Soil Science Studies at Centrum Sø, Northeast Greenland, 1960

by Stanley M. Needleman *)

Abstract. During the period May to August 1960, an Air Force scientific field party conducted earth science studies and tested a raised sand terrace, at lat. 80° 08′ N and lang 22° 30′ W, located about 224 km south of Station Nord, Northeast Greenland. The operation staged from Thule Air Force Base was climaxed by successful test landings on the terrace by C-119 and C-130 aircraft.

Significant data were obtained from related investigations on a typical arctic lake, ice-free soils, meteorology, engineering geology, geomorphology, and electrical resistivity of soils.

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Zusammenfassung: Bodenkundliche Studien am Centrum Sø, Nordost-Grönland, 1960. Eine wissenschaftliche Feldgruppe der U. S. Air Force führte von Mai bis August 1960 bodenkundliche Studien durch und untersuchte eine erhöhte Sandterrasse in Nordost-Grönland auf 80° 08′ N und 22° 20′ W. ungefähr 224 km südlich der Station Nord. Das Unternehmen, das von der Thule Air Force Base aus durchgeführt wurde, wurde durch erfolgreiche Versuchslandungen von Flugzeugen vom Typ C-119 und C-130 auf der Terrasse in Aktion gesetzt.

Bemerkenswerte Ergebnisse über einen typischen arktischen See, eisfreie Böden, die Meteorologie, Ingenieurgeologie, Geomorphologie und den elektrischen Bodenwiderstand wurden gewonnen.

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Introduction

Since 1955, the Terrestrial Sciences Laboratory of Air Force Cambridge Research Laboratories has been investigating ice-free natural land areas in North and East Greenland in order to obtain basic scientific data applicable to aircraft operation in the Arctic. The importance of such data arises from the need for emergency airstrips to serve the increased air traffic over Arctic regions.

The scientific program included studies in geology (engineering, glacial, and geomorphology), soils engineering, permafrost, meteorology, and electrical resistivity of soils. A topographic survey was made of Centrum Sø and the area surrounding the terrace and lake. Studies were also conducted on snow, ice, lake depth, thermal profile, and ablation.

A survey, similar to that at Centrum Sø, was conducted, with helicopter support, in Kronprins Christian Land within a 50-km radius of Centrum Sø.

Geomorphic Setting of the Area

Information on the glacial geology of North Greenland is incomplete. Ground observations of glacial deposits in Hall Land, Peary Land, and Kronprins Christian Land have provided a basis for evaluating the glacial record of North Greenland in addition to using photogeologie techniques. Radiocarbon dates have been obtained from samples located on key geomorphic features in North Greenland.

Evidence indicates that the most recent glaciation can be traced to the Greenland Ice Cap. Subsequent retreat and minor readvances occurred between 3500 and 6000 years ago. Radiocarbon dating of samples collected in 1960 will provide the time scale for the deglaciation of Kronprins Christian Land within an accuracy ± 200 years.

A series of marginal channels can be traced from the Centrum Sø area to the Greenland Ice Cap. The area appears to have been subjected to lacustrine deposition as ice dams were alternately formed and destroyed.

Of five terraces in the immediate area of Centrum Sø, the most prominent is at an altitude of 240 m along the north and south slopes of Centrum Sø valley. The others include altitudes at 22 m, 40 m, 90 m, and 100 m above Centrum Sø.

