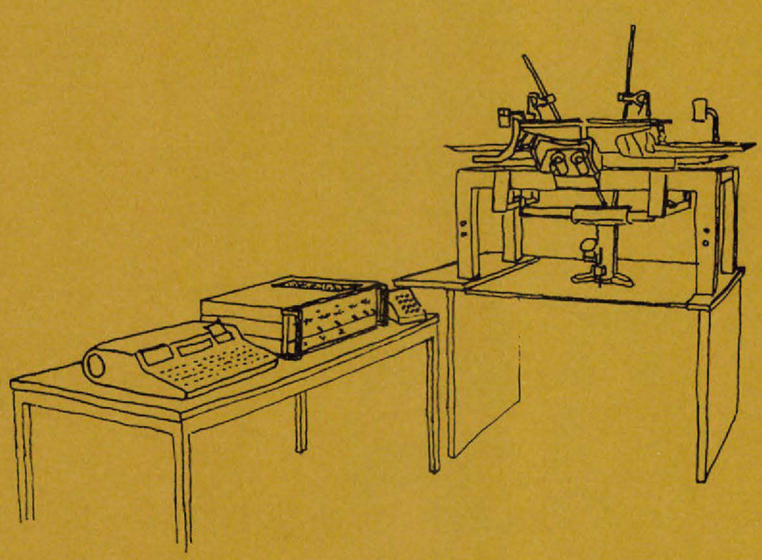
ØNLANDS GEOLOGISKE UNDERSØGELSE
Bulletin No. 155

Topographical and geological maps of Hall Land, North Greenland

Description of a computer-supported photogrammetrical research programme for production of new maps, and the Lower Palaeozoic and surficial geology

Peter R. Dawes



1987

Grønlands Geologiske Undersøgelse

(The Geological Survey of Greenland)

Øster Voldgade 10, DK-1350 Copenhagen K

Bulletins

No. 140 Upper Pleistocene and Holocene marine deposits and faunas on the north coast of Nûgssuaq, West Greenland. 1981 *by* L. A. Símonarson. D.kr. 160.00

No. 141 Dresbachian trilobites and stratigraphy of the Cass Fjord Formation, western North Greenland. 1981 *by* A. R. Palmer & J. S. Peel. D.kr. 290.00

No. 142 Silurian graptolites from Washington Land, western North Greenland. 1981 *by* M. Bjerreskov. D.kr. 112.00

No. 143 Stratabound copper–lead–zink mineralisation in the Permo-Triassic of central East Greenland. 1982 *by* B. Thomassen, L. B. Clemmensen & H. K. Schønwandt. D.kr. 90.00

No. 144 Upper Jurassic bivalves from Milne Land, East Greenland. 1982 *by* F. T. Fürsich. D.kr. 205.00

No. 145 Stratigraphy of the Silurian turbidite sequence of North Greenland. 1982 *by* J. M. Hurst & F. Surlyk. D.kr. 280.00

No. 146 Paleocene gastropods from Nûgssuaq, West Greenland. 1983 *by* H. Kollman & J. S. Peel. D.kr. 280.00

No. 147 The stratigraphy of the Upper Jurassic and Lower Cretaceous sediments of Milne Land, central East Greenland. 1984 *by* T. Birkelund, J. H. Callomon & F. T. Fürsich. D.kr. 106.00

No. 148 Upper Ordovician and Silurian carbonate shelf stratigraphy, facies and evolution, eastern North Greenland. 1984 *by* J. M. Hurst. D.kr. 125.00

No. 149 Benthic macroinvertebrate associations from the Boreal Upper Jurassic of Milne Land, central East Greenland. 1984 *by* F. T. Fürsich. D.kr. 135.00

No. 150 Stratigraphy and structure of the Fiskenæsset Complex, southern West Greenland. 1985 *by* J. S. Myers. D.kr. 200.00

No. 151 The geology of the Qôrqut granite complex north of Qôrqut, Godthåbsfjord, southern West Greenland. 1985 *by* C. R. L. Friend, M. Brown, W. T. Perkins & A. D. M. Burwell. D.kr. 155.00

No. 152 Reaction between picrite magma and continental crust: early Tertiary silicic basalts and magnesian andesites from Disko, West Greenland. 1985 *by* A. K. Pedersen. D.kr. 275.00

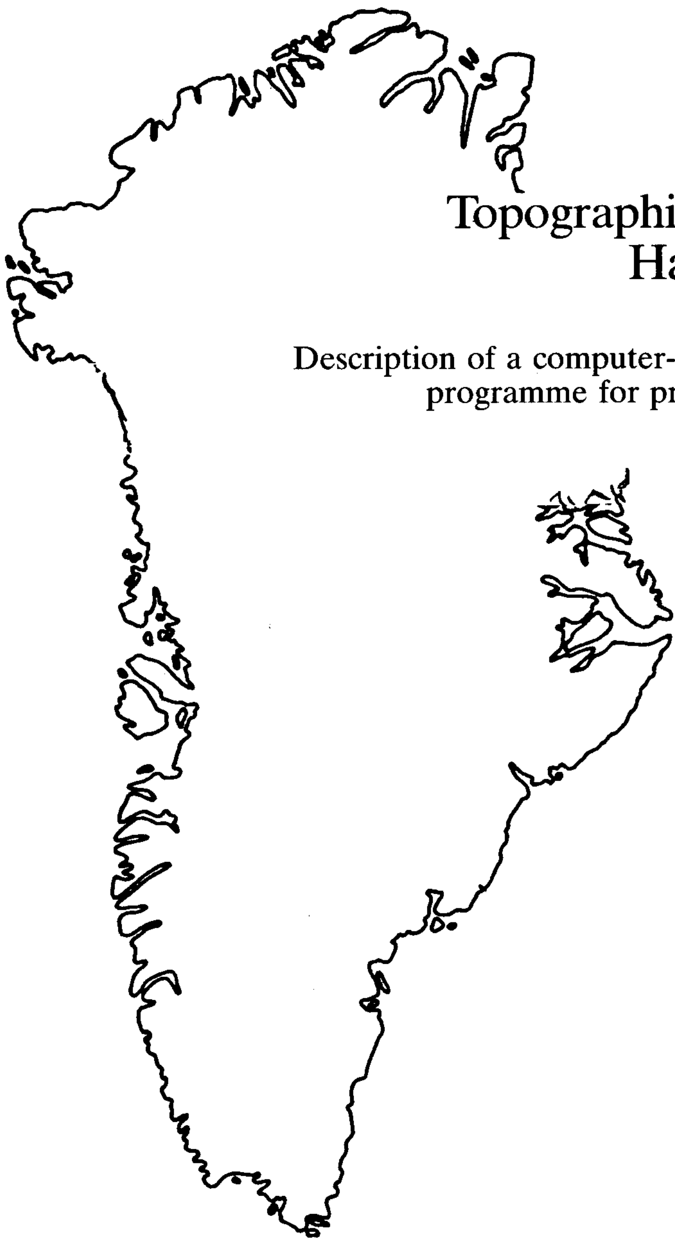
No. 153 The Kimmeridgian ammonite faunas of Milne Land, central East Greenland. 1985 *by* T. Birkelund & J. H. Callomon. D.kr. 185.00

No. 154 The early Archaean to Proterozoic history of the Isukasia area, southern West Greenland. 1986 *by* A. P. Nutman. D.kr. 235.00

No. 155 Topographical and geological maps of Hall Land, North Greenland. Description of a computer-supported photogrammetrical research programme for production of new maps, and the Lower Palaeozoic and surficial geology. 1987 *by* P. R. Dawes.

No. 156 Stratabound scheelite and stratiform tourmalinites in the Archaean Malene supracrustal rocks, southern West Greenland. 1987 *by* P. W. U. Appel & A. A. Garde.

GRØNLANDS GEOLOGISKE UNDERSØGELSE
Bulletin No. 155



Topographical and geological maps of Hall Land, North Greenland

Description of a computer-supported photogrammetrical research programme for production of new maps, and the Lower Palaeozoic and surficial geology

Peter R. Dawes

1987

Abstract

Topographical and geological map sheets covering the northern part of Hall Land (81°–82°N) are presented – an area of about 3000 km^2. The maps are the products of a research programme in which newly developed photogrammetric techniques have been used in the interpretation and compilation of the topography and the geology (both solid and surficial).

The *topographical map* has been constructed with a minimum of geodetic ground control. The topographic contours have been calculated from a digital elevation model using computer programmes, and automatically plotted out. The *geological map* has been hand-drawn from 74 manuscript sheets compiled from aerial photograph models on second-order analog stereo-plotting instruments with computer facilities.

The maps, the photogrammetric programme and the solid and surficial geology are described in seven chapters. The first two provide an introductory background that explains the motivation for the research, summarises the history of cartographic, geodetic and geologic work and provides a status of research at the start of the programme.

The third chapter discusses the various aspects of the photogrammetric programme, instrumentation and the on-line computer facilities utilised, and is followed by a chapter dealing with compilation method, map presentation and assessesment of cartographic accuracy compared to previous maps and modern geodetic ground data.

The next chapter describes the topography and geomorphology and relates the three main physiographic provinces to the solid and surficial geology.

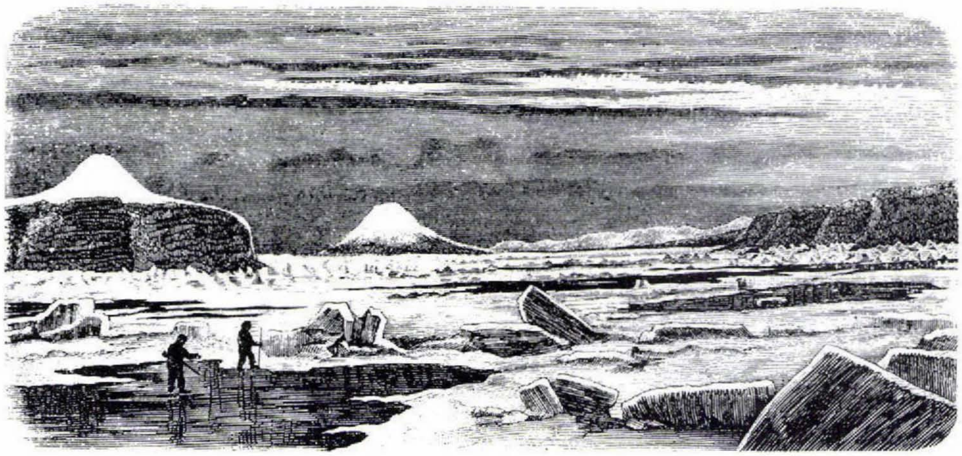
The penultimate chapter outlines the stratigraphy and structure of the Upper Ordovician – Silurian (Llandovery–Pridoli) section through the E–W trending Franklinian basin. In Ordovician – earliest Silurian time, the map area was part of the carbonate platform; in the Llandovery a major shift southwards of the deep-water basin occurred. The Silurian succession displays a regional facies change from platform carbonates in the south, through a major reef belt on the shelf and upper slope to, in the north, clastic turbidites of the lower slope and trough. Facies transitions and interdigitation of shelf–slope–trough lithologies are complex. The northern part of the map exposes the autochthonous margin of the mid-Palaeozoic North Greenland fold belt characterised by E–W folds. The regional structure is an asymmetric synclinorium; a décollement zone probably occurs in the shale sequence that overlies the Lower Silurian carbonate platform.

The final chapter describes eight groups of Quaternary deposits and features: moraine, fluviatile-glaciofluvial, marine, lacustrine, colluvial, solifluction, aeolian and periglacial. Hall Land was formerly entirely ice covered, and deposits of several ice advances are preserved; six major marginal moraine systems are defined. Marine deposits are prominent and terrace levels and raised shorelines are well preserved; the Holocene marine limit is at least 125 m above present sea level. Major events are placed within a Pleistocene–Holocene chronostratigraphic framework.

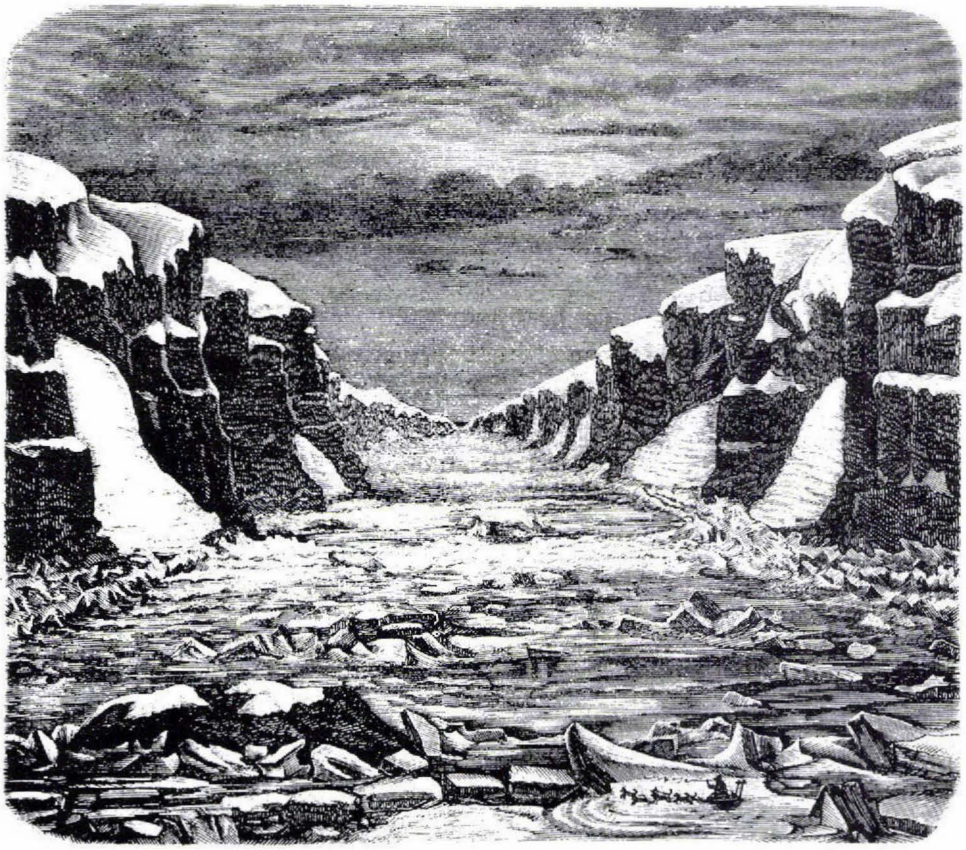
Comments on place names are given in an appendix.

Author's address:
Geological Survey of Greenland
Øster Voldgade 10
DK-1350 Copenhagen K
Denmark

Contents



Ueber das Eis der Newmans-Bucht.



Der Petermann-Fjord.

Frontispiece
Engravings from Bessels (1879) of Newman Bugt and Petermann Fjord. "There appear signs around Newman Bay of extinct glaciers, as the moraines may be seen on the shores, but at present there is only one at the head" (Capt. George E. Tyson *in* Blake, 1874, p. 187).

Fig. 1. Hall Land viewed from the south with Robeson Channel (RC) and Ellesmere Island, Canada, in left background. Numbers refer to the physiographic provinces described in the text. 'X' marks valley containing slumped strata of uncertain origin mentioned in text – bedrock or glacial. A = Atka delta; G = 'Gråstenelv' delta, H = Hauge Bjerge, HB = Hall Basin, NB = Newman Bugt, S = 'Sun Mark Mountain.' Aerial photograph 546D–N, 11464, copyright Geodetic Institute.

Introduction

Hall Land is a broad ice-free peninsula located between 81° and 82° on the northern coast of Greenland, bordered by Petermann Gletscher, Petermann Fjord and Hall Basin on the west, Robeson Channel on the north and Newman Bugt on the east (figs 1 & 2). The map sheets accompanying this report cover an area of about 3000 km^2 and represent all but the southern part of Hall Land adjacent to the Inland Ice (fig. 3).

The maps are products of a research programme initiated to evaluate and develop various laboratory methods aimed at combining geologic and topographic mapping using computer-supported photogrammetrical techniques. Four maps at approximate scale 1:66 500, two geologic and two topographic, are presented, and these represent the first map sheets published by GGU in which advanced photogrammetrical techniques have been used extensively in the interpretation and compilation of the topography and geology.

The majority of the place names used in this paper are official, authorised names, i.e. approved by the Greenland Place Name Committee. However, for descriptive convenience several unapproved names are also used and three of these, 'Gråstenelv', 'Monument' and 'Saint Anthony's Nose', are included on the maps. All unauthorised names are distinguished in the text by inverted commas (fig. 3), and clarification of the toponymic usage in this paper is given in a note on place names.

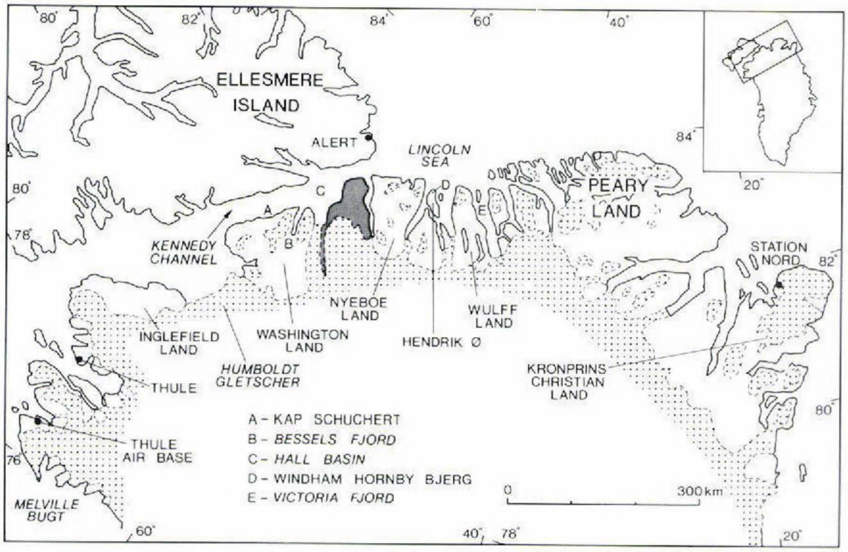


Fig. 2. Locality map of northern Greenland and adjacent Canada showing Hall Land (dark) and other areas mentioned in the text. Ice caps and border of Inland Ice shown by dotted signature.

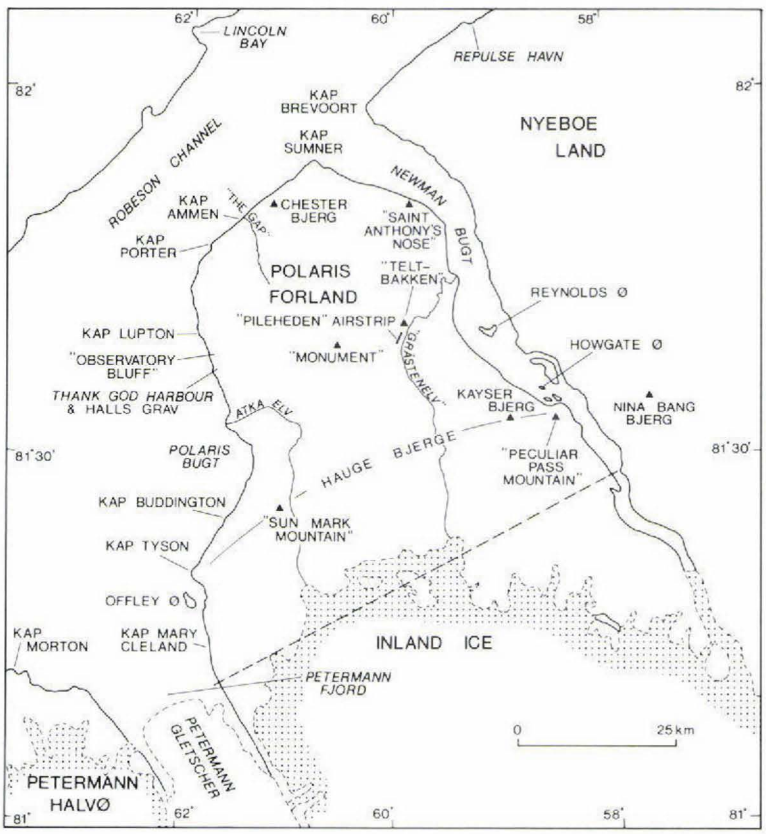


Fig. 3. Toponymic map of Hall Land and environs. Dashed line indicates the southern limit of the map area. Unauthorised place names used in the text are placed in inverted commas. See also Table 5 and Appendix.

Initiation of the Hall Land programme

In the early 1970s, the Geological Survey of Greenland (Grønlands Geologiske Undersøgelse = GGU) began planning a systematic geological mapping project in northern Greenland, from Washington Land in the west to Kronprins Christian Land in the east – a region with an ice-free area of some 130 000 km^2 (fig. 2; Dawes & Henriksen, 1973). At that time, the region represented one of the few parts of the world for which fundamental mapping errors were known to exist; for example, Lillestrand & Johnson (1971) concluded the region to be approximately 8000 km^2 larger than shown by existing maps. Such maps were unacceptable as the basis of a modern geological mapping programme.

A complete geodetic survey of northern Greenland with the establishment of a ground control net, as well as new aerial photograph coverage, were not imminent in the early 1970s. Therefore, a large part of GGU's planning concerned assessment of the existing map coverage, seen in relation to the aims of the geological work and mapping scale. Evaluations were made as to the ways in which map material might be modified in order to produce an acceptable base-map for documentation of the geology.

Discussions were held with a number of organisations about field and laboratory programmes to meet this aim, and about existing map and geodetic data. These organisations included: Geodetic Institute, Copenhagen; Institute of Surveying and Photogrammetry, Technical University of Denmark; Control Data Corporation, Minnesota; Grumann Ecosystems, New York; Department of Energy, Mines & Resources, Ottawa; U.S. Geological Survey, Virginia and Directorate of Military Survey, England. At the same time, evaluation of the photointerpretation techniques that might be used on the different geological provinces of the region was made, and both geological and topographical aspects were assessed with a view to the construction of maps by untraditional methods (Dueholm, 1973, 1975, 1976; Lillestrand, 1974).

In 1975, a research project, led by K. S. Dueholm at the Institute of Surveying and Photogrammetry, was initiated to investigate how photogeological, photogrammetric and geodetic working methods could best be combined. The project was supported by GGU and the Danish Natural and Technical Science Research Councils (SNF & STF). The main part of this study was to examine in the laboratory how topographical and geological mapping could be coordinated, particularly in remote and essentially unmapped regions, and to evaluate and develop methods for an increased extraction of geological information from aerial photographs using advanced photogrammetric techniques. GGU was involved in all stages of the project, from formulation through to the processing of the main results (Dueholm, 1979). The present author was attached to the project and began work in 1975 with Hall Land as the study area; later H. F. Jepsen extended the study to the southwest to Washington Land (Dawes, 1977; Jepsen & Dueholm, 1978).

Hall Land became the first of several areas evaluated in the project. The choice of Hall Land as the pilot test area was governed by several factors, the most important of which were:

(1) existence in GGU archives of geological field data from several localitites but without regional map representation;
(2) lack of a suitable topographical base map on which to plot existing geological data;
(3) insufficient modern geodetic field data precluding construction of a base map by traditional methods;
(4) presence of a complete, good quality vertical aerial photograph coverage at approximate scale 1:54 000;
(5) variable solid geology, representing a cross-section through a Palaeozoic geosyncline from homoclinal platform in the south to deformed trough in the north;
(6) significant areas of a diverse Quaternary cover; and
(7) presence of a landing strip for heavy aircraft ensuring relatively easy access should supplementary field work be required.

The Hall Land programme was styled as an experiment in geological photointerpretation and digitised photogrammetric mapping which, in addition to providing relevant map representations of characteristic geological provinces where detailed field work was pending, also gave an insight into photogrammetric method, e.g. instrument composition, computer support and definition of programme requirements (Dueholm, 1979). Following the initial photointerpretation of Hall Land and work on several other test areas, all executed at the Technical University of Denmark, GGU established in 1978 its own photogrammetrical geological–topographical mapping system. This system has been used extensively in the mapping campaign in northern Greenland, the field work of which has spanned a decade (1975–77, Washington Land; 1978–80, Peary Land; 1984–85, Hall Land – Nansen Land).

History of scientific research

Initial scientific observations in Hall Land were made by two voyages of discovery towards the North Pole, the first expeditions to navigate Nares Strait. The first, the U.S. North Polar Expedition, 1871–73, led by C. F. Hall, wintered at Thank God Harbour in western Hall Land (Blake, 1874; Bessels, 1876, 1879; Davis, 1876); the second, the British Admiralty Arctic Expedition, 1875–76, under G. S. Nares, wintered in Ellesmere Island but travelled widely by sledge in adjacent Greenland (Feilden & De Rance, 1878; Nares, 1877, 1878). These expeditions mapped the basic geographic, geologic and physiographic features of the region. The next important geo-scientific results were obtained in 1917, when Koch (1918) visited the region as cartographer and geologist on the 2nd Thule Expedition, 1916–18. Koch's activities and those of later American, Canadian and Danish expeditions, which added significantly to scientific knowledge, were seasonal operations planned directly towards specific tasks which included cartographic, geodetic and geologic studies.

Cartographic and geodetic work

The coastal outline and physiographic divisions of Hall Land – northern and southern mountainous areas and a low-lying central plain – were established by the Hall and Nares expeditions whose main surveying instrument was the sextant. The official map from the Nares expedition is particularly interesting; it shows a height of 1300 ft (400 m) for the mountains of Polaris Forland (fig. 4D). The U.S. Lady Franklin Bay Expedition, 1881–84, led by A. W. Greely, also travelled in Hall Land, but surveying in Greenland was directed

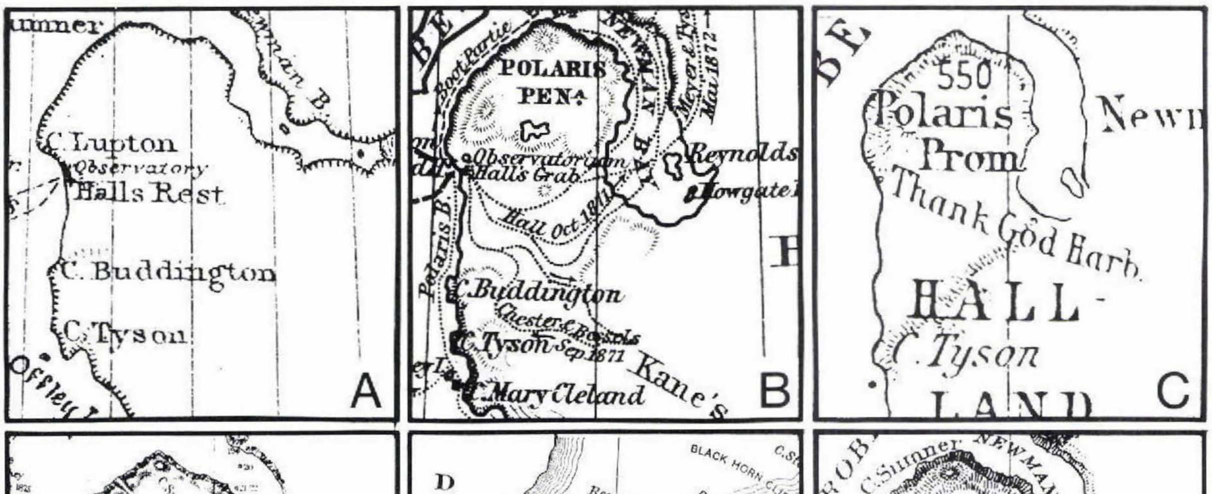


Fig. 4. Facsimile maps of Hall Land stemming from the earliest expeditions to the Robeson Channel region. All are parts of larger maps and reproduced at a common scale. A: Davis (1876), B: Bessels (1879) – U.S. North Polar Expedition, 1871–73; C: Nares (1877), D: Nares (1878) – British Admiralty Arctic Expedition, 1875–6; E: Greely (1886), F: Greely (1888) – U.S. Lady Franklin Bay Expedition, 1881–4.

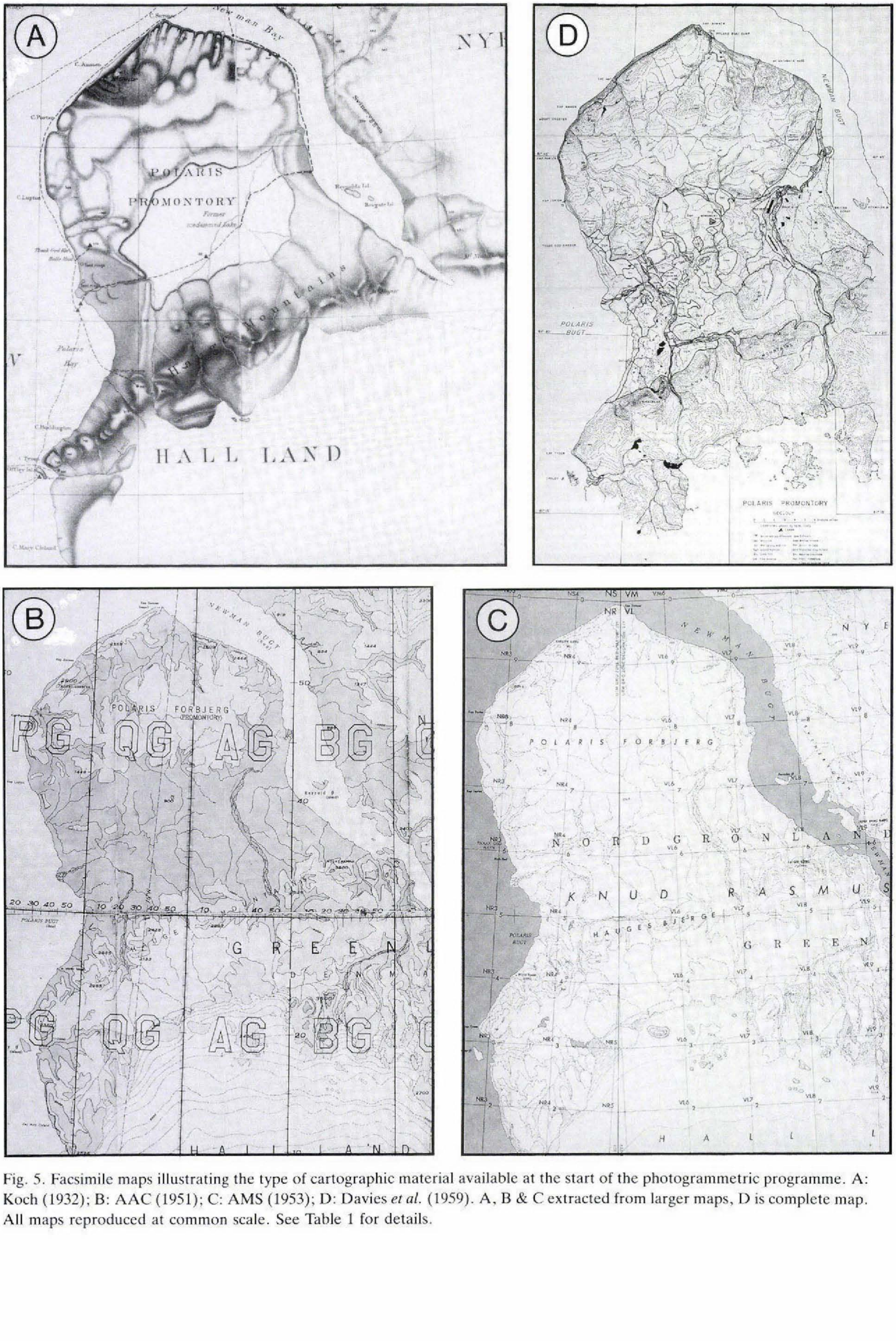


Fig. 5. Facsimile maps illustrating the type of cartographic material available at the start of the photogrammetric programme. A: Koch (1932); B: AAC (1951); C: AMS (1953); D: Davies *et al.* (1959). A, B & C extracted from larger maps, D is complete map. All maps reproduced at common scale. See Table 1 for details.

Table 1. Topographical maps of Hall Land published prior to the present mapping programme

	Type	Country	Data source/ publisher	Designation of Hall Land	Graphic depiction of topography	Scale	Publication year
1.*	Map of North Greenland	Denmark	L. Koch, Geodetic Institute	Hall Land Blackhorn Cliffs	Colour shading	1:300 000	1932
2.	World Aero-nautical Chart	U.S.A.	ACIC	WAC 8 Lincoln Sea	1000 ft contours with colour tones	1:1 000 000	1951
3.*	Aeronautical Approach Chart	U.S.A.	ACIC	Newman Bay 8D II	1000 ft contours with colour tones	1:250 000	1951
4.*	Army Map Service C – 501	U.S.A.	AMS	Polaris Forbjerg 19,20,21,22,23 24 – 10	200 m contours	1:250 000	1953
5.*	Operation Groundhog	U.S.A.	W. E. Davies – Cambridge Research Center	Polaris Promontory	50 – 100 m form lines	1:173 000	1959
6.	National Topo-graphic System 3rd Edition	Canada	DMTS	Kennedy Channel NW 80/72	1000 ft contours	1:500 000	1960
7.	World Aero-nautical Chart ICAO	Canada	DMTS	Robeson Channel, 2008	1000 ft contours with colour tones	1:1 000 000	1961
8.	Operation Nav-igation Chart	U.S.A.	ACIC	ONC A – 5 Canada, Greenland	1000 ft contours with colour tones	1:1 000 000	1969

ACIC = Aeronautical Chart and Information Center; AMS = Army Map Service; DMTS = Department of Mines and Technical Surveys.
Asterisks refer to maps illustrated in fig. 5.

farther northwards along the coast (Greely, 1886, 1888).

Lauge Koch's field work during two Danish dog-sledge expeditions, viz. the 2nd Thule Expedition, 1916–18 and the Bicentenary Jubilee Expedition, 1920–23, was a major step forward in the surveying of the region and led to a set of maps of northern Greenland – 18 sheets at 1:300 000 published by the Geodetic Institute (Koch, 1932). Koch used a theodolite for the measurement of angles, and astronomical determinations were measured by zenith distances of the sun (Koch, 1922). The map of Hall Land (fig. 5A) was constructed on the basis of 16 survey stations; 11 land stations on Hall Land, the remainder at positions to the west and east. Astronomical fixes were attained at eight of these stations. Topography is depicted by means of toned colour shading and 28 spot heights are shown on Hall Land: 'Mt Chester' in the north at 780 m and 'Mt Kayser' in the south-east at 1065 m are the highest peaks.

The first aerial surveys for the purpose of map making were carried out by the U.S. Air Force in 1947 and the resultant trimetrogon photography taken at 6000 m altitude formed the basis of several map series with topographic contours. Following compilation in 1948 of the A.F. Preliminary Base map at 1:250 000 by the radial template method, three map series on the Polar Stereographic Projection were published in the early 1950s by two offices, viz. the U.S. Army Map Service, Corps of Engineers, Washington D.C. (AMS maps) and the U.S.A.F., Aeronautical Chart and Information Center, St. Louis (ACIC).

Table 1 summarises maps produced by these cartographic services, as well as other maps of Hall Land published prior to the present photogrammetrical programme; facsimilies of four maps are shown in fig. 5.

The ACIC and AMS map series covering northern Greenland are characterised by very poor absolute map accuracy. All show fundamental map errors: in scale (both overall and map warp), relative geodetic displacements and in altitude. The poor accuracy is mainly due to lack of a ground control net and reliance on the same astronomical fixes as those which were incorporated into Koch's map of 1932. The AMS and ACIC series have about the same order of map error; the largest single error in absolute location is about 23 km and the highest proven map scale error is about 20% (Lillestrand *et al.,* 1968; Lillestrand & Johnson, 1971). In Hall Land, the error vectors show a westerly displacement which is slightly larger on the AMS map than on the ACIC map. This reaches a little over 7 nautical miles (13 km) in north-western Hall Land at the ground station, 'Kap Porter', determined in 1966 to be at 81° 42.4'N 61° 52'W (E. F. Roots & N. M. Anderson *in* Lillestrand & Johnson, 1971). It should be noted that this locality is about 10 km south of the position of Kap Porter shown on the present map of Hall Land (see note on place names).

For representation of detailed geological documentation, the AMS and ACIC maps are a totally inadequate base (fig. 5B–C). Information content is exceptionally poor and the 200 m (AMS) and 1000 ft (330 m, ACIC) contour intervals leave large areas blank. An altitude error of several hundred metres leads to poor representation of topographic features; for example the prominent mountain range striking across Polaris Forland, west of 'Saint Anthony's Nose', with peaks over 600 m, is not defined.

In 1950–54, during a Canadian geodetic survey of Ellesmere Island, several astronomical fixes were made in adjacent Greenland. One of these, undertaken in 1953 by E. S. Fry, was on the northern coastal cliffs at a station designated 'Kap Porter'. This locality is 5 km north of the ground station erected by E. F. Roots and N. M. Anderson in 1966 (see above), at a position determined to be 81° 46'N 61° 51'W (see note on place names).

In 1958, W. E. Davies of the U.S. Geological Survey undertook cartographic and geodetic work in Hall Land during Operation Groundhog, and a map at approximate scale 1:175 000 was compiled of the northern part, i.e. Polaris Forland (fig. 5D; Davies *et al.,* 1959). The geodetic control of the map is based on two solar fixes, at the mouth of Atka Elv and at the north-eastern end of the 'Pileheden' airstrip adjacent to 'Gråstenelv' (W. E. Davies, personal communication, 1976). From these stations and from the summit of 'Monument' (the inselberg-like mountain standing above the central lowland plain, see fig. 18), intersections were cut to all the prominent peaks and other landmarks.

The geographical coordinate net corresponds essentially to that of the ACIC 8D II map and map scale error and error of displacement are of the same order as on the AMS and ACIC maps. However, Davies' map has a far greater information content than those maps. The topography is shown by form-lines that represent intervals between 50 and 100 m constructed with a stereosketch-master using the U.S. trimetrogon photography from 1947. Some areas were modified by random lines of other vertical aerial photographs and also oblique photographs taken with a hand-held camera in 1958. Some modifications to the form-lines were made in the field. The height of 'Monument' (876 ft – 267 m – see Table 2) was determined by altimeter survey with base stations at sea-level in the Thank God Harbour area and on the 'Pileheden' airstrip (W. E. Davies, personal communication, 1976).

In 1966–67, the Geodetic Survey of Canada and the Polar Continental Shelf Project attempted to establish a precise geodetic tie between Greenland and Ellesmere Island in the Robeson Channel – Lincoln Sea region, and a number of triangulation-net fixes were made at stations along the northern coast of Hall Land and at 'Kap Porter' (see above and note on place names).

In 1972, a Danish–Canadian project involved in the determination of the territorial boundary in Nares Strait, carried out latitude and longitude fixes at three stations in the north coast mountains and at Kap Tyson at the western end of Hauge Bjerge. Finally in 1979, about 10 new ground control points were established in Hall Land by the Geodetic Institute as part of a regional programme aimed at the production of a new topographic map series (T. I. H. Andersson, personal communication, 1984; Madsen, 1984).

Geological work during Operation Grant Land 1965–66

The geological field data used in the photogrammetric programme was collected by the writer and J. H. Allaart in 1965 during Operation Grant Land – a two summer, Canadian–Danish geological project in the northern Nares Strait region (see Dawes, 1984). About 30 working days were spent in Hall Land and traverses were made on foot from the seven camps marked on the map sheet. The work was undertaken in reconnaissance style aimed at obtaining stratigraphical and structural data in key areas; during camp moves, mainly by fixed-wing aircraft, some 'mapping' was also accomplished.

The 1965 field work was not specifically directed to map compilation at a given scale. Unfortunately, large gaps existed in the available vertical aerial photograph coverage taken by the Geodetic Institute in 1961, and photographs covered only about 25% of Hall Land. Much use was made in the field of an enlarged version of W. E. Davies' topographic map (fig. 5D). In 1966, field work was concentrated in the region east of Hall Land, although B. S. Norford of the Geological Survey of Canada undertook stratigraphic studies in south-west Hall Land at the type sections of the Silurian Offley Island and Cape Tyson Formations of Koch (1929) (Norford, 1967, 1972).

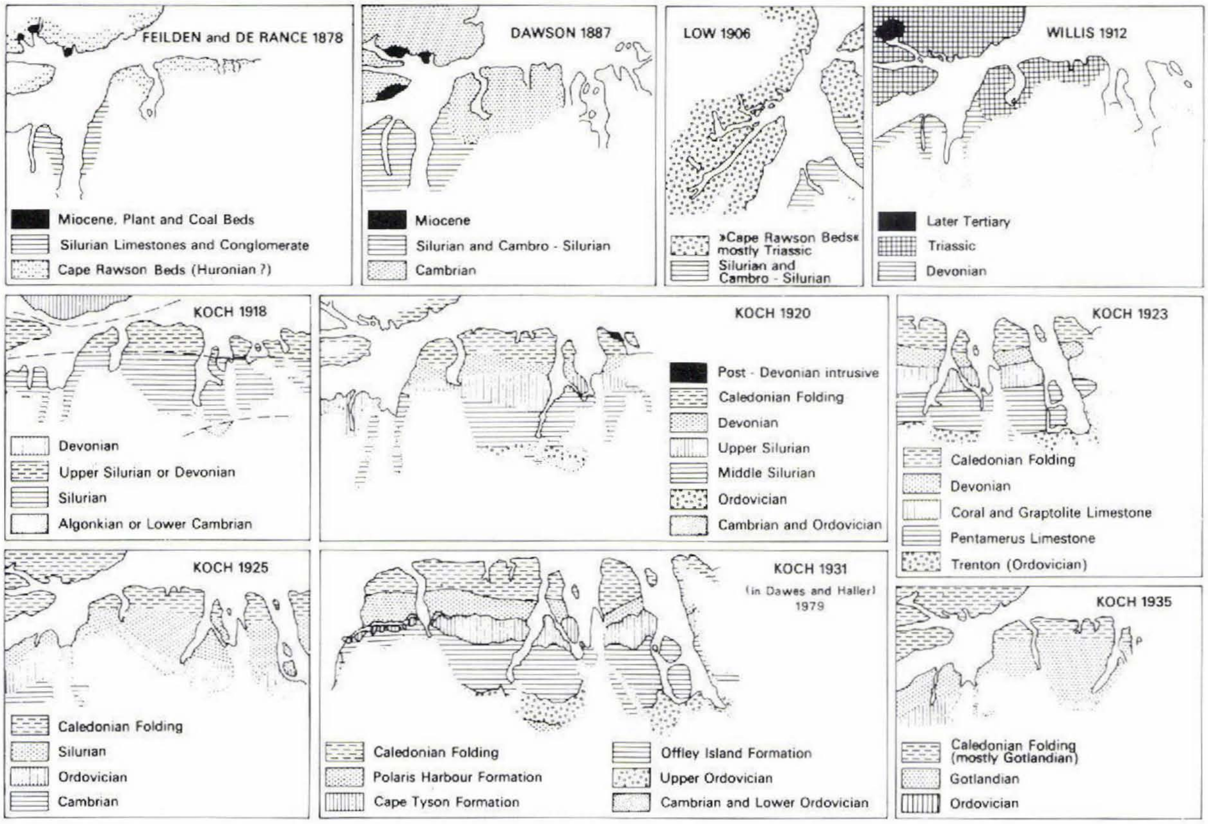


Fig. 6. Early geological maps of Hall Land and environs, extracted and redrawn from larger maps with slight modifications. Designation of Triassic strata on maps by Low (1906) and Willis (1912) is based on interpretative correlation with Mesozoic outcrops in Ellesmere Island.

A result of the 1965 field work was the revision of the Silurian stratigraphy established by Koch (1929), which had been essentially based on a layer-cake framework with major erosional unconformities separating formations. The succession was reinterpreted as representing a complex arrangement of different facies associated with large-scale reef structures, with lateral facies changes between limestones and off-reefal shales. The clastic strata of the fold belt were demonstrated to be stratal equivalents of shelf carbonates to the south (Allaart, 1965, 1966; Dawes, 1971). The GGU Report 'Biostratigraphic studies in western North Greenland: Operation Grant Land 1965–1966' (no. 121, 1984) provides a summary of the biostratigraphy of Hall Land and adjacent country to the east based on fossils collected in 1965–66. Prior to publication of the present map sheets, basic data had only been available in map form at scales of less than 1:1 000 000 (e.g. Dawes, 1976).

Other geological work

The initial geological observations in Hall Land were made in the period 1871–1876 by the Hall and Nares expeditions. Hall's expedition differentiated between northern folded, mainly clastic rocks, and southern unfolded, light coloured, fossiliferous limestones (Bessels, 1879). Naturalists of the Nares expedition confirmed this bipartite division and produced a geological map of the region (fig. 6; Feilden & De Rance, 1878). Etheridge (1878) made the first systematic description of Lower Palaeozoic fossils from northern Nares Strait which included Silurian species from Hall Land, mainly from Offley Ø.

The presence of large areas of Quaternary deposits in central Hall Land, including terminal moraines and fossiliferous marine strata, was noted by both expeditions, as was the widespread occurrence of glacial granite erratics (Davis, 1876; Feilden, 1877, 1895; Jeffreys, 1877a,b; Bessels, 1879).

Geological knowledge of Hall Land was not expanded until Lauge Koch's work on the 2nd Thule Expedition (led by Knud Rasmussen) and his own Bicentenary Jubilee Expedition. Koch visited western and northern Hall Land; in 1917 for about 3 days, en route to Peary Land (Rasmussen, 1927), and in 1922 for about two weeks (Koch, 1926). Koch collected large quantities of fossils, mainly from Silurian strata of the Kap

Tyson – Offley Ø area, and formal descriptions were undertaken by Poulsen (1941, 1943, 1974). Koch (1929) finally referred the bedrock of Hall Land to four formations, viz. the Upper Ordovician Cape Calhoun Formation, present only in the extreme south-west along Petermann Fjord, the Lower Silurian Offley Island and the Middle Silurian Cape Tyson Formations that form an east–west belt across southern Hall Land, and the Devonian(?) Polaris Harbour Formation shown as outcropping across the central plain (fig. 6, 'Koch, 1931').

Northern Hall Land was designated part of the 'mountain chain' of Caledonian folding that was illustrated by a structural map and cross-sections that showed crystalline basement in major anticlinal cores (Koch, 1920). Later, Koch (1929) rectified this misinterpretation and referred massive carbonates at Kap Ammen to the Offley Island Formation, and overlying darker, mainly clastic rocks to the Cape Tyson Formation (Koch, 1929, p. 280; Dawes & Haller, 1979, fig. 12).

While results of Koch's first trip to the northern coast formed the basis of his 'Stratigraphy of Northwest Greenland', including a geological map at scale 1:2 500 000, data from his second trip, on which he spent much more time on geological studies, were never published in full. In fact, the most detailed map, showing the outcrop of formations in Hall Land, was not published in Koch's lifetime (Dawes & Haller, 1979, see fig. 6).

