughout the entire access route. Following a study of winter photography, the location was adjusted to avoid areas exhibiting excessive snowdrift.

Frederikshaab-Kvane area—third priority.

31. This area was rated low in priority because of poor ice-cap access, difficult terrain for road construction, and poor conditions in the littoral region for port location and development. Two possibilities for port location exist but construction would be very difficult and costly.

Sondrestrom (BW-8).

32. As this area does not offer access to shipping during the entire year, it has been considered only as a possible access point from the air base and port to the inland for a limited period during the year. The shipping season is 1 June through 15 November. Movement over the marginal zone of the ice cap (70 miles wide) is almost impossible during the two- to three-month summer thaw period. During the remainder of the year, movement over the marginal ice is possible.

INFORMATION SOURCES

The following were used in conducting the study and in preparing the report.

Maps.

WAC Charts, sheets 85, 109.

AAC Charts, sheets 109DI, 109DII, 109CI, 85AI, 85AII, 85AIII, 85AIV.

AMS C501 Series, sheets NP 21, 22-8; NP 21, 22-12; NP 23, 24-9; NQ 21, 22-3; NQ 21, 22-4; NQ 21, 22-7; NQ 21, 22-8.

AMS C701 Series–Ivigtut, No. 1414II.

Aerial photography.

Ivigtut Area

M16-6P-173 (310-324) RLV-April 1947
M16-6P-173 (556-574) RLV-August 1946
M16-6P-173 (511-533) RLV-August 1946
M8-6P-173R (30-50) RLV-April 1947
M34 (2-54) (170-182) RLV (date unknown)
M55 (2-54) LV (date unknown)
7P14 (3-15) RLV-April 1947

Frederikshaab Area

M6-6P 173R (366-390) VLR
M8-6P 173R (88-110) VLR
M6-6P 173 (494-520) VLR
M16-6P 173 (213-223) VLR
M16-6P 173 (443-472) VLR
M16-6P 173 (700-730) VLR
2-54 R53 (130-156) VLR
2-54 R39 (113-129) VLR
2-54 R55 (1-19) LV
2-54 R21 (128-155) VLR
6P 173 M16 (621-634)
Navy-Gre 2 (78-82) V

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