The best developed terrace is (fig. 1) at the west end of the lake, lying between the Saefaxi and Graeselven Rivers. It lies 2 m above the high water line at the east end of the lake and 5 to 6 m at the west end. The terrace was formed as a delta by rivers carrying glacial discharge during a period when the lake was about 9 m higher than the present level. It is relatively flat the entire 5 square km, with a maximum relief of 2 m in the vicinity of the airstrip and a change in grade of less than 2 m per mile. The terrace trends east-west between the Saefaxi and Graeselven Rivers. It is 2 km

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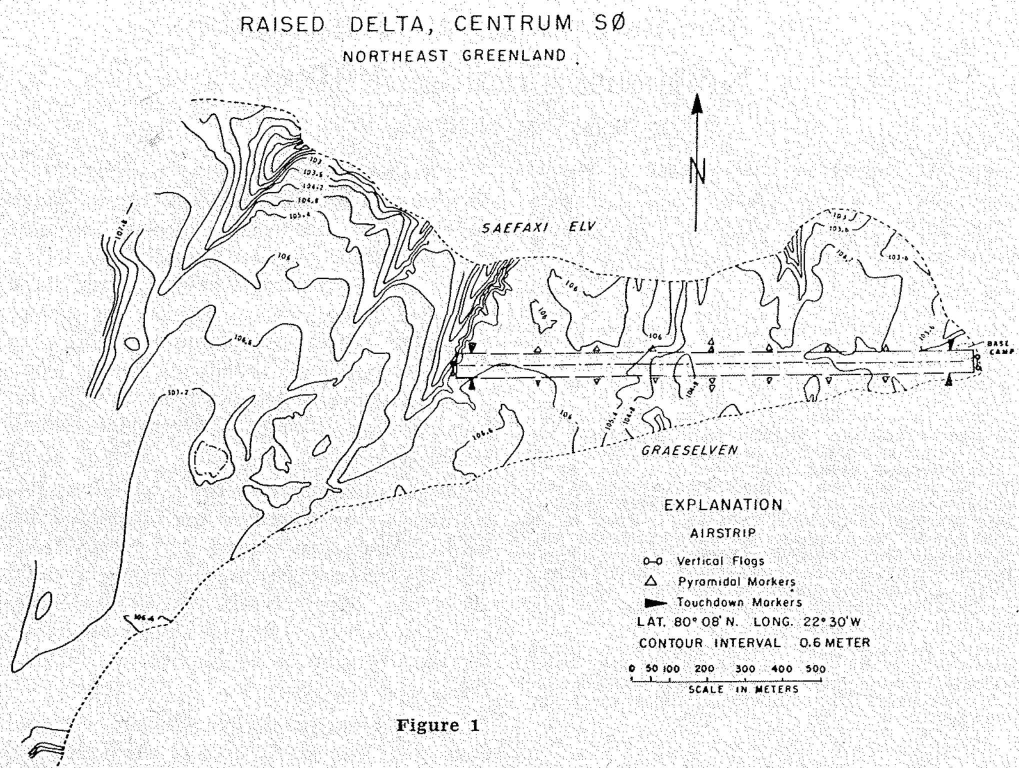

Figure 1

long and 1 km at the widest point at its west end. It narrows to a width of 310 m at the east end where the airstrip is situated. The terrace was 107 m above mean sea level or 9 m higher than the level of the lake.

Four broad channels or gullies, shallow in depth, transect the northern part of the terrace (fig. 2). These gullies trend southwest-northeast and range from 1 to 3 m in depth; they are about 31 m wide and from 160 m to 310 m long. The eastern sides of the gullies are generally steep slopes while the western sides are very gentle. They serve as the main drainageways for the surface meltwater of the terrace.

Surface features commonly associated with permafrost in areas of wet or saturated soils generally are lacking. Slump and heave are absent on the terrace in the vicinity of the airstrip except along the banks of the Graeselven River. The principal features observed were ponds and small mounds at the west end of the vegetated terrace, which lies at the foot of the upper terrace (130 m above sea level). Mounds were common in this area, and numbered several hundred in typical patches measuring 10,000 square m. The west end of the main terrace (110 m), which is poorly drained due to the underlying frozen ground and high silt content, remained moist during the height of the dry season; but the ponds were largely evaporated leaving mud cracks which were very soft. These cracks formed polygons 10 to 20 cm on a side.