In addition to geological work, Koch made important physiographical and glaciological observations; for example, he mapped the terminal moraine systems flanking Hall Basin and Newman Bugt, assessed the former extents of the Inland Ice and the sea, and interpreted central Hall Land as the site of an ice-dammed lake (Koch, 1928a, b, fig. 7).

Hall Land was not visited again for geological study until the 1950s, when various 'military' operations reached northern Greenland. Prest (1952) made cursory observations during an ice-breaker passage of Robeson Channel, and following initial aerial reconnaissance under Operation Defrost in 1956 (Needleman, 1962), W. E. Davies and D. B. Krinsley of the U.S. Geological Survey carried out the first helicopter-supported survey during Operation Groundhog 1957–60 (Davies, 1961a,

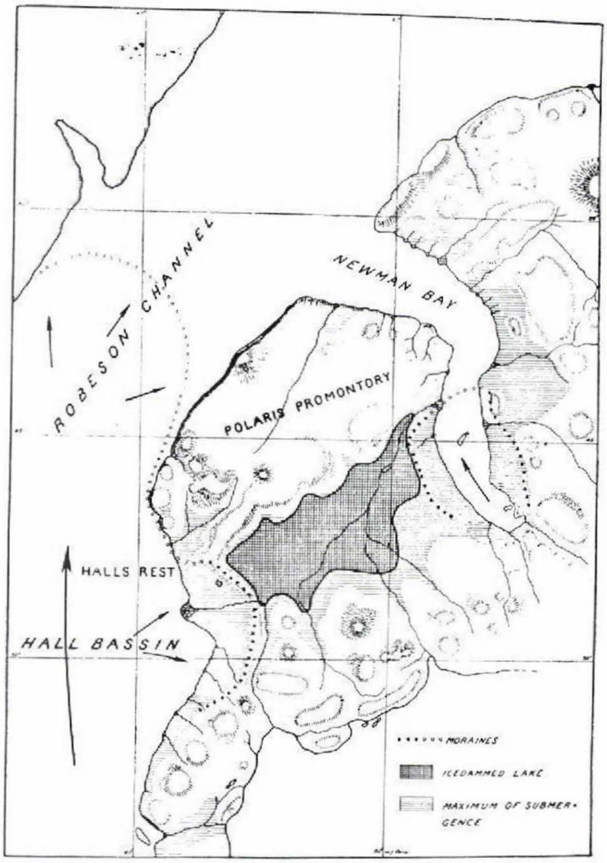


Fig. 7. Early map of Hall Land showing conditions in 'late glacial times' with two prominent glaciers occupying Hall Basin and Newman Bugt, and an ice-dammed lake in the central lowland plain. From Koch (1928b).

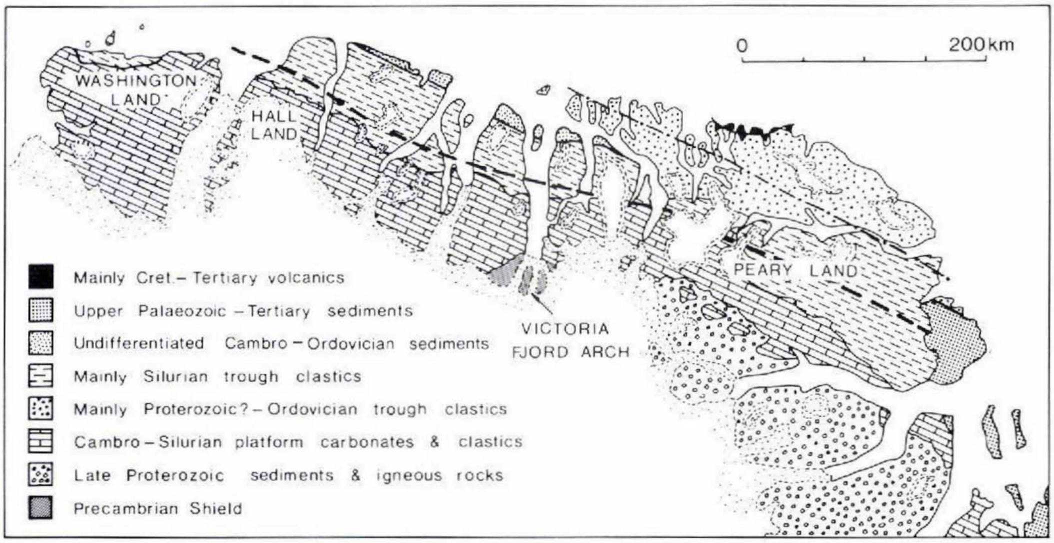


Fig. 8. Geological sketch map of northernmost Greenland. Heavy dashed line indicates the southern margin of the North Greenland fold belt.

1972; Davies & Krinsley, 1962). In 1958, Polaris Forland was surveyed, principally surficial and engineering geology in connection with mapping and testing of landing sites (Davies *et al.*, 1959; Needleman *et al.*, 1961). This work resulted in the topographical–geological map (scale *c.* 1:175 000) which has already been described (fig. 5D). A division of the bedrock into dark, thin-bedded platy limestones with graptolites, and lighter, thick-bedded, massive, highly fossiliferous limestones, was employed on the map. Quaternary deposits were differentiated and mapped out in some detail on the central plain.

Following Operation Grant Land, mentioned above, and a regional survey in 1969 by Greenarctic Consortium – a Canadian commercial company (Stuart-Smith, 1970), Hall Land was visited in the late 1970s during GGU's mapping programmes centred on regions to the east and west. Thus, during the study of Silurian stratigraphy of Washington Land in 1977, Hurst (1980) visited type sections of the Offley Island and Cape Tyson Formations at Kap Tyson. This led to a revision of the stratigraphic nomenclature of Koch (1929), Dawes (1971) and Norford (1972). Strata of the Kap Tyson area were referred to four formations, viz. Offley Island, Hauge Bjerge, Lafayette Bugt and Kap Morton Formations (see fig. 37).

In 1979, J. M. Hurst & F. Surlyk spent several days inland from Kap Ammen, to study the Silurian clastic sequence. Strata were referred to three formations – the Wulff Land, Lauge Koch Land and Chester Bjerg Formations of the Peary Land Group; the Chester Bjerg Formation was defined with a type area at Chester Bjerg in Hall Land (Hurst & Surlyk, 1982).

Several recent visits to Hall Land have been specifically directed to Quaternary geology. In 1976, A. Weidick made observations, mainly on marine deposits of the central plain, during which ground checks were made on features shown on the present map sheet (Weidick, 1977). Likewise in July 1982, during a stop at the 'Pileheden' airstrip, the present author made a traverse towards 'Monument' to check features recognised on aerial photographs.

In 1982, England (1985) undertook a 5 week reconnaissance in Polaris Forland; a study aimed at determination of the last glaciation limit and an analysis of postglacial emergence. Finally, in 1984, during GGU's current mapping campaign in central North Greenland (1984–85), general Quaternary studies were carried out in Hall Land in the course of a regional survey (Kelly & Bennike, 1985). Investigation of aspects of the solid geology of Hall Land took place in 1985, after completion of the work reported on here.

Photogrammetrical programme

From the onset, the Hall Land programme was to be supported by on-line computer with the aim of digitising both geology and topography. However, a prolonged delay in the construction of equipment necessitated abandoning the attempt to digitise the geology, and digitisation of the topography (i.e. contours) was carried out independently (Bengtsson, 1977; Dueholm, 1979).

The photogrammetrical work was split into four main phases:

Phase 1: Aerotriangulation of 76 models. September to October, 1975. Instrumentation: Zeiss-Jena stereo-comparator Stecometer. Personnel: K. S. Dueholm and photogrammetric operator Ole Ørslev.

Phase 2: Physiographical–geological interpretation and map-

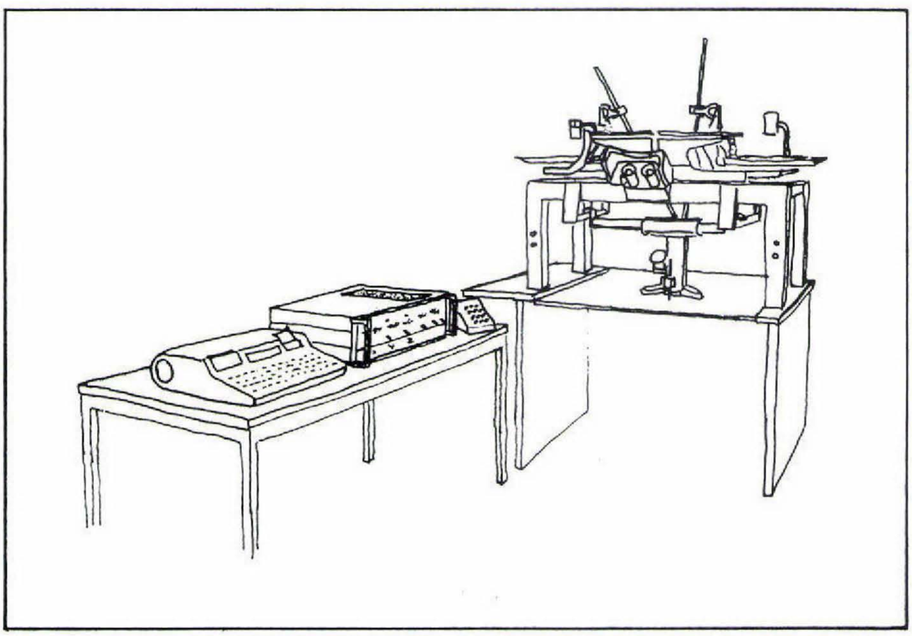


Fig. 9. Sketch of the Zeiss Planitop F–2 topographic plotter, with desk-top computer HP 9815A and digitising module. After Bengtsson (1977).

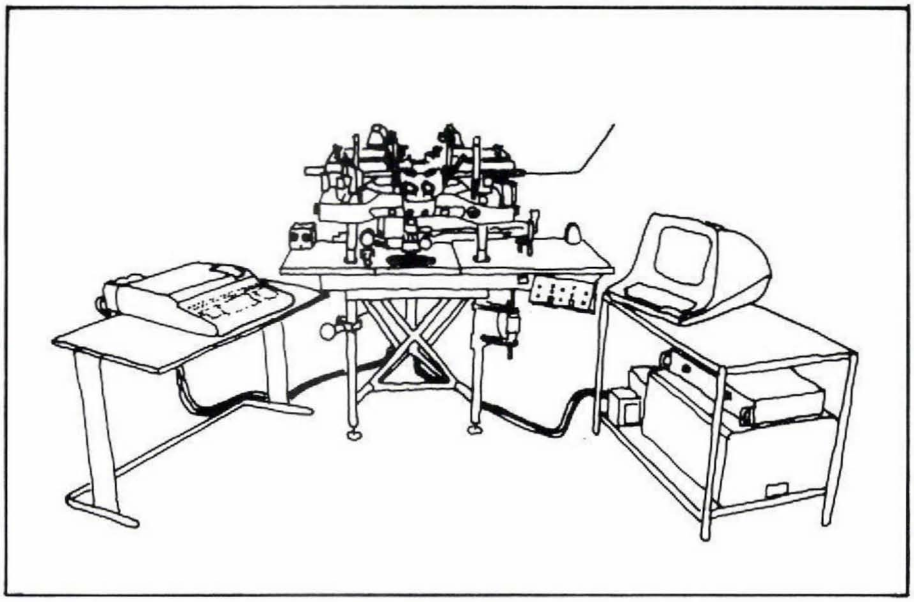


Fig. 10. Sketch of Kern PG 2–D stereo-plotter with digitising module DC 2–B and desk-top computer HP 9825A. From Dueholm (1979).

ping of 74 models. November 1975 to April 1976. Planitop F–2. Personnel: P. R. Dawes and photogrammetric operator Ole Ørslev.

Phase 3: Digitisation of the terrain and analytical treatment of the topographic contours. Refinement of aerotriangulation. June 1976 to June 1977. Instrumentation: Planitop F–2 with Hewlett Packard desk-top calculator HP 9815A, Calcomp drum plotter and Kingmatic Mk. III plotter. Personnel: K. S. Dueholm and photogrammetric operator Ole Ørslev.

Phase 4: Computer-supported geological interpretation and structural measurement of 59 models. May, June and October, 1978. Instrumentation: Kern PG 2–D stereo-plotter with a Hewlett Packard desk-top computer HP 9825A. Personnel: P. R. Dawes and photogrammetric operator Olav Winding.

The first three phases were carried out at the Institute of Surveying and Photogrammetry, Technical University of Denmark; the final phase took place on instrumentation and with computer programmes that were being installed and developed at GGU.

Instrumentation

Two second-order analog plotting instruments were used in the programme: the Zeiss (Oberkochen) Planitop F–2 Topographic Plotter and the Kern PG 2–D stereo-plotter (figs 9 & 10). Both instruments have the facility for attachment of on-line computer support; model coordinates can be digitised by linear electronic pulse generators and handled by an automatic registration system. Thus, both instruments allow for automatic plotting of topographic contours, physiographic features and geological structures. The combination of a desk computer with these instruments enables precise and speedy calculations of many structural parameters with statistical control, thus supplying data that can be utilised immediately in the photogeological interpretation (Dueholm, 1979). In the Hall Land experiment such computer support was available only towards the end of the work on the Kern PG 2 in phase 4.

Operation of the stereo-plotting instruments

Both stereo-plotting instruments were operated by the present author without prior training. The controls of the floating mark and the actual tracing head are combined in a single hand-operated model carriage; operation is easier than on hand-wheel or foot-wheel control instruments. The model carriage allows for rapid, free-hand and accurate movement within the model. The mechanism for movement of the floating mark is connected to an altitude scale and this provides continuous height readings. This facility and the fact that the actual plotting takes place immediately in front of the operator on a built-in tracing table, greatly assisted in the theoretical and practical aspects of the geological interpretation.

Both instruments have sharp, clear optics and bright illumination. The Planitop F–2 has a fixed optical system with × 6 magnification and a field of view of 32 mm diameter on the photoscale. In contrast, the Kern PG 2 is equipped with an optical system allowing for × 2, × 4 and × 8 magnification with a maximum field of view of 36 mm at × 2 magnification; this variable magnification facility proved of considerable advantage for the geological interpretation in phase 4.

Computer-supported geological interpretation

The computer-supported geological work on the Kern PG 2 (phase 4) was conducted during the establishment of the photogrammetrical system in GGU and coincided with the development of the main computer programming by H. F. Jepsen and K. S. Dueholm. The reader is referred to Bengtsson (1977) and Dueholm (1979) for a description of the technical details of the photogrammetric and computer equipment, the computer programmes and the mathematical modelling on which they are based, as well as an assessment of the precision of the calculated structural parameters. In the following, only an outline of the photogrammetric and computer facilities used in the geological part of the Hall Land programme is given.

The Kern PG 2–D stereo-plotter is equipped with *x, y* and *z* encoders that are connected to a digitising module (DC2–B) which displays *x, y* and *z* ground coordinates. This digitising module is connected to a Hewlett Packard desk-top computer (HP 9825A) by which various structural parameters were calculated. The coordinate points in the terrain were registered point by point (operated by foot-pedal) or continuously, and so transmitted from the stereo-plotter to the computer. Theoretically, a minimum of three points (three sets of *x, y* and *z* values) are necesseary for the definition of a planar surface; these are measured and then stored in the computer from which the parameters of the plane are calculated. However, caution should be observed in basing the definition of a planar surface on but three points, particularly in small outcrop situations. Measurements become readily inaccurate if the points are too closely spaced and/or have a near linear distribution. In general, the greater the number of well-defined points registered in a planar definition, the greater the accuracy of the calculation.

By means of computer programmes, calculations can be made to describe various structural features, for example the attitude of a planar surface (strike and dip of bedding), the distance between two planes or between displaced parts of the same plane (stratal thickness or fault displacement), or fold definition (direction and plunge of fold axis). Further, they can provide statistical control of the reliability of the calculated parameters (Dueholm, 1979).

The various on-line computer facilities were utilised as they were developed and became operational. Thus, models processed late in the programme underwent a more thorough investigation than those treated earlier. This is an important consideration to note in assessment of the overall character of the geological map. At the start of phase 4, only single strike and dip measurements were made; later, it became possible to store and recall pre-defined geological planes for correlation purposes and to use them in composite structural calculations. Later programmes aimed at the definition of deformed surfaces were developed enabling determination of direction and plunge of fold axes. Near conclusion of the work, the so-called '*z*-guiding facility' was introduced in which the desk computer is interfaced to a stepping motor on the *z* column of the stereo-plotter. In this, the *z* value of a planar surface is guided automatically as a function of *x* and *y*, for example in response to a pre-delimited plane. Finally, programmes for measuring distances, either from a point to a given plane or between planes were developed, thereby making stratal thickness calculations possible, besides distance and direction calculations between given points in the horizontal field.

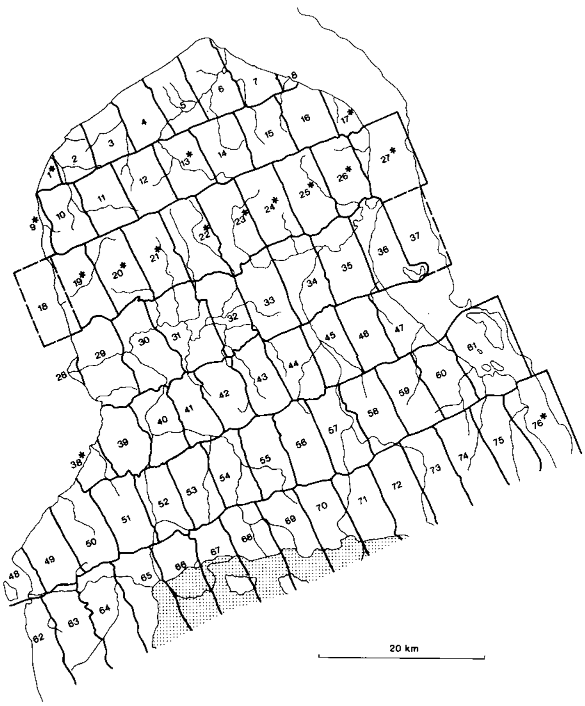


Fig. 11. Distribution of the 76 models used in the aerotriangulation of Hall Land. Irregular borders reflect the limits of geological interpretation of individual models. Models 18 and 37 were not utilised in phases 2 and 4; those marked by an asterisk were omitted from the structural computer calculations of phase 4.

Aerial photographs

Vertical aerial photographs at a scale of approximately 1:54 000 were made available through Greenarctic Consortium of Edmonton, Canada. This photography, taken in July 1971 at an altitude of 8000 m, is of good quality with a minimum of snow cover. Seventy-six stereo pairs of photographs cover the map area in seven E–W routes (fig. 11). Diapositives were used in the Planitop F 2 and Kern PG 2 instruments; this increased definition and led to the identification of features that were not recognisable on paper prints.

The geological interpretation was supplemented by oblique photographs taken in 1964 by the Geodetic Institute. These proved very useful, particularly for the northern coast which is characterised by high, extremely steep cliffs, and also elsewhere, e.g. where cliffs are in shade on the vertical photographs. Some measurements were carried out on the oblique photographs with a Zeiss-Jena stereo-comparator, Stecometer; for instance to determine the stratigraphic thicknesses of the units in the Kap Ammen section (see later).

Mapping scale

Two of the general aims of the programme were to examine how much geological information could be extracted from aerial photographs, and to assess the 1:54 000 photographs for the pending geological mapping campaign in North Greenland. This campaign was aimed at the production of map sheets at 1:500 000 with key or representative areas at 1:100 000. Accordingly, a plotting scale of 1:50 000 was chosen for the geological interpretation with a view to publication of a map at 1:100 000. Publication scale was later enlarged to *c.* 1:66 500 (see following chapter).

A coloured geological map in four sheets at 1:50 000, compiled directly from the 74 model plots, is deposited in GGU's map archives. Four sketch maps drawn directly from that map and illustrating different geological terrains have been published elsewhere (Dawes, 1979).

Photogrammetric procedure

In the following description, emphasis is placed on the geological aspects of the work undertaken in phases 2 and 4. The reader is referred to Dueholm (1979) for a detailed discussion of the principles and procedures involved in the aerotriangulation (phase 1), i.e. establishment of a consistent control point system enabling orientation of the stereoscopic models in the analog plotting instruments, and in the production of the digital elevation model, including analytical processes carried out to produce the final topographic contour representation (phase 3).

It should be noted that photogrammetric work of phase 2 was conducted using the coordinates derived from the initial aerotriangulation (phase 1), while phase 4 work was governed by the coordinate values from a new aerotriangulation made when ground control data became available. The consequences of this are discussed in the next chapter.

Aerotriangulation – phase 1

Aerotriangulation of the 76 stereo models was made from measurements carried out with a Zeiss-Jena stereo-comparator, Stecometer. A total of 215 tie points cover the map area. Following identification and annotation on the photographs, each point was described and photographed to ensure re-identification. In general, six tie points were identified in each complete model, the points being aligned approximately along the eastern and western sides of the model. In some coastal models as few as three tie points were identified.

Although at that time several ground control points existed in Hall Land, mainly adjacent to Robeson Channel (see preceding chapter), the majority were not available to the programme, and others could not be identified on the aerial photographs. Thus, the calculations were carried out *without* ground control. This resulted in the construction of a 'control point system' – composed of the 215 tie points – which connected the 76 models together but was uncontrolled in the absolute geodetic coordinate system.

In the absence of ground control, map scale and azimuth had to be derived from available maps or from the height and orientation of the aerial photography. The AMS C 501 map was used as the main source; this was assessed to be the best map covering the entire area of the Hall Land programme (Table 1, fig. 5). Height control was based on selected points along the ice-free part of the coastline in Polaris Bugt, Robeson Channel and northern Newman Bugt, and an absolute height error of up to 20 m in the central part of the area was estimated (Dueholm, 1979).

Geological interpretation – phase 2

During this phase the initial geological interpretation and mapping was accomplished and physiographic features were drawn out.

Orientation of the models in the Planitop F–2 was carried out using the coordinate values of the tie points. Seventy-four out of the 76 models included in the aerotriangulation were utilised (fig. 11). Two coastal models, No. 18 at Thank God Harbour in the west and No. 37 in the east at Newman Bugt, were not used since the geology could be drawn out from adjacent inland models. Three of the models spanned Newman Bugt and on these the geological interpretation was extended to coastal Nyeboe Land.

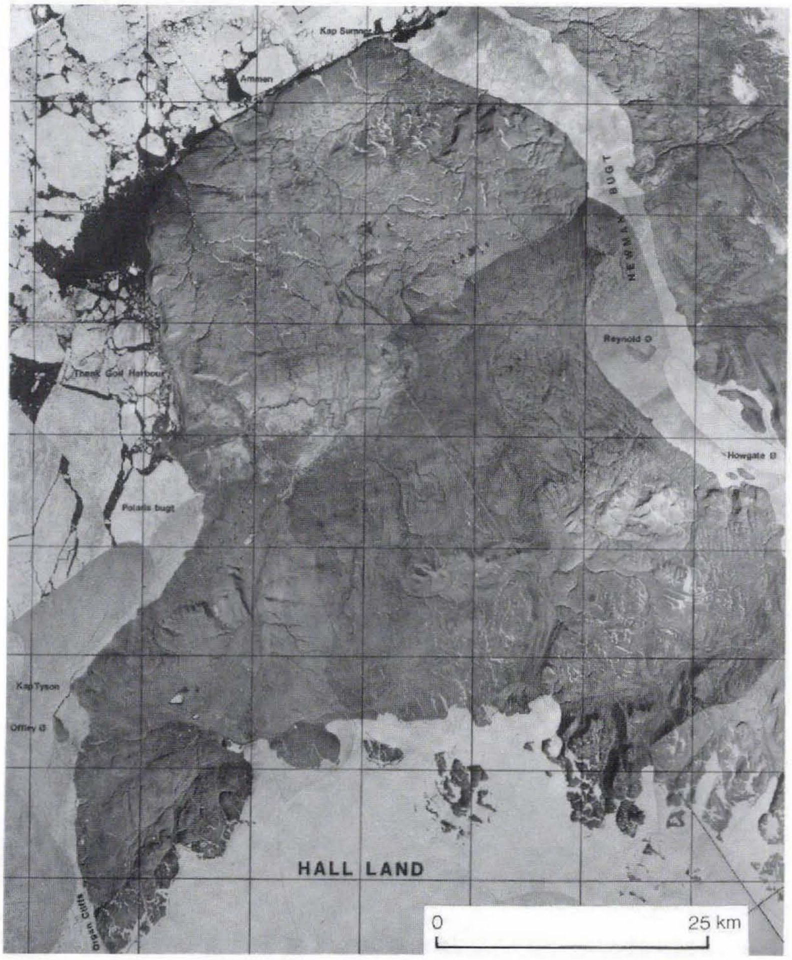


Fig. 12. Provisional aerial photo-mosaic of Hall Land prepared by the Geodetic Institute; from map sheet no. AA, 1:500 000, March 1979 (photography in July 1978). Conspicuous light coloured areas inland from Polaris Bugt are predominantly marine strata. Copyright Geodetic Institute.

In fig. 11 the boundaries between the models are shown as irregular lines. These reflect the limits of the geology mapped on each model rather than the tie point net or the instrumental limits of the model. On average, complete land models cover about 50 km^2, although the area drawn out in each model varies from about 40 km^2 (e.g. models No. 10 and 41) to over 60 km^2 (models No. 29 and 31).

The field of view on the Planitop F–2 is about 2.25 km^2. The drafting was carried out at 1:50 000 on the illuminated built-in tracing table. Separate drafting sheets were used for each model. This provided for the eventual correction of the planimetry of single models when coordinates to the tie points changed due to the availability of ground point control (see phase 3). However, this proved impracticable for the geological work since adjacent overlapping models were not automatically visible for tie-in and as a guide to the interpretation.

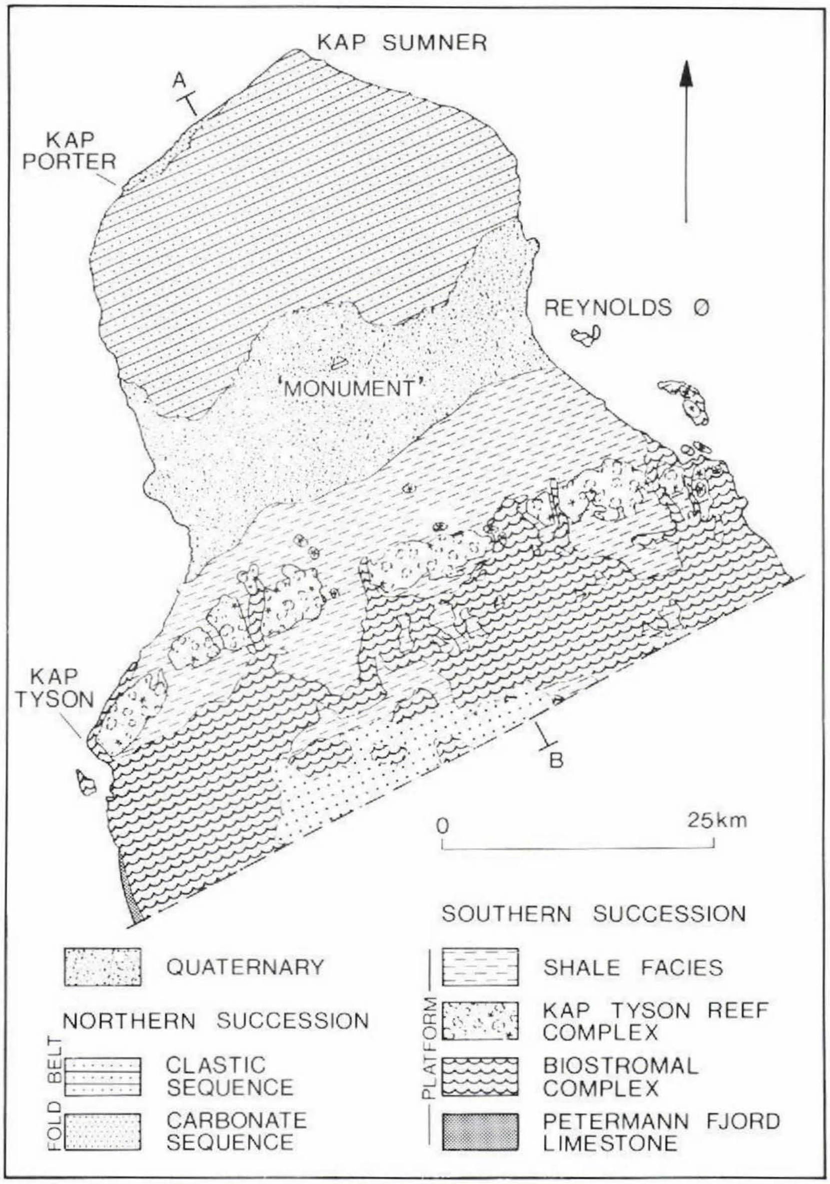
Various physiographic features, such as coastline, rivers, snow-fields, ice margins and lakes, were drawn out by the photogrammetric operator who also included in the plot some Quaternary features that needed a minimum of interpretation, e.g. terraces, alluvial fans, etc. In addition, heights of selected terraces and mountain summits were measured. After checking this representation, the author carried out the main interpretation to produce a coloured manuscript map.

The working method employed was governed by a number of criteria; some were known at the commencement of the programme, others arose during work and necessitated changes in approach. Two main factors can be mentioned:

(1) Mapping of the Quaternary geology in the central plain was planned at the onset as an integral part of the photogrammetric exercise. The differentiation of the surficial cover in that area led to the recognition of corresponding deposits on the adjacent bedrock provinces to the north and south. Thus, for the sake of consistency, Quaternary strata were drawn out on these bedrock regions and correlations made with the central plain. This practice would not have been carried out to the same extent given other circumstances and mapping aims.

(2) Very limited geological data from field work were available on aerial photographs prior to the photogrammetric work and no traditional interpretation in a mir-

Fig. 13. Geological sketch map showing distribution of main bedrock groups, and separation of northern and southern successions by the Quaternary covered central lowland plain. Inland Ice shown by regular dotted signature. A–B refers to the line of section shown in fig. 48.



ror stereoscope was made prior to work in the Planitop F–2 plotter. Thus, phase 2 involved a basic geological appraisal of the photographic models and an initial graphic representation of the interpretation. Transference of data from marked-up photographs was minimal.

An aerial photomosaic of Hall Land and a map showing the main geological map groups recognised are given in figs 12 & 13.

The first models investigated were of the central lowland plain that W. E. Davies (Davies *et al.*, 1959) had demonstrated was composed of a variety of Quaternary deposits. Thus the initial interpretation of surficial geology was of a region containing the most complete range of deposits. This necessitated immediate reference to a comprehensive legend covering eight map groups: marine, fluviatile, moraine, lacustrine, colluvial, solifluction, periglacial and aeolian.

Mapping of the Quaternary proved more time consuming than work on the bedrock. Differentiation of the cover proved difficult in many areas, particularly where field data were totally lacking. Many boundaries are arbitrary, for example those between moraine and fluvial or outwash deposits of Atka Elv and 'Gråstenelv', where moraines have been reworked to varying extents by glaciofluvial processes. Irrespective of the nature of the contact relationships between the various surficial deposits, only one class of boundary was eventually utilised on the map.

Bedrock in Hall Land is rather poorly exposed compared to other areas of North Greenland. A monotonous clastic sequence without clear stratigraphic variation forms much of Polaris Forland, and to the south the platform is composed of a thick, rather massive limestone sequence with carbonate buildups and complex facies changes. These two sequences lack obvious marker horizons and the tracing of bedding was possible only over relatively short distances and in limited areas.

Only in two areas, along the steep northern coast and in the extreme south in the layer-cake succession of the biostromal limestone complex, could bedding surfaces be traced over longer distances. Some of these were selected as boundaries of mapped stratal units. Mapping of these areas was carried out on the basis of variable field knowledge. Data from the northern coast were available from a camp at Kap Ammen; for the layer-cake stratigraphy south of Hauge Bjerge, field observations were restricted to the west, from one camp south-east of Kap Tyson. In the west, apart from the recognition of stratal units at Kap Tyson and along the Petermann Fjord coast, no subdivision of the platform sequence was made. However, to the east, adjacent to the Inland Ice at the headwaters of 'Gråstenelv', it was possible – on the basis of the colour and morphological character – to map out a number of units. This stratigraphical division was extended over a larger area during phase 4.

Some of the geological boundaries within the Kap Tyson reef complex represent irregular surfaces inclined at variable and high angles to bedding. Such boundaries mark lateral lithological changes, for example between off-reefal argillaceous rocks and biohermal limestones, such as at Kap Tyson (see fig. 38A). Facies boundaries can be abrupt or gradational. In the latter case, even in the field, consistent positioning of a boundary is problematic; thus in areas lacking field data, photogrammetric plotting of such boundaries proved to be difficult and many are arbitrarily placed.

To illustrate the structure, as many bedding traces as could be graphically represented were drawn; in some well exposed areas, representative traces were selected. However, the resultant map pattern shows inhomogeneity that in part reflects bedrock lithology. Hence, in the northern clastic terrain large areas shown devoid of bedding traces are composed essentially of fine-grained siltstone and mudstone, while in other areas, for example west of 'Saint Anthony's Nose', abundant bedding traces reflect the presence in the sequence of prominent and continuous sandstone beds. Likewise in the southern carbonate terrain sub-parallel bedding surfaces can be traced in photogrammetric models throughout much of the homoclinal biostromal complex; fewer traces could be mapped out in the more massive biohermal limestones and conglomerates of the Kap Tyson reef complex.

Digitisation of the terrain – phase 3

The photogrammetric work in this phase was primarily concerned with digitisation of the terrain and production of a topographic contour plot. Physiographic–topographic features, such as the coastline, rivers and lakes, which are specific entities of the terrain, were drawn out manually together with the geology as described in phase 2; only the topographic contours are the products of digitisation. Topographic contours do not describe tangible features of the terrain but represent lines in a coordinate system the definition of which depends on a number of variables. The contours were calculated from a digital elevation model ('dem').*

Scanning of the 76 models (photogrammetric profiling) was carried out in the Planitop F–2 instrument that was coupled to a desk-top calculator, HP 9815A (fig. 9). Between 25 and 30 profiles were measured in each model with some 40–50 coordinate points registered on each line, making in the order of 100 000 points for the whole map. Observations were stored on magnetic tape and then transferred to an IBM 370/165 computer. From this dem, and by using a computer programme and the procedure described by Dueholm (1978), topographic contours were extracted. In view of the proposed publication scale of 1:100 000, a contour interval of 25 m was chosen. To improve topographic form, the contours were smoothed by application of the so-called Fourier process, with a minimum loss of actual information (Frederiksen *et al.*, 1978; Dueholm, 1979).

Various experiments using the Hall Land contour data are described by Dueholm (1979), Frederiksen (1979) and Frederiksen & Knudsen (1979); examples are presented of analytical contour maps that include vertical and oblique colour terrain plots.

New aerotriangulation

The initial aerotriangulation described in phase 1, was carried out without ground control. Following digitisation of the terrain, several control points from a field survey in 1972 were made available by the Geodetic Institute and an adjustment of the aerotriangulation was undertaken. Two stations on the west coast, at Kap Tyson and Kap Lupton (designated TYSO nr. 1008 and HALL nr. 1009, respectively) were introduced into the system and new coordinates for the tie points of the aerotriangulation were calculated. Other ground stations in the mountains east of Kap Ammen (e.g. HOLD nr. 1010 and CHESTER nr. 1011) could not be identified on the aerial photographs and they were not incorporated into the system.

The final topographic contour plot presented here in two sheets is based on a recalculation of the 'dem' due to the new aerotriangulation, as well as a new contour interpretation. The contours were ultimately plotted out on a Kongsberg Plotter at the Søkortarkiv, Copenhagen.

Computer-supported structural calculations – phase 4

The computer-supported structural calculations and geological interpretation were carried out on the Kern PG 2–D stereo-plotter and a desk-top calculator HP 9825A (fig. 10). The models were orientated in the stereo-plotter using coordinate values derived from the

*The Hall Land model is strictly a 'dem', rather than a digital terrain model (dtm) as described by Dueholm (1979).

new aerotriangulation. Only 59 models were processed in this phase (fig. 11); height values in the outstanding models were regulated on the basis of the rectified values obtained from adjacent models.

Two main aspects were accomplished in phase 4; firstly, measurement was attempted of structural elements plotted out in phase 2 and, secondly, checking and reappraisal of the geological plot was undertaken using the available computer facilities. The 15 models not reappraised in this phase were omitted mainly because they contained little or no measureable structure and/or lacked geological 'problems' that might be solved by the computer facilities.

Strike and dip measurements of bedding were made wherever possible. In those areas where bedding traces are prominent, a representative number of measurements are included on the map. However, many of the bedding traces drawn out in phase 2, particularly in the folded clastic terrain, proved impossible to measure with reasonable accuracy. In many cases, this was because of limited exposure and thereby lack of sufficient variation in the *z* coordinate. In other cases, bedding lacked distinct definition, and in both reasonably well-exposed areas and in areas of moderate surficial cover, many traces plotted in phase 2 were found to represent bedding *forms* or *trends* rather than discrete *beds* or planar *surfaces*.

Strike and dip readings were calculated generally on the basis of three to five registered points. On less well-defined or even diffuse planar surfaces, a continuous registration of coordinates was made as the bedding was retraced. This resulted in more constant readings than those obtained by point to point registration. A calculator print-out indicating the number of points in a calculation, the errors in degrees of the strike and dip values, as well as the standard error in metres of the definition of the plane, i.e. mean distance of the observed points to the plane, provided accuracy control. This was extremely useful in the testing, and eventually in the selection of measurements to be included on the map. As a general rule, single readings with errors in excess of 1° for strike and dip, and 2 m for standard error of definition of the plane, were discounted.

An important computer facility, developed during phase 4, allowed for composite strike and dip measurements to be calculated, i.e. with points from different bedding traces within the same stratigraphic section or within a given area. This facility was used extensively in the homoclinal terrain of the south where many readings on the map represent a composite average strike and dip for a given area. The method was also of considerable value in the northern clastic terrain, and in the off-reefal strata of the Kap Tyson reef complex where measurement of single bedding traces proved difficult due to lack of definition, small outcrop area and poor exposure.

Measurement of direction and plunge of fold axes was carried out following principles described above for the strike and dip calculations. Accurate measurement proved possible only in about 30% of the fold belt models; many folds plotted out in phase 2 could not be precisely measured due to poor definition and/or small size. Fold traces plotted out in the 1:50 000 manuscript maps all have fold limbs less than 1 cm apart, i.e. wavelengths below 500 m, and many limbs are less than 5 mm apart. Several folds plotted on the map are derived essentially from a converging bedding trace pattern – the actual hinge zones are not visible on the photographs.

Lack of a wide and well-defined hinge zone to many folds resulted in fold-axis calculations based on only two strike and dip readings, one defining the attitude of each limb. Many such calculations were judged unreliable and are not included on the map. Considerable caution had to be observed in the selection of strike and dip readings in a fold axis calculation since incorporation of one erroneous plane can fundamentally affect the direction and plunge readings. Each measurement used in the calculation must represent a tangent plane to the fold and this became increasingly more difficult to achieve as the apex of the hinge zone was approached.

Absence of marker horizons, and the lateral facies changes that characterise the Silurian sequence, proved drawbacks to regional stratigraphic correlation. However, towards the end of phase 4 development of the *z*-guiding facility made it possible to extend both local and regional correlations. This electronic mechanism automatically controls the measuring mark's vertical movements as moved laterally in the model, based on a pre-defined plane. This, together with the facility for storage and recall of geological planes, enabled correlations suggested in phase 2 to be checked, modified and eventually extended. Since measurements of planes are defined in terms of ground coordinates, correlations could also be achieved from model to model and between planes in non-adjoining models. Furthermore, the *z*-guiding facility made it possible to extrapolate and trace out geological planes into poorly exposed terrain; theoretically, well-defined planes can be mapped beneath surficial cover (Jepsen & Dueholm, 1978). However, mapping of the surficial geology formed an integral part of the programme and only limited modifications of this nature were made.

The use made of the *z*-guiding facility can be illustrated by reference to two specific features of the platform stratigraphy that are of fundamental importance for the interpretation of the stratal divisions of the map. In the region at the headwaters of 'Gråstenelv', subdivision of the biostromal limestone complex was attempted during phase 2. By means of the motor-guiding mechanism stratal units were extended into adjoining areas, particularly along the regional strike, and correlation was suggested with the east coast. Unfortunately application of the *z*-guiding facility was not made throughout the platform to the west. Thus the inference that the basal strata of the 'Gråstenelv' succession is at about the same regional level as the Petermann Fjord limestone, was not photogrammetrically tested.

The second use concerned correlation in the regional dip direction between the biostromal limestones and the Kap Tyson reef complex. Storage of geological planes of the 'Gråstenelv' stratigraphy, calculated from composite strike and dip readings, and the recall and projection of these northwards into adjoining models suggested that bioherms at the base of the Kap Tyson reef complex in easternmost Hauge Bjerge (on the map, coloured blue), may have stratigraphical equivalents in the reefoid limestones of the biostromal complex – strata that are coloured green; this correlation is not apparent on the map.

If full computer support had been available during the initial photo-interpretation instead of only in the concluding stages of phase 4, then a more detailed subdivision and correlation of platform sequences could have been accomplished.

Cartography

As described in the previous chapter the intention of the Hall Land programme was to digitise and combine geologic and topographic mapping to produce a single computer-drawn plot containing geology and topographic contours. As explained, digitisation of the geology had to be abandoned for technical reasons and the geologic and topographic parts of the programme were carried out as independent experiments. The geological map was compiled by traditional hand-drawn method; the topographic map was constructed by an automatic plotter from contours interpolated in a transformed digital elevation model ('dem'). The two maps are published as separate sheets.

Map compilation

Geology

Initial compilation of the geological map was made by tracing of the 74 hand-drawn manuscript maps on to a 1:50 000 overlay marked with the tie points. This was then reduced to 1:100 000 – the originally intended publication scale (see previous chapter). However, to accommodate satisfactorily the degree of detail shown in some areas an intermediate map scale was selected (*c.* 1:66 500); this was also convenient with respect to a production size as two map sheets. Certain modifications were then made to clarify detail due to over-reduction of physiographic and geologic features, e.g. removal of surficial outcrops in connection with river courses, simplification of river and marine terrace systems and omission of structural trend lines.

Topography

Following production of the topographic contours on the Kongsberg Plotter (see previous chapter), the coastline was added to the map by direct transference from the geological plot, and certain hand-drawn modifications to the topographic contour plot were made. These were to simplify the 25 m contour interval along steep cliff sections (e.g. Robeson Channel and at Kap Tyson), to rectify certain irregularities in contour form due to limitations of the analytical method and to adjust contour form to physiographic features (e.g. river courses) that were part of the hand-drawn geological map.

However, not all irregularities in contour form have been rectified, and the published map remains essentially an example of the quality of topographic expression produced by scanning of the terrain in profiles and the interpolation of contours without the use of breaklines. The most obvious irregularities are the 'closed' rather than 'V-shaped' contour forms in many valleys. Had the rivers been digitised during the scanning process, the data could have been used in the interpolation of the contours and such closed contour forms could have been avoided.

Publication form

The aim of superimposing geology and topography on a single map was abandoned at a late stage in the research programme. The availability of ground control points during the programme and their incorporation into a new aerotriangulation enabled the topographical map to be produced from refined coordinates (see previous chapter). It transpired that the scale difference between the geological and revised topographic maps was not simply an overall standard variation but included also map warp. Thus the two maps could not be matched by simple photographic adjustment. The necessary meticulous hand-drawn modification to synchronise geological and topographic detail was given up as impractical and uneconomic, and was considered inappropriate when seen in respect to the aims of the research project and to the recent geological and geodetic field work in North Greenland (1978–1985). The topographic map is thus printed separately.

Scale and displacement

Based on the most recent cartographic and geodetic information, the Hall Land map has a precise scale of 1:66 491, and there is a maximum displacement of up to 500 m in the overall geographical position as determined by ground control points obtained by the Geodetic Institute in 1979 (T. I. H. Andersson, H. F. Jepsen, F. Madsen, personal communication, 1982).

The slight displacement between the topographic and geologic maps is basically due to the larger scale of the former, although some anomalous displacement vectors of the topographic contours occur, for example along the steep high coast west of Kap Ammen where displacements are to the south.

Altitude

The height control used in the construction of the Hall Land map is based on selected points at sea-level

Table 2. Comparison of heights on the Hall Land map with other map sources and modern ground control stations

	PRESENT MAP		G. I. control point	DAVIES et. al. (1959)	AMS (1953)	KOCH (1932)
	Spot height	Topo. contour				
'TELTBAKKEN'	101	100	103	106 (348)	-	-
'MONUMENT'	244	225	255	267 (876)	274	-
KAP TYSON	740	725	733	719 (2360)	719	720
KAYSER BJERG	1110	1075	1099	-	1067	1065

Absolute error on Geodetic Institute (G.I.) ground control points from 1979 is less than 3 m (T. I. Hauge Andersson, personal communication, 1982). Heights in metres; values in brackets are original cited heights in feet.

around Polaris Forland: thus the absolute error on altitude increases away from the coastline. Based on the standard deviation of the models used in the aerotriangulation, the maximum error on heights in the centre of the map sheet is estimated at 20 m (Dueholm, 1979). However, a comparison of the values of spot heights shown on the map with those determined by modern geodetic measurement with field control and established by the Geodetic Institute, indicates a relatively low discrepancy on heights; at maximum about 4% (Table 2). The errors on spot heights on Kayser Bjerg – the highest summit on Hall Land – and on Kap Tyson are both below 1%.

Several spot height values on the geological map are more than a single contour interval (25 m) above the highest topographic contour at that locality (e.g. Kayser Bjerg, see Table 2). Several of these discrepancies are probably due to a technical error in the digitisation of the terrain (construction of the 'dem') rather than an excessively high reading for the spot height.

Recent GGU field data based on altimeter measurements (O. Bennike & M. Kelly, personal communication, 1984) suggest that certain marine and glacial features shown on the map at around 100 m a.s.l. in the interior of the central lowland plain are consistently too low, in places by as much as 10 m.

Physical geology

The landscape of northern Greenland was studied by Davies (1972) who has defined the main physiographic provinces. The topographic map illustrates the tripartite nature of the physiography of Hall Land: these provinces reflect the contrasting geology and the regional E–W strike (figs 1, 12, 13 & 14).

Southern upland plateau – province 1

This province is composed of dome-shaped to flat-topped hills etched out of homoclinal strata (fig. 1). Drainage is dominantly northwards from the Inland Ice and Hauge Bjerge into the headwaters of Atka Elv and 'Gråstenelv', but a major drainage basin empties into Petermann Fjord. Three units are recognised (figs 14 & 15).

Unit 1A

This southern unit is a highly dissected plateau of rounded to flat-topped hills between 500 and 800 m in altitude; the plateau rises gently southwards towards the Inland Ice where several low-relief nunataks occur. In places the rivers form canyon-like valleys up to 300 m deep and steep cliffs characterise the coasts (see figs 32 & 40). In the extreme south tableland landscape occurs; fairly level or slightly undulating hills are separated by deep, flat-bottom valleys (fig. 16). This type of mesa-like landscape characterises Hall Land south of the present map sheets, and also large areas across North Greenland (Davies, 1972).

The plateau is mainly underlain by shallow northerly-dipping limestones, giving rise to concordant uplands with the upper topographic surface parallel to bedrock structure (fig. 1); to the north, south of Hauge Bjerge, less resistant shales produce more rounded hills of lower elevation.

Unit 1B

Hauge Bjerge – a central, narrow upland ridge 4 to 6 km wide – comprises a chain of dome-shaped hills with summits

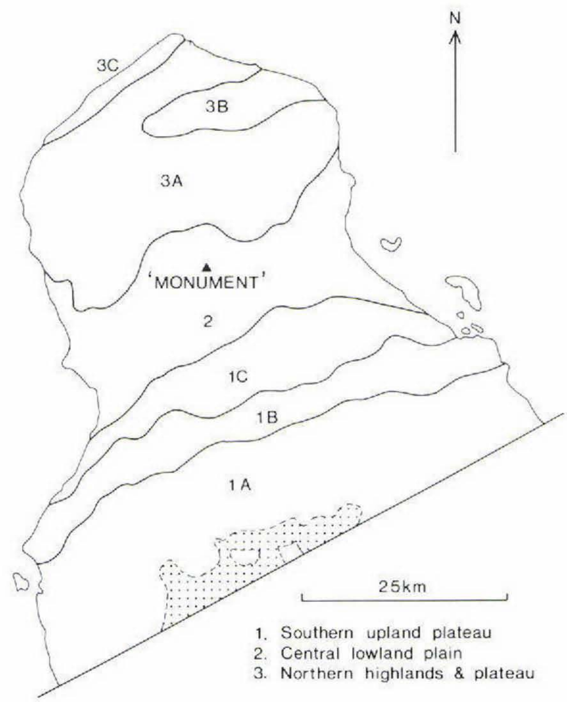


Fig. 14. Main physiographic provinces of Hall Land – modified from Davies (1972). See text for sub-divisions of provinces 1 and 3. Inland Ice shown by dotted signature.

mainly between 700 and 1000 m high. Kayser Bjerg in the east at *c.* 1100 m is the highest peak in the map area. Several northerly flowing rivers in gorge-like valleys cut through the ridge, and steep cliff sections characterise the western and eastern mountain sides and the coasts (figs 1, 38 & 40). Northern and southern mountain flanks have moderate to shallow gradients.

The mountain chain is a reflection of a Silurian barrier reef; many of the actual summits represent reef cores with northern and southern mountain flanks being sub-parallel to deposition planes (figs 40 & 41).

Unit 1C

This unit, north of Hauge Bjerge, is a dissected plateau of gently rounded to rolling hills, 10 km wide in the east but less than half this in the west. Individual summits are between 300 and 500 m high. The bedrock comprises fine-grained clastic strata that produce a smooth topography with low gradients; glacial till cover is moderate to heavy (fig. 15).

Central lowland plain – province 2

This is the 'Polaris plain' of Davies (1972) (fig. 17). A dominant feature of the landscape, it forms a broad, gently undulating tract about 10 km wide in the east and west, 15 km in the central part, and represents a raised marine shelf. A prominent inselberg-like hill, *c.* 250 m high, the 'Monument' occurs in the central part (fig. 18). Much of the plain is below 100 m in altitude; in the south-east it reaches 150 m. In the central part relief is less than 25 m; in the east and west two arcuate rounded morainic ridges (Polaris Bugt and Newman Bugt moraines) parallel to the coasts reach heights of over 100 m (figs 19 & 20). In the south elevation rises, gradually in the south-west and south-east, fairly abruptly in the central part, forming a transition into the rolling hills of unit 1C (fig. 15); to the north a well demarcated scarp up to 200 m high limits the plain (figs 19, 20 & 71).

The surface of the plain is extremely level and uniform over large areas and has proved extremely suitable for the establishment of emergency landing sites for heavy aircraft (Davies *et al.*, 1959) (see fig. 68). Apart from 'Monument' and some bedrock exposures in the south-east and along the two major rivers – Atka Elv and 'Gråstenelv' – the entire plain has a cover of Quaternary deposits.

The drainage pattern is irregular; run-off is from highlands in the north and south into the two rivers mentioned above which, respectively, reach Polaris

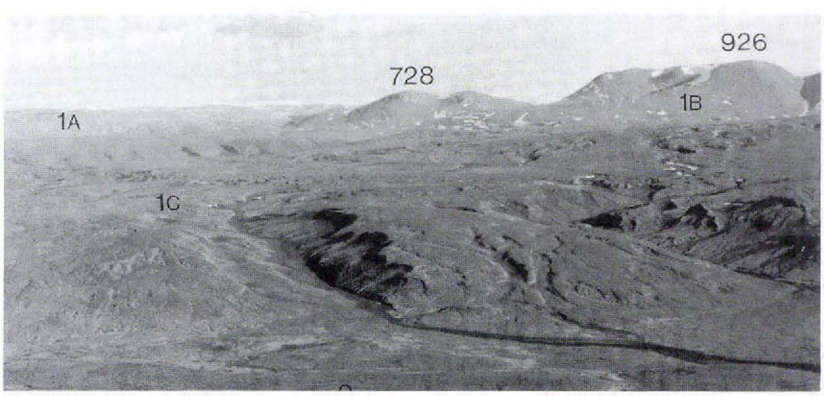


Fig. 15. View over southern upland plateau showing broad alluvial area at foot of escarpment on central lowland plain. Alluvium at about 125 m; figures on Hauge Bjerge summits are heights in metres (see map sheet). Bedrock shales of uplands (1C) have prominent ground moraine cover. Physiographic provinces – see fig. 14.

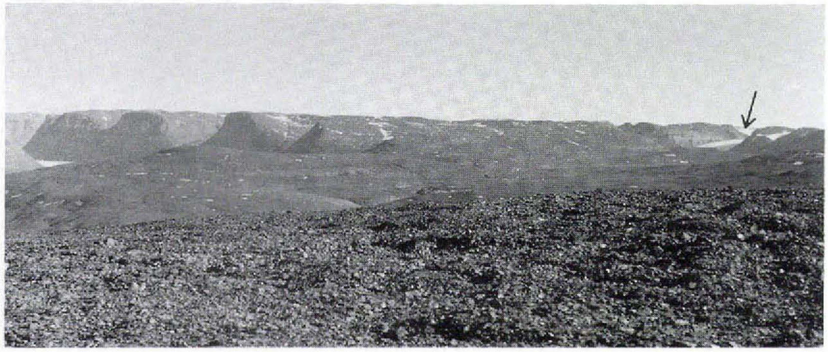


Fig. 16. View over southern upland plateau from Hauge Bjerge to inner Newman Bugt (sea-ice just visible on left) showing tableland landscape with surface at *c.* 800 m. Rubble (bedrock debris) map unit covers foreground. Inland Ice arrowed.

Fig. 17. The central lowland plain viewed over the 'Gråstenelv' delta with Hauge Bjerge on left, northern highlands on right.

Bugt and Newman Bugt in deltas (figs 19 & 60). The river in the central part draining westwards into Atka Elv has an open meandering course with ox-bow developments; the lower reaches of 'Gråstenelv' contain prominent incised oxbow meanders that reach bedrock. The northern and southern borders of the plain form areas of alluvial deposits (figs 15 & 67); fans, deltas and slopes are particularly prominent along the northern scarp.

Many areas underlain by friable marine deposits resemble badland landscape characterised by a high density of rivulets which produce an intense gullied topography with relatively sharp ridge interfluves (fig. 21). Davies (1972) describes one such area in the west, north

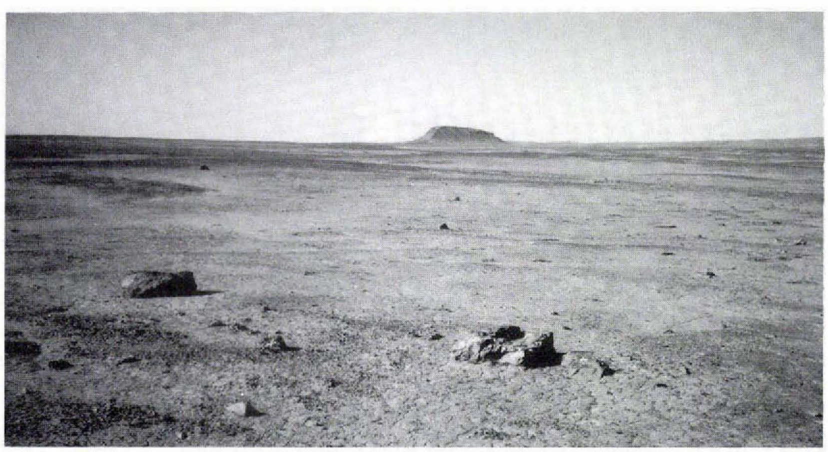


Fig. 18. View westwards across the central lowland plain to 'Monument' (see fig. 81). Fluviatile gravels with glacial erratics in foreground, low morainic ridges on left.

Fig. 19. North-western Polaris Forland showing physiographic units of northern highlands and plateau, and central lowland plain. Varied surficial deposits composing the latter are Atka delta with prominent raised marine terraces and plains, large dried-up lake (L) and Polaris Bugt moraine (M) flanked by light coloured marine clay and silt. Aerial photograph 546C–N, 15384, copyright Geodetic Institute.

Fig. 20. Eastern part of central lowland plain showing 'Gråstenelv' raised fluvial plain (G) and Newman Bugt moraine (M), with intervening areas of outwash. Distinction between ice-lain deposits and outwash is arbitrary; moraines have been reworked to varying degrees by glaciofluvial action. Note areas of thermokarst topography and ice-wedge polygons along line x-x. Mt = 'Monument'. Aerial photograph 546E–V, 11491, copyright Geodetic Institute.

Fig. 21. Badland topography developed in marine silt and clay. Newman Bugt, south of 'Gråstenelv' delta. Maximum width of coastland shown is about 1 km.

of Atka Elv where the relief reaches 15 m, as 'dissected plains'. Some areas underlain by glaciofluvial deposits, e.g. in the south-west, display desert-like karst topography characterised by dry valleys, beaded drainage and lakes (fig. 22).

Northern highlands and plateau – province 3

This province, underlain by gently to severely folded, mainly clastic rocks, is characterised by a sub-dendritic drainage pattern. A major NE–SW watershed crosses the area; drainage is either southwards into Atka Elv and 'Gråstenelv', or northwards into Robeson Channel or northern Newman Bugt. Three units are recognised (figs 14 & 19).

Unit 3A

Rolling dissected plateau between 200 and 400 m high forms the main part of this unit. Topographic form is smooth, with rounded hill summits, with rivers generally occupying wide gentle-sided valleys. The only steep profiles occur in river sections and at the coasts; at Kap Lupton, for example, the steep cliffs are nearly 400 m high. In the south-east, south of 'Saint Anthony's Nose', deeply incised rivers form a highly dissected plateau ('channelled uplands' of Davies (1972)) characterised by sub-parallel drainage channels with a general north-east direction. The channels have fairly steep sides, with separate moraine-covered rounded ridge interfluves less than 500 m wide, and provide good bedrock exposure.

The plateau is covered by thick glacial till (fig. 25); bedrock exposure is extremely poor except in deeper valleys and at the coasts.

Unit 3B

An elongate chain of mountains about 6 km wide composes the watershed mentioned above; highest summits are between 500 and 700 m altitude. The chain is cut by several N–S steep-sided river valleys producing a relief of 300–400 m. This is highest in the east where, at the coast north of 'Saint Anthony's Nose', the steep cliffs are over 500 m high. Mountains have dome-shaped summits and their disposition is often controlled by bedrock structure; for example, several summits mark synclinal cores (fig. 49).

Unit 3C

The north-western coastal strip forms a high mountainous ridge with summits reaching between 600 and 800 m; Chester Bjerg is the highest peak at about 835 m. The coast is formed of very steep cliffs, in parts precipitous, that expose a spectacular profile through the carbonate-clastic succession of the fold belt (fig. 25). Inland, the ridge slopes southwards into the rolling dissected plateau and bedrock exposures are poor. Mountain summits are generally rounded (e.g. Chester Bjerg), but summits etched out of the lower carbonates are more alpine in character (e.g. Kap Ammen) (fig. 26). One prominent valley, 'The Gap', cuts through the mountain chain down to sea-level; several cols represent hanging valleys to Robeson Channel.

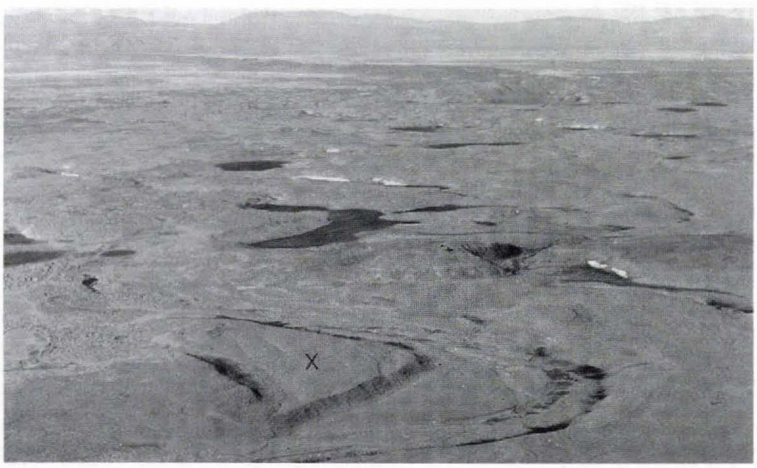


Fig. 22. Desert-like landscape in outwash deposits on the central lowland plain, showing areas of thermokarst topography. Polaris Bugt moraine crossing marine plain is visible in background. Terrace in foreground (X) is 250 m across. Southern Polaris Bugt.

Palaeozoic geology

In Hall Land a section is exposed through a linear east–west trending Palaeozoic basin – the Franklinian geosyncline of Schuchert (1923). This basin can be traced through the Queen Elizabeth Islands of Arctic Canada (Hazen trough) and across northern Greenland (North Greenland trough). The basin is composed of a geological couplet: in the north a deep-water clastic trough, and to the south a shallow-water mainly carbonate platform which, to the east of Hall Land in the Victoria Fjord arch, has an exposed sedimentary contact with the Precambrian Shield (fig. 8). Following Proterozoic to Devonian sedimentation the northern part of the basin was deformed and metamorphosed into a linear tectonised zone that now comprises the North Greenland fold belt (Dawes, 1976). Modern descriptions of the Proterozoic–Palaeozoic sedimentary and structural evolution of North Greenland can be found in Hurst & Surlyk (1984), Surlyk & Hurst (1984), Higgins & Soper (1985), Higgins *et al.* (1985) and Soper & Higgins (1985).

The regional structure of Hall Land is fairly simple, and folding and faulting have not unduly complicated the regional disposition of rock units. Outcrops are of the upper part of the Franklinian succession, and over 95% of the bedrock exposed is Silurian. The underlying Ordovician strata are only seen on the maps sheets in the tectonically upturned succession along Robeson Channel; outside the map area in south-east and south-west Hall Land homoclinal Ordovician strata outcrop. The upper part of the trough succession may extend into the Devonian.

A summary of biostratigraphic data from Operation Grant Land 1965–66 is found in Dawes & Peel (1984), to which the reader is referred for details of fauna and age of the exposed sequences. A stratigraphic summary chart taken from the report is reproduced as fig. 23, while schematic cross-sections illustrating the relationships of the rock groups mapped are given in fig. 24.

In Late Ordovician – Early Silurian time the entire map area was part of the carbonate platform; shallow-water carbonates along Robeson Channel are overlain by a deep-water turbidite sequence indicating major subsidence and expansion of the basin during the Llandovery (Dawes, 1976; Hurst & Kerr, 1982a). The Silurian succession shows a regional lateral facies change from platform carbonates in the south through a major reef belt on the shelf and upper slope to the argillaceous and arenaceous strata of the lower slope and trough (fig. 24). Facies transitions and interdigitation of shelf–slope–trough lithologies are complex, and on a local scale facies boundaries can be steeply inclined and fairly abrupt. Continued basin expansion is demonstrated by the overlap of Late Silurian trough clastics onto platform carbonates and off-reefal shales.

The central lowland plain coincides with the site of the major facies change, and more or less with the southern margin of the fold belt. It forms a natural divide between northern tectonised and southern homoclinal areas that, apart from lowest correlatable carbonate units, are underlain by different successions (figs 13 & 24). Thus, in the present mapping the bedrock has been referred to a bipartite legend. While the gross relationship between the northern clastic, and the southern carbonate, successions is obscured beneath Quaternary strata, the contact between the successions is seen north of Hauge Bjerge. Here the shale facies outcropping on the fore-reef side of the Kap Tyson reef contains basinal mudstone, siltstone and greywacke that sedimentologically are part of the trough succession. However, on the basis of the limited field data available it proved impossible during the photo-interpretation to differentiate satisfactorily between trough deposits and fore-reef strata of the upper slope. Hence all strata between Hauge Bjerge and the central plain have been mapped together as part of the southern succession. This relationship between the two successions is not directly apparent on the map.

Stratigraphy

In the following, descriptions of the stratal groups and units recognised on the map are given. Subsequent to compilation, field studies by Hurst (1980, 1984), Peel & Hurst (1980) and Hurst & Surlyk (1982), predominantly in areas to the east and west, have led to a revision of the stratigraphic nomenclature for the Upper Ordovician – Silurian sequence of North Greenland. Biostratigraphic studies of the shelf carbonates at Kap Tyson and the trough clastics of Chester Bjerg have led to the designation of type sections of new or revised formal stratigraphic units. Correlations of the map units with the newly erected formational scheme are given in the text.

It should be noted that the 'Offley Island Formation' of the map legend is used in the sense of Dawes (1971) and Norford (1972) to cover a wide range of strata, including Koch's (1929) Offley Island Formation and the carbonate facies of his Cape Tyson Formation (see Dawes & Haller, 1979). The Offley Island Formation has subsequently been redefined by Hurst (1980) as one

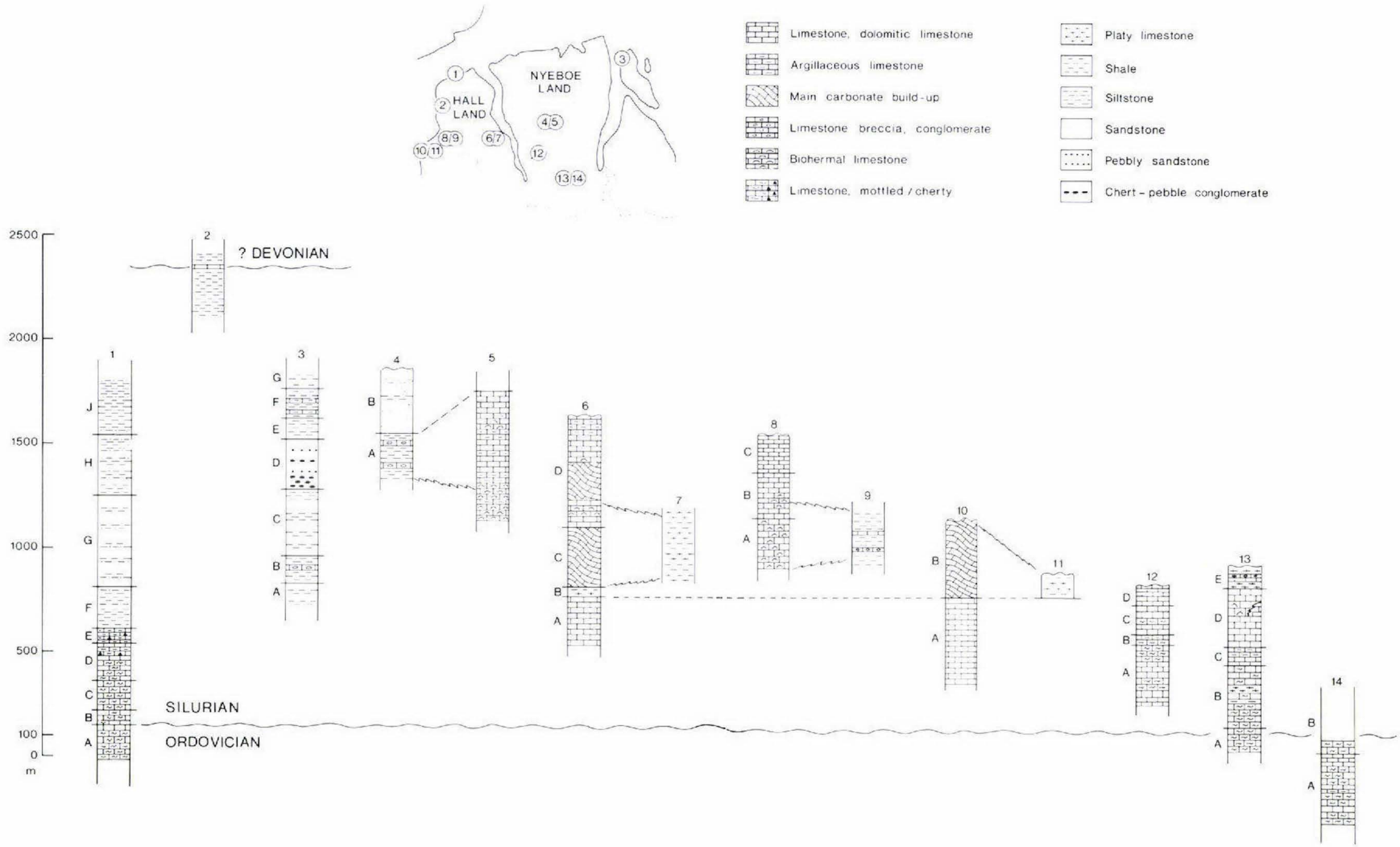


Fig. 23. Stratigraphic chart of Lower Palaeozoic sections of Hall Land and adjoining area; from Dawes & Peel (1984) with original annotation. Correlation between these units and the map groups recognised on the map is given in the text. Sections 1 and 2 represent the northern succession of the map legend; sections 6 to 11 are part of the southern succession.

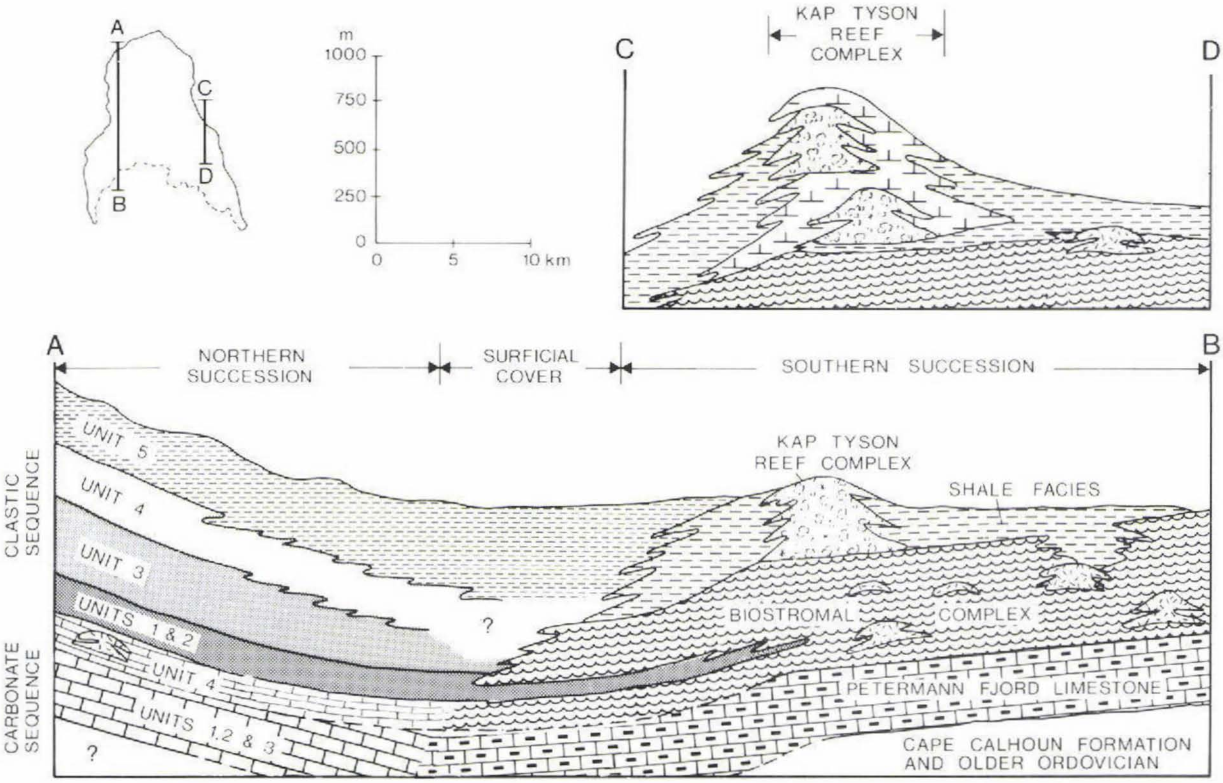


Fig. 24. Schematic north–south cross-sections illustrating relationships of the northern and southern successions and inherent map groups. Presence of carbonate platform, presumably with reef developments, beneath central Hall Land is inferred from the similarity of sections at Kap Ammen and Petermann Fjord; southern extent of basal units of clastic sequence is based on occurrence of 'Cape Schuchert lithologies' in the Hauge Bjerge area.

of ten formations that presently compose the Washington Land Group.

The 'Kap Tyson reef complex' is used in the sense of Dawes (1971, 1976) for the intricate accumulation of biohermal and biostromal limestones that compose a major east–west trending barrier reef in which individual reef masses are several hundred metres thick. The complex forms a mountain range – Hauge Bjerge – and it was envisaged as the central part of a regional belt of carbonate build-ups stretching for over 400 km across western North Greenland (Dawes, 1976, fig. 267). At Kap Tyson it corresponds to the carbonate facies of the Cape Tyson Formation of Koch (1929) and to the Cape Tyson Member of the Hauge Bjerge Formation of Hurst (1980). Elsewhere the complex may be referable to several formations of the Washington Land Group of Hurst (1980).

Northern succession

The northern succession is well exposed in the high steep cliffs of Robeson Channel between Kap Porter and Kap Sumner (fig. 25). This spectacular section has been illustrated in several publications since first sketched by Koch (1920), e.g. Dawes (1976, 1982), Hurst & Kerr (1982a) and Hurst & Surlyk (1982). The section was examined in 1965 from a camp at Kap Ammen (fig. 23, section 1).

In addition to the above-mentioned papers, various aspects of this coast have been mentioned by Bessels (1879), Koch (1929), Davies *et al.* (1959), Allaart (1965, 1966), Kerr (1967), Dawes (1971), Davies (1972) and Dawes & Haller (1979). Apart from fossil identifications summarised by Dawes & Peel (1984), specific faunas have been described by Bendix-Almgreen & Peel (1974), Berry *et al.* (1974), Peel (1975), Bendix-Almgreen (1976), Boucot & Hurst (1979), Lane *et al.* (1980), Pickerill *et al.* (1982), Armstrong & Dorning (1984) and Lane (1984).

The succession is composed of two parts: a lower Upper Ordovician – Lower Silurian carbonate sequence and a Lower Silurian – (?)Lower Devonian predominantly clastic sequence. The lower sequence at the base of the cliffs has a thickness of more than 550 m; the upper sequence, which may reach 2000 m, forms the major part of Polaris Forland (fig. 13).

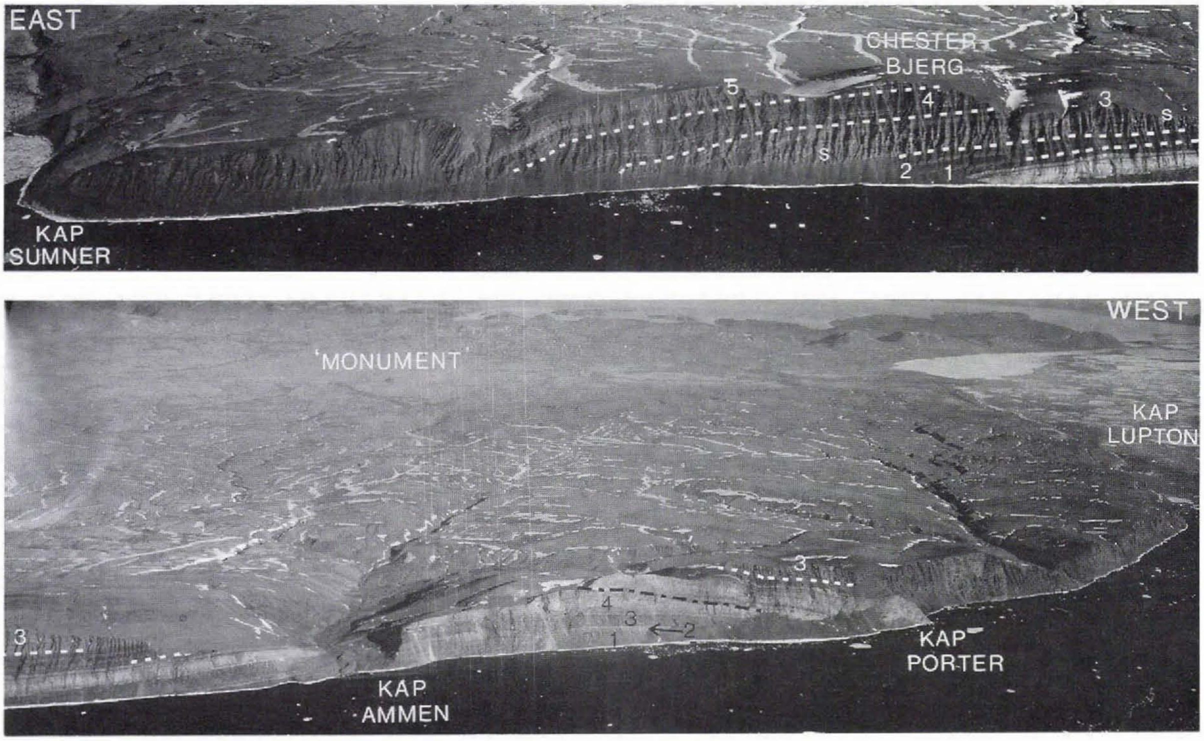


Fig. 25. North-western coast of Hall Land showing the Late Ordovician – Early Silurian carbonate sequence (black figures, cf. units in fig. 32) and overlying Early Silurian – ?Early Devonian clastic sequence (white figures). S–S refers to a thin shale bed present also at Kap Porter (see fig. 29). Supposed contraction fault is shown by dot-dash line (see fig. 54). Note heavy ground moraine on uplands behind the coast. 'The Gap' is the prominent col in the cliffs east of Kap Ammen. Aerial photographs 546K–SØ, 2187 (eastern) and 2191 (western), copyright Geodetic Institute.

Lower carbonate sequence

Four map units are recognised (figs 25 & 26); they can be referred to units 1A–1D of the Kap Ammen section shown in fig. 23. The thicknesses given are calculations carried out on a Zeiss stereo-comparator, Stecometer, using oblique aerial photographs (Dawes, 1979).

Unit 1 (unit 1A of fig. 23). Strata of this unit are the oldest shown on the northern map sheet. The unit is mainly composed of dark weathering, dark grey to bluish grey, variously mottled, fine-grained dolomitic limestone, with some pale limestones near the top. In places actinoceratid cephalopods are conspicuous on weathered surfaces (fig. 27). Thickness exposed: about 160 m.

A gastropod–cephalopod–stromatoporoid fauna is of Late Ordovician age.

Unit 2 (unit 1B of fig. 23). The main lithology of this unit is pale weathering, weakly mottled, massive, fine-grained limestone and dolomitic limestone. Crinoid-rich beds and dark, strongly mottled beds similar to the lithology of the underlying unit occur; one such interval of dark dolomitic limestone is conspicuous in the middle of the unit. At Kap Ammen the unit is about 60 m thick, but to the west lens-shaped thickening is prominent (fig. 25).

A coral–cephalopod–brachiopod–stromatoporoid fauna suggests an age at about the Ordovician–Silurian boundary.

Unit 3 (unit 1C of fig. 23). Strata of this dark weathering unit resemble those of unit 1; some beds are rich in pentamerid brachiopods. Mottling is generally strong, but its intensity varies throughout the unit. Thickness: about 150 m.

A brachiopod–coral fauna suggests an Early Silurian (Late Llandovery) age.

Unit 4 (unit 1D of fig. 23). The lithology of this light weathering unit resembles in part that of unit 2 – variously mottled and veined, grey to brownish grey limestones – but in the uppermost part thinner bedded intervals with platy limestones, calcareous slates and shales occur, and to the west massive reef limestones come in. Two sub-units have been mapped out. In the upper part at Kap Ammen a conspicuous sub-unit is composed of dark beds of shale, chert and nodular limestone (fig. 26B); in the section between Kap Ammen and Kap Porter irregularities in bedding, interdigitation of different facies and stratal thickening are interpreted as due to carbonate buildups (figs 28 & 29). In addition to sedimentary thickening, unit 4 appears to be cut by a contraction fault that causes some stratal repetition. Thickness: at Kap Ammen about 190 m; thicker to the west.

A trilobite–gastropod–ostracod–brachiopod–mollusc fauna is of Silurian, probably Early Silurian (Llandovery), age.

Correlation. The carbonate strata are regarded as a platform–shelf sequence. Correlation can be made with

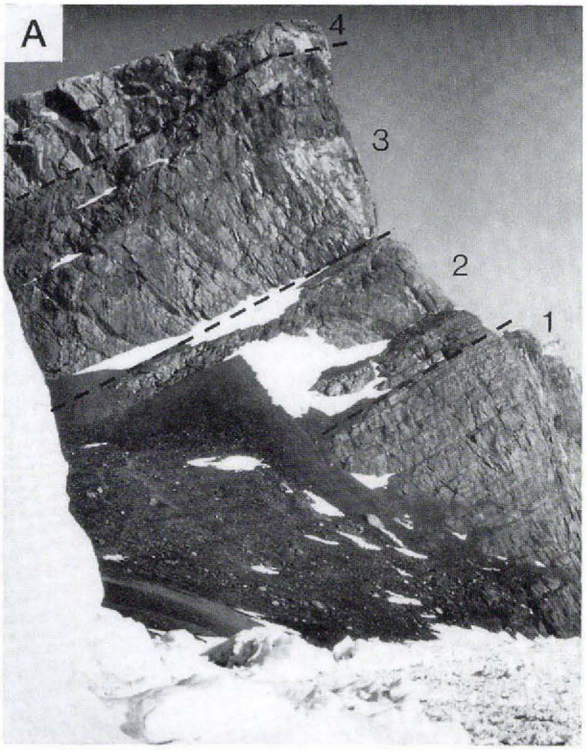


Fig. 26. Palaeozoic succession on Robeson Channel coast (see fig. 25). A: Kap Ammen (about 250 m high) seen from the east showing four units of the lower carbonate sequence; B: upper cliffs east of Kap Ammen showing five units of the upper clastic sequence. Mapped sub-units visible are thin, dark chert and shale-rich interval at top of unit 4 of the carbonate sequence and the four shale intervals in unit 4 of the clastic sequence. CB = Chester Bjerg.

units of the platform succession to the south (fig. 23); within the map area, correlation is suggested with the Petermann Fjord limestone and basal strata of the biostromal limestone complex (see fig. 32). The lower part of the sequence (units 1, 2 & 3) is referred to the Aleqatsiaq Fjord Formation of the Morris Bugt Group of Peel & Hurst (1980); unit 4, with carbonate buildups, correlates with the Petermann Halvø and Bessels Fjord Formations of the Washington Land Group of Hurst (1980).

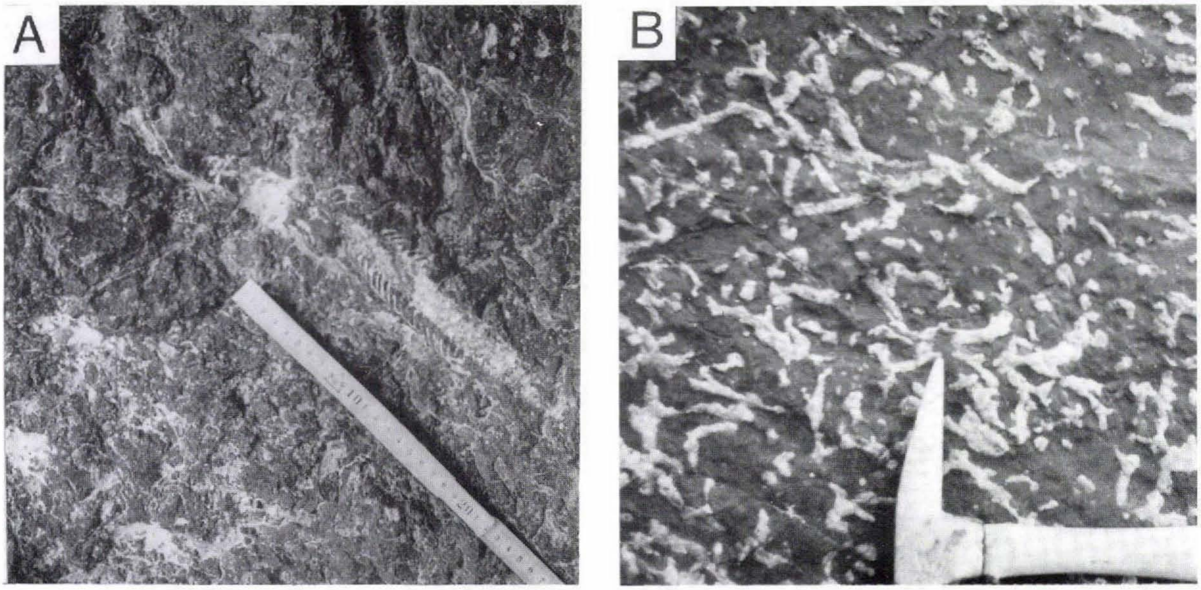


Fig. 27. Late Ordovician fine-grained dolomitic limestone, Kap Ammen. A: actinoceratid cephalopod in mottled to brecciated dolomite; B: strongly mottled bioturbated variety.

Upper clastic sequence

Five units are recognised in this sequence (fig. 23, section 1), but only four are shown on the map. Certain intervals or beds rich in shale or sandstone have also been mapped out. The five units were established in the cliffs east of Kap Ammen (fig. 25) and extrapolated on aerial photographs. In western outcrops it was, however, not possible to subdivide the conspicuously dark, basal part of the sequence (fig. 29) and for convenience units 1 and 2 have been combined on the map.

The sequence is predominantly composed of clastic turbidites, but at the base (unit 1) and within unit 5, limestones occur. The clastic strata comprise a brown to buff weathering sequence of interbedded fine to medium grained sandstone, siltstone and shale of typical 'flysch' appearance. The sandstones are characterised by having a calcareous matrix that can exceed 50 per

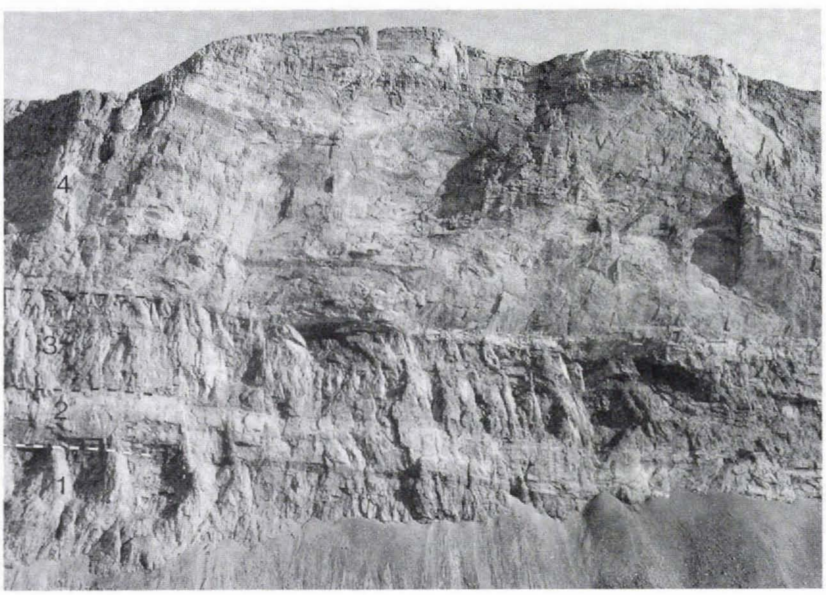


Fig. 28. Lower carbonate sequence west of Kap Ammen showing intertongueing relationships and massive carbonate buildup in unit 4. Height of cliffs about 650 m.

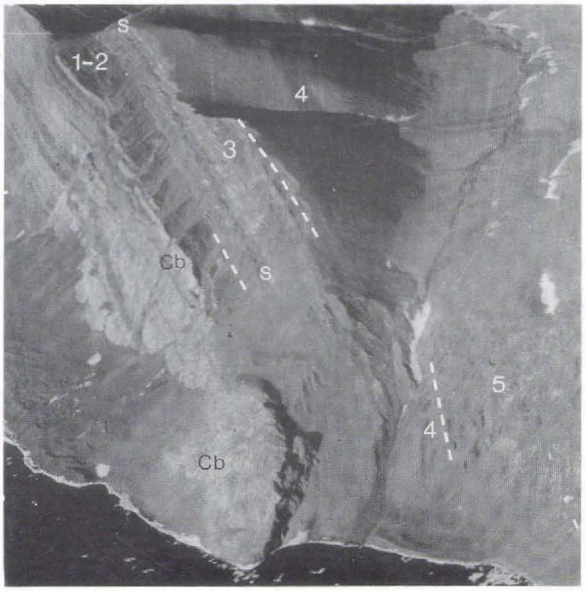


Fig. 29. Kap Porter showing buildups (Cb) in uppermost part of the carbonate sequence, and dark overlying strata equivalent to units 1 and 2 of the clastic sequence at Kap Ammen. S–S marks a persistent shale bed – see fig. 25. Fault is inferred in valley cutting out part of unit 4. Note patterned ground in talus on north side of Kap Porter. Aerial photograph 546K–SØ, 2200, copyright Geodetic Institute.

cent of the rock; generally, however, quartz slightly exceeds carbonate in total rock mineral composition. Feldspar is present in accessory amounts (generally less than 1 per cent); mica (both biotite and muscovite) is often conspicuous and can form over 5 per cent of the rock. Petrologically the sandstones are calcareous greywacke. The clastic strata are characterised by well-preserved sedimentary structures related to turbidite deposition, e.g. current and deformational sole markings, convolute bedding and slumping (fig. 30).

Unit 1 (unit 1E of fig. 23). The basal unit is composed of dark weathering, platy limestones with some pale, calcareous shales and dark, in places nodular, chert beds. Thickness: about 70 m.

A gastropod–brachiopod–cephalopod–coral fauna indicates a Silurian age.

Unit 2 (unit 1F of fig. 23). Like the underlying strata this unit is dark weathering; it is composed of grey to black shales, calcareous slates and siltstone with some beds of fine-grained calcareous greywacke. Thickness: about 195 m.

No fauna is known.

Unit 3 (unit 1G of fig. 23). This unit is composed of brown-weathering fine-grained calcareous greywacke and siltstone with thin shale interbeds. One discrete shale bed about 5 m thick has been mapped out (figs 25 & 29) as well as a sandstone-rich interval near the top. Some thin, fine-grained quartzites occur. Thickness: about 445 m.

A graptolite fauna indicates a late Early – early Middle Silurian (Late Llandovery – Early Wenlock) age.

Unit 4 (unit 1H of fig. 23). This unit is composed of alternating packages dominated by siltstone and fine-grained calcareous greywacke and silty mudstone and shale. Four shale-rich intervals and two sandstone-rich intervals have been mapped out; some of the sandstones are reddish weathering and abnormally quartz-rich. Thickness: about 285 m.

A graptolite fauna suggests an early Late Silurian (Early Ludlow) age.

Unit 5 (unit 1J of fig. 23). This upper map unit encompasses all fold belt terrain south of the northern coast, but stratal equivalents to older units may occur. The main lithologies are a brown to buff weathering grey to pale green, laminated mudstone and shale but many sections contain important intervals of siltstone and fine-grained calcareous greywacke (see figs 49, 50 & 51 – abundance of bedding traces on the map is a general indication of abundant greywacke beds). The lowermost part of the unit, which forms the top of the sea-cliffs east of Chester Bjerg (fig. 25), contains thick sandstone intervals. Ripple marks are common (fig. 30D) and slumping characterises mudstone intervals (fig. 31). In the Halls Grav area, beds of platy limestone, crinoidal limestone and limestone breccia occur. Thickness: at least 500 m, possibly reaching 1000 m.

The only identifiable fauna from this unit in Hall Land is from its upper part; graptolites from shale and a vertebrate and variable shelly fauna from limestone indicate a latest Silurian (Pridoli) or possibly Early Devonian (Downtonian) age. A graptolite from equivalent strata in Nyeboe Land (Larsen & Escher, 1985) suggests that the lower part of unit 5 is Late Silurian (Early Ludlow) in age.

Correlation. The clastic sequence essentially comprises turbiditic sandstones, siltstones and mudstones deposited in a deep-water basin which Hurst & Surlyk (1982) have referred to the Peary Land Group. Strata of units 1 to 4 were regarded by these authors as representing an interdigitation of the Lauge Koch Land and Wulff Land Formations; however, other formations are present.

Unit 1, composed of dark limestone and chert, is considered to be a slope deposit transitional between the underlying shelf carbonates and the trough turbidites (Dawes, 1982). Correlation is invited with the Cape Schuchert Formation of Washington Land.

Unit 2 may be wholly or in part equivalent to the Thors Fjord Member of the Wulff Land Formation of Hurst & Surlyk (1982) that Larsen & Escher (1985) have mapped as far west as Kap Brevoort in northwestern Nyeboe Land.

Unit 3 has been correlated with strata within the Nyeboe Land linear belt (Dawes, 1982), a succession recently mapped as mainly Merqujôq Formation (Larsen & Escher, 1985). However, according to Larsen & Escher (personal communication, 1985) the Merqujôq Formation thins rapidly to the west and may not be present in northern Hall Land. If so, unit 3 is all or in part equivalent to the 'lower mapping unit' of the Lauge Koch Land Formation as used by Larsen & Escher (1985).