The central and east parts of the terrace contain a small amount of polygons retaining raised centers and depressed borders. The bulk of these polygons were wind eroded leaving deflated centers; between the polygons are ridges up to .3 m in relief. The ridge stucture between polygons contains vegetation cover, high silt content, and has resisted erosion in contrast to the polygon centers. Many of the depressed borders are being buried with sand from the deflated areas. This process exceeds development of new polygons.

Figure 2: Raised Delta at Centrum Sø, July 31, 1960, Photo from 800 meters

The larger polygons are found in the coarser grained soils of medium sand with low moisture content. The active zone in this arid area is of high strength and stability in contrast to those areas with higher precipitation and moisture retaining soils. The low rate of precipitation is greatly exceeded by evaporation, and the moisture in the active zone is concentrated at its base next to the upper level of frozen ground. Frost action does not penetrate to the high moisture zone in depth, and therefore surface permafrost features disappear quickly when the ground thaws.

Meteorology

North Greenland is classified as a High Arctic Desert. Temperatures range from —51 °C to + 16 °C. Annual precipitation averages less than 10 cm per year. Wind velocity and evaporation rate are high. Summers are relatively mild and the land area is largely snow-free during the summer months.

In 1960 meteorological observations on a 24-hour shift basis were begun on 14 May at the base camp at the west end of Centrum Sø. Readings every two hours included wet and dry bulb air temperatures at the surface, wind speeds and direction at the surface, and, up to a height of 9000 m, surface barometric pressure, relative humidity, visibility, cloud cover and type, sunshine duration, and snow and soil temperatures. Observations at six-hour intervals included maximum-minimum temperatures, precipitation, soil and snow temperatures, and visibility. Balloon observations were also made every six hours. The meteorological station was closed on 27 July.

Summary of Data for Period 14 May — 27 July

	May	June	July
Absolute Maximum Temp., °C	+ 6	+ 14	+ 16
Mean Maximum Temp., °C	+ 0	+ 7	+ 11
Mean Temperature, °C	— 3	+ 5	+ 8
Mean Minimum Temp., °C	— 7	+ 2	+ 5
Absolute Minimum Temp., °C	— 20	— 1	+ 2

The highest temperature recorded during the 72 days of operations was 16° C on 7 July. The lowest temperature recorded was —20° C on 5 May. Daily mean temperatures below freezing were observed until 28 May; however freezing temperatures occurred until 6 June.

The mean snow temperature for the month of May was —1° C and mean surface soil temperature was 6° C for June and July. The mean soil temperature for the month af May was 2° C. The mean maximum soil temperature for the period was 11° C on 7 July.

Visibility was usually very good, exceeding 50 km, except in a few periods of inclement weather.

The prevailing wind direction was east with the strongest wind from the north. Of the 571 wind observations made during the period, the wind was from the east in 202 of these. The second predominant direction was from the southwest. Observations from a secondary station located on the highest terrace at an altitude of 620 m, about 3 km from base station, showed the prevailing wind direction to be from the southwest while the base station in the valley was receiving easterly winds from the lake.

Wind speeds were 28 miles per hour with measured gusts up to 42 miles per hour. The recorded mean wind speeds for the months of May, June, and July were 6, 8.8, and 9.5 miles per hour respectively.

The mean relative humidity for the entire period of observation was 67 percent with a maximum of 98 percent and minimum of 41 percent. The mean relative humidity for May was 60 percent, June 74 percent, and July 68 percent.

A total of 3.2 cm of precipitation fell during the period with 91.3 percent of it, in the form of rain and snow, occurring in the last half of June.

The sky was generally fair with a mean cloud cover of six-tenths for the entire period of the operation. Cloud heigths ranged from 100 m to above 6000 m. The predominant clouds were altocumulus occurring 27 percent and stratocumulus 26 percent.