One of the shale units mapped in unit 4 is referred to

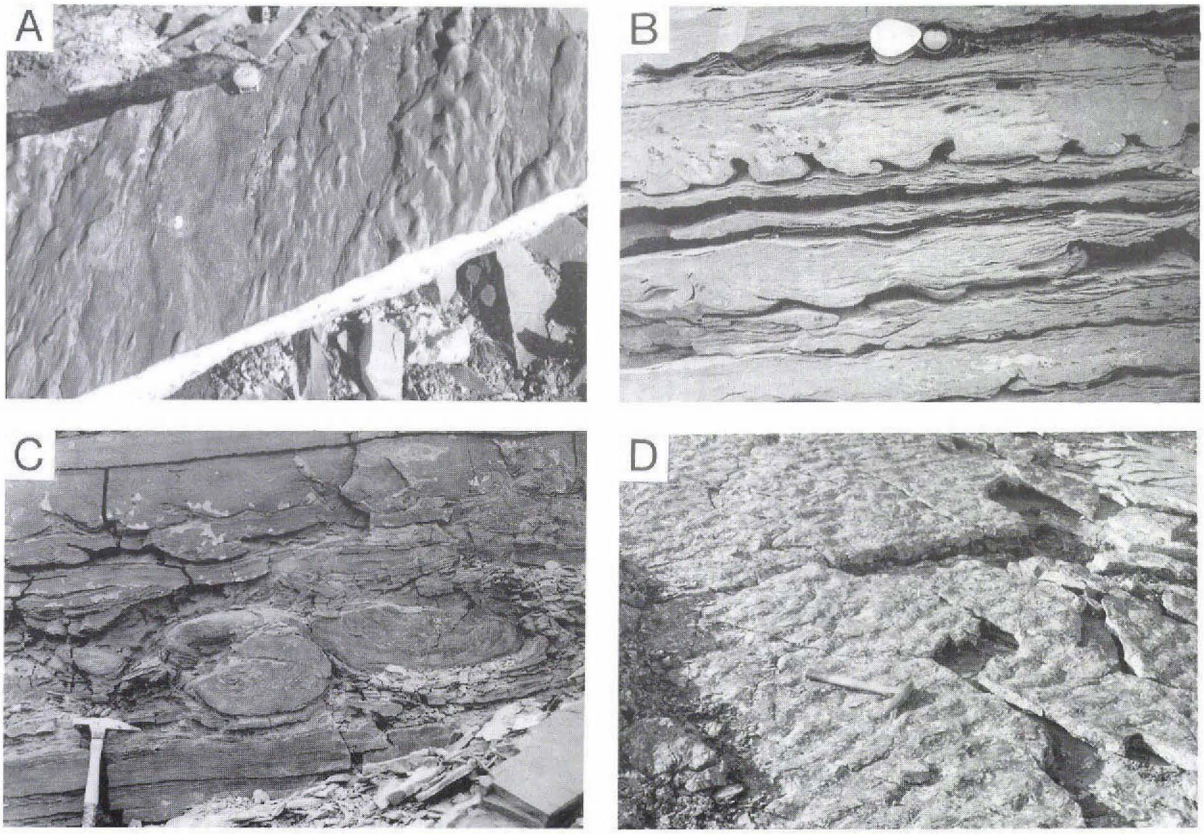


Fig. 30. Sedimentary structures of the clastic greywacke sequence. A: elongate flute casts; B: small-scale cross bedding, loaded greywacke bed with flame structures; C: convolute bedding with ball-and-pillow structure, D: asymmetrical ripple marks. Map unit 5, northern Polaris Forland.

the Repulse Havn Member of the Wulff Land Formation by Hurst & Surlyk (1982) (see Dawes & Peel, 1984, fig. 5); the three remaining units, which are equally prominent (fig. 26B), were not formally named but referred to the Wulff Land Formation. It seems almost certain that unit 4 also contains mudstone strata that in northern Nyeboe Land have been informally named the 'Hand Bugt beds' by Larsen & Escher (1985). The 'Hand Bugt beds' are equivalent to the shale sequence forming the uppermost part of unit 3C on Hendrik Ø (fig. 23).

Unit 5 corresponds mainly to the Chester Bjerg Formation, although it contains appreciably more sandstone than implied in the description by Hurst & Surlyk (1982). The lowermost part, in which sandstone predominates, is part of the Lauge Koch Land Formation of Hurst & Surlyk (1982, fig. 82).

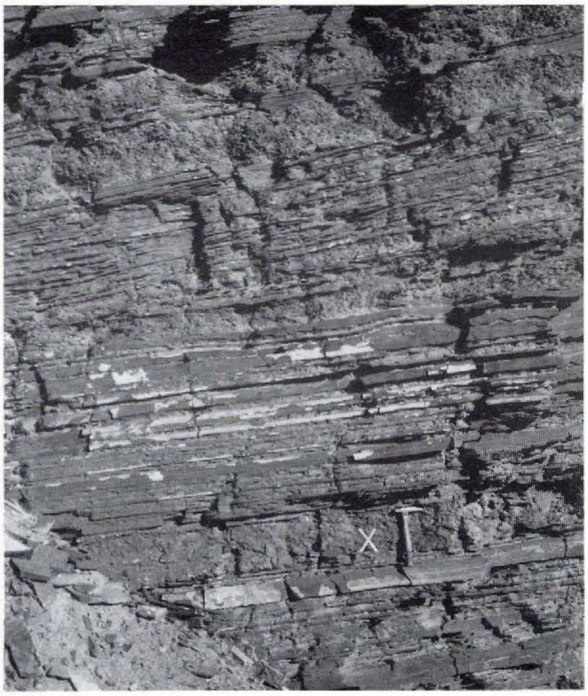
Southern succession

Bedrock south of the central lowland plain is referred to this succession. Four groups of strata have been mapped:

4. Shale facies
3. Kap Tyson reef complex
2. Biostromal limestone complex
1. Petermann Fjord limestone

The placing of these groups in the legend in a vertical column does not here imply a consistent younging-upwards chronostratigraphy; facies transitions occur between groups 2, 3 and 4 (fig. 24). The Petermann Fjord limestone is older than groups 3 and 4 and, where recognised in the west, underlies group 2. In the east stratigraphic equivalents of group 1 may occur within the lowermost part of group 2.

Group 1 has not been investigated in the field; groups 2, 3 and 4 were only studied in 1965 in the west, east of



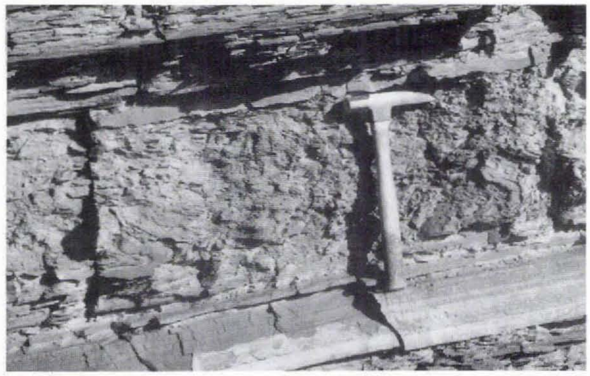


Fig. 31. Slumping in intercalated mudstone-siltstone sequence (unit 5). At X, seen in detail, several folds are visible in slumped bed. Eastern Polaris Forland.

Offley Ø, and in the east, north of Kayser Bjerg. Three reconnaissance sections were established; at Kap Tyson – Offley Ø, at 'Sun Mark Mountain' and at Kayser Bjerg (fig. 23, sections 6 to 11). Norford (1972) and Hurst (1980) logged in some detail the Kap Tyson – Offley Ø section (see figs 35 & 36); the central and eastern part of the platform was studied for the first time since 1965 during GGU's field work in 1985.

The platform limestones are generally highly fossiliferous. Apart from fossils collected in Hall Land by the early expeditions reported on by Etheridge (1878) and Bessels (1879), collections by Lauge Koch in 1917 and 1922 form the basis of several palaeontological accounts (Poulsen, 1934, 1941, 1943, 1974). Dawes & Peel (1984) summarised the main age-diagnostic fossils of the diverse fauna; specialised descriptions have been given by Jackson & Etherington (1969), Berry & Boucot (1970), Norford (1972), MacLean (1977), Peel (1979, 1984), Hurst (1980), Armstrong (1983), Jones & Hurst (1984), Lane (1984) and Stouge & Stouge (1984).

Petermann Fjord limestone

This unit has only been mapped in the cliffs of Petermann Fjord where it includes the lowest strata of the platform succession within the map area. It is readily recognised as a dark weathering, rather massive unit in contrast to the overlying banded succession (fig. 32). The upper boundary of the unit is taken at the base of a thin, light-weathering unit that forms an extremely useful marker horizon in the cliffs bordering Petermann Gletscher. The base of the unit (outside the map area) is taken at the top of a recessive bench that is referred to the Cape Calhoun Formation of Peel & Hurst (1980). In the middle of the unit a white marker bed is conspicuous; this shows abrupt thickness changes that resemble lens-shaped carbonate buildups (fig. 32).

The Petermann Fjord limestone is about 400 m thick; only the uppermost 200 m is exposed within the map area.

Age and correlation. Correlation is suggested with the lower carbonates at Kap Ammen and the unit is referred to the Aleqatsiaq Fjord Formation of the Morris Bugt Group of Peel & Hurst (1980). According to H. F. Jepsen (personal communication, 1983) the overlying light-weathering unit is referable to the Petermann Halvø Formation – the lowermost formation of the Washington Land Group in the Bessels Fjord – Petermann Fjord region (fig. 32, cf. Hurst, 1980, figs 33, 34, 35 & 38).

Based on the age of comparable sequences in Washington Land (Hurst, 1980) and at Kap Ammen, that part of the Petermann Fjord limestone shown on the map is probably of Early Silurian (Early(?) – Middle Llandovery) age.

Biostromal limestone complex

This complex forms the southernmost part of the platform stretching from Petermann Fjord to Newman Bugt (units 6A and 10A on fig. 23). Most of this area has been included as undifferentiated limestones on the map within which several units are recognised locally. In the south the complex overlies the Petermann Fjord limestone (fig. 32). In northern outcrops it is overlain by the Kap Tyson reef complex and shale facies (fig. 38); in detail it interdigitates with these map groups (fig. 44).

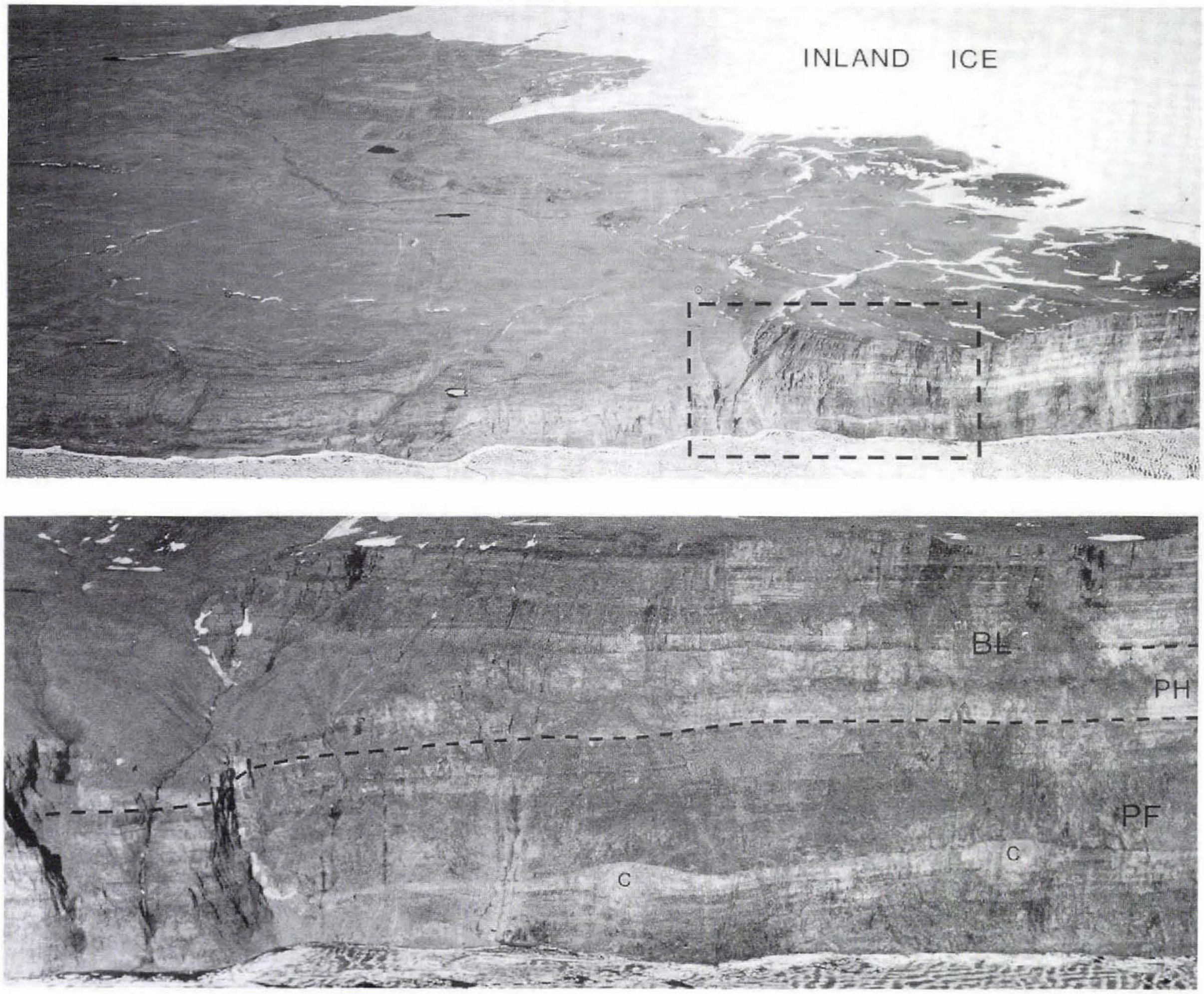


Fig. 32. South-west Hall Land with Petermann Fjord cliffs about 400 m high, showing Petermann Fjord limestone (PF) overlain by biostromal limestone complex (BL). Thin, light coloured unit of variable thickness in PF with carbonate mounds (C) may be equivalent to carbonate unit 2 at Kap Ammen (cf. fig. 25). The lower light coloured unit of the biostromal complex (PH) is correlated with the Petermann Halvø Formation of Hurst (1980). Aerial photograph, above, 545G–NØ, 11523, copyright Geodetic Institute.

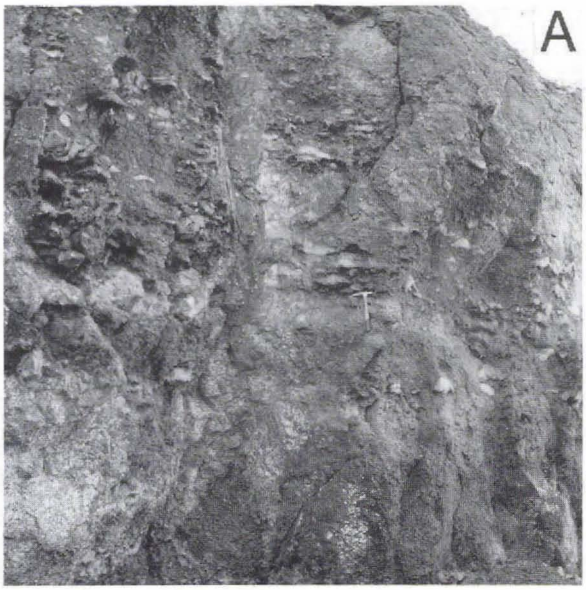
The complex is of unknown but undoubtedly substantial thickness; at least 500 m, possibly more than 800 m.

Undifferentiated biostromal limestone. This map unit comprises a thick sequence of dark and light weathering biostromal limestones with thinner intervals of calc-mudstones and calc-siltites; in steep, well-exposed cliffs the succession typically displays a banded character. Pale, rather massive limestones and dolomites (Petermann Halvø Formation of Hurst, 1980) occur in the basal part (fig. 32).

A wide variety of limestone lithologies make up the succession which essentially represents an intricate association of various facies in which lateral changes are common. A dominant lithology is a biostromal stromatoporoid (and coral) constructed limestone with a calc-arenite and often crinoid and coral-rich matrix (fig. 33). This limestone grades into intraformational conglomerates and breccio-conglomerates composed essentially of pebbles and cobbles of shells and calc-arenites. These lithologies can be interbedded with dark and light, variously mottled calc-arenites in which shell fragments may be rare or common, as well as some intervals of crinoid-rich limestones.

Bioherms have been located at several intervals in the Offley Ø – Kap Tyson area. These have the form of patch reefs and small mounds up to a few metres thick, and have shallow depositional dips. These buildups are conspicuous in cliff sections where they cause irregularities and breaks in the banding of the biostromal limestones (figs 34 & 38A). Norford (1972) illustrates such bioherms with shallow domal dips from the summit of Offley Ø.

Stratigraphic sections through the uppermost part of the biostromal complex at Kap Tyson and Offley Ø are given in figs 35 and 36, and located and illustrated in figs 37 and 38A.



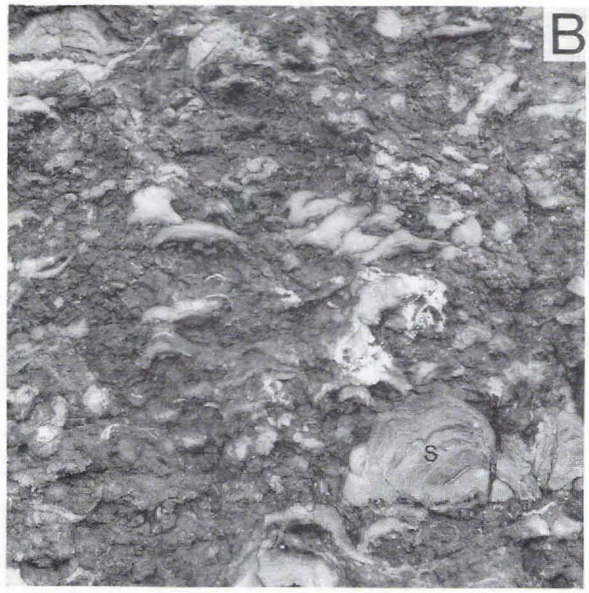


Fig. 33. Stromatoporoid and coral skeletal limestone of the biostromal complex. In detail view (B) the large stromatoporoid (S) is about 20 cm high. South-west Hall Land, near Inland Ice.

Biostratigraphic details can be found in Norford (1972), Hurst (1980) and Dawes & Peel (1984); references to descriptions of the rich diverse faunas are given above.

Dark biostromal limestone at Kap Tyson. This map unit comprises a sequence of dark, banded limestones about 200 m thick that forms the base of the coastal cliffs around Kap Tyson (fig. 38A). A thin but prominent dark grey limestone bed forms the uppermost stratum of the unit and this can be traced for some distance south-east of Kap Tyson. The main lithologies are rather massive, variously mottled and veined, porous limestones with some breccias (fig. 39).

This map unit contains fewer biohermal developments and a higher proportion of calc-siltite and calc-mudstone than the overlying biostromal strata; Norford (1972) notes a gradation within the unit into thin-bedded dark argillaceous limestones of 'Cape Schuchert lithology'.

'Gråstenelv' map units. Around and east of the headwaters of 'Gråstenelv', five units have been recognised; one unit has been mapped for more than 40 km in an east–west direction. The strata have not been examined in the field and differentiation of the sequence is solely based on colour and gross morphological character as seen on aerial photographs.

Units have been differentiated on the nature of bedding that varies from rather massive and thick-bedded, and in which some irregularites are interpreted as carbonate buildups, to thin-bedded, often darker, lithologies interpreted as finer grained lithologies – platy limestone and shales.

The strata form a conformable sequence which, from the

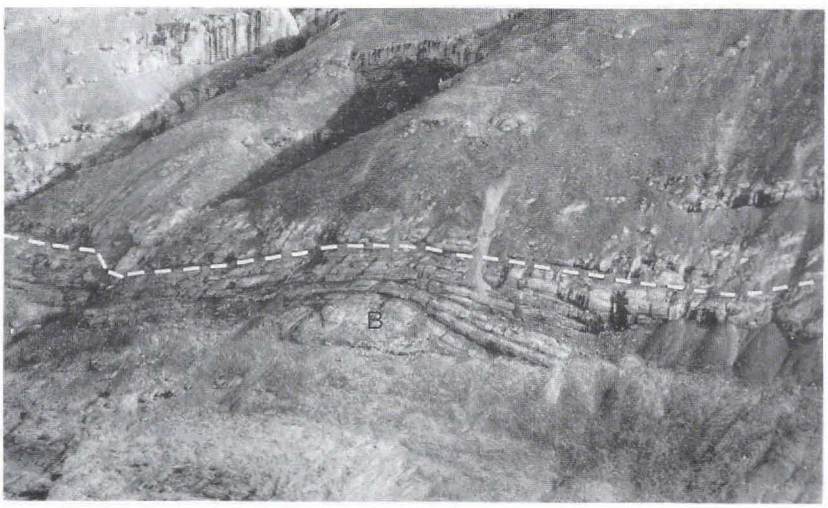


Fig. 34. Bioherm (B) about 15 m thick in the upper part of the biostromal limestone complex; Kap Tyson reef complex above. North side of Kap Tyson.

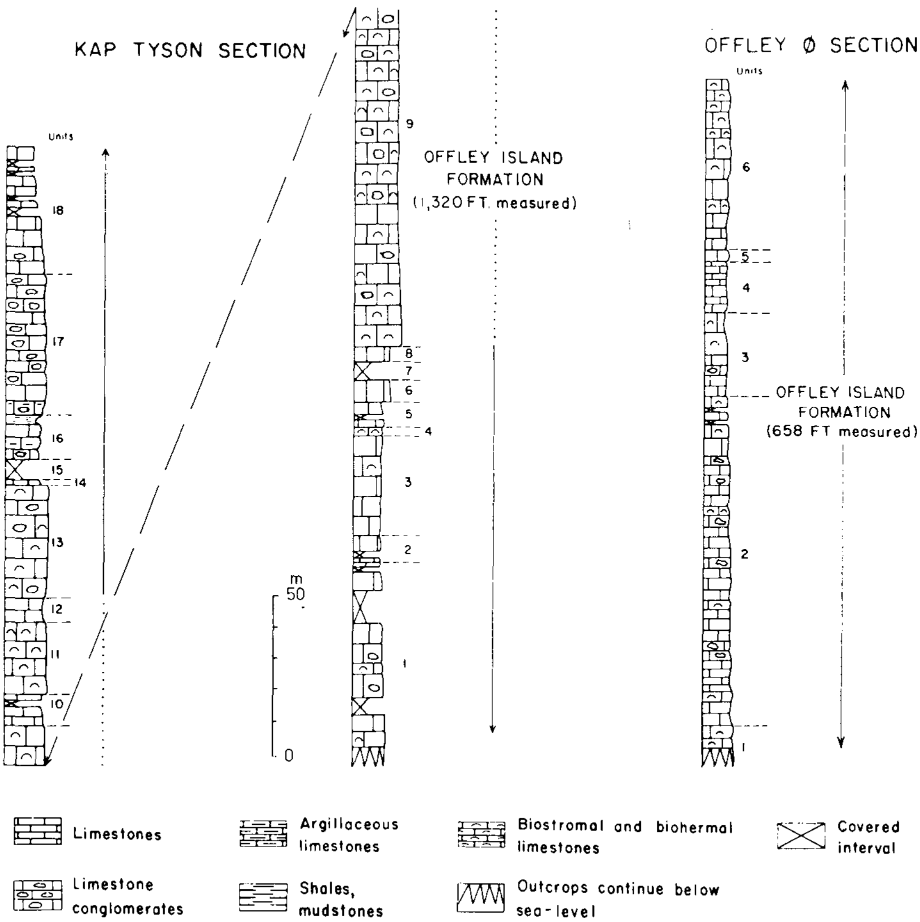


Fig. 35. Stratigraphic sections from Kap Tyson and Offley Ø from Norford (1972). Location of former section is shown on fig. 38A; the Offley Ø section is from the south-western tip of the island to the summit. Offley Ø and beds 1–13 at Kap Tyson represent the uppermost part of the biostromal limestone complex of the present map; beds 14–18 form the lowermost strata of the Kap Tyson reef complex.

basal dark limestones exposed in the valley east of the north-east glacial lobe of the Inland Ice to the uppermost dark unit (thin-bedded limestone and shale), is at least 500 m thick. In several places a dotted symbol has been used on the map sheet to denote prominent light-coloured, massive outcrops interpreted as carbonate buildups. On the broad, gently domed hill at the Newman Bugt coast, steeper than normal dips and convergence of bedding traces suggest the presence of a large reef.

Age and correlation. The biostromal limestone complex is part of the Washington Land Group of Hurst (1980), although the lowest part of the succession in the east may reach down into the Morris Bugt Group (see section 3). Based on faunas from the Offley Ø – Kap Tyson area and on corresponding strata in Nyeboe Land, the complex is of Early Silurian (Middle(?) – Late Llandovery) age.

The main part of the succession – perhaps a thickness of 500 m – correlates with the redefined Offley Island Formation, but the sequence extends down into the Bessels Fjord and Petermann Halvø Formations recognised in Petermann Fjord (fig. 32). Thus, based on the age of these formations in Washington Land, the complex most probably contains strata as old as Middle Llandovery.

Units containing carbonate buildups in the lower part of the succession may be correlations of the Bessels Fjord and/or Pentamerus Bjerge – Adams Bjerge Formations, and units of the 'Gråstenelv' succession may correlate with other map units of Washington Land – for example, the uppermost, dark thin-bedded unit resembles in gross appearance the Kap Lucie Marie Formation which in eastern Washington Land overlies the Offley Island Formation (Hurst, 1980).

Outcrops at the base of the dark biostromal limestone map unit at Kap Tyson were referred by Norford (1972) to the Cape Schuchert Formation by comparison with strata in the type section at Kap Schuchert in Washington Land. This was not upheld by Hurst (1980) who referred all strata in the lower cliffs at Kap Tyson to the Offley Island Formation. However, some significance is

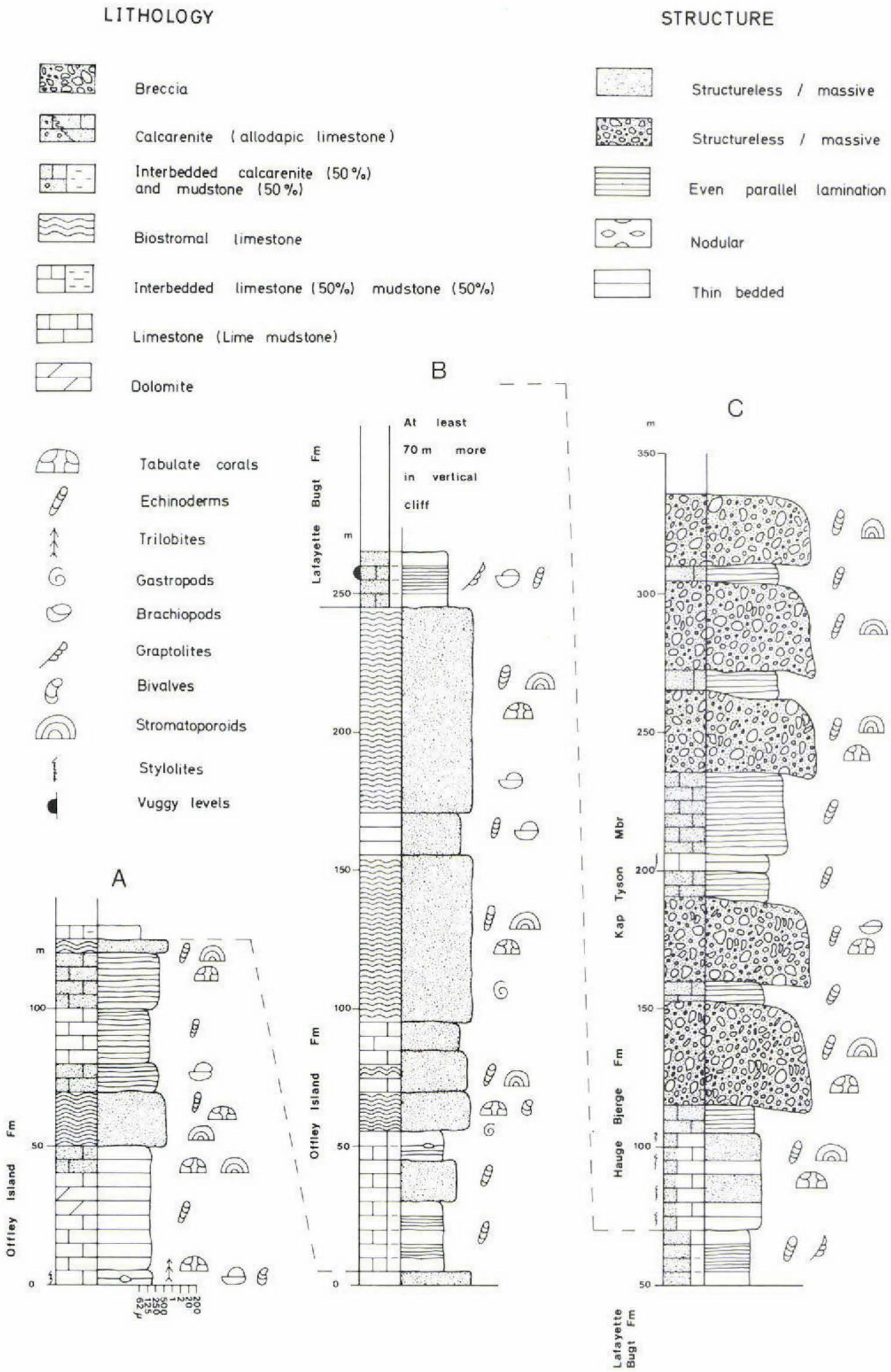


Fig. 36. Sedimentary log from Kap Tyson with original annotations from Hurst (1980). Biostromal limestone complex of present map = Offley Island Formation; Kap Tyson reef complex = Hauge Bjerge Formation; shale facies = Lafayette Bugt Formation. Locations of the three sections are shown in figs 37 & 38A.

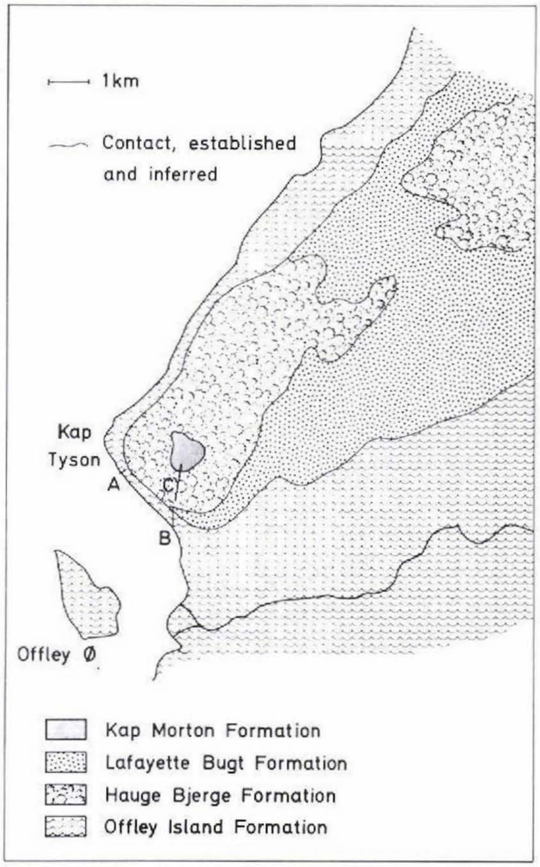


Fig. 37. Geological sketch map of the Kap Tyson area from Hurst (1980) showing locations of sections given in fig. 36.

placed on the presence of such dark argillaceous limestones in the complex ('Cape Schuchert lithologies' – fig. 24).

Kap Tyson reef complex

This complex forms a roughly linear belt of mountains – Hauge Bjerge – that cross the map from Kap Tyson in the west to summit 378 m in the east (units 6C–D, 8A–C, 10B on fig. 23). The complex occurs on islands in Newman Bugt and reefs also form mountainous terrain in Nyeboe Land (figs 38B & 40).

The complex represents a Silurian barrier reef in which several north–south narrow channels (now valleys) divide the complex into isolated masses. Several 'isolated' reef outcrops are present on either side of the main barrier; those up to 5 km beyond the reef front have been mapped photogrammetrically. The reef strata are characterised by much steeper bedding dips than the regional inclination of the platform, by typically southern dips and by variable strike directions.

The complex comprises a wide variety of limestones representing both core and flank deposits. These form a complicated facies association in which interdigitation of lithologies and lateral facies transitions are common. Reefs characteristically thin southwards and facies gradation and intertongueing relationships occur with off-reefal shales (figs 38, 41B & 42). The total thickness of strata in the complex is uncertain; it is difficult to estimate accurately on account of the complicated disposition of bedding. The thickest sequence occurs in the east, where a composite section reaches 800 m (fig. 23, section 6).

Four units are recognised, although on the map much of the complex has been depicted as one unit – undifferentiated biohermal limestone and conglomerate.

Undifferentiated biohermal limestone and conglomerate. This unit covers a wide range of strata from thick massive core deposits in which bedding is generally weakly developed, to flank deposits characterised by well-bedded, in places laminated, limestones with conglomerates that in places form relatively thin resistant beds within the flanking off-reefal shales (fig. 40). Small carbonate buildups and reef talus derived from the core form irregularities in the otherwise regularly bedded flank strata.

Core deposits have stromatoporoids and corals as the main construction elements. Skeletal limestones dominate and these grade into conglomerates containing pebbles and cobbles of calc-arenite and diverse shells set in a calc-arenite, often sparry calcite, matrix. These lithologies are interbedded with calc-arenites, which can be rich in corals, brachiopods and crinoids, and calc-mudstone.

The huge reef structure forming Kap Tyson, in which the inclination of core and flank deposits is more or less congruous with topography, has been mentioned in several publications (Norford, 1972; Hurst, 1980) (figs 35 & 36). Other major bioherms are well-exposed, particularly on the steep sides of the valleys that cut through the mountains; in some the interdigitation relationship to off-reefal shale facies is well seen (fig. 41B). However, not all summits of Hauge Bjerge represent individual bioherms, and thick, well-bedded biostromal strata also form an important part of the complex.

Breccio-conglomerate. A large proportion of the complex is composed of calcirudites – conglomerates and breccias – that show a varying relationship to the associated reef deposits. Calcirudites vary from intraformational bioclastic strata interbedded with other lithologies of the core and flank sequences to discrete olistostrome beds composed of chaotic clast-supported conglomerate in which blocks commonly reach several metres across. Far-travelled reef debris can be in the form of large isolated angular blocks up to many metres across, which are exotic with respect to the calc-arenite and calc-mudstone off-reefal strata (fig. 42).

Based on sporadic field data, several breccio-conglomerate ocurrences are indicated on the map – in reality calcirudites are present throughout the complex.

Mixed facies. The reef complex is characterised by major facies changes. The section through the reef at Kap Tyson (fig. 38A) illustrates a transitional relationship both in lithology and thickness between core, flank and off-reefal deposits. The problem of consistent map representation of these facies has been discussed earlier.

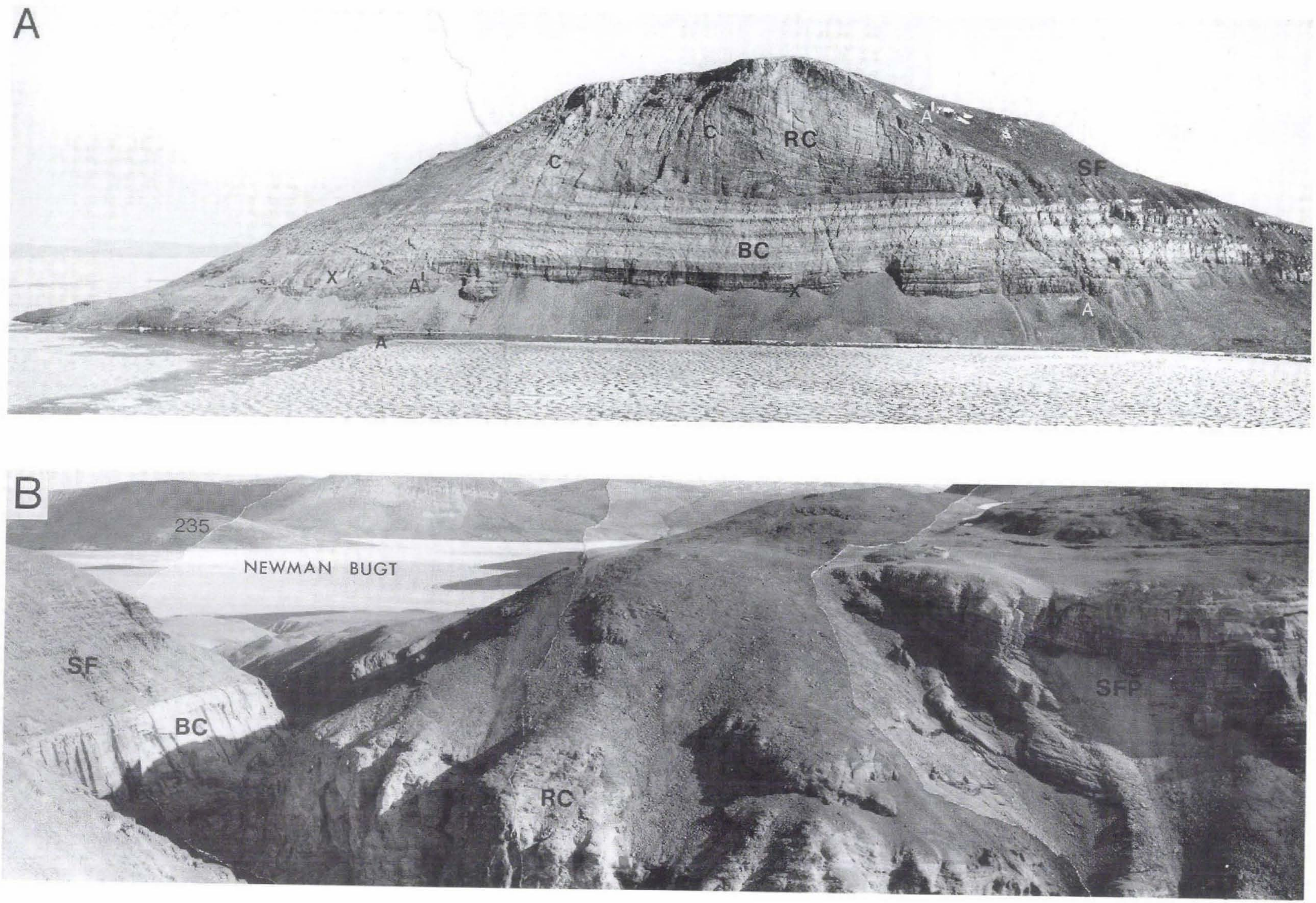

A
C
C
RC
A'
SF
BC
X
A'
X
A
A
B
235
NEWMAN BUGT
SF
BC
RC
SFP

Fig. 39. Pale weakly mottled limestone overlain by dark mottled and brecciated limestone; such interbedding produces the banding in the biostromal complex. Gorge east of Offley Ø.

Transitions can be rapid or gradational and in some cases the passage from core to off-reefal facies takes place over more than 1 km. The mixed facies designated on the map covers prominent areas in the reef flank environment that are essentially transitional to off-reefal shales. Where examined in the field at 'Sun Mark Mountain' (fig. 1) the facies is composed of limestone and conglomerate interbedded with light weathering platy limestone and calcareous shales, with occasional darker argillaceous shales.

Well-bedded limestone with calc-mudstone. Several areas have been differentiated as being composed of rather well-bedded limestones, mainly calc-arenites, but also with beds of calc-mudstone. One such area at 'Sun Mark Mountain' is composed of a sequence of regularly bedded biostromal limestones and conglomerates (with some biohermal developments) that in the upper part contains dark, thinner bedded calc-mudstones (fig. 23 – section 8, fig. 43). The well-bedded nature of these strata, represented on the map by the conspicuous and concordant bedding traces, contrasts with the rather massive, weakly structured biohermal limestones.

Fig. 38. Facies relationships in Hauge Bjerge between the main map groups of the platform succession: biostromal limestone complex (BC), Kap Tyson reef complex (RC) and off-reefal shale facies (SF). A: Kap Tyson seen from Offley Ø, summit of the cape about 730 m above sea level. Banded sequence of biostromal limestones (BC) in which irregularities are due to biohermal developments (X), overlain by the huge Kap Tyson reef in which two reef cores are visible (C). Note steep southerly depositional dips and the major facies change into the thinner sequence of platy limestones and shale (SF). A–A[1] delimit the sites of sections shown in figs 35 & 36. B: River section on north-eastern flank of Kayser Bjerg – height of section about 100 m. Off-reefal shales (SF) and platy limestones (SFP) overlap and grade into biohermal (RC) and biostromal (BC) limestones. The reef complex is visible on island 235 m in Newman Bugt and in coastal Nyeboe Land (see fig. 40 for location).

Age and correlation. The Kap Tyson reef complex is part of the Washington Land Group of Hurst (1980). Based on faunas from Kap Tyson, 'Sun Mark Mountain' and Kayser Bjerg, the complex is known to contain strata of Early to Late Silurian (Middle(?) – Late Llandovery to Ludlow) age (Dawes & Peel, 1984; Lane, 1984). The presence of Ludlow strata in the complex is particularly interesting; no limestone stratum as young as this occurs in Washington Land to the west or Peary Land to the east (Hurst, 1980, 1984).

The major bioherm at Kap Tyson represents the type section of the Hauge Bjerge Formation of Hurst (1980) and of the Kap Tyson Member. Other biohermal developments can undoubtedly be referred to that formation. The Kap Tyson reef is divided into a number of isolated reef masses surrounded by off-reefal shales (Peary Land Group – see below, fig. 13). If, to achieve stratigraphic consistency, the practice of Hurst (1980, p. 69) regarding the naming of spatially separate reefs is maintained, there would be a case for referring individual reef masses to members of the Hauge Bjerge Formation or even to new formations. However, in view of the vast area of Silurian reefs in northern Greenland and their known complex facies associations, this is hardly practical. How far correlation can be achieved with formations established in Washington Land without introduction of new nomenclature must await renewed field assessment.

In eastern Hauge Bjerge there appear to be two main levels of carbonate buildups (fig. 23, section 6) and some reefs may represent lower stratal levels than the Kap Tyson Member at Kap Tyson. Hurst (1980) refers an outcrop of mudstone at Kap Tyson (previously referred by Norford (1972) to the Cape Phillips Formation) to the Kap Morton Formation (fig. 37) and it is probable that other areas of calc-mudstone, e.g. at 'Sun Mark Mountain' and Kayser Bjerg, are referable to this formation.

Shale facies

This map unit forms an extensive, east–west belt on the northern and southern flanks of Hauge Bjerge and also within the mountain chain (units 6B, 7, 9 & 11 on fig. 23). The strata generally form low-lying, smooth terrain, and many valleys through Hauge Bjerge, etched out of shales, represent the former deep-water passes of the barrier reef. Over the larger part of the map the upper surface of the shale facies is the present erosion surface. However, in detail, outcrop patterns in contact with the Kap Tyson reef complex and underlying biostromal limestones are complex and facies gra-

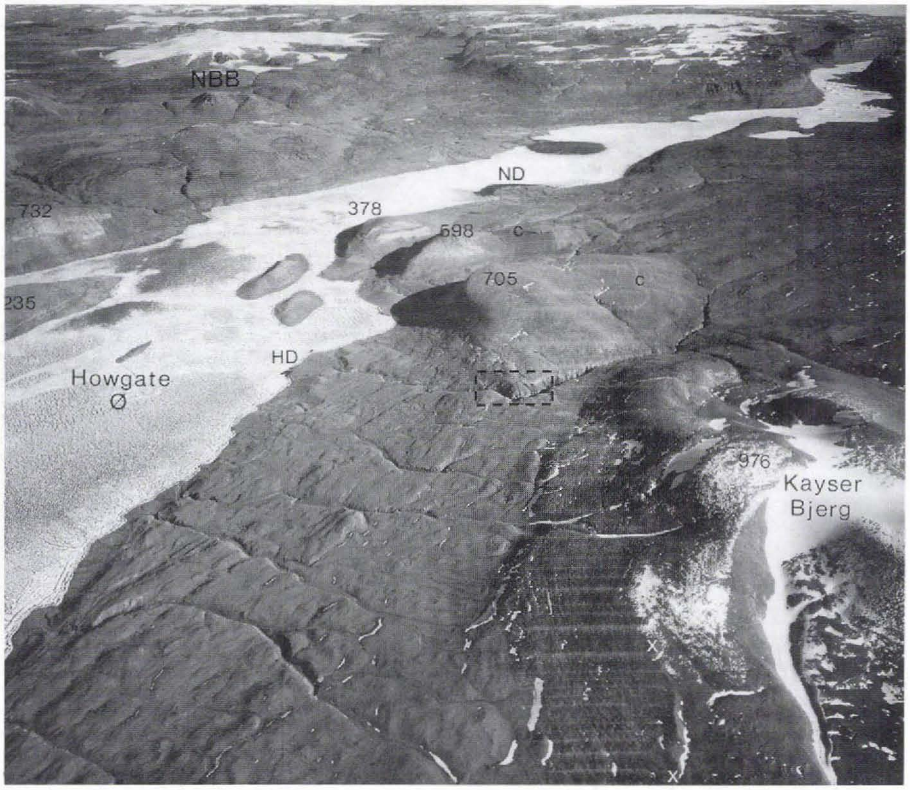


Fig. 40. Eastern Hauge Bjerge and Newman Bugt showing Kap Tyson reef complex and its continuation into Nyeboe Land. Summits are composed of individual reefs displaying steep sedimentary dips; off-reefal shales contain resistant limestone and breccio-conglomerate, well seen in back reef outcrops (c). Detail of summits 378 and 598 shown in fig. 41; frame marks locality of fig. 38B. X–X on the northern flank of Kayser Bjerg denotes a high elevation moraine ridge of uncertain origin. Summit heights in metres; 732 m is taken from AMS (1953) (see fig. 5C); the rest are spot heights from present map. NBB = Nina Bang Bjerg, HD = Howgate delta, ND = Newman delta. Aerial photograph 546E–Ø, 11547, copyright Geodetic Institute.