During the month of May, the snow cover on the terrace was from 5 cm to 1 m deep. A typical profile of the snow indicated that the upper 71 cm were dry and fine-grained; from the 71- to the 92-cm level dry and coarse-grained. The snow was soft to hard on the top layer, medium hard in the middle, and hard on the bottom. Wind-packed elliptical mounds with very hard surfaces were similar to sastrugi common. These mounds were composed of thin multi-layered bands of fine sand and wind-packed snow, and were sufficiently resistant to be hazardous for ski landings and tracked vehicles. During the thaw period, these mounds melted faster than the surrounding snow cover, leaving a number of large potholes.

Composition of the Terrace

The test area was on a fine to medium-grained sand terrace located on the west shore of Centrum Sø. During the month of May, the snow cover ranged from a couple of cm to 1 m in thickness, and the underlying soil profile was frozen at 46 cm below the surface. When the snow cover melted, the ground (active zone) thawed to a maximum depth of 1½ m with the average being 92 cm. The surface consisted of soil polygons of irregular shape from 3 to 13 m on a side with depressed polygon borders serving as drainage channels.

The 0 to 30-cm layer of soil in the polygons was composed of medium-grained sand of non-plastic nature with less than 6 percent fine gravel, and is classified as a poorly graded sand. The depressed borders between polygons, which serve as common drainage ways, were composed of fine-to medium-grained sand and were classified as well-graded sand in the field laboratory at base camp. A temperature profile was obtained, ground water level and upper layer of permafrost checked, and soil load-bearing strength measured. The soil profile was generally uniform throughout the entire terrace area. Load-bearing strength with 3 types of penetrometers and cone index profiles showed an average CBR equivalent of 8 at the 15-cm level, which is more than adequate in accordance with established airfield engineering soil strength criteria to support heavy cargo aircraft.

Surface Conditions

The terrace consists of three principal types of surface features, (1) areas within soil polygons, (2) areas between soil polygons, and (3) relic and present drainage channels. The surface area within polygons is more than 4/5 of the entire terrace and is very dry except for small scattered moist patches during the period from late June to about mid-September. The areas between polygons and some of the drainage channels are generally moist during the dry season The terrace is partly saturated in several locations for a two-week period in mid-June because of the rapidly melting snow cover. Evaporation and surface runoff quickly dissipates the bulk of the moisture, as very little is absorbed by the soil.

The area between the polygons ranges from a few cm to as much as 1½ m in width and contains nearly all the vegetation of the terrace.

The surface soil within polygons is largely loose, fine to medium sand with the exception of cemented hardpan-like sand at the east end of the terrace. The common color is gray at the surface, and tan, black, and white below the surface.

The surface soil between polygons is fine-grained sand with a clay fraction. The soil is relatively soft and moist. It is brown at the near surface layers and gray and tan below.

The west end of the terrace is covered with numerous vegetation mounds appearing as hemispherical tussocks from 15 to 30 cm in diameter and 5 to 15 cm high. Beneath the mounds is a 15- to 75-cm thick layer of silt and fine sand largeley tan in color.

Soil Type and Soil Section

The soil of the terrace consists primarily of silt, fine to medium sand, fine gravel, and few fines, with the surface layers having a higher percentage of silt (5.1 percent fine gravel, 12.6 percent coarse sand, 40 percent medium sand, 28.9 percent fine sand, and 11.6 percent fines). The typical soil profiles and test pit data in table 1A and B show that the 1-m soil section underlying the terrace is relatively uniform. The 0 to 15-cm layer in the polygons is composed of fine to medium sand in predominance with a small percentage of fine gravel, and is classified as a poorly graded sand (5 percent fine gravel, 8 percent coarse sand, 40 percent medium sand, 45 percent fine sand, and 2 percent fines). The corresponding layer between the polygons or drainageways consists of a well-graded fine sand with a higher percentage of clay fines (2 percent fine gravel, 10 percent coarse sand, 30 percent medium sand, 48 percent fine sand, and 10 percent fines). It is also a borderline of well-graded fines and silty sand.