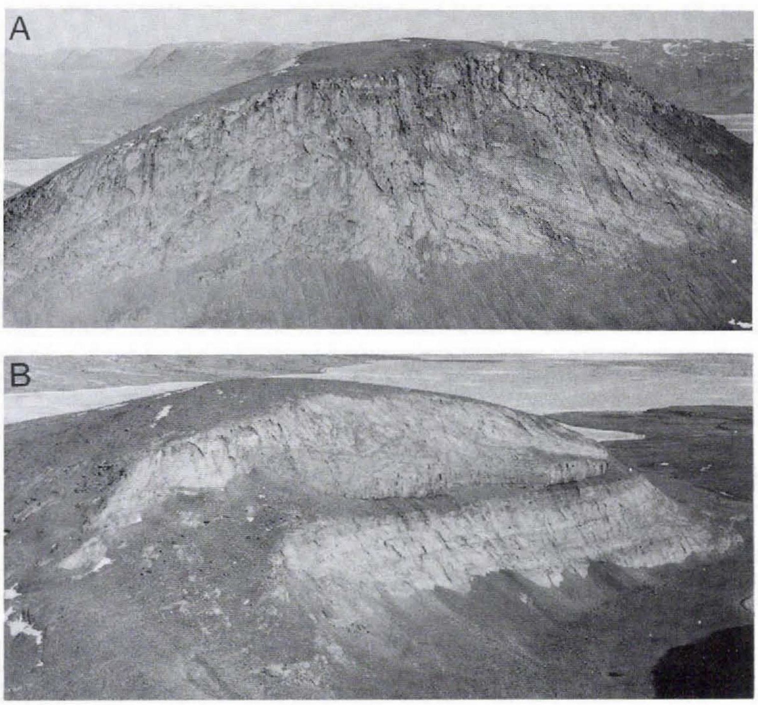


Fig. 41. Major bioherms in eastern Hauge Bjerge. A: Mountain 598 m showing steep opposing dips off central reef core; height of core above talus to summit is about 250 m; B: Mountain 378 m showing southerly dips and interdigitating shale unit separating reef (about 150 m thick) from underlying biostromal limestones. For location see fig. 40.

Fig. 42. Interdigitation of massive limestones and conglomerates (L) of the Kap Tyson reef complex with platy limestones and shales (S) of the shale facies. Some of these carbonate masses may represent exotic blocks. Cliff is about 150 m high, 'Sun Mark Mountain'.

dations and interdigitation are common (figs 38, 41 & 44).

Shales also occur as outliers on the biostromal complex over 10 km south of the Kap Tyson reef; more southerly outcrops in two valleys immediately north of the Inland Ice have been identified solely on aerial photographs. Some doubt is placed on these identifications; the slumped, somewhat structureless material may represent moraine (see fig. 1).

The map unit is composed of a variable sequence that changes in character with distance from the Kap Tyson reef. The dominant lithology is argillaceous shale, often graptolitic, with important calc-mudstone intervals and minor, thin units of limestone conglomerate, calc-siltite and fine calc-arenite (fig. 45). Silicified and rather bituminous mudstones occur. Near the main reefs platy limestones with resedimented limestone breccias and conglomerates are common (fig. 46); more distant exposures are dominantly dark-weathering graptolitic shales with, particularly in the north, important units of siltstones and fine-grained greywacke of the trough sequence. In some places, for example at Kayser Bjerg, small bioherms are developed; elsewhere the unit contains large, isolated limestone blocks that represent exotic material eroded off the surrounding reefs.

The one sub-unit recognised occurs adjacent to the Kap Tyson reef, where abundant limestones in the sequence produce a transitional facies to reef flank deposits (fig. 47). Many such outcrops were deliminated during the photogrammetric mapping in areas where boundaries between the reef and off-reefal map units were particularly difficult to define.

The shale facies has an unknown but substantial thickness; about 500 m is estimated for the eastern part of the area. South of Kap Tyson a little over 100 m of

Fig. 43. Well-bedded reef flank limestones with conglomerates and calc-mudstone of the Kap Tyson reef complex. Section, about 550 m thick, forms a shallow syncline in the western face of summit 910 m, 'Sun Mark Mountain'. Regional location seen in fig. 1.

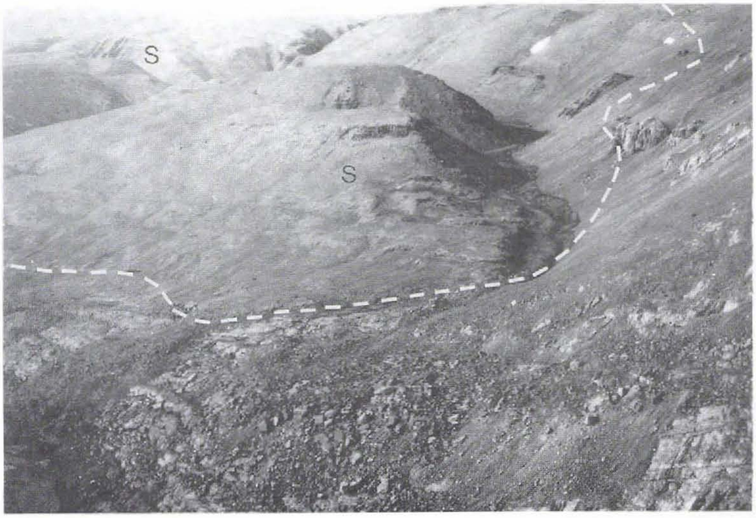


Fig. 44. Irregular, interfingering contact between shale facies (S) and biostromal limestone complex. In central outcrop shales are about 100 m thick. South side of central Hauge Bjerge.

off-reefal strata represents a stratigraphic equivalent of over 400 m of reef core deposits (fig. 38A).

Age and correlation. The shale facies can be referred to the Peary Land Group of Hurst (1980). Based on graptolites, conodonts and shelly faunas from Kap Tyson, 'Sun Mark Mountain' and Kayser Bjerg (Dawes & Peel, 1984), the map unit is known to contain strata from Early to Late Silurian (late Llandovery to Ludlow) age – thus having a stratigraphic range equivalent to the Kap Tyson reef complex.

The majority of the sequence represents an off-reefal facies of the upper slope and slope–platform margin, and can be referred to the Lafayette Bugt Formation. However, certain lithologies resemble other units described by Hurst (1980) from Washington Land, i.e. Cape Schuchert and Kap Lucie Marie Formations. North of Hauge Bjerge the map unit includes clastics derived from the trough and correlations are suggested with the northern succession. Mudstone, shale and fine-grained greywacke resembling unit 5 (Chester Bjerg Formation of Hurst & Surlyk, 1982) occur, and the Wulff Land and Lauge Koch Land Formations might be recognised with detailed study.

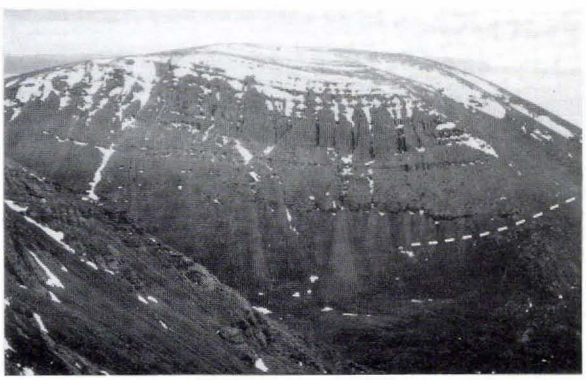


Fig. 45. Shales and calc-mudstones of the off-reefal shale facies (about 250 m thick) overlying biostromal limestone complex. Southern side of central Hauge Bjerge.

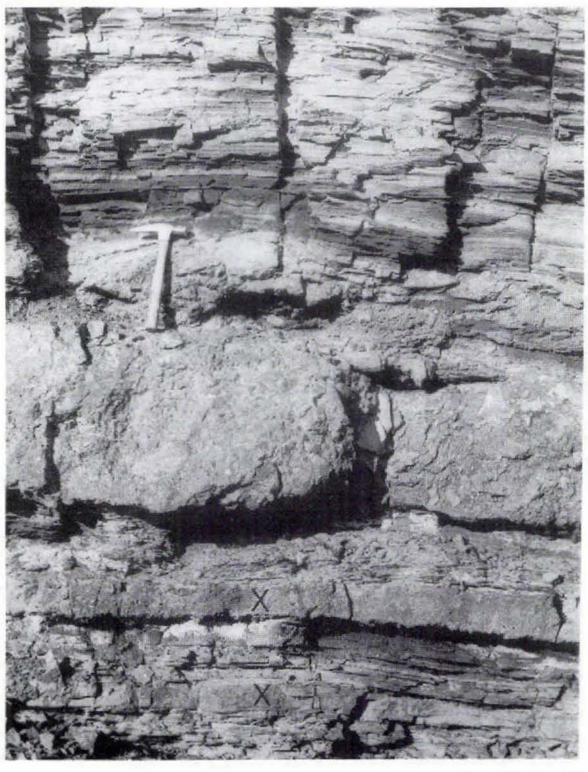


Fig. 46. Limestone breccio-conglomerate beds (X) within off-reefal shales. South-west 'Sun Mark Mountain'.

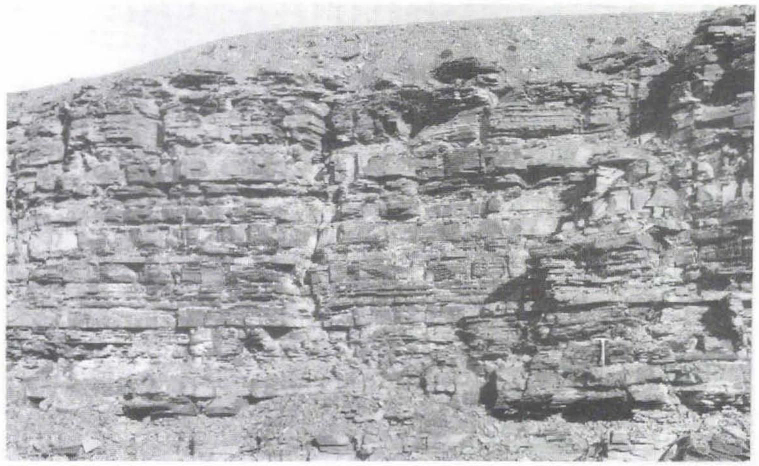


Fig. 47. Shales and platy limestones with tabular limestones and conglomerates – mapped as sub-unit of shale facies. Southern 'Sun Mark Mountain'.

Structure

Hall Land exposes the southern marginal zone of the North Greenland fold belt that is characterised by roughly east–west tectonic elements. Exposure in central Polaris Forland is poor and the actual passage from folded to unfolded strata is not well displayed. No large-scale faults have been detected at the margin and the fold belt is autochthonous with respect to the homoclinal platform. This structural pattern simulates that in adjacent Nyeboe Land where fjord-wall exposures illustrate the gradual incoming of structures towards the north.

Regional structure

The regional structure of Hall Land is an asymmetric synclinorium with a considerably steeper northern flank; the broad structure is controlled by the carbonate platform that is assumed to form a continuous substratum (fig. 48). Southerly dips in the upturned succession along the northern coast are up to 50°; the inclination of the homoclinal platform is shallow but with some steeper northern dips occurring in the clastic strata north of Hauge Bjerge. The folded clastic strata in the core of the synclinorium are characterised by small to medium amplitude, open folds that show a progressive increase in deformation intensity northwards. These folds do not radically disturb the regional disposition of rock units and their style suggests that there is a décollement above the platform carbonates. The lower two units of the clastic sequence are composed of argillaceous lithologies and the décollement horizon is presumably situated in this interval separating a warped competent platform from relatively tightly folded clastics above.

The carbonate and clastic strata show varying structural styles. The well-bedded clastic rocks have been deformed essentially by concentric folding with cleavage development; the underlying massive carbonates show evidence of brittle fracturing and faulting. A surmised thrust in the cliffs west of Kap Ammen (fig. 25, see below) may represent a surface expression of the décollement mentioned above.

The upturned strata along the northern coast are part of a linear belt of steeply dipping to vertical strata that can be traced from Robeson Channel for more than 200 km to the east, and which represent the southern limb of a huge structure – the Wulff Land anticline (Dawes, 1982). Larsen & Escher (1985) interpreted this linear belt in Nyeboe Land as representing the common limb of a major fold pair; the Nyeboe Land syncline to the south, the Wulff Land anticline to the north. The upturned strata form a tectonic zone that has a dominant SW–NE trend, more or less parallel to Robeson Channel; inland the regional trend of major structures is more easterly, about WSW–ENE. These two trends converge in north-western Polaris Forland and may indicate a major fold closure in the area south of Kap Porter or a structural discordance controlled at depth – possibly by the early Palaeozoic platform margin (Dawes, 1982; Hurst & Kerr, 1982).

Folds

Well-exposed ENE-trending folds in the mountains west of 'Saint Anthony's Nose' have an open, concen-

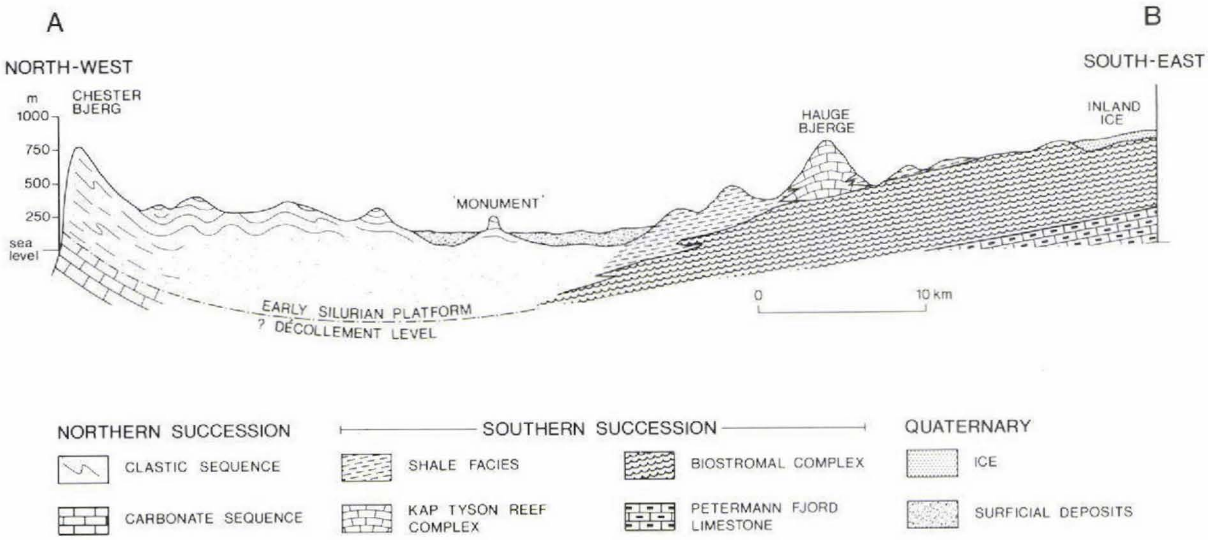


Fig. 48. Schematic cross-section of Hall Land to show structural relationship of northern and southern successions and inferred décollement level above carbonate platform. Line of section shown in fig. 13.

tric style with mainly rounded hinges and more or less upright axial planes (fig. 49). Variations to somewhat angular cuspate hinges and to chevron folds occur, and in the south folds are more open with generally larger wave-lengths. Small-scale folds are typically disharmonic (fig. 50).

Open folds compose much of the fold belt, but due to poor exposure, representation of fold distribution on the map is rather patchy. The folds have generally horizontal to shallow plunging axes with variations up to 25° to the east and west. Most of these folds are characterised by northern and southern limbs of moderate, more or less similar dips; asymmetrical folds tend to have steeper southern limbs in synforms and steeper northern limbs in antiforms (fig. 51); in the south the style of the folds is monoclinal.

In the upturned strata along the northern coast, northerly overturned to isoclinal folds occur in which limbs dip south parallel to the regional dip. These structures have small to moderate wave-lengths (up to 200 m) and they cause local stratal repetitions. The majority of measured folds have shallow eastwards plunging axes. Small-scale isoclinal folds have been noted as far south as Halls Grav. On balance the isoclinal folds appear to pre-date the main ENE open folds.

Zig-zag folds and kink bands occur (figs 52 & 53);

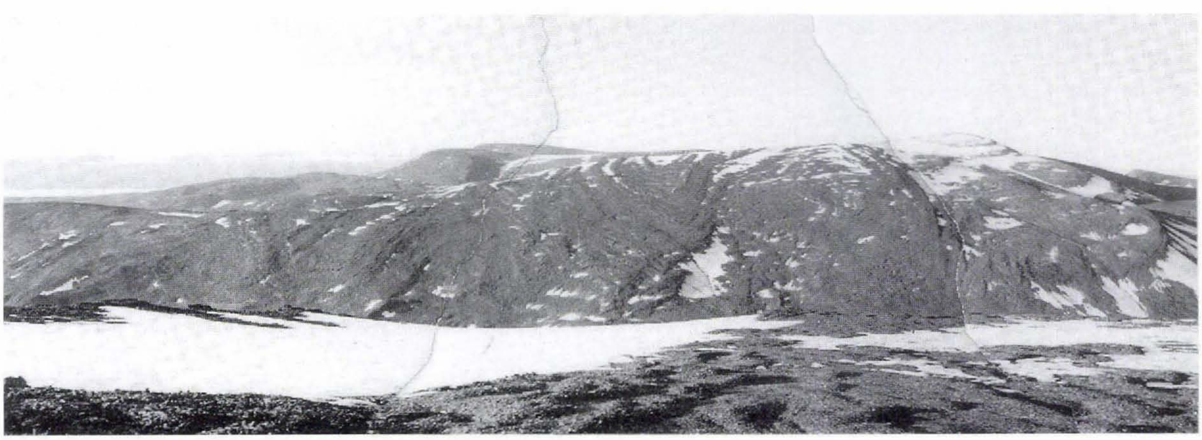


Fig. 49. Major ENE–WSW trending open folds in clastic sequence, mountains west of 'Saint Anthony's Nose'. View eastwards towards Nyeboe Land. Length of section along river valley is about 2 km.

Fig. 50. Small-scale disharmonic folds in thin-bedded sandstone-shale turbidites. Style varies from open to tight chevron folds (at X). South of 'Saint Anthony's Nose'.

Fig. 52. Small-scale zig-zag folds in ripple-marked calcareous siltstone. South-east of 'Saint Anthony's Nose'.

these appear to post-date the open folds, having developed on major fold limbs.

Faults and joints

Three categories of linear fractures are shown on the map; faults, joints and lineaments of uncertain origin. Two prominent fault directions are north–south (varying NNW to NNE), seen particularly in the platform, and east–west, a trend that is also followed by major joints. Most faults mapped are high-angle structures that seem to have involved only small displacements. Northerly-trending faults and joints are common throughout northernmost Greenland and such structures are late tectonic features. For example, Friderichsen & Bengaard (1985) describe from Peary Land a steep crenulation cleavage, trending 160° in places associated with folds and kinks, that they refer to the Eurekan (Cretaceous–Tertiary) deformation.

The contraction fault mentioned earlier in the Kap Ammen cliffs, surmised from photographs and aerial reconnaissance, appears to be a low-angle, southerly-dipping thrust that cuts the upper part of the carbonate succession (fig. 54). Location of the dislocation plane in the west within the massive reef carbonates is uncertain; if present to the east of Kap Ammen it must be essentially parallel to bedding.

Dislocations in the folded clastic strata in the sea-cliffs between Kap Lupton and Kap Porter and along the Newman Bugt coast, noted in 1965 from the air, could not be recognised on aerial photographs and they are not shown on the map. Likewise Allaart (1965)

Fig. 51. Slightly asymmetric open folds in thin-bedded sandstone-shale sequence. Coarse ENE trending fractures are axial planar surfaces. West of 'Saint Anthony's Nose'.

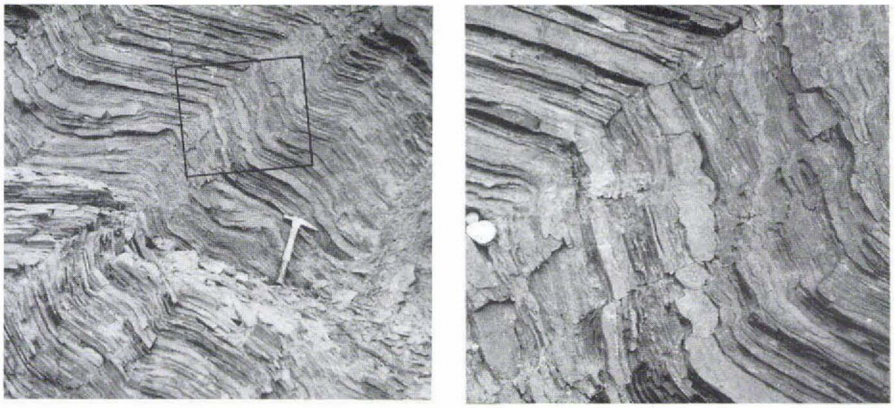


Fig. 53. Kink bands in fine-grained greywacke and shale. Detail shows fracture cleavage surfaces with small-scale displacements. North-west of 'Teltbakken'.

reported some thin mylonite zones with steep to moderate dips in the fold belt, also not shown on the map.

Small-scale dislocations are common on the limbs of folds. Jointing can be intense and in places outcrops show a characteristic breakdown into long prismatic fragments (fig. 55).

Cleavage and superimposed folding

Cleavage and brittle fracturing is developed in the upper clastic sequence of the fold belt, particularly towards the north. Cleavage can be closely spaced in fine-grained lithologies; more competent sandstone beds are uncleaved or only penetrated by irregular fissures (fig. 56).

Cleavage-fold relationships can be complex (Allaart, 1965). A main cleavage direction trending generally east-north-east is axial planar to the main open folds, but in places cleavage is superimposed incongruously across fold limbs. A later cleavage is also developed in connection with kink bands (fig. 53). Allaart (1965) reports that in some places cleavage is folded by open ENE-trending folds.

Cleavage-fold relationships, although not fully elucidated, indicate that the strata have been affected by several phases of deformation. At least two, possibly three, ages of folds exist, with the kink bands representing the youngest structures. In certain areas in the mountains west of 'Saint Anthony's Nose' superimposed folding was inferred during the photogrammetric interpretation; chaotic structural measurements suggest the interference of two co-axial fold phases.

Metamorphism

Strata of the fold belt show the effect of dynamic metamorphism – cleavage and fracturing – but in a regional metamorphic sense the rocks are non-metamorphic. The southern boundary of the regional tectonic-metamorphic zone characterised by the incoming of muscovite is drawn in northernmost Hall Land (Dawes & Peel, 1981). The cleavage development is seen petrographically in argillaceous lithologies as irregularly shaped, brown sinuous streaks along which secondary sericite has crystallised.

Some recrystallisation has occurred along crush zones

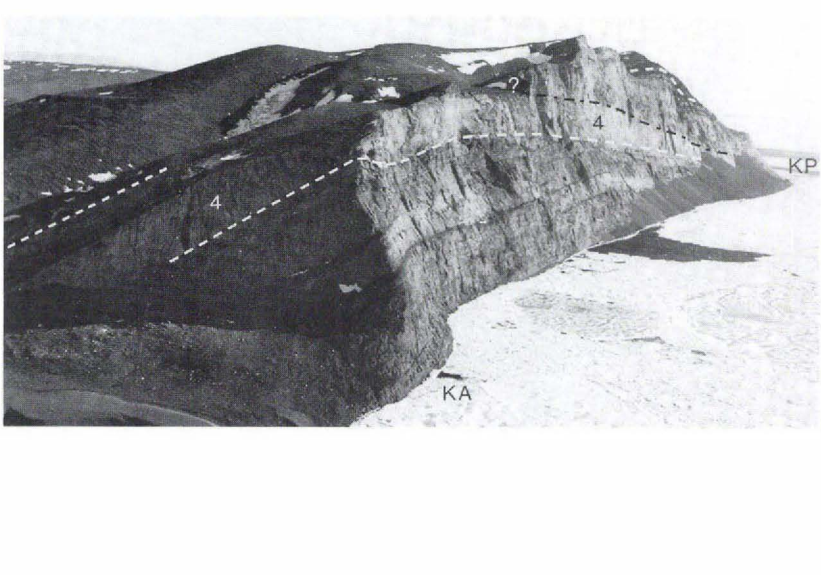


Fig. 54. Cliffs between Kap Ammen (KA) and Kap Porter (KP) showing location of supposed thrust (black dot–dash line). Lower and upper contacts of unit 4 are shown in white; thickening of unit is probably due to both carbonate buildup development and tectonism. Highest summit is 735 m high.

Fig. 55. Typical outcrop of jointed mudstone breaking down into prismatic fragments. Northern Polaris Forland.

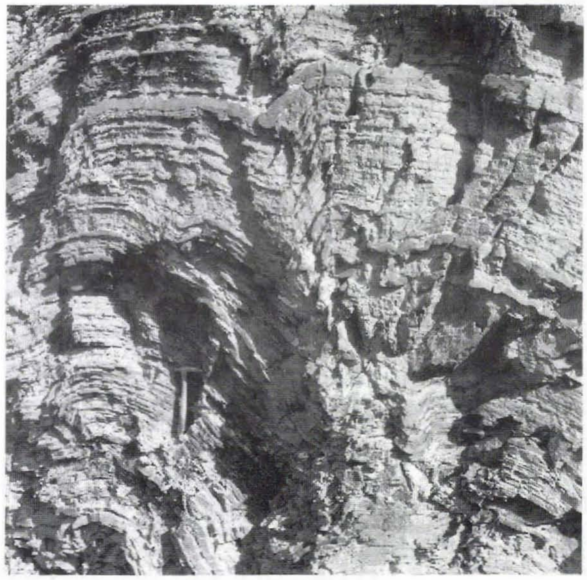


Fig. 56. Small-scale ENE-trending folds with axial plane cleavage, closely spaced in mudstone beds with coarser spacing in resistant sandstone beds. 'Saint Anthony's Nose'.

and thin steep mylonite zones, and locally quartz and carbonate form impersistent veins and tension joint infillings.

Age of deformation

The youngest geosynclinal strata in Hall Land are of latest Silurian (Pridoli) or earliest Devonian age (fig. 23, section 2). The main Palaeozoic deformation is assumed to have taken place in the Devonian, possibly extending into the Carboniferous. Sverdrup Basin deposits, unconformably overlying folded Lower Palaeozoic and Devonian rocks in Ellesmere Island, restrict the age of the late Palaeozoic (Ellesmerian) orogeny to this interval (Balkwill, 1978; Trettin & Balkwill, 1979; Kerr, 1981).

Faulted and weakly folded Tertiary rocks on the western side of Kennedy Channel have been affected by at least three deformational phases of the Cenozoic (Eurekan) orogeny (Mayr & de Vries, 1982). Faulted Tertiary outcrops south-west of Lincoln Bay (fig. 3) are only 25 km distant from Hall Land and it is assumed that Cenozoic deformation also affected Greenland (Haller & Kulp, 1962). In the absence of strata of Sverdrup Basin age the differentiation of late Palaeozoic and Cenozoic structures is problematical (Dawes, 1982; Higgins *et al.*, 1982).

Quaternary geology

Quaternary deposits form extensive outcrops in Hall Land totally concealing the Palaeozoic bedrock over large areas. The entire peninsula was formerly ice-covered and deposits of several ice-advances are preserved.

Six types of Quaternary deposits are recognised on the map: moraine, fluviatile-glaciofluvial, marine, lacustrine, colluvial and solifluction. Aeolian and periglacial features are represented by symbols. Quaternary deposits dominate the central lowland plain, some 500 km^2 in area, which is composed of several map units flanked on the west and east by prominent lateral moraine systems. Ground moraine, fluviatile and glaciofluvial deposits occur over the northern and southern highlands, while marine strata outcrop along the low-lying parts of Polaris Bugt and Newman Bugt. Raised delta terraces are developed at the mouths of major rivers, and important areas of alluvial deposits occur inland. Periglacial activation, seen in the form of a patterned ground and solifluction processes, is widespread.

Mapping principles and terminology

Explanation of the terminology used in the map legend is given in the descriptions of the map units that follow. Map units have been erected on the basis of 'mode of formation', rather than on lithological or compositional criteria, and without emphasis on age. Thus, apart from the separation of recent river detritus as 'alluvium' – with the reservation of the term 'fluviatile' to cover generally older river accumulation – no distinction is made between ages of a particular type of deposit. For example, ground moraine and ice-margin moraines have not been divided into 'older', 'younger' (i.e. last glaciation limit) or 'historic' categories.

There is appreciable overlap between some of the map units. As described earlier much of the mapping has been accomplished photogrammetrically – in many areas with very limited ground control. This, added to the fact that there exist natural transitions between several rock units, has led to arbitrary boundaries in many places. Hence, in areas where ice-laid accumulations have been reworked to varying degrees by glaciofluvial processes, recognition of deposits as moraine or outwash is difficult. A similar problem of definition applies in the case of colluvial, solifluction and alluvial deposits. The geological processes producing these deposits merge and it proved impossible to differentiate categorically between deposits produced by gravity, ground water or river action.

Glacial deposits and features

Hall Land is at present virtually ice-free. Erratics and moraines indicate that the land was formerly totally ice covered. Glacigene deposits, both moraines and meltwater accumulations, are widespread and form prominent parts of the surficial cover.

On the map sheets ice-laid deposits are divided into two main categories: undifferentiated moraine and ice-margin moraines. These map units also include some meltwater deposits, but prominent glaciofluvial outcrops have been mapped separately and are described in the section on river deposits. A third map unit, rubble, is recognised in highland areas.

Moraine, undifferentiated

This unit, comprising mainly ground moraine or glacial till (drift), forms the most extensive surficial strata on the map. The deposits are typically unsorted and non-stratified, varying from relatively fine-grained lithologies, boulder clay and silt, to deposits having a high percentage of cobbles and boulders. The deposits vary markedly in thickness from locality to locality.

On the highland regions glacial till forms a thick mantle draped over bedrock topography (figs 25 & 57). For the most part the till has a rather level to undulating surface that is affected by periglacial processes; in some areas broad, smooth ridges of low relief occur. In many valleys and on the lower slopes of hills the deposits are commonly several metres thick; some valley accumulations, although of irregular thickness, often reach 10 m or more. Above 400–500 m altitude, till is characteristically thinner and more scattered in distribution. At the highest altitudes, along the northern coast and in Hauge Bjerge, deposits have not sufficient thickness or consistency to be mapped, although erratic blocks occur.

The ground moraine map unit contains areas of glaciofluvial material. These deposits are poorly stratified but outcrops show evidence of water abrasion. Promi-

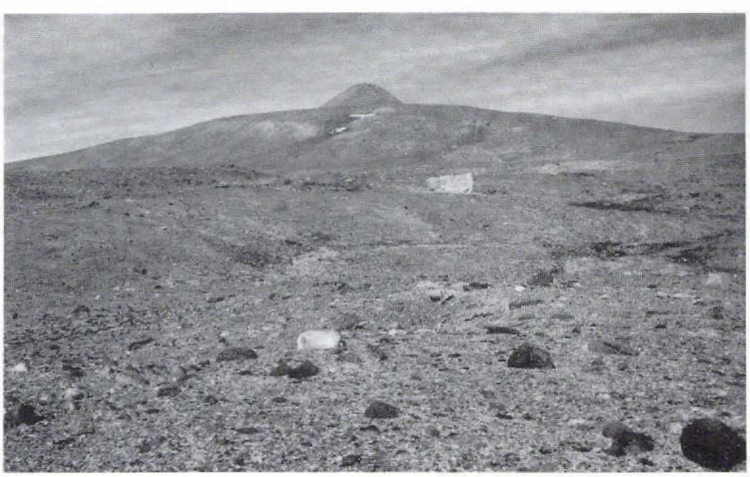


Fig. 57. Ground moraine mantle on northern highland plateau; poor bedrock exposures in background. Blocks are diverse limestones with some crystalline rocks; light limestone block in middle distance is about 3 m across.

Fig. 58. View northwards across the western part of lowland plain showing low moraine ridges separated by pale marine strata with fluviatile and outwash fan deposits in foreground. Scale: about 1 km across fan.

nent areas of such deposits occur, in association with drift, in the central part of the southern uplands between Hauge Bjerge and the Inland Ice (fig. 1).

Davies (1972) drew a distinction between the glacial cover north and south of the central plain; the northern highlands were designated an area of 'morainal ridges', the southern highlands were described as 'till-covered uplands'. This distinction is probably not so much due to original depositional character, but rather that the moraine on the southern uplands and plateau has been generally more severely reworked by glaciofluvial processes.

On the central lowland plain, south and west of 'Monument', ice-laid deposits display undulating topographic expression, mainly in the form of mounds and low rounded ridges (fig. 58), and the region is characterised by many dried-up lakes. The moraine forms a thick, continuous cover and, apart from in the north where the outcrops abut on bedrock, the substratum is not seen. Marine clay and silt overlie moraine in some areas, and in the north a series of prominent shore-lines are preserved. In the east and west the deposits grade into prominent marginal moraines; to the north and south there is a passage into thick fluviatile and meltwater fan deposits.

Much of the glacial till mapped on the lowland plain may represent hummocky ground moraine or ancient marginal moraines considerably modified by glaciofluvial, glaciomarine and glaciolacustrine processes.

Rubble

This map unit is used for small areas of bedrock debris that characteristically contain glacial erratic blocks. Rubble occurs in the northern coastal mountains and Hauge Bjerge where the surface is commonly composed of a thin veneer of loose, angular rock fragments that have been derived primarily by frost shattering of bedrock (fig. 16). This frost-derived debris can be mixed with varying amounts of glacial material, and on lower slopes there is a gradation into ground moraine.

Ice-margin moraines

Ice-margin (terminal and lateral) moraines are widespread forming prominent features of the landscape. Such deposits occur on all sides of the peninsula, viz. around the western, northern and eastern coasts, as well as on the central plain, over 20 km from the nearest coast (fig. 59). The major deposits are *old moraines* that are totally divorced from their ice source. *Recent* or *historic moraines* occur in association with the present Inland Ice margin.

A *heavy red line* is used on the map to denote the crest location of any linear morainic feature. The symbol covers a variety of structures: from well demarcated

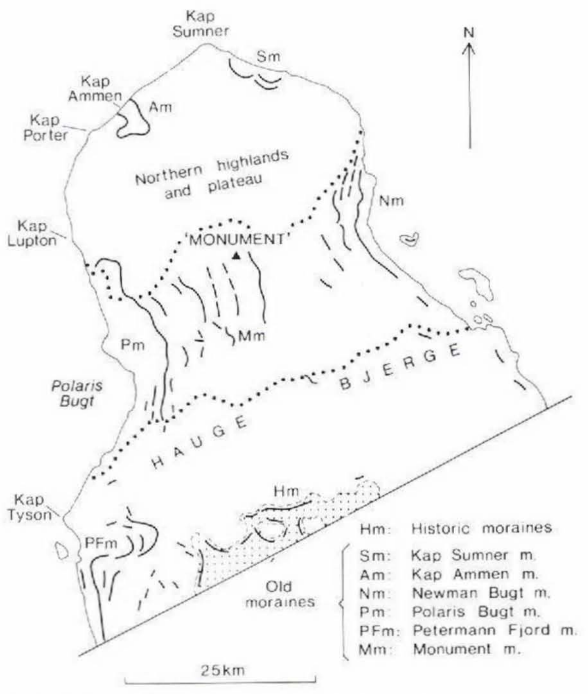


Fig. 59. Location of the main marginal moraine systems of Hall Land. Escarpments bordering the central lowland plain are shown by dotted lines; Inland Ice shown by dotted signature.

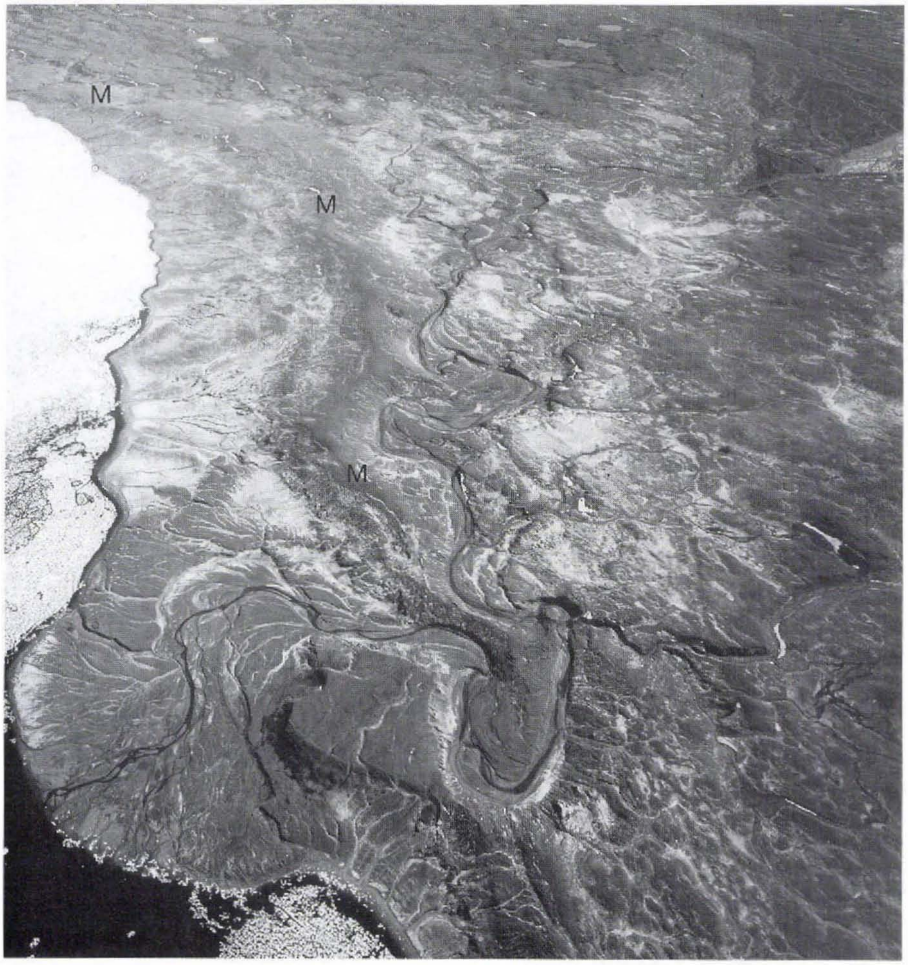


Fig. 60. View from north over 'Gråstenelv' delta showing Newman Bugt moraine system with master ridge (M) and smaller distal ridges, with associated marine silt and clay. Aerial photograph 546B–S, 11701, copyright Geodetic Institute.

but small and often isolated ridges which may have widths narrower than that depicted by the size of the red line, to major embankments and elongated mounds over 1 km in width.

The majority of the linear features are interpreted as ice-laid deposits marking former frontal positions of ice masses – for the most part valley glaciers. However, certain linear features may represent ice-contact deposits, e.g. kames or eskers formed by subglacial or englacial streams. One such area occurs about 6 km east of 'Monument', where a group of well-defined ridges form an irregular outcrop pattern. Individual ridges vary from over 100 m to 10–15 m wide. One ridge increases from 10 m to 50 m in width over a distance of about 1 km.

Old moraines

The six major occurrences mapped are here named after nearby geographical features: the Polaris Bugt, Newman Bugt, 'Monument', Kap Sumner, Kap Ammen and Petermann Fjord moraines (fig. 59). The three first-named moraines have been discussed in the early literature (e.g. Koch, 1928a,b; Davies *et al.*, 1959; Weidick, 1971); the others were mapped during the present work.

Polaris Bugt and Newman Bugt moraines. These are discussed together; they have the aspect of mirror image moraines flanking opposite sides of the central plain. Both can be traced for about 25 km and they constitute prominent morphological features forming 'highland' barriers enclosing the flat central part of the plain (figs 19 & 60). Both are composed of several ridges and mounds forming arcuate moraine systems sub-parallel to the respective coasts. Each system is dominated by a master ridge, very much larger and more continuous than associated ridges.

The master ridges are similar in morphology, size and structure. They are characterised by fairly smooth, subrounded crests and shallow sides; spot heights on the

Fig. 61. Northern part of Polaris Bugt moraine system showing master ridge and a distal ridge (X–X) with marine silts overlying ridge flanks. Summit of master ridge is about 75 m above Atka Elv.

map indicate that the highest parts of the crests are comparable at 126 m and 130 m a.s.l., respectively. Both have a length of about 15 km and are about 1.5 km across in their widest part.

The *Polaris Bugt moraine system* has a maximum width of about 5 km. In its central part it is formed solely by the master ridge which is flanked by extensive outcrops of marine and glaciofluvial sediments (figs 19 & 61). The system can be traced from Hauge Bjerge where small isolated ridges abut on the mountain flanks, across the plain as a broad embankment and onto the northern highlands. The master ridge abuts at about 125 m altitude against the northern scarp and continues as a narrow ridge for 8 km across the highlands reaching about 300 m a.s.l. (fig. 59). In its northernmost extent, the moraine has an arcuate form closing to the north, and it is shown on the map as terminating on Observatory Bluff. This distribution of the Polaris Bugt moraine is at variance with the conclusion of England (1985) who stresses that the moraine is confined to the central lowland plain rising only to a little over 100 m a.s.l. (for discussion, see Quaternary history section later). No morainic ridges have been identified along the cliffs towards Kap Lupton (as suggested by Weidick, 1971), although this area has not been investigated in the field.

The *Newman Bugt moraine system* has a maximum width of nearly 10 km and is bordered on the west by 'Gråstenelv'. On its distal side is a broad area of irregular and undulating topography composed of morainic mounds and discontinuous ridges (figs 20 & 60). These inland moraines are associated with an extensive area of outwash, and outcrops show evidence of water abrasion and modification by glaciofluvial processes.

In the south the moraine peters out some 5 km from Kayser Bjerg as small isolated low ridges and elongated outcrops; in this area the moraine is cut by several rivers flowing into Newman Bugt which expose bedrock. The master ridge can be traced northwards as a broad embankment for about 15 km, as far as 'Gråstenelv', where it is overlain by fluviatile terraces. To the north the ridge is markedly narrower and less pronounced. To the west and north-west the moraine has the form of a belt of small, rather discontinuous ridges associated with marine and glaciofluvial sediments and a broad area of undulating moraine. These ridges abut against and form a sub-parallel border to the southern escarpment of the northern highlands.

The termination of the Newman Bugt moraine along the northern highlands essentially closing off the eastern side of the central lowland plain, is at variance with the work of England (1985) who terminates the moraine at the 'Gråstenelv' about 3 km from the southern escarpment. This has important implications for the deglaciation and marine history of the region (for discussion, see sections on marine deposits and features, and Quaternary history).

The Polaris Bugt and Newman Bugt moraines show a lithological range comparable to that displayed by the 'moraine, undifferentiated' map unit. Where examined by the writer, in the area of Atka Elv and 'Gråstenelv' valleys, the moraine is characterised by an abundance of coarse blocks – pebble to boulder size and of varying composition – set in a varying sand–silt–clay admixture. Clays and silts are intimately associated and many sections show mixing of morainic material with fossiliferous silts of marine or glaciomarine origin. The moraines are overlain, both on the seaward and inland sides, by silt and clay and also by fluvial and outwash deposits, and both moraines show the effects of modification by glaciomarine and glaciofluvial processes. The reader is referred to England (1985) for stratigraphic detail.

As originally suggested by Koch (1928a, b; fig. 7) the two moraine systems represent terminal moraines to major glaciers that formerly occupied the Petermann Fjord – Hall Basin and Newman Bugt depressions. Corresponding moraines depicting the eastern termination of the Newman Bugt glacier are present in Nyeboe Land, and moraine on Reynolds Ø is interpreted as an end moraine to a more southerly glacier position (W. E. Davies, personal communication, 1980). In view of the height of the marine limit (at about 125 m, see below) and association with marine deposits, the moraines are regarded as having been deposited – at least in part – in submarine conditions (England, 1985; Kelly & Bennike, 1985). However, parts of the moraines, for example the high altitude northern section of the Polaris Bugt moraine, were deposited subaerially. The two moraine systems display evidence of water abrasion, and marine shells have been collected on both master ridges (England, 1985; O. Bennike, personal communication, 1984).

'Monument' moraines. The 'Monument' moraines, as defined here, refer to all ice-margin deposits in the central plain distal to the Polaris Bugt and Newman Bugt moraines (fig. 59). They form part of the 'modified morainal ridge' terrain of Davies (1972). Although subparallel to the Polaris – Newman Bugt systems, the 'Monument' moraines are considered separately on account of contrasting morphology.

The map displays four north–south trending morainic outcrops separated by mainly marine deposits. Only the outer two have been mapped as ice-margin moraines. The inner two, south and south-west of 'Monument', are of much less pronounced topography; they may represent ice-margin moraines of the same system, or remnants of an extensive hummocky ground moraine mantle.

The two outer outcrops are low relief, sinuous ridges standing 10–20 m above the general level of the plain (fig. 62). The eastern ridge is the most pronounced – its summit reaches above 120 m a.s.l. Both ridges have smooth, rounded surfaces and are composed of cobbles and pebbles of varying composition set in a sand–silt matrix. The poorly sorted material of the eastern ridge grades into the glaciofluvial sands and gravels of the 'Gråstenelv' outwash plain. Marine silts overlie parts of both ridges and raised shorelines up to 116 m in altitude are preserved on their flanks and upper surfaces.

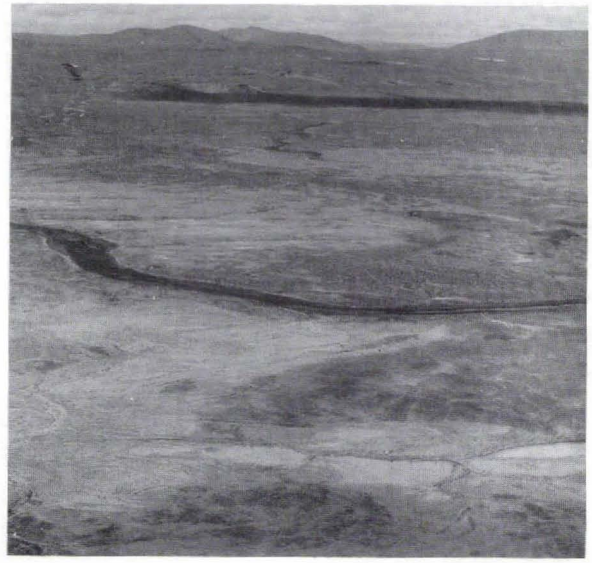


Fig. 62. View northwards over western ridge of 'Monument' moraine illustrating shallow relief, sinuous form and association with marine strata. Raised shorelines are just visible on ridge flanks. Scale: middle distance is about 2 km across.

The 'Monument' moraines are interpreted as lateral moraines to ice masses that occupied the western and eastern sides of the central plain; as such they must pre-date the Polaris – Newman Bugt moraine systems. However, whether they represent older stages of these two systems or a substantially older glacial event is uncertain (see discussion later).