Table 1. Typical Soil Sections, Centrum Sø

A. Soil Section in Polygon

Date: 14 Juli 1960. Location: Test pit 20 S, 625 m from west end of runway, 9 m from southern margin

Thickness cm	Description	Depth cm	Soil Temp.,/°C	Moisture Content, percent	Bearing/ Strength (CBR)
5	Silty sand and pea gravel; less than 5 % gravel.	surface	8	0.4	3
5	Fine sand, gray	570	7	1.9	4
13	Fine to medium sand, gray and white	10—23	7	2.1	8
75	Fine sand, gray	23—30	6	3.4	12
15	Medium, gray and black sand	30—45	4	3.7	20
5	Medium to coarse sand, variegated	45—51	4	9.8	over 20
7.5	Medium sand, gray and black	51—60	4	15.3	over 20
30	Coarse sand, gray and black	60—79	2	15.3	over 20
12	Free water	79—90	1	30*)	
**)	Permafrost	90	0	20.3	over 20

*) Estimated **) Unknown

Table 1. Typical Soil Sections, Centrum Sø (Continued)

B. Soil Section Between Polygon

Date: 15 July 1960 Location: Test pit 15 N, 1457 m from east of runway, 12,2 m from northern margin.

Thickness cm	Description	Depth cm	Soil Temp., °C	Moisture Content, percent	Bearing Strength (CBR)
7.5	Clayey sand, brown, with 20% fines and 5% fine gravel	8	8	13.1	2
30	Fine to medium sand, gray	7.5—38	6	7.4	8
18	Medium sand, gray	38—60	3	18.4	12
29	Medium to coarse sand, black and white	60—90	2	20.4	15
23	Free water	72—90	1	30 *)	
**)	Permafrost	90	0	20.3	over 20

*) Estimated **) Unknown

Below the top layers in polygons down to frozen ground, the amount of coarse and fine sand increases, with cross-bedding and lensing common throughout the terrace. The amount of fine sizes increases with depth, but 55.5 percent of the total fines are concentrated in the upper 15-cm layer between polygons. Within polygon areas below the top layers, the soil is poorly graded but increases in fine sand and clay sizes (2.3 percent fine gravel, 2.9 percent coarse sand, 39.3 percent medium sand, 50 percent fine sand, and 5.5 percent fines).

The plasticity characteristics of the soil profile are very low and the soil has little shearing strength when either wet or dry. Cementation of fines with medium sand occurred at the east end of the terrace.

As the moisture content was a critical factor, various methods were used to monitor the moisture content. By bulk sampling, weight-volume ratios of individual layers, and restivity techniques using installed soil test blocks of nylon and gypsum, the optimum moisture content was determined to be 2.5 to 3.5 percent in the 0 to 15-cm layer and 3.5 percent in the 15- to 30-cm layer in July.

Soil Strength

Penetrometer surveys were conducted daily in order to obtain readings in cone index which were converted to equivalent relative soil load-bearing strength values. The data indicated a soft surface but a rapid increase in shearing strength with depth. As the critical depth factor was considered to be the 15- to 30-cm layer, readings were taken at 2.5, 7.5, 13, 23, and 30 cm. Additional readings were taken at levels of maximum bearing strength. The mean equivalent CBR values were determined to be 8 at the 15-cm level, 15 at the 30-cm level, and over 20 at the 51-cm level. With compaction, the mean equivalent CBR value at the 15-cm level was increased from 8 to 10. In only 3 locations was the equivalent CBR less than 10 at the 15-cm level. The softer areas were generally in the polygon drainageways and averaged 30 percent lower CBR values than mean values in the polygons.

The soil was in its weakest condition in June during the period of saturation which was due to the melting snow and precipitation. Subsequent recovery of strength was due to the drying of the soil from evaporation and subsurface runoff. Recovery of strength occurred in early July and averaged 30 to 50 percent in the between polygons areas and as much as 30 percent in the polygons.