Kap Sumner moraine. This moraine is situated near the northern tip of Hall Land, south-east of Kap Sumner (fig. 59). It is composed of several broad, low relief, sub-angular ridges rising from a broad mantle of moraine. The ridges can be traced along the coastal cliffs in a broad arcuate form for about 7 km. The farthest inland ridge is about 2.5 km from the coast and the highest part is above 300 m a.s.l. The moraine is primarily composed of a coarse boulder clay with some gravels, and on its distal side there is a transition into poorly sorted glaciofluvial deposits. The surfaces of both types of deposits are characterised by widespread patterned ground.

The Kap Sumner moraine represents a lateral (?terminal) moraine to a glacier that formerly occupied Newman Bugt. It may represent the distal expression of the

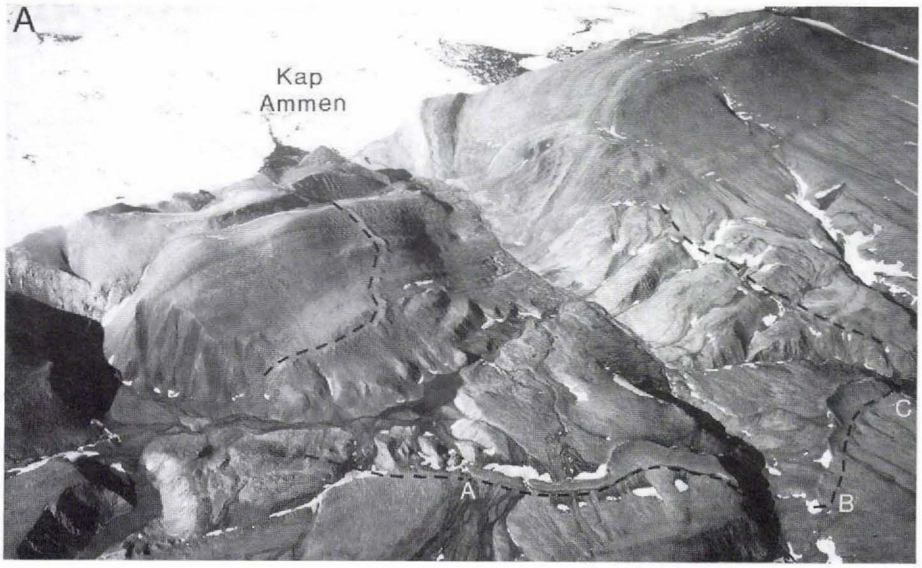


Fig. 63. The Kap Ammen moraine; A: general view showing 'The Gap' and location of moraine; dotted line is on the distal side of ridge. A–B marks the well-preserved section where the ridge approaches 30 m high. Aerial photograph 546B–N, 11745, copyright Geodetic Institute; B: detail of moraine ridge B–C with proximal side to right.

southerly derived glacial advance that produced the Newman Bugt moraine although it has been correlated with lateral moraines of the central lowland plain – 'Monument' moraines of this paper (Weidick, 1972; see fig. 88). Conversely the moraine could theoretically represent the outermost deposits of an ice mass of a northern source (see discussion later).

Kap Ammen moraine. This moraine, situated in the coastal mountains south of Kap Ammen, is composed of a single, narrow ridge of fresh morphology (fig. 63). The moraine outcrops in the main valley that reaches Robeson Channel as a pronounced break in the steep cliffed coastline ('The Gap') and on the sides of the broad western tributary valley. The moraine outcrops across the head of this valley and can be traced northwards where it reaches an altitude of 540 m on the coastal cliffs (O. Bennike & M. Kelly, personal communication, 1984).

The moraine is best preserved where it crosses the main valley at about 300 m altitude, some 4.5 km inland; here the ridge is over 100 m in width and reaches a height of over 25 m with a sharp angular crest and asymmetrical form (fig. 63). Where preserved as remnants it forms a narrow embankment that peters out to a thin veneer of moraine debris.

The moraine consists of coarse polymict debris, cobbles with some boulders that reach 1 m in size, set in a variable but mainly fine-grained silt-clay matrix. Boulder composition is of three main categories: a carbonate group of dark and light dolomites and limestones, including fossiliferous Ordovician–Silurian types, a clastic group including calcareous sandstones, arkoses and some chert, and a metamorphic group, including a range of gneisses, granites and amphibolites.

The Kap Ammen moraine is interpreted as a terminal moraine to a former glacier that encroached on Hall Land from the north, an ice mass that may have been derived from an Ellesmere Island rather than Greenland source (Dawes, 1977; see discussion later).

Petermann Fjord moraine. This moraine system occurs in the south-western part of the map flanking Petermann Fjord (fig. 59). It is composed of a series of sub-parallel morainic ridges and elongated outcrops

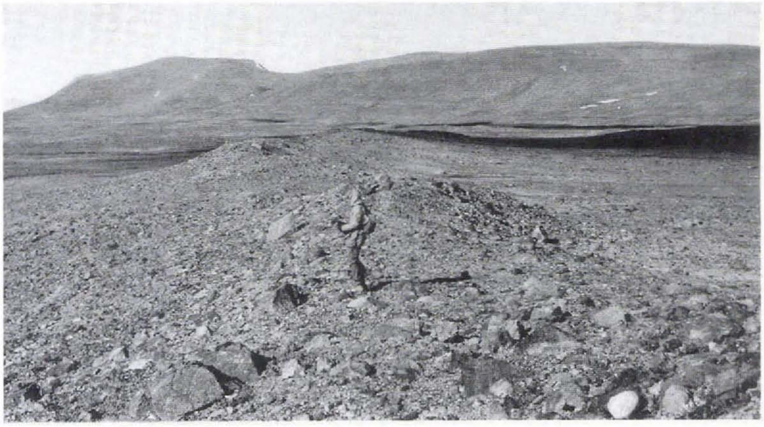


Fig. 64. Ridge of Petermann Fjord moraine system; blocks are predominantly limestone. View westwards to Kap Tyson.

that can be traced for about 10 km along the outer coast and for 11 km up the valley east of Offley Ø, where the moraine terminates in arcuate outcrops. Ridges along Petermann Fjord reach 400 m a.s.l.; in the north several short ridges abut on the southern flanks of Hauge Bjerge at about 300 m.

The ice-margin features vary from discrete, rather sub-angular narrow ridges, like some of those in the valley (fig. 64), to broad, rather smooth low embankments such as the largest outcrop on the top of the cliffs along Petermann Fjord. The moraines are generally composed of unsorted coarse gravels, but in the valley, ice-margin features are associated with prominent glaciofluvial deposits which in some places are developed as kame terraces (fig. 69).

The sub-parallel morainic ridges outline the shape of a former ice mass that occupied Petermann Fjord and from which an easterly glacier lobe penetrated far inland south of Hauge Bjerge. This interpretation is at variance with England (1985) who regards morainal ridges in this valley as deposits from an ice advance from the outlet glacier in the east. It seems probable that the Petermann Fjord moraine was formed during the same glacial stage that produced the Polaris Bugt moraine. The most distal ridges are situated less than 5 km from the present Inland Ice margin; an indication that the moraine dates from a relatively late stage in the glacial evolution, i.e. post-dating any substantial fluctuations in the extent of the Inland Ice.

Other ice-margin moraines situated approximately mid-way between Petermann Fjord and the Inland Ice margin are of uncertain affiliation. They may represent distal deposits of the Petermann Fjord moraine or mark a previous position of the Inland Ice margin.

Historic moraines

Historic ice-marginal moraines form relatively small outcrops compared to the older moraines described above. These moraines occur on, and adjacent to, the Inland Ice, and also separated from the ice margin.

The most prominent moraines of this type shown on the map are several relatively narrow but continuous zones of mixed glacial debris that occur within, and parallel to, the margin of the Inland Ice both at the outer margin and around nunataks (fig. 65). These moraines are predominantly composed of coarse gravel and cobbles with minor amounts of sand. They form fairly angular ridges and elongated mounds that may reach over 10 m in height but which grade into areas composed of a thin veneer of gravel and cobbles on the ice surface. The majority of these features are regarded

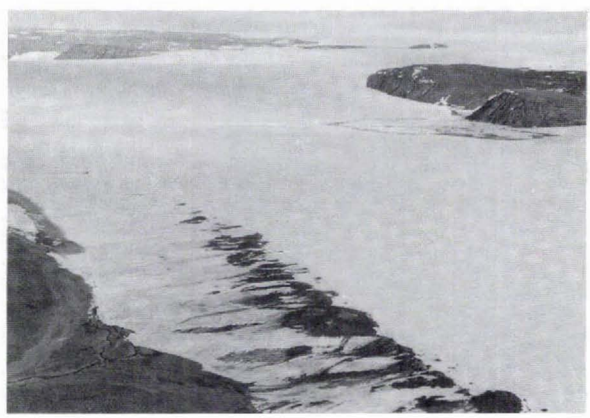


Fig. 65. Recent shear moraine along Inland Ice margin. View is east towards the eastern glacial lobe with nunatak on right.

as shear moraines (W. E. Davies, personal communication, 1980).

Some gravel ridges situated on bedrock flanking the Inland Ice margin represent glacial or fluvioglacial debris. Certain small, discontinuous ridges to the west of the north-western outlet glacier of the Inland Ice are up to 2 km from the ice margin. These represent terminal moraines to a former position of this outlet glacier, although the age of these moraines is unknown.

Two other areas probably contain important Recent ice-margin moraines. These are two valleys adjacent to the present ice margin; the western valley is parallel to the ice margin (fig. 1), the eastern one stretches eastwards from the eastern glacial lobe. These valleys have not been investigated in the field, but they probably contain much more glacial material than depicted on the map. The outcrops in the lower reaches of these valleys contrast markedly with the stratified limestone that forms the bedrock. Little stratification is seen and outcrops are characterised by slumping. These deposits have been tentatively mapped as fine-grained bedrock with a subsidiary cover of moraine. However, without field control it proved generally difficult to distinguish photogeologically between poorly exposed, flat-lying shale and mudstone and some glacial or glaciofluvial deposits. These valleys probably contain important surficial deposits that represent ice-margin features to the present Inland Ice.

Glacial erratics

The presence of glacial erratics in Hall Land has been known since the first expeditions to the region (Davis, 1876; Bessels, 1879; Feilden, 1895). From their widespread distribution, Koch (1928a) suggested that the Inland Ice reached as far as the Lincoln Sea during the glacial maximum. Later observations (e.g. Davies, 1961a) have supported this conclusion.

Glacial erratics are of both 'local' sedimentary bedrock and crystalline rocks that are foreign to Hall Land and environs. Erratics of the latter type are in general small and boulders above 1 m across are rare; on the other hand limestone erratics above this size are common. The largest erratic noted, east of 'Monument', is a crudely circular block of limestone about 20 m across. This displays congelifraction break-down surfaces and resembles a tor.

Erratics occur in all three physiographic provinces demonstrating that land-derived ice has covered the entire area. Erratics are present at around 800 m a.s.l. on the summit of Chester Bjerg along the northern coast and also at comparable heights in Hauge Bjerge. As yet, no erratics have been located at higher elevations. The rounded form of Kayser Bjerg (at 1100 m the highest peak in Hall Land), matching that of other summits, strongly suggests that the peak was also completely ice covered. This is supported by the regional distribution of glacial erratics (Koch, 1928a; Prest, 1952; Davies, 1961a); for example, erratics occur on the summit of Windham Hornby Bjerg, a peak at about 1150 m a.s.l. in northern Hendrik Ø (fig. 2; Koch, 1928a), and on other high peaks along the coast (Kelly & Bennike, 1985) – locations over 100 km from the present ice margin.

A critical feature of the glacial block distribution is the presence on the northern highlands and on the central plain (figs 18 & 57) of a variety of limestone lithologies that can be matched with Silurian formations composing the carbonate platform to the south. This indicates a mainly southerly provenance. Indication of the former presence of *far-travelled* ice masses – in contrast to local ice-cap regimes – is provided by 'foreign' erratics. These are almost entirely crystalline basement erratics, although rare sandstone erratics (of unknown age) of a type not present in the Silurian deep-water clastic sequence of northern Hall Land, occur on the southern upland plateau.

The *crystalline erratics* form an important component of the ground moraine and are present in all six marginal moraine systems. A wide variety of rocks are represented: granites and gneisses with subsidiary metabasic rocks and rare dolerite. These include veined and banded gneiss, and rather homogeneous gneiss and granite, indicating a source of essentially amphibolite facies metamorphic terrain. Main rock types are reddish to pink leucocratic granite, grey microgranite, grey granitic gneiss, pink feldspar porphyroblastic gneiss and red veined gneiss. Biotite is the main mafic mineral of the gneiss-granite suite; hornblende is present in some rock types. The metabasic erratics include homogeneous rocks and strongly foliated varieties, and range from hornblende-plagioclase amphibolites to pyribolitic rocks containing biotite and pyroxene. Garnet can be present in both gneisses and metabasic rocks.

The nearest outcrops of plutonic rocks, representing the most northerly outcrops of the Greenland shield, occur at the head of Victoria Fjord, some 400 km to the east of Hall Land where they form the Victoria Fjord arch (fig. 8; Dawes & Soper, 1973). Precambrian basement also outcrops in the Humboldt Gletscher region 500 km to the south-west. The crystalline erratics on Hall Land are comparable in lithology and metamorphic grade to the granodiorite orthogneiss-granite complex of the Victoria Fjord arch (Dawes, 1978; Henriksen & Jepsen, 1985). Only one rock in the existing collection (GGU 83482) cannot be matched with a rock type from this area. This is a granulite facies foliated metabasite containing orthopyroxene. Pyroxene-bearing metabasic rocks are known from Inglefield Land (Koch, 1933; Dawes, 1972, 1976).

Davies (1961a) has drawn attention to the widespread occurrence of a pink leucogranite in the drift of northern Greenland (Melville Bugt to Peary Land, fig. 2) which he refers to an *in situ* outcrop of a similar granite in the Thule district. Pink granite erratics also occur on Hall Land; the rock is essentially composed of plagioclase (altered), potash feldspar, (microcline, perthite) quartz and muscovite (GGU 83479). Christie (1967) also records the same rock among erratics on adjacent Ellesmere Island and suggests a Greenland source. This was assumed to lie under the Inland Ice, rather than in the Precambrian areas of the Thule district or southern EllesmereIsland which "would require a trunk glacier flowing northward through the Kennedy Channel" for which there was otherwise no evidence (Christie, 1967, p. 8). Recent geological work in Greenland supports this conclusion; *in situ* red-pink granites are known to occur at the head of Victoria Fjord and in Inglefield Land.

Glacial erosion features

The gross morphology of Hall Land is essentially a reflection of bedrock composition rather than the glacial epoch. However, glacial erosion has severely modified the landscape; the land surface is characterised by smooth, rounded hill forms, and many valleys, particularly in the southern uplands, have a typical U-shaped profile.

Erosional features, such as glacial striae are reported in the early literature (Coppinger, 1877; Feilden, 1878; Bessels, 1879); Feilden & De Rance (1878, p. 567) remark that "the whole of Offley Island is traversed by glacial planings, scorings, and groovings from summit to sea-level". Erosional phonomena are mainly developed on the competent limestone terrain of the south, although roches moutonnées are seemingly rare.

The inner parts of Newman Bugt and Petermann Fjord are characterised by glacially eroded, high, steep limestone walls, while along the precipitous cliffs of Robeson Channel several hanging valleys occur, indicating considerable glacial deepening of this waterway. Inland, Davies (1972) draws attention to one particular area of 'channelled uplands' south of 'Saint Anthony's Nose', due to erosion by incised glacial streams.

Western North Greenland is characterised by a NNW-trending fjord direction; Hall Land is bounded by two such fjords. This pattern suggests tectonic control. Northerly trending faults and joints are common in the Hall Land – Nyeboe Land – Hendrik Ø region; A. K. Higgins (personal communication, 1980) reports that structures of this trend are widespread in western Peary Land. Hurst & Kerr (1982b) commented on the parallelism between the fjord direction and certain crush zones in Washington Land and concluded that the fjords represent major lineaments controlled by fracture or fault zones. Whatever the primary control, Newman Bugt and Petermann Fjord have developed by deepening and widening of depressions by glacier action.

Fluviatile and glaciofluvial deposits

River deposits form a prominent part of the surficial cover; three groups are recognised on the map: alluvium, fluviatile and outwash.

An attempt has been made to adhere to the traditional definition of alluvium for deposits laid down during comparatively recent geological time. Thus the 'alluvium' map colour is used for deposits at the active deposition level of a river; in contrast, the 'fluviatile' map unit covers a wider variety of generally older deposits. This differentiation into 'recent' and 'old' categories is, however, not everywhere strictly upheld. For example, detritus on the floors of some upland and seasonal 'dry' valleys, or some of the inland delta fans, may represent ancient alluvium and have an age comparable to, or older than, some river terrace deposits included in the fluviatile unit.

The third map unit, outwash, is reserved for prominent areas of ancient glaciofluvial deposits, associated with the Atka Elv and 'Gråstenelv' drainage systems.

Alluvium

Alluvial deposits have been mapped in three main settings: on the floors of valleys, as deltas at the mouths of major rivers, and as cones and fans at major breaks of slope. Alluvial detritus varies markedly in character with setting and also with the rock type of the catchment area.

Valley floor deposits

These deposits vary from narrow and relatively thin outcrops along watercourses in the northern and southern highlands, to extensive, thick deposits forming the broad alluvial plains of the two major rivers – Atka Elv and 'Gråstenelv'. These rivers are typical alluvial rivers; water flows in braided channels within a flood plain where the alluvium has a depth at least equal to the scour of the melt season flooding (fig. 66).

Much of the detritus in stream beds, on valley floors and on flood plains is coarse sand and gravel with rounded pebbles and cobbles of mainly local derivation. In the meandering rivers crossing extensive areas of marine strata on the central plain, finer grained detritus, silty sand to mud, forms alluvial banks; in contrast, in many deeply incised mountain rivers coarse alluvium contains a high percentage of cobbles and boulders washed out from ground moraine.

Alluvial deltas

Deltas occur at all major river mouths on the eastern and western coasts; even small rivers, some less than 1 km from source to mouth, occurring along the low-lying, central parts of Polaris Bugt and Newman Bugt, display small alluvial fans and deltas. The northern coast is characterised by an absence of deltas, presumably due to strong currents and drifting ice in Robeson Channel.

The main deltas have braided streams cut several metres below the lowest marine terraces (fig. 17). The alluvium is generally composed of sand and silt, with coarser fractions of gravel with pebbles and cobble, that grade seawards into pro-delta fans.

Fig. 66. Braided middle reaches of Atka Elv showing broad alluvial plains and fluviatile terraces. View towards northern highlands with Polaris Bugt moraine visible.

Alluvial cones and fans

These features occur in two main inland locations: at tributary junctions in fairly steep-sided valleys on the northern and southern highlands, and along the E–W scarps that bound these highland regions from the central plain. Valley cones and fans are generally small, but coalescing fans can occur along valley sides or across their floors. The largest fans are at the base of the two scarp lines; those in the north form a prominent fan line from Thank God Harbour to north-west of the 'Gråstenelv' delta; those in the south are generally smaller in size. In the central part of the northern scarp several large, low relief fan deltas are present, and one area, north of 'Monument', is developed as an alluvial slope or apron some 8 km wide – a sort of miniature bajada (fig. 67).

Fluviatile deposits

This map unit includes all river detritus not otherwise categorised as recent alluvium; it includes many areas of glaciofluvial deposits. In addition the fluviatile map colour is used for the 'marine' delta terraces present at major river mouths; for convenience these terrace systems are described in the section on marine deposits. Many of the inland fluviatile deposits occur in association with terrace systems.

River terraces

Terraces are well developed along all main rivers, prominent examples occurring along 'Gråstenelv' from its source at the Inland Ice to its mouth, along stretches of Atka Elv and in the river valley east of Offley Ø. Along many rivers several prominent terrace or bench levels occur (fig. 66); in places they are developed in a tiered system simulating the marine delta terraces. The terraces have even surfaces, slope downstream and can be up to several tens of metres above the present river.

On the west side of 'Gråstenelv' an extensive raised plain, up to 3 km wide, forms a very prominent feature of the landscape (fig. 20). This is dissected by shallow drainage channels (fig. 83). The plain has extremely shallow relief with a flat surface, suitable for heavy aircraft landing; the 'Pileheden' airstrip is sited here (fig. 68; Needleman *et al.*, 1961).

The fluviatile deposits vary widely in lithology: from coarse gravel and sand to silt and, less commonly, mud. Many ter-

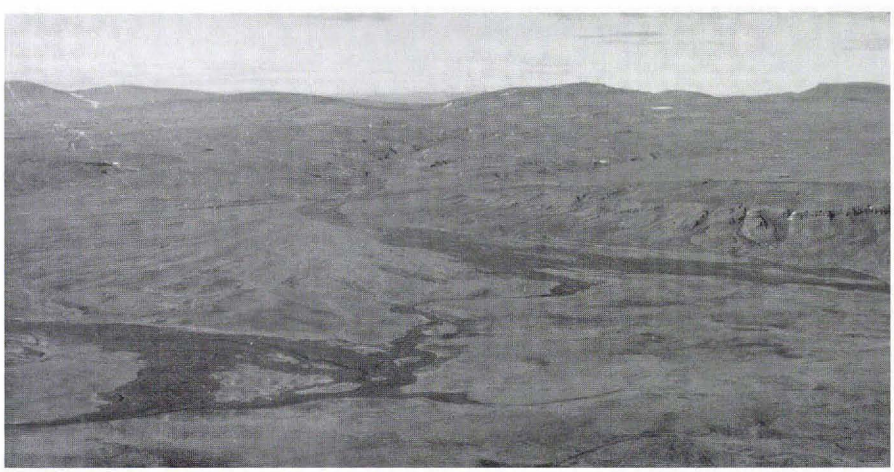


Fig. 67. Major alluvial fan at the northern scarp, north of 'Monument'. Width of view across alluvial slope is about 4 km.

Fig. 68. 'Gråstenelv' raised fluviatile plain showing shallow drainage channels and polygonal ground. View is south-west with river on left. Tyre marks delimits 'Pileheden' airstrip about 1500 m long; hut on extreme right is about 8 m long.

races, including the marine delta terraces, are composed of subrounded to rounded pebbles and cobbles in a silty sand or silt matrix. Pebbles and cobbles generally vary in size up to 15 cm; boulders up to 50 cm occur, but larger sizes are rare. The 'Gråstenelv' raised plain is characterised by having a generally finer grain size than many of the lower river terraces and the delta terraces; cobbles or boulders are rare. The surface of the plain is composed mainly of a sandy soil characterised by large-scale polygon structures (fig. 68). According to Davies *et al.* (1959) the upper 15 cm of the 'Pileheden' airstrip ranges from very fine sandy silt to poorly graded gravel–sand–silt mixtures.

Glaciofluvial deposits

On the northern highlands and southern uplands, south of Hauge Bjerge, glaciofluvial gravel and sand show varying relationships to the present drainage pattern. Some deposits associated with benches and kame terraces are related to present water courses, although in thickness and extent several outcrops are out of proportion to the size of the existing river. On the southern uplands some deposits are situated several hundred metres above the present river, while other outcrops apparently show little or no relationship to present drainage.

These coarse deposits are interpreted as glaciofluvial detritus laid down during a period of active glacial retreat. High melting and a fairly rapid change in the nature and position of the ice front would enable outwash to be deposited by meltwater in established valleys, but also by relatively short-lived ice-margin streams that would be abandoned before the production of marked topographic expression.

Important glaciofluvial deposits outcrop in benches and kame terraces in many river valleys on the northern highlands, e.g. the valleys flowing into the Sumner delta south-east of Kap Sumner, and on the southern uplands, e.g. the valley stretching from the Inland Ice to the Tyson delta, east of Offley Ø (figs 69 & 78). The surface of the gravels in the latter valley is irregular; mounds and ridges occur which probably represent ice-contact deposits (fig. 70). Thermokarst topography characterises the outcrops (fig. 86).

Outwash deposits

Glaciofluvial sand and gravels with minor silts form substantial areas associated with the lower reaches of Atka Elv and 'Gråstenelv'. The deposits form extensive outwash plains of smooth relief developed in close asso-

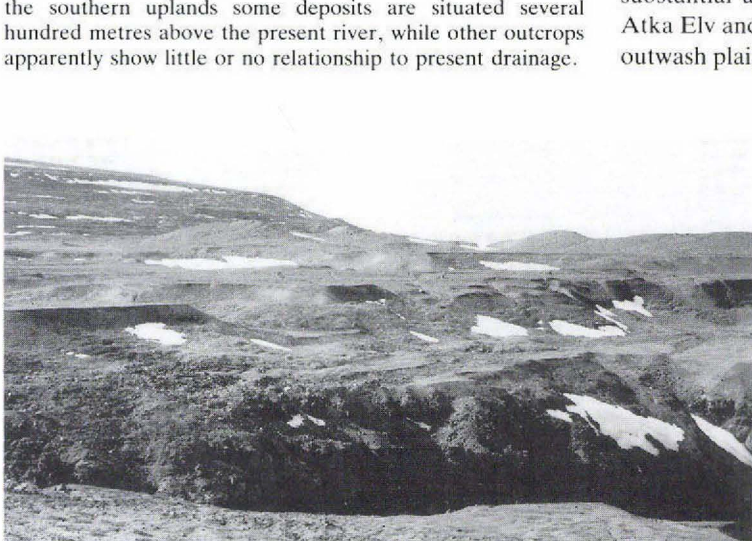
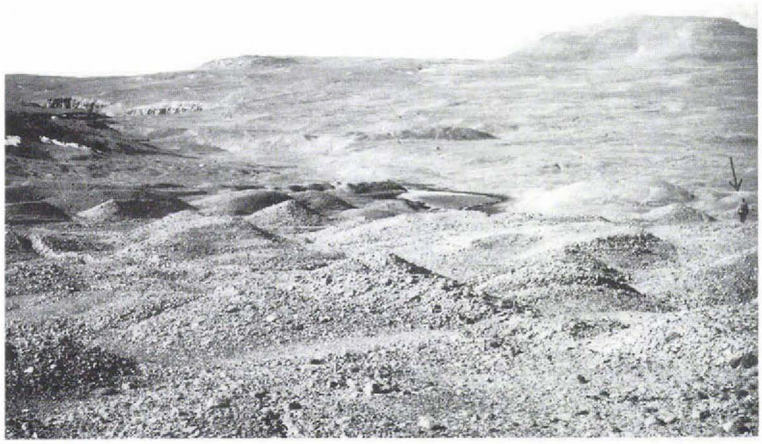


Fig. 69. Tiered terrace system developed in glaciofluvial gravels; present river is in limestone gorge in foreground. Terraces behind are ridges of the Petermann Fjord moraine with limestone bedrock in left background. Valley east of Offley Ø.

Fig. 70. Glaciofluvial gravels showing kame-like mound topography. Valley east of Offley Ø, view towards Kap Tyson. Scale: person arrowed.



ciation with the Polaris Bugt and Newman Bugt moraines. The map unit covers a range of deposits from the terraced accumulations laid down by meltwater streams, to morainic material that has been substantially reworked, washed or levelled.

Atka deposits

These deposits are dominated by a major outwash fan, more than 5 km across, developed on the landward side of Atka Elv. This fan is composed mainly of dark weathering gravels that outcrop in several, smooth-surfaced terraces; the fan has an abrupt, in places steep, contact with marine sediments (fig. 71). On the seaward side of Atka Elv, outwash has a much more irregular surface with frequent lakes (fig. 22); this topography is due to the presence of moraine ridges as well as periglacial activation.

'Gråstenelv' deposits

Outwash deposits occur on both sides of the present river. In the west a broad outwash plain, 6 km wide in its southern part, has a fairly flat, gently northwards sloping surface on which several low terraces are preserved. To the east outwash forms an 8 km wide plain, bounded by the master ridge of the Newman Bugt moraine. These deposits are intimately associated with terminal moraine outcrops forming a more irregular, undulating topography (fig. 20). The eastern plain is characterised by prominent periglacial surface configurations, lakes, and northerly sloping terrace levels.

The Atka and 'Gråstenelv' outwash plains are joined by a belt of glaciofluvial accumulations at the base of the hills bounding the central plain. These deposits form a vast outwash apron, some 10 km long and 3–4 km wide, presumably derived from meltwater streams issuing from a former ice-margin that covered the northern part of the southern uplands.

Marine deposits and features

Marine deposits and features are prominent in Hall Land. Extensive inland outcrops occur on the central plain; more sporadic outcrops are found along the low-lying coasts of Polaris Bugt and Newman Bugt. Marine plains and terraces form dominant features of the coastal geology.

Fig. 71. Major outwash fan with Atka Elv on left. Front of fan at contact with marine silts is about 5 km wide. Northern highlands and plateau in background.

Fig. 72. Marine silts showing laminated intervals. Inland part of 'Gråstenelv' delta.

Two categories of marine deposits are recognised on the map: a predominantly argillaceous facies and a mixed facies. Although deposited in the littoral zone, sands and gravels composing the delta terraces are mapped together with the 'fluviatile' deposits described in the preceding section.

Silt and clay

The dominant deposits are light weathering, grey to buff silt and clay that are generally poorly stratified. Units several metres thick can be composed of structureless silt, but more often laminated intervals occur (fig. 72). Well sorted, rhythmically bedded sands, often darker in colour can be interbedded with the silt. These sands probably represent littoral marine or glaciomarine strata. In summer marine deposits can be extremely soft; when dry they are friable and easily eroded. Badland topography is commonly developed (fig. 21).

The silt and clay commonly contain pelecypod shells, which in places are abundant and can be in growth position (fig. 73), and also rare gastropods. The main species are *Hiatella arctica* and *Mya truncata*. Jeffreys (1878) and W. E. Davies (*in* Rubin & Alexander, 1960) record *Astarte borealis* while England (1985) collected *Portlandia arctica* and *Thyasira* sp. Kelly & Bennike (1985) report shells of the tidal and subtidal barnacle *Balanus balanus* reworked in glacial till.

On aerial photographs, and in the absence of fossils in the field, the marine clays and silts resemble argillaceous deposits of lacustrine or glaciolacustrine origin; where in doubt, outcrops have been included on the map sheet in the marine map unit.

Mixed facies

These deposits are distinguished on aerial photographs by their darker colour; they contain a greater proportion of coarser grained material than the previous map unit. In many cases the mixed facies consists of grey silt and sand with a veneer of darker weathering gravel and sand, together with pebbles and cobbles of mainly local bedrock. The veneer varies from a few scattered pebbles and clasts (fig. 73) to a more or less continuous cover of debris; generally the underlying grey silt is clearly visible. The dispersed or scattered nature of the veneer suggests it is a lag deposit, probably generated from ice-rafted clasts following winnowing or washing away of the finer material.

Davies *et al.* (1959) regarded such cover deposits on the marine silt and clay in the central plain as representing post-marine ground moraine; England (1985) referred to a 'boulder carapace' of marine deposits produced as 'ice-rafted debris'.

Several areas of raised intertidal deposits, e.g. beaches, strand plain, are also mapped as 'mixed facies' (fig. 74A); such

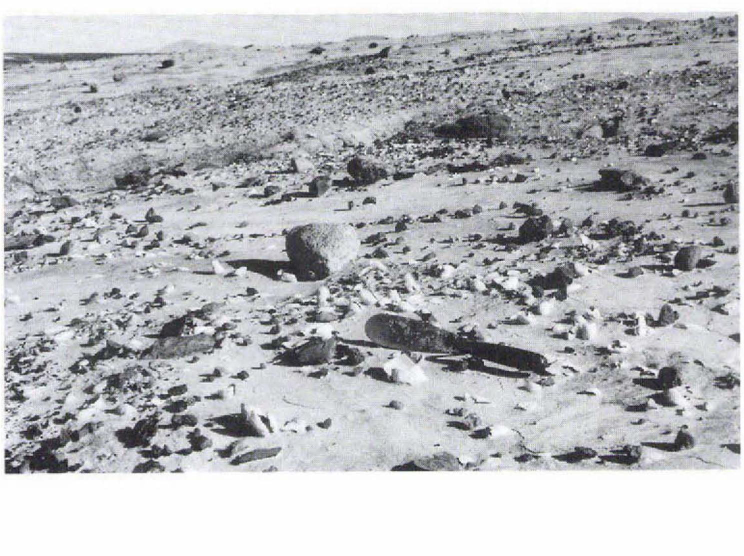


Fig. 73. Marine silts with prominent mollusc shells, some of which are in growth position. Surface is strewn with erratic blocks interpreted as ice-rafted lag deposits. Western central plain, distal to Polaris Bugt moraine.

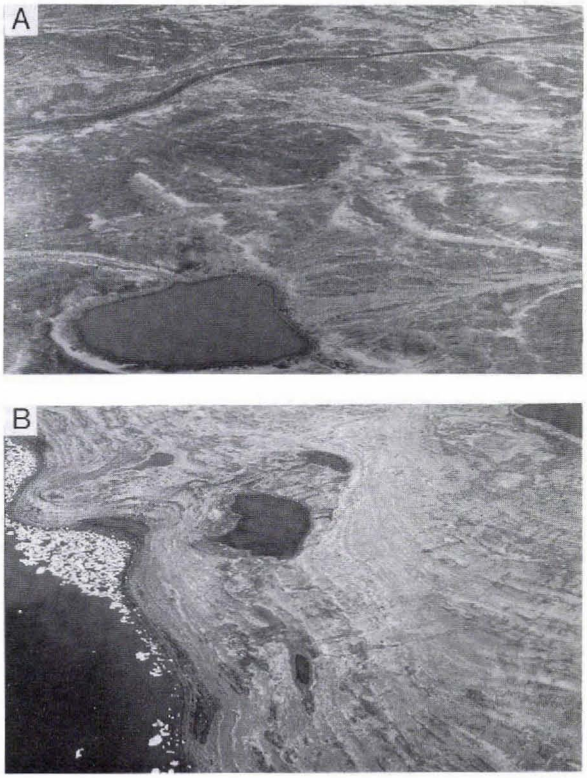


Fig. 74. Coastal marine plain south of Atka Elv. A: light coloured marine silts and darker coarser areas mapped as 'mixed facies'; lake is 200 m across. B: prominent beach ridges and berms with lakes; main lake is 150 m across.

features are prominent along the shores of Polaris Bugt, with lesser developments along Newman Bugt. Most commonly these deposits comprise fairly well sorted pebbles and cobbles in a sandy to silty matrix, and this lithology may be interbedded with grey argillaceous material. These intertidal deposits grade into the brown weathering sands and gravels composing the delta terraces. On the broad marine terraces and plains north and south of the Atka delta, extensive gravel beaches and berms are developed (fig. 74B). These contain depressions of varying size that are seasonally water filled and are bottomed in silt or sand.

In summary, the map unit 'mixed facies' encompasses a heterogeneous group of strata; it comprises mainly marine and glaciomarine deposits, but includes also littoral (intertidal) and lacustrine sediments, as well as the drift-ice carapace deposits.

Raised shorelines

Littoral linear features are mapped by a solid black line. This symbol represents all raised shorelines, ranging from modern storm-wave beach ridges to older features that correspond to the maximum limit of the Holocene sea. Most shorelines are regarded as marine features, others may be glaciomarine or glaciolacustrine.

Raised shorelines occur on the central plain and along the Polaris Bugt and Newman Bugt coasts. Many of these are constructional features, like the beach ridges and berms that are common between Thank God Harbour and Kap Buddington (fig. 74B); others are destructional, for example benches and terraces that are common on the distal side of the Polaris Bugt moraine and in the interior of the central plain (fig. 75). The latter shorelines vary from tiered bench levels which may or may not have a beach deposit of gravel (fig. 75A) to abrupt changes in slope (wave-cut features – fig. 75B), to rather vague levels that can be difficult to detect in the field but which on aerial photographs are seen as distinct changes in morphology and colour. Many of these levels represent the upper lapping or washing limit where erosional effects are minimal and only a crude strand line is seen.

The shorelines of the central plain form an extensive arcuate system preserved on the undulating moraines that form the slopes south of the mountain scarp and the north–south trending moraine ridges. This system is probably a product of both marine and non-marine (lacustrine) processes.

The mapped features are the remnants of an extensive 'inland' water body that occupied much of the central plain; the presence of fossiliferous marine deposits in association with the shorelines indicates, at least at some time, connection with the sea. England (1985) suggests that such a sea occupied central Hall Land for 25 000 years (between > 33 000 and 8200 B.P.). However, the Polaris Bugt – Newman Bugt moraine systems essentially enclose the central plain and it is envisaged that the water body – at least during the maximum expansion of the fjord glaciers – represented an ice-dammed lake; a conclusion initially reached by Koch (1928a, b, fig. 7) and supported by the recent work of Kelly & Bennike (1985).

Furthermore the presence of N–S trending shorelines on the western flanks of the easternmost 'Monument' ridge in continuation with the E–W shorelines, indicates that at some stage a closed body of water occupied the western part of the plain (for discussion – see Quaternary history section).

Some of the linear features mapped on the central plain may represent degraded till ridges, with linearity being due to the original pattern of the glacial deposition (M. Kelly, personal communication, 1984). Some of these ridges might also be the focus of subsequent beach development, either marine-glaciomarine or lacustrine-glaciolacustrine.

Marine terraces and plains

Raised plains and terraces are prominent at Polaris Bugt, both north and south of Atka Elv; they are less extensively developed at 'Gråstenelv'. At the mouths of all major rivers, deltas are developed and many of these form impressive tiered systems of raised terraces (fig. 76).

Terraces are composed of two main lithologies: gravel and sand with individual clasts from pebble to cobble

A

B

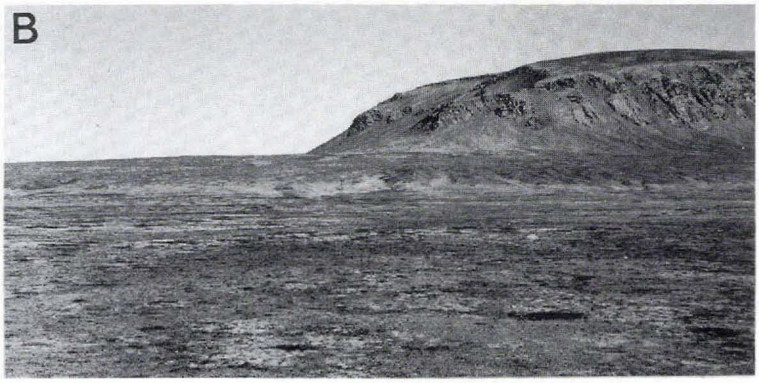


Fig. 75. Raised shorelines on the central lowland plain. A: series of bench levels with marine deposits developed on distal side of Polaris Bugt moraine; view north-east towards bedrock escarpment of northern highlands that is about 150 m high. B: a high-level (about 110 m a.s.l.) shoreline developed on moraine as abrupt change in slope; view northwards to the south-western end of 'Monument'.

size, and grey silt and clay. The majority of the terraces, including all the delta terraces, are composed of gravel and sand; silt and clay (including mixed facies) make up the plains and terraces of Polaris Bugt south of Kap Tyson and to a lesser extent along Newman Bugt (figs 74 & 77).

The marine terraces have characteristically level, sea-planed surfaces, although the larger plains, for example at Atka Elv, show irregularities in the form of lakes and beaches. The delta terraces have extremely even surfaces, a shallow seawards tilt (fig. 77), and characteristically display frost polygons.

Eight coastal deltas are named in this paper (fig. 78). Field and photogrammetric measurements indicate a total of 16 terrace levels in the coastal deltas. A summary is given in Table 3.

The distribution of delta terraces is not uniform, and the number of levels developed (or preserved) varies from locality to locality. Four to seven levels are present on the western coast; between 9 and 11 levels in Newman Bugt. The deltas are not symmetrical; terrace levels developed on one side of a river may not necessarily occur on the opposing side (fig. 76). The largest number of levels preserved in any one location is 11 at the Howgate delta (Table 3) which is characterised by having the lower levels developed only on its southern side; on the next major delta to the north – the Reynolds delta – three of the lowest terraces are found only on its northern side (fig. 76A).

Marine terraces range in altitude from 2 m to at least 120 m (possibly 140 m) above sea-level. Terraces, above 70 m, are well developed in the interior of Newman Bugt, and the highest levels of 120 m and 140 m are represented in the Howgate delta (fig. 79). This delta has not been investigated in the field, and the 140 m level cannot be positively identified as truly marine. Several other terraces of comparable altitude occur north of the delta, as well as terrace levels of unknown origin upslope, including some on bedrock. These high features could be connected to a glaciomarine event associated with a former position of a glacier in Newman Bugt, or they may be kame terraces.

Similar high levels occur above the delta south-east of Kap Sumner, where a series of terraces developed mainly south of the river reach 150 m a.s.l. At least 5 true marine levels occur below an upper series that are developed as gravel terraces on bedrock and which are undoubtedly kame terraces.

Previous information about marine terrace levels on Polaris Forland has been given in Davies *et al.* (1959) who record 10 levels: 6 ft (~ 2 m), 10 ft (~ 3 m), 18 ft (5.5 m), 25–32 ft (8–10 m), 46 ft (14 m) and 59–65 ft (18–20 m) in Polaris Bugt, and at 10 ft (~ 3 m), 30–38 ft (9–11.5 m), 75 ft (22 m), 135 ft (41 m) and 155 ft (47 m) along Newman Bugt. Correlation between these levels and those of the present study is suggested in Table 3, although a direct comparison based on heights above sea-level is not possible.

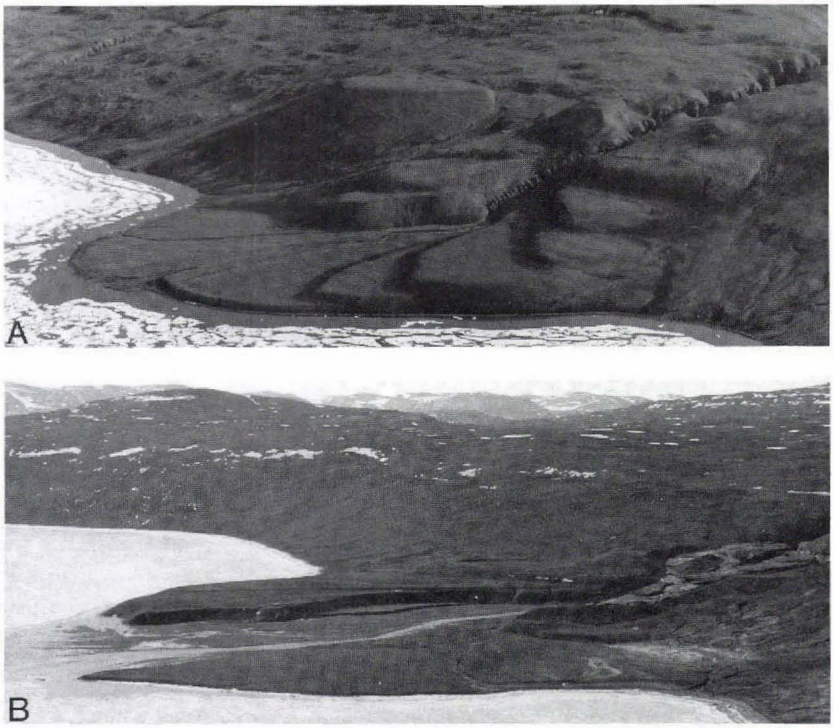


Fig. 76. Raised deltas along Newman Bugt showing tiered systems of marine terraces. A: Reynolds delta with highest level south of river at 100–105 m a.s.l. (possibly as high as 110 m a.s.l. (see Table 3)). B: Newman delta with prominent terrace level south of river at about 20 m a.s.l. See fig. 78 for location and Table 3 for definition of terrace levels.

Marine limit

The highest shorelines shown on the map are the negative features (?wave-cut benches) west of 'Monument'. A value of 126 m was photogrammetrically recorded for the uppermost linear feature (?upper washing limit) in this area (Dawes, 1979). Recent field data suggest that this value may be 10 m or more too low (see Cartography) and that these high negative features may reflect a lacustrine stage prior to the main marine incursion (O. Bennike & M. Kelly, personal communication, 1984). However, two other lines of evidence suggest that the marine limit is at least 125 m a.s.l. Firstly, the highest marine silt-clay deposits mapped in the north-eastern part of the 'Gråstenelv' plain are between 100 and 125 m a.s.l. and, secondly, to the south the highest marine terrace in Newman Bugt is 120 m (possibly 140 m, see above).

There has been considerable discussion about the marine limit in the Robeson Channel region since Feilden (1877), Feilden & De Rance (1878), Bessels (1879) and Koch (1928a) recorded it to be several tens of metres above present sea-level. Davies (1961a) reported the highest marine clays on the central plain to be at 105 m; from east of 'Monument' Weidick (1977) recorded an altimeter reading of the limit (based on undis-

Fig. 77. Typical flat-topped, gravel delta terraces shallowly inclined seawards. Atka Elv with Hauge Bjerge to left. Height of terrace above river about 15 m.

Table 3. Summary of marine delta terrace levels

	POLARIS BUGT			NEWMAN BUGT				DAVIES et al. 1959 DAVIES 1961a, 1972 Heights in feet	
Average height metres	1	2	3	4	5	6	7	POLARIS BUGT	NEWMAN BUGT
1 - 2		+	+	+			+	6	
3 - 4	+	+	+		+		+	10	10
5 - 7		+		+		+	+	18	
10 - 12		+	+	+	+	+		25 - 32	30 - 38
15 - 16	+		+	+		+	+	46	
17 - 22	+	+		+	+		+	59 - 65	75
25 - 26				+	+				
28 - 33	+	+		+	+		+		
36				+		+			
40 - 45	+*			+	+	+	+		135
48 - 57	+*			+	+	+			155
60 - 68	+*				+	+			
70 - 75							+		
80 - 86						+			
100 - 105					(+)	+	+		
120						+			
140						+			

DELTAS: 1 - ATKA, 2 - BUDDINGTON, 3 - TYSON, 4 - GRÅSTENELV, 5 - REYNOLDS, 6 - HOWGATE, 7 - NEWMAN.

Asterisks: uncertain height correlation; circle: may be as high as 110 m – altimeter reading by O. Bennike and M. Kelly (personal communication, 1984).

turbed shell-bearing clay) at 100 ± 10 m. Both these values come from sites that are topographically below the high shorelines shown on the present map. On the other hand, England (1985) records much higher values for the marine limit, from 144 m north-west of the 'Gråstenelv' delta, to about 150 m in the south-west on the distal side of the Polaris Bugt moraine. He concludes that the marine limit tilts down north-westwards,

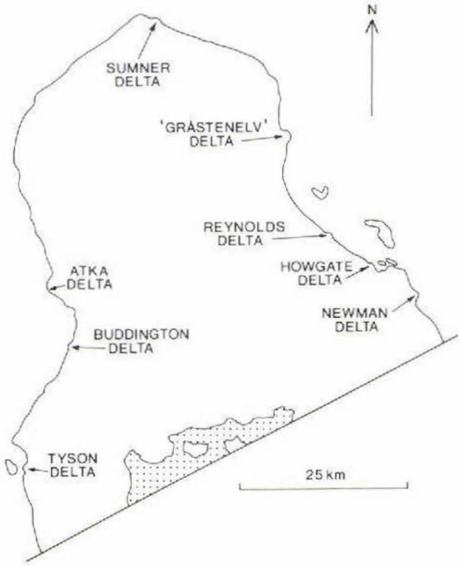


Fig. 78. Location map showing the main coastal deltas of Hall Land – see Table 3.

as well as southwards towards the heads of the fjords – an isostatic uplift that fits his extrapolated Holocene shoreline curve established for Ellesmere Island where, at Robeson Channel, the marine limit is quoted at 116 m (England, 1983).

Even accepting that marine values on the Hall Land map may be consistently too low, there is a discrepancy with the marine limit as defined by England. This is probably mainly due to the criteria used in the definition of the limit; the localities at 144 m and 150 m mentioned above are described by England as glaciomarine sediments in close association with moraines; on the present map the strata at these localities are designated glacial or glaciofluvial deposits. Moreover, as noted by Kelly & Bennike (1985), the marine limit is generally extremely difficult to define precisely, particularly in areas away from raised beaches; these authors note, for example, the uncertainty in the recognition of marine influence in sections where fossiliferous marine silt grades into unfossiliferous silt

Fig. 79. North side of Howgate delta, Newman Bugt, showing several marine levels accentuated by snow. 140 m level is at the base of the first bedrock slope (marked X). Distance from bedrock gorge to gravel terrace in foreground is about 1.5 km.

that may be glaciomarine or even glaciolacustrine. Kelly & Bennike (1985) conclude that the marine limit, representing a washing level in moraine west of 'Monument', is at 125 ± 5 m and that the elevation decreases generally from west to east (as well as south to the heads of the fjords), rather than to the north-west as indicated by England (1985).

Lacustrine deposits and features

Only minor areas of lake deposits are recognised on the map sheets. Small outcrops occur on the central plain and in the low-lying valley terrain east of Offley Ø. The largest single outcrop covers an area of about 2 km^2 on the central plain, south of Atka Elv, where the floor of a former lake is composed of light coloured clay and silt (Davies *et al.*, 1959). In summer this area also contains several small lakes, and the deposits display rectilinear frost polygons (fig. 19).

Grey clay and silt composes the main lacustrine lithology. Apart from the absence of fossils the deposit is very similar to argillaceous marine strata. The clay and silt can be fairly well bedded and can contain sand intervals. Lacustrine clays and silt are often closely associated with deposits of marine origin, for instance on the central plain, and here differentiation into two map units is problematic. Many lacustrine areas have been identified only by their outcrop in local catchment basins or their association with lakes or seasonal pools; where origin is in doubt outcrops have been included in the marine map unit.

In many areas the deposits appear to be glaciolacustrine, or they are associated with glaciomarine or glaciofluvial strata. The deposits in the south-west which form irregularly shaped areas, generally contain coarser grained material than those of the central plain as they were probably derived from meltwater streams from the nearby ice margin. Glaciolacustrine deposits also occur on the central plain, for example in the area of the large outwash plain of Atka Elv, but these have not been differentiated on the map from the more abundant marine-glaciomarine deposits.

Certain small outcrops of lacustrine deposits occur in thermokarst areas, particularly in the western central plain, north-east of Kap Buddington. Here several dried-up, cave-in or kettle lakes in the glaciofluvial gravels are floored in clay, silt and sand.

The presence in the central plain of lacustrine shorelines has been mentioned in the section on marine shorelines.

Colluvium and talus

The term colluvium is used as a general term for all loose and incoherent deposits accumulated in the lower reaches of a slope or cliff, the movement of which has been dominated by gravity but in which water may have played an important part in assisting down-hill creep. Two categories of colluvial deposits are recognised on the map: *colluvium*, undifferentiated, which mainly includes those deposits collecting on or at the base of gentle slopes in valleys or on hillsides; *talus*, which refers to the disintegrated rock fragments that form masses of debris at the foot of cliffs or very steep slopes.

Fig. 80. Prominent colluvial and solifluction deposits on the proximal flanks of Polaris Bugt moraine (dashed line). Width of view in foreground is about 700 m.

As used on the map, there is appreciable overlap between the two categories. Outcrops mapped as talus are essentially coarser deposits than those included in the colluvium map unit; they are products of erosion of bedrock, whereas colluvial deposits are derived from both bedrock and surficial strata. A morphological contrast is that colluvium can form steeper gradients than the parent slopes; talus slopes are characteristically shallower than parent declivity.

Colluvium, undifferentiated

Deposits of this map unit are widespread; typical locations occur in the fairly open valleys of the northern highlands and on shallower gradients, such as, for example, the flanks of the Polaris Bugt and Newman Bugt moraines (fig. 80).

In the valleys, particularly the more open types, and at valley heads, there is a transition between deposits accumulated by gravity and water action, and those deposited by river action. In many places the colluvial map unit includes alluvial deposits. Moreover, particularly in the northern highlands, the map unit also contains soliflucted material; for example on the southern slopes of Chester Bjerg several colluvial areas of mainly bedrock debris contain waterlogged ground in which solifluction material is common.

Talus

Talus or scree characterises the lower part of all appreciable steep cliffs; in river valleys, on inland scarps

Fig. 81. 'Monument' viewed from the south showing colluvial slopes with talus cones below bedrock cliffs. Summit is about 250 m high, plain below is at about 120 m.

and along the coasts (fig. 81). Prominent accumulations occur along the steep coasts of Polaris Forland, on east and west mountain faces in Hauge Bjerge (fig. 41) and along the scarp limiting the central plain to the north.

The talus along inland scarps contain appreciable areas of alluvial and solifluctcd material. In some of the deeper valleys, especially in north-west Polaris Forland, the scree forms talus cones, often coalescing forms; these grade into alluvial cones produced at the bottom of gullies by rapid stream action. In places deposits are deformed by periglacial processes producing patterned ground. Rock glaciers also occur (fig. 82); on the map they are marked by a terrace symbol.

Solifluction deposits and features

The solifluction map unit covers all deposits produced, or substantially reworked, by the slow movement or flowage of generally waterlogged surficial material downslope. Hall Land is underlain by permafrost; water percolation is restricted to the uppermost metre and thus solifluction processes are rife. All slopes of prominent unconsolidated material, particularly in areas of perennial or seasonal snow banks, are influenced by solifluction action.

The majority of solifluction deposits have been mapped on the northern highlands and plateau where extensive glacial till covers the rolling hill terrain. The deposits are mainly in the form of solifluction sheet or mantle composed of unsorted locally derived material developed on veneers of bedrock or glacial till. In a few places solifluction lobes or tongues are developed generally where gradients are steep; in those cases where a lobe has a steep front, a terrace symbol has been used on the map – for example for the landslipped masses at the junction of the Polaris Bugt moraine with the northern highlands.

Where prominent soliflucted veneers of bedrock debris and glacial drift occur, but are not of sufficient area or consistency to warrant mapping as a discrete unit, the symbol 'S' is used to denote the general area of the solifluction. In many cases this symbol indicates waterlogged ground or soliflucted striped ground (fig. 87) and in places soliflucted streams, where material moved

Fig. 82. Rock glacier in scree slopes at Kap Lupton. Top of scree is about 200 m a.s.l.

downslope is concentrated in small open gullies or rills. Elsewhere 'S' denotes areas primarily of colluvial rock veneers in which the role of water is minimal.

Aeolian deposits and features

Both wind-blown accumulations and wind erosional phenomena occur in Hall Land; however, neither form prominent features of the landscape and only one area of supposed aeolian deposits is indicated on the map.

Sediments

Small accumulations occur on the central plain where shallow depressions are filled with wind-blown sand and silt, e.g. desiccation cracks and the depressed edges of larger polygons. On the extensive, and flat, raised fluviatile terraces of 'Gråstenelv', aeolian sands form small accumulations in relic fluvial channels, as well as being mixed with relatively coarse-grained gravels that form the surface of channel bars.

The only supposed aeolian deposits shown on the map occur on the 'Gråstenelv' raised plain, east of 'Monument'. The map symbol refers to crescent-shaped features discovered during the photogrammetric interpretation; in the field these features are indistinct. Diapositive prints with higher resolution than normal paper prints are necessary for their identification. The features are light coloured with a relief of less than 1 metre and they are orientated with the convex side facing west. Average wave-length and amplitudes are 30 and 20 m, respectively. Based on their consistent shape and orientation, and the knowledge that wind-blown deposits occur on the terraces, the crescent-shaped bodies were interpreted as miniature barkhans or parabolic dunes (Dawes, 1977, 1979).

Conditions for dune accumulation are present in Hall Land, viz. dry climate, strong prevailing winds and the availability of fine-grained material (i.e. widespread and friable moraine, fluvial and marine plains); dune accumulations have been reported from similar desert-like terrain in Peary Land (Fristrup, 1953). However, sand dunes have not been observed in the field in Hall Land. A traverse west of 'Pileheden' airfield by the author in 1982 failed to confirm a dune origin for the crescent-shaped features, and sand accumulation in the area examined does not reach the proportions necessary for dune construction.

The few crescent-shaped features observed in the field are thus now interpreted as relic channel bars (fig. 83). The crests of the bars are characteristically lighter in colour (in summer drier); the corresponding channels are darker. Aeolian sand and silt occurs in association with these features, particularly as a matrix in the loose surface of the gravel on the bars. This aeolian material may accentuate the lighter colour of the relic bars, thus rendering the features more visible on aerial photographs.

Ventifacts

Apart from the effects of wind abrasion seen on artifacts at various historical sites (including Halls Grav in the west), ventifacts are fairly common in Hall Land. Polished and faceted surfaces have developed on erratic blocks and cavernous weathering characterises many of the large erratic blocks conspicuous on the central plain. Limestone blocks have deeply pitted surfaces (rather than honeycombed), a phenomenon in which solution weathering must have played an important role.

Permafrost and periglacial features

North Greenland is underlain by perennially frozen ground – permafrost. On the central plain, in the area of 'Pileheden' airstrip, the permafrost level is on average 80–90 cm below surface (Lollike & Olesen, 1976), with the deepest level at just over 1 m (Davies *et al.*, 1959; Davies, 1961b). According to Davies (1972) the permafrost is as shallow as 60 cm on some raised terraces of 'Gråstenelv', and ground ice can also develop at this

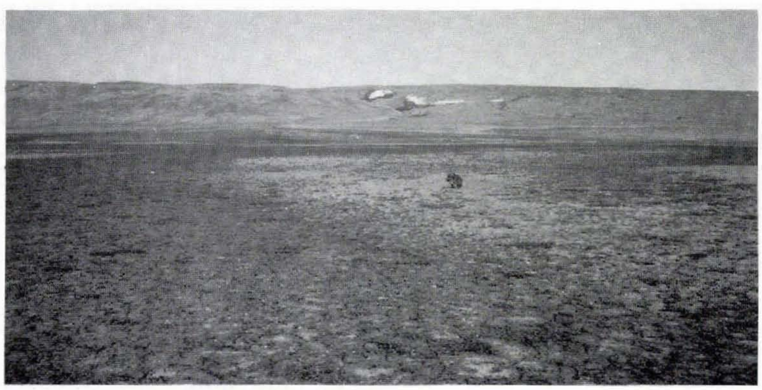


Fig. 83. Light-coloured relic channel bar on raised fluviatile terraces of 'Gråstenelv'. Aeolian silt occurs in surface gravel. Bedrock escarpment to northern highlands in background.

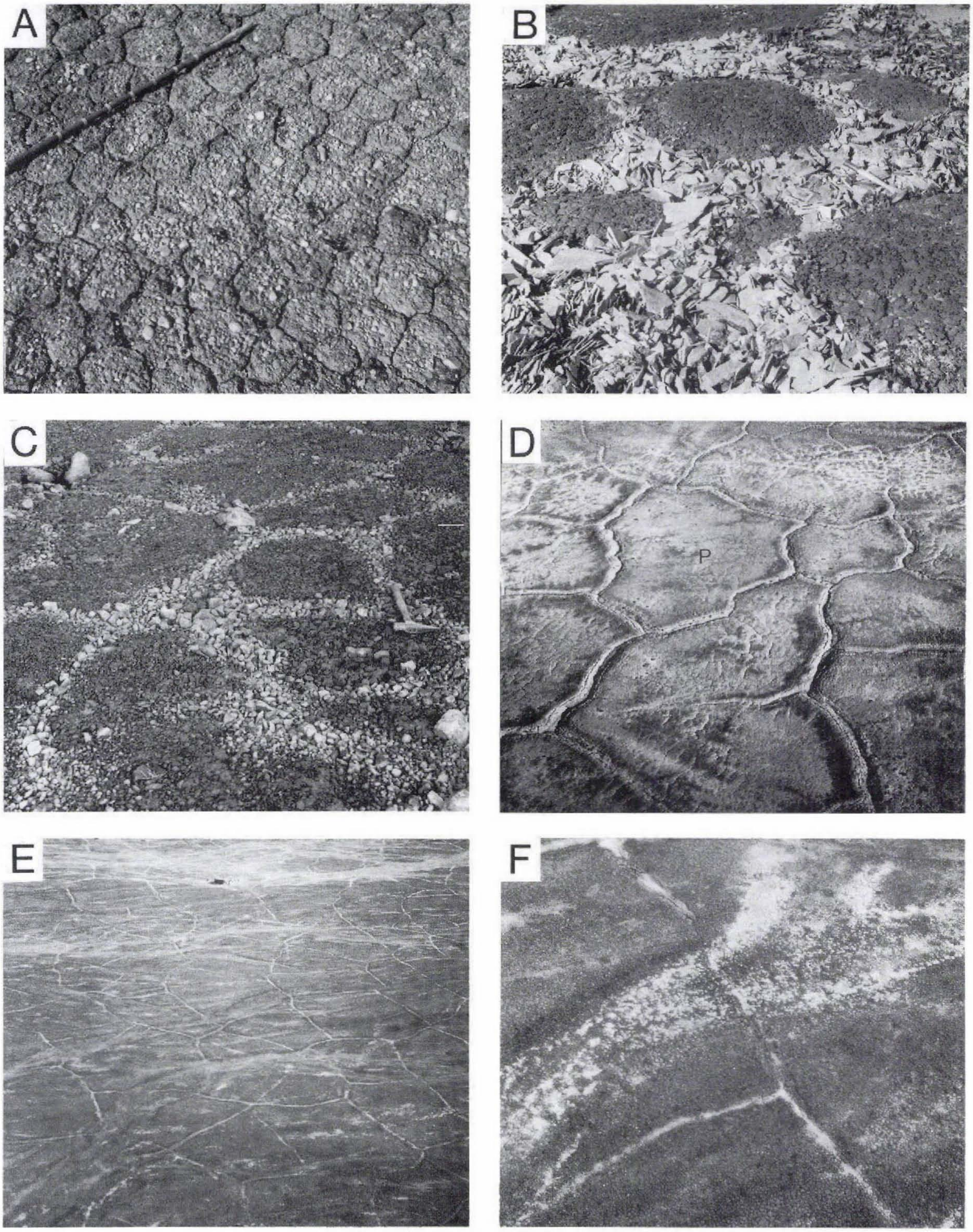


Fig. 84. Diversity of polygonal ground. A: desiccation crack polygons; B: non-sorted stone nets; C: well-sorted stone circles; D: low-centred sorted polygons showing smaller polygons in central area; E: large-scale depressed-edge polygons; F: shallow relief border of E showing superimposition of frost polygons. *Scale.* A: intervals on shaft are 10 cm; B, C: hammer is 35 cm long; D: polygon marked P is about 35 m across; E: hut is about 8 m long and largest polygons over 100 m across; F: width of borders are about 1 m. *Location.* A, E, F: 'Gråstenelv' raised fluviatile plain, F is from 'Pileheden' airstrip with tyre marks visible; B, C: valley deposits south of 'Sun Mark Mountain'; D: fluviatile gravels, valley east of Offley Ø.

depth. At Thule Air Base (fig. 2) the continuous permafrost zone is estimated 500 m thick (Roethlisberger, 1961); in Hall Land, 600 km to the north, the zone is assumed to be considerably thicker.

Features usually regarded as being due to, or radically controlled by, permafrost are common in Hall Land. In this section periglacial structural features, including patterned ground and thermokarsts, shown on the map by letter symbols, are described. Slope transverse features, e.g. distinct breaks in slope associated with stone or soil steps, are shown by the terrace symbol. Features due to seasonal freezing of the active layer and to frost action on bedrock, i.e. frost heave, riving, shattering, splitting (congelifraction and congeliturbation processes of Bryan, 1946) are also common, but no indication of these phenomena is given on the map.

Patterned ground

Patterned ground is used in the sense of Washburn (1956, 1979) to include all sorted or unsorted patterns in soil, loose rock fragments, or bedrock, e.g. polygons, circles, nets, stripes, etc. Polygonal ground is the commonest form in Hall Land and is developed in many surficial deposits, more rarely on bedrock. Polygons vary markedly in type and size, and on the basis of field data, supported by aerial photography, six main types are recognised. A variety of 'irregular polygons' also occur in connection with thermokarst topography.

Desiccation crack polygons – type 1

These features are widely developed in fine-grained lithologies and represent the smallest type of non-sorted polygons. The polygons are typically symmetrical and characterised by tetragonal, pentagonal or hexagonal shape, with sides up to about 15 cm long, and with narrow but deep, limiting cracks (fig. 84A). Such polygons are common throughout the area in fine-grained lithologies, for example on the central plain.

Stone nets and circles – type 2

Nets and circles are common in many areas of glacial and fluviatile deposits. Mesh shape is typically pentagonal (less commonly tetragonal or rarely hexagonal) varying to circular. Such polygons show considerable variation in the degree of sorting, from crude (fig. 85) or well-defined non-sorted stone nets (fig. 84C) to extremely well-sorted, high-centre polygons composed of a central, raised fine-grained core with lower coarse-grained borders (fig. 84B). In lowland areas dominated by coarser rock fragments, soil or debris islands bear witness to the high degree of sorting.

Low-centred polygons – type 3

These polygons are characterised by very distinct frost trenches or channels producing marked topographic expression

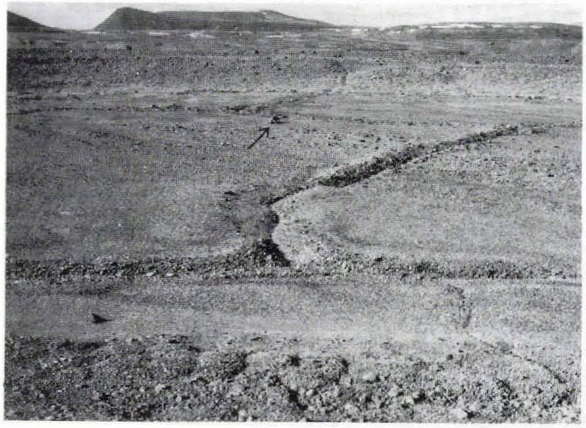


Fig. 85. Low-centred polygonal trough showing typical raised rim and sorting. Foreground, small non-sorted polygons. Rucksack, arrowed, as scale. Glaciofluvial gravels, valley east of Offley Ø.

(fig. 84D). They are commonly developed on glacial drift and on fluvial and marine gravel terraces. The polygons are typically of low-centred type; sorting of material is seen at the trenches that commonly show a raised rim (fig. 85). They generally have an irregular, angular and asymmetric mesh shape being commonly tetragonal or pentagonal, and varying in size from several metres to tens of metres on a side. Trenches vary from linear to sinuous and they can be up to 60–70 cm deep and 1–2 m wide at surface level. Small polygons of both unsorted and sorted type can occur in the central part of larger forms (fig. 84D).

Depressed-edge polygons – type 4

On parts of the central plain certain large polygons are characterised by having extremely shallow bordering depressions. These depressed-edge polygons were interpreted by Davies (1961b) as ancient, mainly non-active features. I arge size and indistinct character make it difficult to detect these polygons in the field; from the air they are conspicuous by the lighter colour of the border depressions (fig. 84E).

In plan these polygons resemble the low-centred type described above with a notably irregular angular mesh and commonly with four or five sides; triangular forms also occur. The polygons vary considerably in size, with length of sides ranging from 20 to 80 m; individual polygons can reach up to 100 m or more across. The polygons are characterised by extremely shallow relief; the border depressions can be over 1 metre wide but only 10–15 cm deep. Dessication cracks are superimposed across the borders (fig. 84F).

Rectilinear polygons – type 5

In some areas of lacustrine clay and silt a distinct type of rectilinear polygon occurs. Such polygons are well seen in the large dried-up lake south of Atka Elv delta where a very regular parallel-sided, often square shaped, pattern is apparently controlled by the lake outline (fig. 19). These polygons reach up to 20 m across and they are bounded by relatively narrow but deep ditch-like depressions.

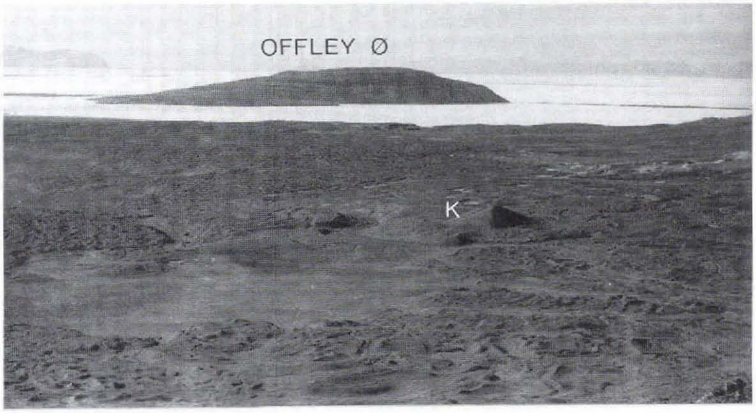


Fig. 86. Fluvial and glaciofluvial deposits in valley east of Offley Ø showing thermokarst landscape with isolated kames (K), together with flat-topped terraces showing only minor karsts. Washington Land (left) and Ellesmere Island (right) in distance.

Bedrock polygons – type 6

Polygonal ground on bedrock was recognised during the photogrammetric work in the limestone terrain of Hauge Bjerge and upland plateau farther south. In some of these areas rock accumulations and ridge-like features characterised by frost shattered and heaved debris and rubble were interpreted in the field as congelifraction and congeliturbation deposits, the form of which was controlled in some places by a prominent joint direction. The polygons identified on the aerial photographs have a general rectilinear shape, bounded by somewhat raised ridge-like sides that may be 10–20 m long. They resemble certain polygonal features described by Davies (1961c) from Peary Land.

Thermokarst topography

Prominent areas of karst-like topography occur most notably in the fluvial and glaciofluvial deposits, such as those on the seaward sides of Atka Elv and 'Gråstenelv' and in the valley east of Offley Ø (figs 20 & 86). This landscape is formed of irregular mounds and depressions, often including linear and polygonal troughs and ridges, and is characterised by small thaw or cave-in lakes and beaded drainage (fig. 87). This land surface is the result of freezing and thawing of ground ice and a subsequent settling of the ground.

In those areas examined in the field, for example east of Offley Ø, polygonal structures are of irregular form, but they are generally of the low-centred type with raised borders (type 3 above) suggesting a general thawing and decay of the coincident ice-wedges.

Map representation of periglacial features

Mapping of periglacial phenomena was essentially accomplished during the photogrammetric interpretation, and generally only those areas displaying prominent or widespread features identifiable on aerial photographs are marked on the map. It proved impossible photogrammetrically to differentiate between all the types of patterned ground distinguished in the field, and map representation has entailed grouping; five groups are recognised on the map by symbols. These are placed approximately in the centre of an area showing perigla-

Fig. 87. Thermokarst topography in glaciofluvial gravels showing irregular form of ice-wedge polygons, troughs and ridges, and thaw lakes. In background solifluctcd striped ground (S) below outwash terraces. Lake (L) is about 80 m long.

cial phenomena; several more or less equally spaced symbols indicate fairly continuous outcrop.

P symbol

This symbol for undifferentiated, patterned ground is the most common symbol used. It covers all forms of marked ground that cannot be categorised by any of the other symbols given below. It predominantly represents polygonal ground of types 3 and 4 above, but the symbol is also used in areas that display more than one type of patterned ground, e.g. polygons, circles, striped ground. It also covers patterned ground developed on bedrock, as well as rectilinear polygonal ground (types 5 & 6 above).

LP symbol

This symbol is reserved for polygonal ground in which the size of some polygons is above 75 m across. Not all polygons in such a marked area have necessarily this large dimension. It covers examples of polygons of types 3 and 4 above. Important areas of large-scale polygons occur on the raised fluviatile terraces of Atka Elv and 'Gråstenelv'.

SP symbol

This symbol designates areas characterised by small-scale polygons of type 2 above, as well as prominent hummocky ground. The latter includes both earth hummocks due to intense freezing and thawing of saturated soil and also some areas of hummocky moraine (kettled surface) in which the irregularities may be in part due to deposition from ice rather than to periglacial action.

DP symbol

This symbol refers to all extensive areas of patterned ground in which there is a marked down-slope orientation of the main frost-crack or drainage system. It covers striped ground and down-slope furrows and rills. Several areas characterised by tetragonal polygons, which may have a crude to well developed rectilinear shape, are also included under this symbol.

IP symbol

Thermokarst landscape with associated ice-wedge polygons occurring predominantly in areas of glaciofluvial deposits are indicated by this symbol. In the three main areas, viz. Atka Elv, 'Gråstenelv' and the valley east of Offley Ø, important moraine deposits also occur. Thus the irregular land surfaces indicated by the symbol are products of both the melting of ground ice (in association with the continuous permafrost zone or of a stagnant glacier remnant) and, or in part, a primary depositional feature as in classical knob-and-kettle topography (e.g. Gravenor & Kupsch, 1959).

Discussion

The map distribution of periglacial features is heterogeneous, e.g. polygons of types 1 and 2 above cannot generally be discerned on the aerial photographs used; thus absence of symbols in a particular area does not necessarily imply a lack of periglacial activation. In addition, both active and inactive (fossil) periglacial features are present; as a rule the inactive features, being in the process of degradation, are less conspicuous on aerial photographs. In spite of these shortcomings some significant distribution patterns are revealed.

Active patterned ground characterises much of the glacial and glaciofluvial deposits on the northern and southern highlands, as well as the sands and gravels composing the raised terraces of Atka Elv and 'Gråstenelv'. In contrast active patterned ground is not conspicuously developed on the finer-grained marine deposits and associated reworked moraines which outcrop over the central lowland. The maximum development of patterned ground in permafrost regions is usually seen in fine-grained lithologies; in Hall Land this is, in general, not the case. Davies (1961b) noted anomalous distributions of periglacial features in various parts of northern Greenland and suggested a relationship to the peculiar arid climatic conditions that prevail, i.e. low precipitation, high evaporation and generally low moisture content of the active zone. In general the occurrence of thermokarst topography may be taken as an indication of the overall degradation of the permafrost (Washburn, 1979).

Inactive periglacial features occur in the form of the depressed-edge polygons that characterise the raised fluvial plains of 'Gråstenelv' and which are in places also discernible on the marine or glaciomarine deposits. The destruction of these features is apparently well advanced; they are of extremely shallow relief, polygon surfaces are wind abraded and the bounding depressions contain aeolian silt. Consequently this patterned ground is very indistinct and in places only traces of the original polygonal structure are preserved as delicate colour changes in the soil surface. The degree of indistinctiveness can be illustrated by the fact that many examples can only be detected on diapositive aerial photographs – normal paper prints do not possess sufficient high quality resolution.

It is noteworthy that these large-scale, fossil polygons display active desiccation crack networks (fig. 84F); frost action in the uppermost levels of the active zone is dominant over any permanent activation of the surface by deeper periglacial processes. The depressed-edge polygons are either no longer being activated by the permafrost, or any activation is minimal and is exceeded by degradation processes. As pointed out by Davies (1961b) these polygons are presumably indicative of a period when there was greater precipitation and thus much higher moisture content in the active zone.

Quaternary history

The Quaternary record in Hall Land is incomplete and detailed reconstruction of the chronology is impossible. The stratigraphic sequence, supported by radiometric age dates, indicates that late Pleistocene and Holocene deposits are present; nothing is known about the early Quaternary history. Various geochronological models have been put forward for the late Quaternary evolution of the northern Nares Strait region (Davies *et al.,* 1959; Davies, 1961a, 1972; Weidick 1972, 1976a, b, 1978; England, 1976, 1982, 1983, 1985; England & Bradley, 1978; Kelly & Bennike, 1985) and some of these authors have suggested correlations between glacial deposits of Hall Land and established glacial stages of North America and Europe.

Much of the previous discussion has centred on the limit of the last glaciation (late Wisconsin–Weichsel), i.e. whether this represented an extensive expansion of the Inland Ice or a much reduced glacial stage with an advance not far beyond its present position (see e.g. Weidick, 1976a, b; England, 1976, 1983; England & Bradley, 1978). As might be expected, the most prominent and fresh moraines on Hall Land are those supposed to have been formed during the last glaciation. Some interpretations placed on these ice-margin moraines are compiled into fig. 88, together with interpretations based on the present study.

The present mapping has provided a framework in which the Quaternary history can be viewed (Table 4). The age, stratigraphic sequence and detailed relationship of many of the deposits are, however, still poorly understood, although recent ^{14}C dates (England, 1985; Kelly & Bennike, 1985), added to the previously available absolute ages (Rubin & Alexander, 1960; Weidick, 1978; Knuth, 1981), allow some events to be placed within a chronostratigraphic framework.

Two contrasting types of glaciation have affected the region: (1) a continental-type Pleistocene ice-sheet that blanketed the entire peninsula and surrounding coast, and (2) a younger latest Pleistocene–Holocene glacial regime dominated by the readvance of glacial tongues through the fjords. Within these two glaciation regimes a number of events can be recognised.

Pleistocene

The earliest recognisable glaciation was expansion of the Greenland ice-sheet to a position more than 100 km north-west of its present margin, as shown by extensive ground moraine and crystalline erratics. The absolute age of this major advance (in which the Greenland ice was confluent with the Ellesmere Island ice-sheet) is uncertain, but England & Bradley (1978) suggest that the deposition phase on Ellesmere Island ended > 80 000 B.P.

It is unlikely, however, that all the ground moraine mapped dates from this glaciation maximum. For example, Kelly & Bennike (1985) record the presence of a reworked marine shell fauna (characterised by *Balanus balanus*) in ground moraine of northern Polaris Forland and this suggests the existence of an interglacial period sometime in the late Pleistocene.

The ground moraine and associated marginal ridges of the inner part of the central plain may represent recessional positions of the main ice-sheet retreat or even a younger fluctuation of the margin. On the other hand the 'Monument' moraines are probably connected to a later glacial event caused by readvance through Polaris Bugt and Newman Bugt (Davies, 1972). However, the age of these ice-margin features is uncertain. Davies (1972) concluded that they were deposited prior to the Würm–Wisconsin glaciation; England (1985) suggests they were formed prior to 33 000 B.P. This latter suggestion is based on ^{14}C dates of > 33 000 B.P. on marine shells from localities flanking the 'Monument' moraines on the east and west. Some of the dated shells were collected in life position, and England concluded that glacier ice had not passed over these silts since deposition and that deglaciation of central Hall Land must have occurred prior to 33 000 B.P. This contrasts with the glacial model of Weidick (1978) who, on the basis of ^{14}C dates on shells from the inner plain at 85–80 m a.s.l. concluded that deglaciation and initial emergence of the central area began before or at 9500 B.P. It is interesting to note that these dates are corroborated by those reported by England (1985) on shells from the same general area (110–105 m a.s.l.) that are between 9500–9000 B.P. In this scenario, supported by the recent work of Kelly & Bennike (1985), the inner ice-margin features of the central plain are regarded as latest Pleistocene in age, possibly representing the older stages of the Polaris – Newman Bugt moraine systems.

Late Pleistocene – Holocene

The relatively fresh, marginal moraines that occur along the coastal regions characterise the younger glacial regime – movement of ice through the fjords. It is, however, uncertain whether these ice-margin features – Kap Ammen, Kap Sumner, Newman Bugt, Polaris Bugt and Petermann Fjord moraines – belong to one or several glacial events, or even, if *all* were derived from a southerly source. While it seems clear that the latter three moraines were derived contemporaneously from two major southerly derived glacial lobes, there is still

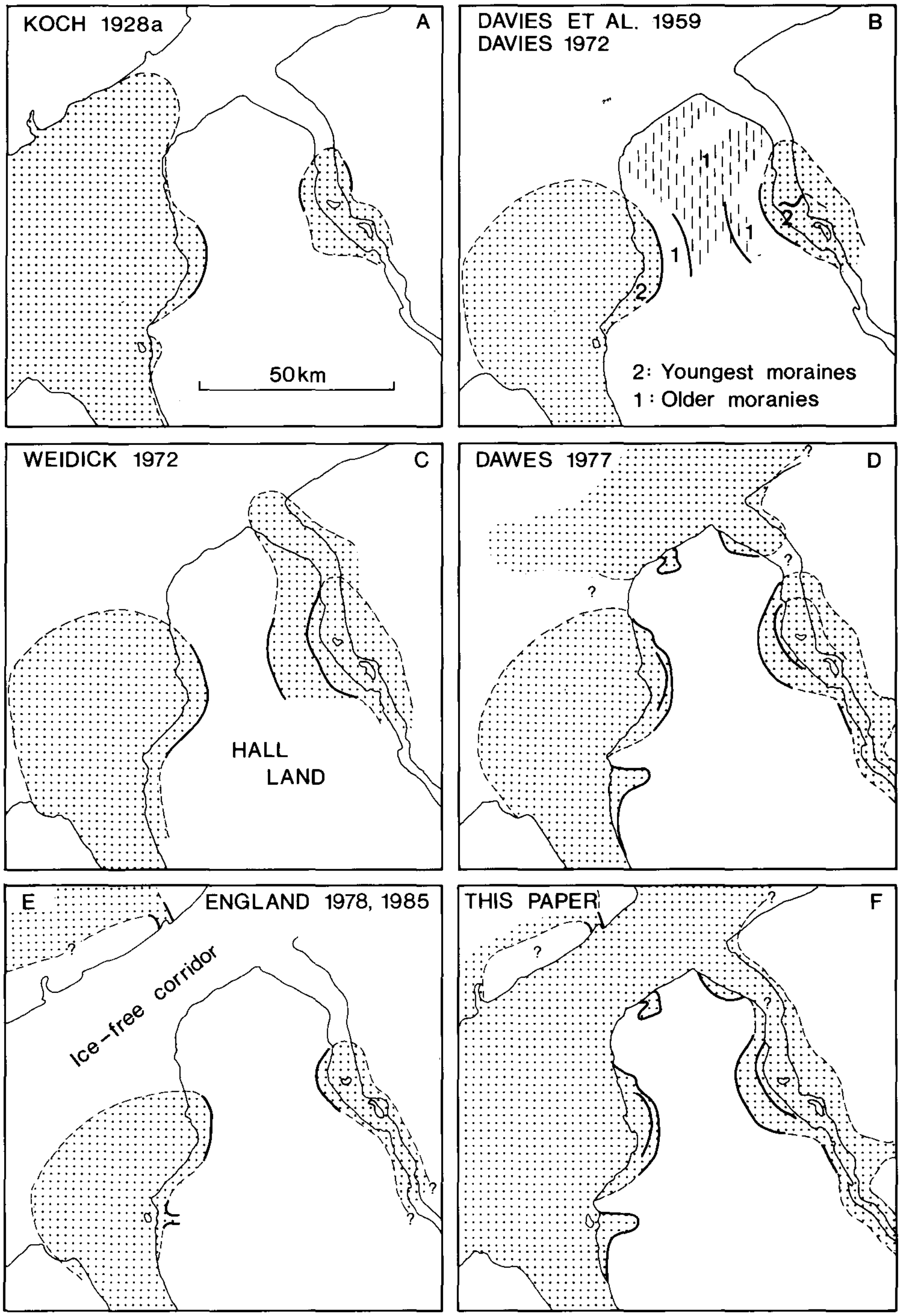


Fig. 88. Sketch summarising major positions of glacier fronts as suggested by several authors. A: positions regarded as main regression stage in deglaciation; B–F: positions regarded as maximum limit of glacial readvance. A, C and E are adapted from published maps; B is compiled from text description in cited papers; D and F are interpretations based on present study. Stippled areas represent ice, heavy lines marginal moraine ridges, broken line inferred ice boundaries. Respective ages of moraines inferred in B, with an alternative interpretation shown on C.

Table 4. Summary of main events in the Quaternary history of Hall Land

PERIOD STAGE	AGE B.P.	GLACIAL REGIME	GLACIAL CONDITION & MAIN PROCESSES	DEPOSITS & FEATURES
HOLOCENE	PRESENT	POST-GLACIAL	Small fluctuations in Inland Ice margin and fjord glaciers	Historic moraines, outwash, alluvium, deltas
	1500–2000		Final stages of glacio-isostatic uplift	Raised delta terraces
	6000		End of main deglaciation, glaciers reach fjord heads	
	8500	FJORD GLACIATION	Isostatic uplift, rapid emergence of land. Recession of ice from mid-fjord positions	Raised fluvial & marine deposits and terraces, raised shorelines in central plain
PLEISTOCENE (Wisconsin-Weichsel-Würm)			Stabilisation of ice fronts in mid-Polaris and Newman Bugt. Sea in central plain	Polaris Bugt, Petermann Fjord & Newman Bugt moraines, outwash, marine silts
	11 000		Main ice advance of fjord glaciers, ice-ridge in Robeson Channel, coalescence of Greenland and Ellesmere ice. Glacial loading, large lake in central plain	Fjord sculpturing, Kap Ammen and Kap Sumner moraines, lacustrine silts
	15 000–20 000	?	Readvance of fjord glaciers and Inland Ice	Reworked shells in moraine, ?Monument moraine
	>33 000	CONTINENTAL ICE-SHEET	Marine transgression over coast and inland lowlands	Silts on lowland plain, overlying moraine
UPPER	>80 000		Southerly recession of ice-cover from Robeson Channel area	Ground moraine
	?		Maximum extension of Inland Ice to reach Ellesmere Island. Total ice-cover	Granitic erratics, glacial sculpturing

uncertainty as to the maximum limits reached by the advance (fig. 88). Davies (1972) and England (1985) regard the Polaris – Newman Bugt moraines as end moraines demarcating the last ice limit; Weidick (1971, 1972) viewed these as marking a major retreat stage of a single glacial advance that reached the head of the fjords.

The relationship between the Kap Sumner and Kap Ammen moraines is not known; neither is that between these moraines and the Polaris – Newman Bugt moraines. Based on morphology and composition the two northern moraines may well be of comparable age and reflect a major glacial stage when the northward advance through the fjords reached the outer coast to produce an ice-filled Robeson Channel; conversely they could reflect the glacial conditions of the shelf across which ice from another source (Ellesmere Island or Nares Strait – Arctic Ocean) encroached on Greenland (fig. 88). In the former scenario the Kap Sumner and Kap Ammen moraines must pre-date the Polaris – Newman Bugt moraines, either representing the distal stages of the same glacial advance or a distinctly older glacial event. In the northern source model, age relationship cannot be defined, but all the moraines might be of comparable age representing the end moraines of two opposing ice systems.

The Kap Ammen moraine indicates that an appreciable thickness of ice must have been present in Robeson Channel. The idea that this may have been derived from a non-Greenland source stems from the lack of correlatable high-elevation ice-margin features farther south; the only well preserved marginal moraine approaching the elevation of the Kap Ammen moraine (540 m) is the northern part of the Polaris Bugt moraine at 300 m a.s.l. It has been documented by England (1976, 1978) and England & Bradley (1978) that at least two expansions of Ellesmere Island ice reached as far as northern Nares Strait: one prior to 33 000 B.P. and the late Wisconsin advance that receded around 8400–8100 B.P. These authors conclude, however, that for at least the last 30 000 years an ice-free corridor existed along the Kennedy Channel – Robeson Channel depression separating the Greenland and Ellesmere Island ice sheets (fig. 88).

The presence of the northern moraines on Hall Land conflicts with this conclusion; the Kap Ammen moraine suggests that northern Nares Strait could have been closed in the late Wisconsin by an ice ridge. This supports the conclusion of Weidick (1976a) who suggested, on regional considerations, ice closure until about 8000 B.P. Whether the ice ridge was composed essentially of Ellesmere Island or of Greenland derived ice must remain speculative. A high stress coalescence of opposing ice sheets, or a substantial influence of an Ellesmere Island component, could have caused a relatively high elevation ridge necessary to produce the Kap Ammen moraine.

The initial dating of the Polaris – Newman Bugt moraines as Holocene, at between 6100 ± 300 B.P. and 3780 ± 300 B.P. (Rubin & Alexander, 1960; Davies, 1961a) has been modified by later work (Weidick, 1978; England, 1985; Kelly & Bennike, 1985) that dates the glacial advance from which the moraines were derived as Pleistocene. According to England the initial retreat of the ice from the two moraine systems occurred between 8000 and 8300 B.P. – comparable to the initial regression of the late Wisconsin Ellesmere Island ice from the coast of Robeson Channel; in contrast, Weidick (1978) concluded that deglaciation began much earlier, and recent work by Kelly & Bennike (1985) indicates that the ice had retreated from middle Newman Bugt by at least 9000 B.P. Age dates reported by England (1985) on shells distal to the moraines near the marine limit fall into the range 8200 – > 33 000 B.P., and this is interpreted by England as indicating the prolonged stability of a 'full glacial sea' in central Hall Land (and the surrounding Nares Strait region) for at least 25 000 years, and thus indicative of a correspondingly stable ice load at isostatic equilibrium.

The distribution of moraines in Hall Land (supported by the regional pattern of ^{14}C dates) conflicts with this conclusion. Firstly, the northern moraines indicate that an ice-ridge occupied northern Nares Strait at some time prior to 8000 B.P., and, secondly, the northern limits of the Newman Bugt and Polaris Bugt glacial ice lay further north than shown by England, enclosing *both* ends of the central plain, so that an extensive glacial lake occurred there at least during part of the period envisaged for England's 'full glacial sea'. Appreciable deglaciation *had* taken place before the Polaris Bugt and Newman Bugt glaciers reached the frontal positions envisaged by England (1985).

Furthermore, the existence of an open sea for more than 25 000 years might be expected to be reflected more accurately in the marine record, both in evidence of the initial transgression prior to 33 000 B.P. and in a more complete age range of marine fauna. The shell dates cited by England (1985) as evidence of the stable marine limit in central Hall Land fall into the two extremes of the critical range 8200 to > 33 000 B.P., i.e. no dates are known between those of 9580 ± 140 and > 33 000 B.P. England (1985) regards the dates as reflecting one geological event, i.e. a 'full glacial sea'; it is equally likely that the dates refer to two quite distinct marine episodes. In addition, of the two shell samples dating the lower limit of the range, only one from the eastern end of the plain 5 km from the Newman Bugt coast at 144 m a.s.l. is regarded as *in situ* material.

Little is known about the significance of the large time gap shown by the dated shell samples, and the presence of more than one marine interval in the glacial sequence may yet be demonstrated. In this context the earlier mentioned discovery of reworked shells (of uncertain age) in degraded moraines (Kelly & Bennike, 1985) is noteworthy; these moraines are considered to be southerly derived and thus pre-date the Polaris – Newman Bugt moraines. The central plain may have been affected by a glacial event following the deposition of the marine sediments dated at > 33 000 B.P. The dates reported by Weidick (1978) and England (1985) from the interior of the central plain in the general area around 'Monument' at between 9500–9000 B.P. are regarded as significant. England (1985) interprets these dates as evidence for the continuing presence of his 'full glacial sea'; they could equally reflect penetration of the sea into the central area at this time; marine transgression connected with initial deglaciation.

In summary, the late Wisconsin glacial-marine chronostratigraphy is not yet fully unravelled. While the spectacular size of the Polaris – Newman Bugt moraines may indicate a fairly long and stable period of glacial deposition (which at least in part took place under submarine conditions), this could have occurred in a few thousand years prior to 10 000 B.P. Deglaciation from the mouths of the fjords probably started around 10 000 B.P. (Kelly & Bennike, 1985). The Kap Ammen and Kap Sumner moraines may reflect an older glacial event but these moraines are regarded as much younger than the marine deposits dated in Hall Land at > 33 000 B.P.

In contrast, the Holocene chronology is better elucidated. The Polaris – Newman Bugt moraines are overlain both on distal and proximal sides by marine deposits. Moraine surfaces show evidence of water erosion and the glacial deposits are cut by marine terraces. Well-developed delta terraces on the east and west coasts indicate a gradual land emergence following the withdrawal of glacial ice from the inside of the Polaris – Newman Bugt moraines. Shells from the surface of the Polaris Bugt moraine at 102 m and 105 m a.s.l. give ages of 7385 ± 190 B.P. and 7600 ± 100 B.P. (England, 1985; Kelly & Bennike, 1985) suggesting that the main part of the ridge was submerged until at least that time. The detailed time framework for the stages of deglaciation, during which glacial lobes retreated up Petermann Fjord and Newman Bugt, remains to be fully elucidated. However, the initial regression to the heads of the fjords was probably complete well before 7000 B.P. (Kelly & Bennike, 1985). The recession probably continued beyond the position of the present ice margin, after which the ice readvanced to its present limits (Weidick, 1976a).

Several ice-margin features and terminal moraine outcrops in the south-west are up to 8 km from the Inland Ice margin. The north-western outlet glacier is less than 5 km from the Petermann Fjord moraine and its former position to the west is marked by several morainal ridges. These marginal moraine features close to the Inland Ice are of uncertain age. They probably represent regression stages of the main deglaciation rather than younger deposits of a glacial readvance.

Radiometric dating work on archaeological sites by Knuth (1967a, b, 1981, 1983) has provided dating of lower marine terrace levels and thus of the later stages of glacio-isostatic uplift. In Hall Land an Independence I site in Polaris Bugt, dated by the ^{14}C method on musk-ox horn-core at around 4300 B.P., has a relation to a sea-level less than 21 m above present; in Peary Land the Independence I culture (4470–3975 B.P.) is related to a former sea-level of 10–15 m. Dating of the Independence II culture at around 3390–2385 B.P. (Knuth, 1981) is related to a former sea-level around 5–7 m above present so that the extended period of glacio-isostatic uplift probably ended at around 2000–1500 B.P.

The historic moraines represent the youngest glacial stage on Hall Land. In historic time, Inland Ice and glacier lobes in North Greenland have only shown small fluctuations. In general, small readvances can be documented in the last century, and since 1920 there has been a small recession of glacial lobes (Davies & Krinsley, 1962). For example, the Petermann Gletscher, studied initially in 1872 by Bessels (1879) and in 1876 by Coppinger (1877) and shown to have a floating snout, was recorded by Koch (1928a) in 1922 to have essentially the same position. In 1960 the glacier snout was estimated to be less than 6 km south of the 1922 position (Davies & Krinsley, 1962); in the past 25 years the position of the snout has not changed radically, although changes in morphology and shape are evident.