Compaction

Inasmuch as the soil compacts poorly and negligibly when too dry or too wet, the airstrip selected on the terrace was near the optimum moisture content or 2.5 to 3.5 percent, and sufficient densification was achieved in the 0 to 5-cm layer at three locations. An average increase of more than 50 percent in strength was obtained after six passes with a garden-type roller of 50-kg-load towed behind a jeep.

Maximum increase was achieved with a moisture content of 3.5 percent near Test pit 22 N (7.0 percent fine gravel, 23 percent coarse sand, 38.7 percent medium sand, 20.8 percent fine sand, and 9.9 percent

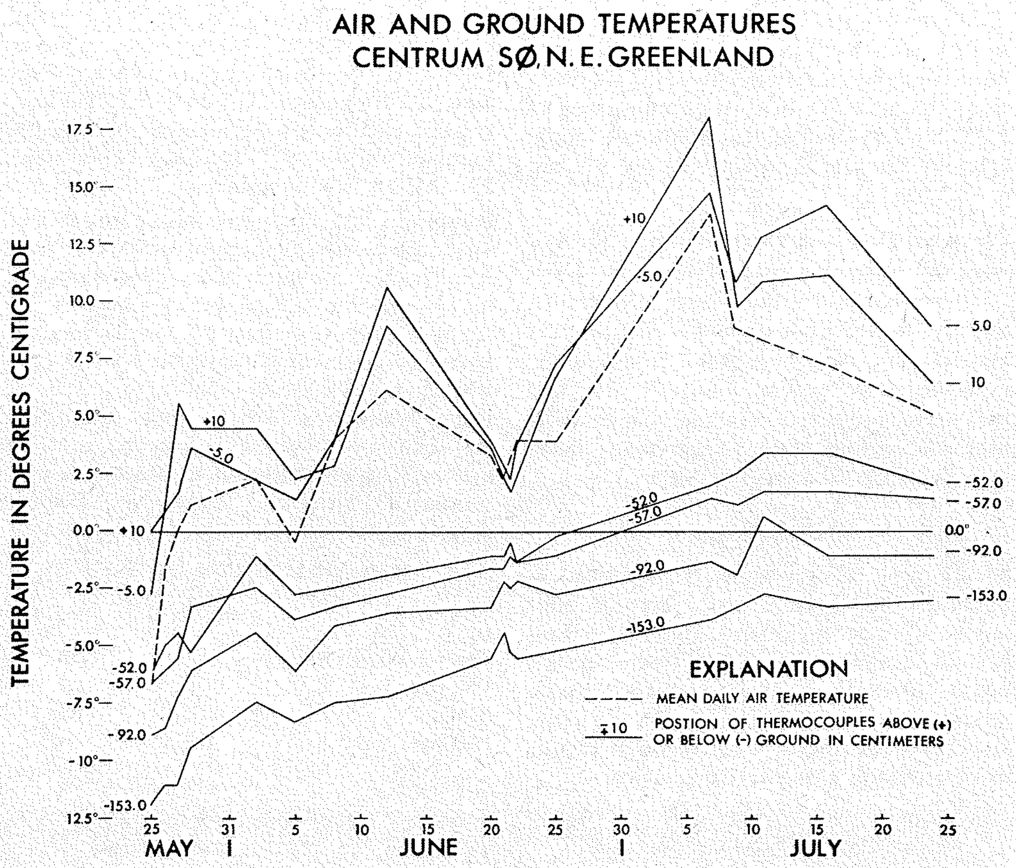

Figure 3

fines). Minimum side displacement of soil occurred in the top layers containing higher percentages of medium sand. It can be assumed that satisfactory compaqtion took place in those soils that were within 1 percent of the optimum moisture content.

Sufficient angularity of the soil particles was present, which contributed to the increased densification and bearing strength because of the mechanical interlocking of the grains developed by compaction through rolling action.

Permafrost

Drilling, electrical resistivity, and test pitting techniques were used to determine the depth below the surface to permanently frozen ground. Average depth to frozen ground was 46 cm in May, 61 cm in June, and 97 cm in July. Permafrost was of the dry variety with the typical arctic frost heaving phenomena absent. Some ice wedges were found at permafrost level along the banks of the terrace on Graeselven River. The characteristics of the active zone lying above frozen ground are described in table 2. Data from 10 pits were averaged and presented in summary form.

Table 2: Characteristics of Active Zone, Centrum Sø (Composite of 10 Pits July 1960 *)

Soil Type	Thickness cm	Depth cm	Temp. °C	Moisture %
Fine Sand	7.5	0—7.5	8	0.4
Fine to Med Sand	7.5	7.5—15	7	1.9
Fine Sand	7.5	15—23	6	2.1
Medium Sand	7.5	23—30	5	3.4
Med to Coarse Sand	7.5	30—38	4	3.6
Medium Sand	7.5	38—45	4	3.8
Med to Coarse Sand	15	45—60	3	12.5
Med to Coarse Sand	28	60—89	2	15.3
Free Water	18	79	1	30**)
Permafrost	***)	89	0	20

*) Soil Profile within Polygons
**) Estimated
***) Unknown

A thermocouple was installed in a hole drilled to a depth of 1½ m below the surface. The thermal gradient varied regularly from the mean surface soil temperature of 10° C to 7.5° C at 60 cm below the upper layer of the frozen ground during the test period (fig. 3).

Permafrost thawed rapidly during the last week of May and reached its mean about 20 June. Air and ground temperatures rose sharply to their maximums about 7 July and leveled off thereafter. The cooling cycle began to appear about 17 July and the curve indicates that the temperatures near the surface were falling much faster than in depth by a ratio of 5.1.

Airstrip Program

By 12 July, soils data were evaluated to establish the location and three possible orientations of an airstrip and the feasibility of landing the C-130 test aircraft. Bearing strength of the soil, surface roughness, amount of grading, length of strip, and approach angles were the key factors in determining the final orientation.

The magnetic bearing of the airstrip and base was N 56° W and the true position N 90° 00′ W, based upon an average magnetic declination of 33° 34′ W. The geographic position of the airstrip site was determined to be 80° 08′ 28″ N latitude, 22° 30′ 29″ W longitude.

Scraping, dragging, and rolling operations were conducted on a portion of the final strip to test strength and smoothness and to prepare the surface where necessary. A strength increase of over 50 percent resulted from the effect of compaction or soil densification by a 310-kg roller towed by a jeep. When preparations were completed, the strip was 1440 m long by 63 m wide and in suitable condition to withstand substantial traffic from heavy type aircraft such as C-119 and C-130.

Summary of Engineering Work

Operation	Man-days	Percent
Scraping (drag-scraper)	5	36
Dragging	4	29
Rolling	3	21
Marking	2	14
	14	100

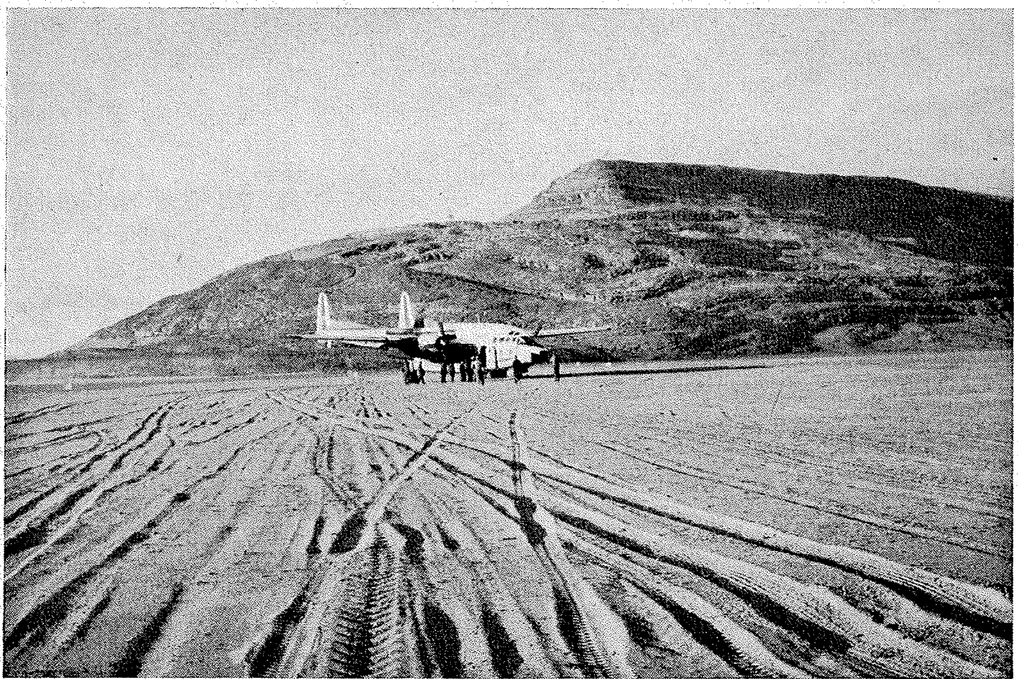

Figure 4: C-119 Aircraft at West End of Airstrip after Landing, July 27, 1960

On 27 July, an unscheduled aircraft landing was made on the strip by RCAF C-119 which weighed 31,000 kg (fig. 4). The aircraft landed with no difficulty and ruts averaged about 7 cm. On 1—2 August, a C-130 (wheeled) which weighed 46 000 kg executed two scheduled test landings successfully. The wheel ruts averaged less than 5 cm.

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Über die Sichtweite im Polar Whiteout

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Zusammenfassung: Es wird über Untersuchungen berichtet, die den whiteout als optische Erscheinung behandeln und zu einer Reihe quantitativer Aussagen über die Sichtweite von Objekten unter whiteout-Bedingungen führen.

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On the Visual Range in the Polar whiteout: It is reported on investigations which treat the whiteout as an optical phenomenon and lead to a series of quantitative statements on the visual range of objects under whiteout conditions.

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„Polar whiteout" ist ein verhältnismäßig junges Wort für einen Begriff, der sowohl Polarforschern als auch manchen Laien, z. B. Wintersportlern, schon lange bekannt ist als eine Situation, in der die visuelle Orientierung in schneebedecktem Gelände erschwert oder gar unmöglich ist. Wohl die erste spezielle Beschreibung dieser Erscheinung stammt von *Hedine* (1), der für sie das Wort „arctic whiteout" prägte; in der Antarktis wurde das Phänomen von *Court* (2) „milky weather" genannt. Heute wird es — obwohl nicht nur auf die Polargebiete beschränkt — in Anlehnung an *Liljequist* (3) als polar whiteout oder nur kurz whiteout bezeichnet.

Jede Betätigung im Polargebiet hängt entscheidend von Transport und Nachschub ab. Für den Verkehr sowohl auf der Schneefläche als auch in dem bodennahen Luftraum bildet der whiteout ein schweres Hindernis. In den letzten Jahren wurden daher weitere Untersuchungen über die Ursachen und Eigenschaften des whiteout angestellt, um damit die Voraussetzungen für seine Vorhersage oder gar Überwindung zu schaffen.

Gerdel und *Diamond* unterscheiden in ihrer eingehenden Monographie (4) folgende Arten des whiteout: 1. „Overcast" whiteout, verursacht durch eine dichte Wolkendecke; 2. Wassernebel-whiteout; 3. Eisnebel-whiteout; 4. whiteout durch Schneefegen; 5. Niederschlags-whiteout.

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