Acknowledgements

This study formed part of a research programme supported by GGU, the Technical University of Denmark (DTH) and the Danish Natural and Technical Science Research Councils (Dueholm, 1979). The field work on which the map is based (1965) was supported by GGU and the Geological Survey of Canada (GSC). I am very grateful to numerous persons who have contributed to the many stages of the study.

Photogrammetric work. Keld S. Dueholm for his master role in organisation and participation in the various phases of the photogrammetric and digital mapping and for introducing me to the photogrammetric techniques used at the Institute of Surveying and Photogrammetry, DTH; Hans F. Jepsen for collaboration and help during the computer-supported mapping programme at GGU; Ole Ørslev and Olav Winding, photogrammetric operators, for friendly cooperation – the former participated in experiments with aerotriangulation, digitisation of the terrain and geological mapping.

Field work and data. The late Jan H. Allaart for good field companionship and use of field notes; T. I. Hauge Andersson (Geodetic Institute) for information about ground control stations in Hall Land; Robert L. Christie (GSC) for organisation of the field logistics; and Ole Bennike, John England (Univ. of Alberta), Michael Kelly, Anker Weidick and William E. Davies (U.S. Geological Survey) for information and discussions on the Quaternary geology. To the latter I owe a special thanks for always being willing to delve into his notes and memory to provide information collected many years ago.

Map compilation. Lis Duegaard, Gurli E. Hansen, Ulla Jensen and Nina Kerrn-Jespersen for draftsmanship; Lis Duegaard was responsible for the final preparation of both geological and topographical maps.

Map production. The topographic contours were plotted out (in 1978) at Søkortarkivet, Copenhagen (now Nautisk Afdeling, Farvandsdirektoratet); both topographical and geological map sheets were printed (in 1985) at the Geodetic Institute, Copenhagen.

Manuscript. O. Bennike, K. S. Dueholm, R. L. Christie, M. Kelly, H. F. Jepsen, J. S. Peel, A. Weidick and A. K. Higgins for critically reading relevant sections of the text and their suggestions for improvement; the latter reviewed the manuscript in its entirety. Esben Glendal for various drafts of the manuscript and for meticulous preparation of the final text.

Illustrations. O. Bennike, Tom L. Harland, Niels Henriksen, Henrik Stendal and Martin Sønderholm for providing photographs reproduced as figs 26B, 63B, 64 ,72–3, 75B; 76A; 22, 58, 61–2, 66–7, 71, 74, 81, 87; 17, 41, 75A, 76B, 77, 79, 82; 16, 28, 54, respectively. The last four named persons undertook photography in 1985 specifically for this report. Bente Thomas for drafting of figures; and Jakob Lautrup, Ole Sand and Jacob Fernqvist for photographic reproductions. Aerial photographs are published with the permission (A. 200/87) of Geodætisk Institut, Denmark.

References

AAC 1951: Newman Bay (8 D II), Greenland. USAF Aeronautical Approach Chart, 1:250 000, 1st Edition. St. Louis: USAF Aeronautical Chart and Info. Center.

Allaart, J. H. 1965: The Lower Paleozoic sediments of Hall Land, North Greenland. Unpubl. intern. GGU rep., 11 pp.

Allaart, J. H. 1966: Hall Land, Northwest Greenland. *Pap. geol. Surv. Can.* **66–1,** 4 only.

AMS 1953: Polaris Forbjerg, Greenland; Canada. Topographical map, 1:250 000 NU 19, 20, 21, 22, 23, 24–10, Series C501, Edition 1. Washington D. C.: U. S. Army Map Service, Corps of Engineers.

Armstrong, H. A. 1983: The Early Silurian conodont micropalaeontology of the North Greenland carbonate platform. Unpubl. Ph.D. thesis, Univ. Nottingham, U. K., 387 pp.

Armstrong, H. A. & Dorning, K. J. 1984: Silurian palynomorphs from the Chester Bjerg Formation, Hall Land, western North Greenland. *Rapp. Grønlands geol. Unders.* **121,** 97–103.

Balkwill, H. R. 1978: Evolution of Sverdrup Basin, Arctic Canada. *Bull. Am. Ass. Petrol. Geol.* **62,** 1004–1028.

Bendix-Almgreen, S. E. 1976: Palaeovertebrate faunas of Greenland. *In* Escher, A. & Watt, W. S. (edit.) *Geology of Greenland,* 534–573. Copenhagen: Geol. Surv. Greenland.

Bendix-Almgreen, S. E. & Peel, J. S. 1974: Early Devonian vertebrates from Hall Land, North Greenland. *Rapp. Grønlands geol. Unders.* **65,** 13–16.

Bengtsson, T. 1977: Et automatisk koordinatregistreringsudstyr. *Meddr Inst. Surv. Photogramm. Danm. Tekn. Højsk.* **9,** 57–70.

Berry, W. B. N. & Boucot, A. J. 1970: Correlation of the North American Silurian rocks. *Spec. Pap. geol. Soc. Am.* **102,** 289 pp.

Berry, W. B. N., Boucot, A. J., Dawes, P. R. & Peel, J. S. 1974: Late Silurian and early Devonian graptolites from North Greenland. *Rapp. Grønlands geol. Unders.* **65,** 11–13.

Bessels, E. 1876: *Scientific results of the United States Arctic Expedition Steamer 'Polaris', C. F. Hall commanding.* Vol. I. Physical observations. Washington: U. S. Print. Off., 966 pp.

Bessels, E. 1879: *Die amerikanische Nordpol-Expedition.* Leipzig: Von Wilhelm Engelmann, 647 pp.

Blake, E. V. 1874: *Arctic experiences: containing Capt. George E. Tyson's wonderful drift on the ice-floe, a history of the Polaris Expedition, the cruise of the Tigress, and rescue of the Polaris survivors.* New York: Harper & Brothers, 486 pp.

Boucot, A. J. & Hurst, J. M. 1979: Silurian biogeography: revision of the North Atlantic Realm in the Llandovery. *Rapp. Grønlands geol. Unders.* **91,** 57–60.

Bryan, K. 1946: Cryopedology, the study of frozen ground and intense frost-action, with suggestions on nomenclature. *Am. J. Sci.* **244,** 622–642.

Christie, R. L. 1967: Reconnaissance of the surficial geology of north-eastern Ellesmere Island, Arctic Archipelago. *Bull. geol. Surv. Can.* **138,** 50 pp.

Coppinger, R. W. 1877: Report on Petermann Fiord, May and June 1876. *In* Journals and Proceedings of the Arctic Expedition, 1857–6, under the command of Captain Sir George S. Nares, R. N., K. C. B. *Parliamentary Paper* **C–1636,** 444–446. London.

Davies, W. E. 1961a: Glacial geology of northern Greenland. *Polarforschung* **5,** 94–103.

Davies, W. E. 1961b: Surface features of permafrost in arid areas. *In* Fristrup, B. (edit.) Physical geography of Greenland. *Folia geogr. Danica* **9,** 48–56.

Davies, W. E. 1961c: Polygonal features on bedrock, North Greenland. *Prof. Pap. U.S. geol. Surv.* **424–D,** D218–219.

Davies, W. E. 1972: Landscape of northern Greenland. *Spec. Rep. Cold Reg. Res. Engng Lab.* **164,** 67 pp.

Davies, W. E. & Krinsley, D. B. 1962: The recent regimen of the ice cap margin in North Greenland. *Publ. Ass. Int. Hydrol. Scient.* **58,** 119–130.

Davies, W. E., Needleman, S. M. & Klick, D. W. 1959: *Report on Operation Groundhog (1958) North Greenland. Investigations of ice-free sites for aircraft landings, Polaris Promontory, North Greenland.* U.S.A.F. Cambridge Res. Center, Bedford, 45 pp.

Davis, C. H. 1876: *Narrative of the North Polar Expedition U.S. Ship Polaris, Captain Charles Francis Hall commanding.* Washington: Gov. Print. Off., 696 pp.

Dawes, P. R. 1966: Lower Palaeozoic geology of the western part of the North Greenland fold belt. *Rapp. Grønlands geol. Unders.* **11,** 11–15.

Dawes, P. R. 1971: The North Greenland fold belt and environs. *Bull. geol. Soc. Denmark* **20,** 197–239.

Dawes, P. R. 1972: Precambrian crystalline rocks and younger sediments of the Thule district, North Greenland. *Rapp. Grønlands geol. Unders.* **45,** 10–15.

Dawes, P. R. 1976: Precambrian to Tertiary of northern Greenland. *In* Escher, A. & Watt, W. S. (edit.) *Geology of Greenland,* 248–303. Copenhagen: Geol. Surv. Greenland.

Dawes, P. R. 1977: Geological photo-interpretation of Hall Land: part of the regional topographical–geological mapping of northern Greenland. *Rapp. Grønlands geol. Unders.* **85,** 25–30.

Dawes, P. R. 1978: Crystalline basement complex of the Victoria fjord arch. Unpubl. intern. GGU rep., 4 pp.

Dawes, P. R. 1979: Computer-supported photogrammetric, geological and topographic mapping of Hall Land, North Greenland. *Meddr Inst. Surv. Photogramm. Danm. Tekn. Højsk.* **10,** 147–170.

Dawes, P. R. 1982: The Nyeboe Land fault zone: a major dislocation on the Greenland coast along northern Nares Strait. *In* Dawes, P. R. & Kerr, J. W. (edit.) Nares Strait and the drift of Greenland: a conflict in plate tectonics. *Meddr Grønland, Geosci.* **8,** 177–192.

Dawes, P. R. 1984: Operation Grant Land 1965–1966; a geological exploration programme in Ellesmere Island and North Greenland. *Rapp. Grønlands geol. Unders.* **121,** 5–17.

Dawes, P. R. & Haller, J. 1979: Historical aspects in the geological investigation of northern Greenland. Part 1: New maps and photographs from the 2nd Thule Expedition 1916–1918 and the Bicentenary Jubilee Expedition 1920–1923. *Meddr Grønland* **200**(4), 38 pp.

Dawes, P. R. & Henriksen, N. 1973: Plan for kartering af Nordgrønland med henblik på publikation af 1:500,000 kort. Unpubl. intern. GGU rep., 30 pp.

Dawes, P. R. & Peel, J. S. 1981: The northern margin of Greenland from Baffin Bay to the Greenland Sea. *In* Nairn, A. E. M., Churkin, M. & Stehli, F. G. (edit.) *The ocean basins and margins 5, The Arctic Ocean,* 201–264. New York & London: Plenum Press.

Dawes, P. R. & Peel, J. S. 1984: Biostratigraphic reconnaissance in the Lower Palaeozoic of western North Greenland. *Rapp. Grønlands geol. Unders.* **121,** 19–51.

Dawes, P. R. & Soper, N. J. 1973: Pre-Quaternary history of North Greenland. *In* Pitcher, M. G. (edit.) Arctic geology. *Mem Am. Ass. Petrol. Geol.* **19,** 117–134.

Dawson, G. M. 1887: Notes to accompany a geological map of the northern portion of the Dominion of Canada, east of the Rocky Mountains. *Geol. Nat. Hist. Surv. Can. Ann. Rep.* **11** (R), 56 pp.

DMTS 1960: Kennedy Channel N.W. 80/72 Canada–Greenland (Denmark). Topographic map, 1:500 000. 3rd Edition. Ottawa: Dept. Mines & Technical Surveys.

Dueholm, K. S. 1973: Untraditional topographic mapping in central West Greenland. *Rapp. Grønlands geol. Unders.* **65,** 26–28.

Dueholm, K. S. 1975: En vurdering af det eksisterende topografiske materiale i Nordgrønland med henblik på dets anvendelighed ved en geologisk kortlægning i målestoksforholdet 1:250.000 – 1:500.000. Unpubl. rep. to GGU. Dansk Specialfotogrammetri i/s, 59 pp.

Dueholm, K. S. 1976: New instruments for geological photointerpretation and mapping. *Rapp. Grønlands geol. Unders.* **80,** 144–148.

Dueholm, K. S. 1978: Programbeskrivelser: Lineær prædiktion, kurveudglatning, plotter program. Unpubl. intern. rep. Inst. Surv. Photogramm. Danm. Tekn. Højsk., 55 pp.

Dueholm, K. S. 1979: Geological and topographical mapping from aerial photographs. *Meddr Inst. Surv. Photogramm. Danm. Tekn. Højsk.* **10,** 9–146.

England, J. 1976: Postglacial isobases and uplift curves from the Canadian and Greenland high arctic. *Arct. Alp. Res.* **8,** 61–78.

England, J. 1978: The glacial geology of northeastern Ellesmere Island, N.W.T., Canada. *Can. J. Earth Sci.* **15,** 603–617.

England, J. 1982: Postglacial emergence along northern Nares Strait. *In* Dawes, P. R. & Kerr, J. W. (edit.) Nares Strait and the drift of Greenland: a conflict in plate tectonics. *Meddr Grønland, Geosci.* **8,** 65–75.

England, J. 1983: Isostatic adjustments in a full glacial sea. *Can. J. Earth Sci.* **20,** 895–917.

England, J. 1985: The Late Quaternary history of Hall Land, northwest Greenland. *Can. J. Earth Sci.* **22,** 1394–1408.

England, J. & Bradley, R. S. 1978: Past glacial activity in the Canadian high arctic. *Science* **200,** 265–270.

Etheridge, R. 1878: Palæontology of the coasts of the Arctic lands visited by the late British Expedition under Captain Sir George Nares, R.N., K.C.B., F.R.S. *Q. Jl geol. Soc. Lond.* **34,** 568–636.

Feilden, H. W. 1877: The Post-tertiary beds of Grinnell Land and North Greenland. *Ann. Mag. nat. Hist.* (4), **20,** 483–489.

Feilden, H. W. 1895: Note on the erratic blocks of Polaris Bay and other localities in North Greenland. *Geol. Mag.* (4), **2,** 378–379.

Feilden, H. W. & De Rance, C. E. 1878: Geology of the coasts of the Arctic lands visited by the late British Expedition under Captain Sir George Nares, R.N., K.C.B., F.R.S. *Q. Jl geol. Soc. Lond.* **34,** 556–567.

Frederiksen, P. 1979: Boundary problems in digital terrain models. *Meddr Inst. Surv. Photogramm. Danm. Tekn. Højsk.* **10,** 195–201.

Frederiksen, P., Jacobi, O. & Justesen, J. 1978: Fourier-Transformation von Hohenbeobachtungen. *Z. Vermessungswesen* **103,** 64–79.

Frederiksen, P. & Knudsen, J. G. 1979: Color plot of the digital terrain model of Hall Land. *Meddr Inst. Surv. Photogramm. Danm. Tekn. Højsk.* **10,** 202–204.

Friderichsen, J. D. & Bengaard, H.-J. 1985: The North Greenland fold belt in eastern Nansen Land. *Rapp. Grønlands geol. Unders.* **126,** 69–78.

Fristrup, B. 1953: High arctic deserts. *19th Congr. geol. Int. Algeria* **7,** 91–99.

Gravenor, C. P. & Kupsch, W. O. 1959: Ice-disintegration features in western Canada. *J. geol.* **67,** 48–64.

Greely, A. W. 1886: *Three years of Arctic service. An account of the Lady Franklin Bay Expedition of 1881–84 and the attainment of the farthest north.* London: Richard Bentley & Son. Vol. I: 428 pp., vol. II: 444 pp.

Greely, A. W. 1888: *Report of the proceedings of the U.S. Expedition to Lady Franklin Bay, Grinnell Land.* Washington: Gov. Print. Off. Vol. 1: 545 pp., vol. 2: 738 pp.

Haller, J. & Kulp, J. L. 1962: Absolute age determinations in East Greenland. *Meddr Grønland* **171**(1), 77 pp.

Henriksen, N. & Jepsen, H. F. 1985: Precambrian crystalline basement at the head of Victoria Fjord, North Greenland. *Rapp. Grønlands geol. Unders.* **126,** 11–16.

Higgins, A. K., Mayr, U. & Soper, N. J. 1982: Fold belts and metamorphic zones of northern Ellesmere Island and North Greenland. *In* Dawes, P. R. & Kerr, J. W. (edit.) Nares Strait and the drift of Greenland: a conflict in plate tectonics. *Meddr Grønland, Geosci.* **8,** 159–166.

Higgins, A. K. & Soper, N. J. 1985: Cambrian – Lower Silurian slope and basin stratigraphy between northern Nyeboe Land and western Amundsen Land, North Greenland. *Rapp. Grønlands geol. Unders.* **126,** 79–86.

Higgins, A. K., Soper, N. J. & Friderichsen, J. D. 1985: North Greenland fold belt in eastern North Greenland. *In* Gee, D. G. & Sturt, B. A. (edit.) *The Caledonide Orogen: Scandinavia and related areas,* 1017–1029. New York: John Wiley & Sons.

Hurst, J. M. 1980: Silurian stratigraphy and facies distribution in Washington Land and western Hall Land, North Greenland. *Bull. Grønlands geol. Unders.* **138,** 95 pp.

Hurst, J. M. 1984: Upper Ordovician and Silurian shelf stratigraphy, facies and evolution, eastern North Greenland. *Bull. Grønlands geol. Unders.* **148,** 73 pp.

Hurst, J. M. & Kerr, J. W. 1982a: Upper Ordovician to Silurian facies patterns in eastern Ellesmere Island and western North Greenland and their bearing on the Nares Strait lineament. *In* Dawes, P. R. & Kerr, J. W. (edit.) Nares Strait and the drift of Greenland: a conflict in plate tectonics. *Meddr Grønland, Geosci.* **8,** 137–145.

Hurst, J. M. & Kerr, J. W. 1982b: Brecciated lineaments in Washington Land, North Greenland, and their relation to Nares Strait. *In* Dawes, P. R. & Kerr, J. W. (edit.) Nares Strait and the drift of Greenland: a conflict in plate tectonics. *Meddr Grønland, Geosci.* **8,** 193–198.

Hurst, J. M. & Surlyk, F. 1982: Stratigraphy of the Silurian turbidite sequence of North Greenland. *Bull. Grønlands geol. Unders.* **145,** 121 pp.

Hurst, J. M. & Surlyk, F. 1984: Tectonic control of Silurian carbonate shelf margin morphology and facies, North Greenland. *Bull. Am. Ass. Petrol. Geol.* **68,** 1–17.

Jackson, D. E. & Etherington, J. R. 1969: New Silurian cyrtograptid graptolites from northwestern Canada and northern Greenland. *J. Paleont.* **43,** 1114–1121.

Jeffreys, J. G. 1877a: The Post-tertiary fossils procured in the late Arctic Expedition; with notes on some of the Recent or living Mollusca from the same expedition. *Ann. Mag. nat Hist.* (4), **20,** 229–242.

Jeffreys, J. G. 1877b: Note (to paper on Post-tertiary beds of Grinnell Land and North Greenland by H. W. Feilden). *Ann. Mag. nat. Hist.* (4), **20,** 489–494.

Jepsen, H. F. & Dueholm, K. S. 1978: Computer supported geological photo-interpretation. *Rapp. Grønlands geol. Unders.* **90,** 146–150.

Jones, B. & Hurst, J. M. 1984: Autecology and distribution of the Silurian brachiopod *Dubaria. Palaeontology* **27,** 699–706.

Kelly, M. & Bennike, O. 1985: Quaternary geology of parts of central and western North Greenland: a preliminary account. *Rapp. Grønlands geol. Unders.* **126,** 111–116.

Kerr, J. W. 1967: Nares submarine rift valley and the relative rotation of north Greenland. *Bull. Can. Soc. Petrol. Geol.* **15,** 483–520.

Kerr, J. W. 1981: Evolution of the Canadian Arctic Islands; a transition between the Atlantic and Arctic Oceans. *In* Nairn, A. E. M., Churkin, M. & Stehli, F. G. (edit.) *The ocean basins and margins 5, The Arctic Ocean,* 105–199. New York & London: Plenum Press.

Knuth, E. 1967a: Archaeology of the Musk-ox Way. *Contr. Centre d'Etudes Arctiques Finno-Scand.* **5,** 70 pp.

Knuth, E. 1967b: The ruins of the Musk-ox Way. *Folk* **8–9,** 191–219.

Knuth, E. 1981: Greenland news from between 81° and 83° north. *Folk* **2–3,** 91–111.

Knuth, E. 1983: The northernmost ruins of the globe. *Folk* **25,** 5–21.

Koch, L. 1918: Oversigt over II Thuleekspeditions videnskabelige Resultater. *Naturens Verden* **2,** 494–509.

Koch, L. 1920: Stratigraphy of Northwest Greenland. *Meddr dansk geol. Foren.* **5**(17), 78 pp.

Koch, L. 1922: Note to maps of Melville Bay from Wilcox Point to Cape York and of North Greenland from 81°–83° 35'N, to 38–56°W. *Meddr Grønland* **65**(2), 77–88.

Koch, L. 1923: Preliminary report upon the geology of Peary Land, Arctic Greenland. *Am. J. Sci.* **5,** 189–199.

Koch, L. 1925: The geology of North Greenland. *Am. J. Sci.* **9,** 271–285.

Koch, L. 1926: Report on the Danish Bicentenary Jubilee Expedition north of Greenland 1920–23. *Meddr Grønland* **70,**1(1), 1–232.

Koch, L. 1928a: Contributions to the glaciology of North Greenland. *Meddr Grønland* **65**(2), 181–464.

Koch, L. 1928b: The physiography of North Greenland. *In* Vahl, H. *et al.* (edit.) *Greenland, vol. 1. The discovery of Greenland, exploration and nature of the country,* 491–518. Copenhagen & London: C. A. Reitzel & Oxford U.P.

Koch, L. 1929: Stratigraphy of Greenland. *Meddr Grønland* **73,**2(2), 205–320.

Koch, L. 1932: Map of North Greenland, scale 1:300 000, surveyed by Lauge Koch in the years 1917–23. 18 sheets. Copenhagen: Geodetic Inst.

Koch, L. 1933: The geology of Inglefield Land. *Meddr Grønland* **73,**1(2), 38 pp.

Koch, L. 1935: Geologie von Grönland. *In* Krenkel, E. (edit.) *Geologie der Erde.* Berlin: Gebrüder Borntraeger, 159 pp.

Koch, L. 1940: Survey of North Greenland. *Meddr Grønland* **130**(1), 364 pp.

Lane, P. D. 1984: Silurian trilobites from Hall Land and Nyeboe Land, western North Greenland. *Rapp. Grønlands geol. Unders.* **121,** 53–75.

Lane, P. D., Dawes, P. R. & Peel, J. S. 1980: A new Silurian *Hemiarges* (Trilobita) from North Greenland and the question of the Polaris Harbour Formation. *Rapp. Grønlands geol. Unders.* **101,** 45–53.

Larsen, P.-H. & Escher, J. C. 1985: The Silurian turbidite sequence of the Peary Land Group between Newman Bugt and Victoria Fjord, western North Greenland. *Rapp. Grønlands geol. Unders.* **126,** 47–67.

Laursen, D. 1972: The place names of North Greenland. *Meddr Grønland* **180**(2), 443 pp.

Lillestrand, R. L. 1974: North Greenland map rectification project. Unpubl. rep. to GGU, 26 pp.

Lillestrand, R. L. & Johnson, G. W. 1971. Cartography of North Greenland. *Surveying and Mapping* **31,** 233–250.

Lillestrand, R. L. Johnson, G. W. & Wells, D. E. 1968: Analysis of measurements made in northern Greenland during Project Nord – 1969. Unpubl. intern. rep. Control Data Corp., Minneapolis, 99 pp.

Lollike, J. G. & Oleson, O. 1976: Geologisk/geoteknisk rapport over rekognoscering for landingsbaner i Nordgrønland i sommeren 1975. Unpubl. intern. rep. Forsvarskommandoen, 93 pp.

Low, A. P. 1906: *Report on the Dominion Government Expedition to Hudson Bay and the Arctic Islands on board the D.G.S. Neptune 1903–1904.* Ottawa: Gov. Print. Bureau, 355 pp.

Madsen, F. 1984: Geodætisk Instituts aktiviteter i Nationalparken. *Forskning i Grønland/tusaut* **3/84,** 28–35.

Mayr, U. & de Vries, C. D. S. 1982: Reconnaissance of Tertiary structures along Nares Strait, Ellesmere Island, Canadian Arctic Archipelago. *In* Dawes, P. R. & Kerr, J. W. (edit.) Nares Strait and the drift of Greenland: a conflict in plate tectonics. *Meddr Grønland, Geosci.* **8,** 167–175.

McLean, R. A. 1977: Early Silurian (Late Llandovery) rugose corals from western North Greenland. *Bull. Grønlands geol. Unders.* **121,** 46 pp.

Nares, G. S. 1877: Journals and proceedings of the Arctic Expedition, 1875–76, under the command of Captain Sir George S. Nares, R.N., K.C.B. *Parliamentary Papers* 1875, 1876. London.

Nares, G. S. 1878: *Narrative of a voyage to the Polar Sea during 1875–6 in H.M. Ships 'Alert' and 'Discovery', with notes on the natural history edited by H. W. Feilden, F.G.S., C.M.Z.S. naturalist to the expediton.* London: Sampson Low, Marston, Searle and Rivington. Vol. 1: 395 pp, vol. 2: 378 pp.

Needleman, S. M. 1962: Arctic earth science investigations, Centrum Sø, Northeast Greenland, 1960. *Surveys in Geophysics* **138,** 132 pp.

Needleman, S. M., Klick, D. W. & Molineux, C. E. 1961: Evaluation of an Arctic ice-free landsite and results of C–130 aircraft test landings, Polaris Promontory, North Greenland 1958–1959. *Surveys in Geophysics* **132,** 70 pp.

Norford, B. S. 1967: Biostratigraphic studies, northeast Ellesmere Island and adjacent Greenland. *Pap. Geol. Surv. Can.* **67–1(A),** 12 only.

Norford, B. S. 1972: Silurian stratigraphic sections at Kap Tyson, Offley Ø and Kap Schuchert, northwestern Greenland. *Meddr Grønland* **195**(2), 40 pp.

Peel, J. S. 1975: *Beatricea* from the Ordovician of Hall Land, North Greenland. *Rapp. Grønlands geol. Unders.* **75,** 31–34.

Peel, J. S. 1979: Revision of Ordovician–Silurian gastropods from North Greenland. *Rapp. Grønlands geol. Unders.* **91,** 61–70.

Peel, J. S. 1984: Autecology and systematics of a new Silurian anomphalid gastropod from western North Greenland. *Rapp. Grønlands geol. Unders.* **121,** 77–87.

Peel, J. S. & Hurst, J. M. 1980: Late Ordovician and early Silurian stratigraphy of Washington Land, western North Greenland. *Rapp. Grønlands geol. Unders.* **100,** 18–24.

Petermann, A. 1874: Die Umkehr der Hall'schen Polar-Expedition nach den Aussagen der Offiziere. *Peterm. geogr. Mitt.* **20,** 252–261.

Pickerill, R. K., Hurst, J. M. & Surlyk, F. 1982: Notes on Lower Palaeozoic flysch trace fossils from Hall Land and Peary Land, North Greenland. *Rapp. Grønlands geol. Unders.* **108,** 25–29.

Poulsen, C. 1934: The Silurian faunas of North Greenland. I. The fauna of the Cape Schuchert Formation. *Meddr Grønland* **72,**2(1), 46 pp.

Poulsen, C. 1941: The Silurian faunas of North Greenland. II. The fauna of the Offley Island Formation. Part I Coelenterata. *Meddr Grønland* **72,**2(2), 28 pp.

Poulsen, C. 1943: The Silurian faunas of North Greenland. II. The fauna of the Offley Island Formation. Part II Brachiopoda. *Meddr Grønland* **72,**2(3), 60 pp.

Poulsen, C. 1974: Silurian Pelecypoda, Monoplacophora, and Gastropoda from the reefy facies of the Offley Island Formation of Washington Land and Offley Island (Northwest Greenland). *Biol. Skr.* **20**(7), 14 pp.

Prest, V. K. 1952: Notes on the geology of parts of Ellesmere and Devon Islands, Northwest Territories. *Pap. geol. Surv. Can.* **52–32,** 15 pp.

Rasmussen, K. 1927: Report on the II. Thule-Expedition for the exploration of Greenland from Melville Bay to De Long Fjord, 1916–1918. *Meddr Grønland* **65**(1), 1–180.

Roethlisberger, H. 1961: Seismic refraction soundings in permafrost near Thule, Greenland. *In* Raasch, G. O. (edit.) *Geology of the Arctic 2,* 970–980. Univ. Toronto Press.

Rubin, M. & Alexander, C. 1960: U.S. Geological Survey radiocarbon dates V. *Am. J. Sci. Radiocarbon Suppl.* **2,** 129–185.

Schuchert, C. 1923: Sites and nature of the North American geosynclines. *Bull. geol. Soc. Am.* **34,** 151–230.

Soper, N. J. & Higgins, A. K. 1985: Thin-skinned structures at the basin–shelf transition in North Greenland. *Rapp. Grønlands geol. Unders.* **126,** 87–94.

Stouge, S. & Stouge, G. B. 1984: An Upper Llandovery conodont fauna from eastern Hall Land, North Greenland. *Boll. Soc. Paleont. Italiana.* **23,** 103–112.

Stuart-Smith, J. H. 1970: Hydrocarbon potential of northern Greenland. *Bull. Am. Ass. Petrol. Geol.* **54,** 2507 only.

Surlyk, F. & Hurst, J. M. 1984: The evolution of the early Paleozoic deep-water basin of North Greenland. *Bull. geol. Soc. Am.* **95,** 131–154.

Trettin, H. P. & Balkwill, H. R. 1979: Contributions to the tectonic history of the Innuitian Province, Arctic Canada. *Can. J. Earth Sci.* **16,** 748–769.

Washburn, A. L. 1956: Classification of patterned ground and review of suggested origins. *Bull. geol. Soc. Am.* **67,** 823–865.

Washburn, A. L. 1979: *Geocryology. A survey of periglacial processes and environments.* London: Edward Arnold, 406 pp.

Weidick, A. 1971: Quaternary map of Greenland 1:2 500 000. Copenhagen: Geol. Surv. Greenland.

Weidick, A. 1972: Holocene shore-lines and glacial stages in Greenland – an attempt at correlation. *Rapp. Grønlands geol. Unders.* **41,** 39 pp.

Weidick, A. 1976a: Glaciations of Northern Greenland. – New evidence. *Polarforschung* **46**(1), 26–33.

Weidick, A. 1976b: Glaciation and the Quaternary of Greenland. *In* Escher, A. & Watt, W. S. (edit.) *Geology of Greenland,* 430–458. Copenhagen: Geol. Surv. Greenland.

Weidick, A. 1977: A reconnaissance of Quaternary deposits in northern Greenland. *Rapp. Grønlands geol. Unders.* **85,** 21–24.

Weidick, A. 1978: Comments on radiocarbon dates from northern Greenland made during 1977. *Rapp. Grønlands geol. Unders.* **90,** 124–138.

Willis, B. 1912: Index to the stratigraphy of North America. *Prof. Pap. U.S. geol. Surv.* **71,** 894 pp.

Note on place names in Hall Land

Some of the names used on the map and in the text are not authorised place names, i.e. recognised as official names by the Greenland Place Name Committee, and several, both authorised and unauthorised names, have been used in the literature for more than one location. In several cases toponymic usage is at variance with the conclusions on geographical positioning presented in the comprehensive study entitled 'The place names of North Greenland' (Laursen, 1972).

This appendix aims to clarify the use and positioning of place names in Hall Land. Authorised and unauthorised names are distinguished in Table 5, and locations as used in this paper are given in fig. 3.

In particular, the geographical locations of four names from two areas – north-western Polaris Forland and eastern Hauge Bjerge – need clarification. These names, coined by the Hall Expedition 1871–73, are: Kap Ammen, Chester Bjerg, 'Peculiar Pass Mountain' and Kap Porter. Chester Bjerg ('Chester Mt.') and 'Peculiar Pass Mt' appear on the official map of the expedition published by Davis (1876) (fig. 89), but the two other names are only found in the text of Bessels (1879), i.e. they are not on his map (fig. 4B). Table 6 and fig. 90 summarise the varying usage of these names.

Kap Ammen – Kap Porter

As evident from Table 6, the names Kap Ammen and Kap Porter have been used in published map sources for as many as three and four different locations, respectively. The usage of the names in this paper is at variance with the most recent published source (Laursen, 1972). The two names are found on the coast between Kap Lupton and Kap Sumner, a coast characterised by steep cliffs in which one major col exists – astutely named 'The Gap' (fig. 25). No ambiguity exists in the literature about the geographical location of 'The Gap' or the two capes, Kap Sumner and Kap Lupton, at either end of this coastline.

The naming of geographic features along this coast is referred to in the description of a northwards boat journey from Kap Lupton to Kap Sumner in June 1871 (Bessels, 1879, p. 287–88). Bessels' text contains observations on geological and physiographical features, and the position of Kap Ammen and Kap Porter can be fixed with a high degree of certainty.

Bessels (p. 288) writes, "Zwischen Cap Lupton und dem 'Dritten Cap' ist das Gestein schieferig und zeigt ähnliche Verwerfungen, wie in den Ravinen in der Nähe des Observatoriums. Die Schichten wechseln durch all Winkellagen von horizontal bis senkrecht. Die Klippen sind ausnahmslos steil, ohne jegliche Bildung eines Strandes. Etwas südlich von Cap Porter wird das Gestein jedoch massig, wie die Wände des Petermann-Fjord, und enthält, gleich jenen, ausgewaschene Höhlungen, die zahlreichen Teisten als Nistplatze dienten."

The Hall Expedition referred to three capes north of Kap Lupton. Bessels (p. 287) states, "Wir hatten uns gewöhnt, drei kleine Vorsprünge der Küste, nördlich von Cap Lupton, als das erste, zweite und dritte Cap zu bezeichen. Auf der Karte blieben dieselben ohne Namen." There can be little doubt that these three capes are at positions marked A, B and C on fig. 90 (cf. present topographic map). As Bessels correctly noted the coastal cliffs in this area are formed of severely folded sandstones and shales ('schieferig') with dips from horizontal to vertical. Of paricular significance is Bessels' reference to a change in geology just south of Kap Porter – a cape farther north along the coast from 'Dritten Cap'. His mention of the incoming of massive rocks and comparison with Petermann Fjord leaves no doubt that these rocks are the light-coloured carbonates forming the somewhat pointed cape 'D' – the contact with the darker well-bedded sandstones and shales being in the bay south of the cape (fig. 29). This limestone cape is the Kap Porter of the Hall Expedition.

There is also little doubt that this cape is identical with 'Promontory Point' of the Greely Expedition (fig. 4E; Greely, 1886, vol. 1, p. 217). Laursen (1972) adopts Greely's name for this limestone cape and places Kap Porter farther south in the position of Bessels' 'Zweite Cap'.

All maps indicate that Kap Ammen is farther north-east along the coast than Kap Porter, and Bessels' writing confirms this. He states (p. 288), "Nachdem Cap Ammen doublirt war, erhob sich eine leichte Brise aus Süden, welche das Eis mit unverhältnissmässig bedeutender Geschwindigkeit vor sich einhertrieb. Hinter uns begann die Fahrstrasse sich zu schlies-

Table 5. Place names from Hall Land used in this paper

Authorised				Unauthorised	
Kap Ammen	1	Offley Ø	1	'Gråstenelv'	5
Atka Elv	5	Petermann Fjord	1	'Monument'	1
Kap Buddington	1	Petermann Gletscher	2	'Observatory Bluff'	1
Chester Bjerg	1	Polaris Bugt	1	'Peculiar Pass Mountain'	1
Halls Grav	1	Polaris Forland	1	'Pileheden'	5
Hauge Bjerge	4	Kap Porter	1	'Saint Anthony's Nose'	1
Howgate Ø	1	Reynolds Ø	1	'Sun Mark Mountain'	1
Kayser Bjerg	4	Kap Sumner	1	'Teltbakken'	5
Kap Lupton	1	Thank God Harbour	1	'The Gap'	3
Kap Mary Cleland	1	Kap Tyson	1		
Newman Bugt	1				

Names given by: 1 = U.S. North Polar Expedition, 1871–73; 2 = British Admiralty Arctic Expedition, 1875–76; 3 = Lady Franklin Bay Expedition, 1881–84; 4 = Danish Bicentenary Jubilee Expedition, 1920–23; 5 = Operation Groundhog, 1958.

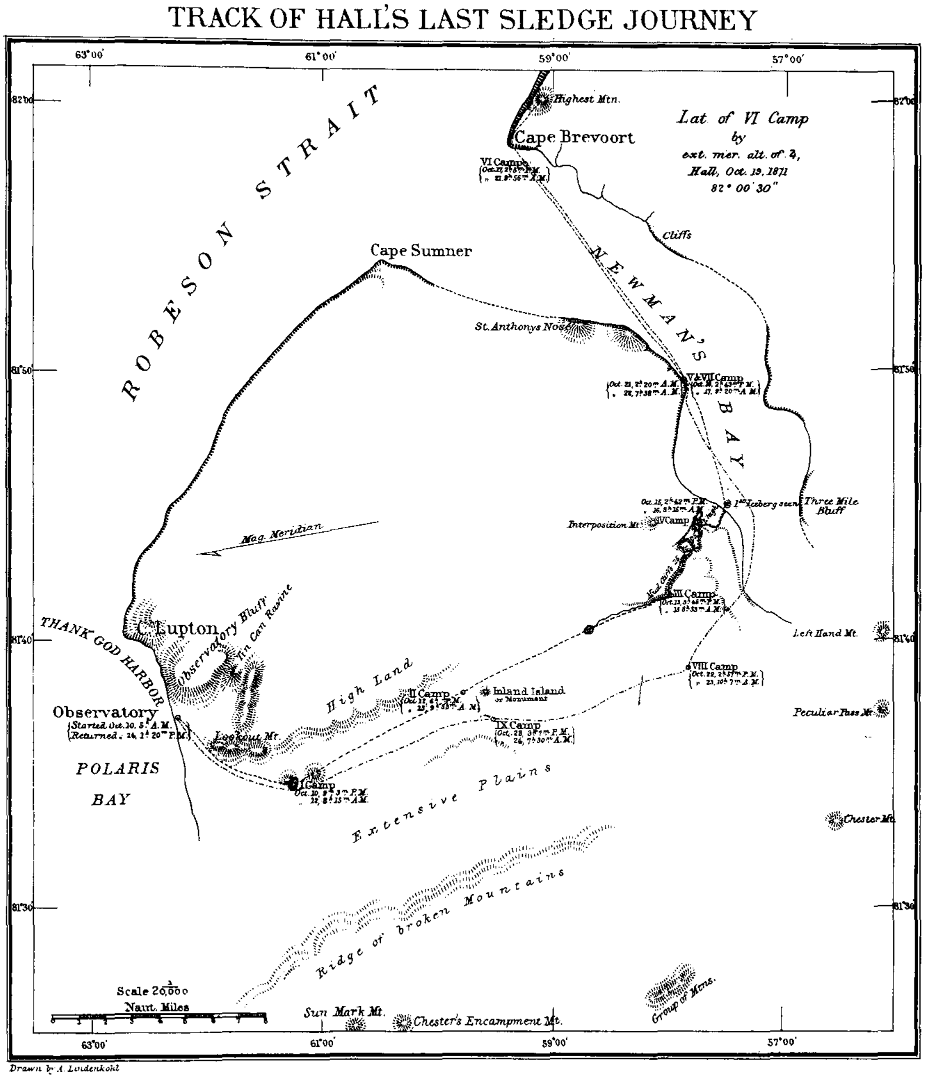


Fig. 89. Map of Polaris Forland from Davis (1876) showing positions of 'Chester Mt', 'Peculiar Pass Mt' and 'Left Hand Mt'.

sen, allein im Norden sahen wir noch immer offenes Wasser. Die Brise nahm bald wieder ab, das Segel wurde nutzlos und die Leute mussten sich in die Remen legen. Aber die Windstille war nur von geringer Dauer."

The only cape-like feature between Kap Porter and Kap Sumner along what is essentially a high, precipitous linear coast is at 'The Gap' (fig. 25), and Bessels' comments also infer that Kap Ammen is the southerly headland at that locality (position E on fig. 90). His reference to the presence of a southerly wind after passing Kap Ammen is highly significant. 'The Gap' is historically known as a windy site, for example the Greely expedition experienced problems in securing a boat cache there (Greely, 1886, vol. 1, p. 235, 304), and serious difficulties were encountered during Operation Grant Land in landing by aircraft at a field camp in the valley due to the strong funnel effect caused by the break in the cliffs.

Laursen (1972) shows Kap Ammen about 8 km north-east of 'The Gap' at what is a very slight bend in the coast. This cape cannot be located in the terrain and the positioning is not in accordance with the original coinage and use by Bessels (1879). It is concluded here that Kap Ammen is the bold limestone cliff at the southerly entrance to 'The Gap' (figs 25, 26A & 54).

Chester Bjerg – 'Peculiar Pass Mountain'

The name 'Chester Mt' was coined by the Hall Expedition for a mountain in eastern Hauge Bjerge and shown on a map in the official report (Davis, 1876, fig. 89). This is apparently the only map source on which the mountain is so named. The name Chester was subsequently used to describe the entire mountain range along the north-western coast of Polaris Forland (e.g. Petermann, 1874), a somewhat mysterious transference discussed by Laursen (1972). The naming of the highest peak (at c. 835 m) in this coastal range as 'Mt. Chester' can be attributed to Koch (1932, fig. 5A; position G on fig. 90); subsequently the name has appeared on some maps to denote a prominent peak south-west of 'The Gap' (fig. 5B; position H on fig. 90) – erroneously shown on these maps to be the highest

Table 6. Chart summarising the naming of twelve geographical localities from published sources (see fig. 90)

PUBLISHED ↓ SOURCE	GEOGRAPHICAL LOCATIONS											
	A	B	C	D	E	F	G	H	I	J	K	L
THIS PAPER	–	–	–	KAP PORTER	KAP AMMEN	–	CHESTER BJERG	735m	781 m	KAYSER BJERG 1110m	PECULIAR PASS MT	LEFT HAND MT
LAURSEN (1972)	–	KAP PORTER	–	PROMON-TORY POINT	–	KAP* AMMEN	–	–	CHESTER BJERG	KAYSER BJERG	LEFT HAND MT	–
LILLESTRAND & JOHNSON (1971)	KAP PORTER	–	–	–	–	–	–	–	–	–	–	–
DMTS (1960)	–	–	–	CAPE PORTER	–	CAPE* AMMEN	MT CHESTER 2600 ft	2900 ft	–	MT KAYSER 3500 ft	–	–
DAVIES ET AL. (1959)	–	KAP PORTER	–	KAP AMMEN	–	–	2900 ft	MOUNT* CHESTER 2900 ft	2526 ft	NO COVERAGE		
AMS (1953)	–	–	KAP PORTER	–	–	–	CHESTER BJERG 780m	884 ± m	770 m	KAYSER BJERG 1067 ft	–	NINA BANG BJERG
AAC (1951)	–	–	KAP* PORTER	–	KAP AMMEN	–	2559 ft	MOUNT CHESTER 2900 ft	2526 ft	MOUNT KAYSER 3500 ft	–	2400 ft
KOCH (1932)	–	–	–	CAPE PORTER	–	CAPE* AMMEN	MT CHESTER	–	770 m	MT KAYSER 1065 m	–	–
GREELY (1886)	–	–	–	PROMON-TORY POINT	–	–	–	–	–	–	–	–
HALL EXPEDITION	ERSTE CAP	ZWEITE CAP	DRITTE CAP	CAP PORTER	CAP AMMEN	–	–	–	–	CHESTER MT	PECULIAR PASS MT	LEFT HAND MT

Sources of Hall Expedition (U.S. North Polar Expedition, 1871–73) are Davis (1876) and Bessels (1879).
Asterisks: 'Mount Chester' on the map of Davies *et al.* is at position H^1 on fig. 90.
Kap Porter of AAC map is situated about two kilometres south of the river more or less at the location on the coastal cliffs used for an astronomical station by E. S. Frey in 1953.
Positioning of Kap Ammen to the north-east of 'The Gap' varies within 5 km in different sources.
DMTS = Department of Mines and Technical Surveys
AMS = Army Map Service
AAC = Aeronautical Approach Chart
For details of maps, see Table 1 and fig. 5.

in the coastal mountains. On the grounds of priority Laursen (1972) suggests transference of the name Chester Bjerg back to Hauge Bjerge to cover a peak east of 'Gråstenelv' (position I on fig. 90, 781 m on the present map), argued by Laursen to be the 'Chester Mt' of Davis' map (fig. 89). This practice is not adopted by the present author for several reasons:

(1) There is considerable doubt that peak 781 m is 'Chester Mt' of the Hall Expedition.

(2) The reason for the transference of the name to the northern mountains is unknown. It cannot be excluded that the U.S. Hydrographic Office, which collaborated on the compilation of the 1874 Petermann map, officially abandoned the initial positioning of the name for a single peak in favour of the entire northern mountain chain.

(3) The name Kayser Bjerg was given by Koch (1932, 1940) to the highest peak (*c.* 1100 m) in Hauge Bjerge that in my opinion is the most likely candidate for the 'Chester Mt' of the Hall Expedition. Kayser Bjerg is now well established in the literature, and all sources are agreed as to its placing (Table 6).

(4) The name Chester Bjerg for the summit at position G on fig. 90 has been used as the type area of a formal stratigraphic unit of the Silurian (Hurst & Surlyk, 1982). Movement of this name to a different locality would cause confusion in the geological literature.

Several summits above 700 m occur in eastern Hauge Bjerge, but it is reasonable to assume that the three peaks shown on Davis' map (fig. 89) – 'Chester Mt', 'Peculiar Pass Mt' and 'Left Hand Mt' – are to be found among the mountains positioned on fig. 90 between summits I (781 m) and L (732 m on AMS map, fig. 5C). Laursen (1972) assumes that the three peaks on Davis' map all lie to the west of Newman Bugt (i.e. in Hall Land) and he states categorically that 'Peculiar Pass Mountain' is the same peak that Koch (1932) later called Kayser Bjerg. The mountains in question can be seen on fig. 40.

The eastern end of the mountain range is cut by two relatively narrow and deep, distinctive, steep-sided cols, and the description of a mountain in this area as 'Peculiar Pass Mt' is astute. Which of the summits, 705 m or 598 m, on the present map is the actual summit so depicted on Davis' map is impossible to determine, but the latter summit flanked by the two parallel passes is perhaps the more likely candidate.

This descriptive naming by the Hall Expedition strongly militates against Laursen's conclusion that 'Peculiar Pass Mountain' is synonymous with Kayser Bjerg. Moreover, Kayser Bjerg stands out prominently as the highest and only snow clad peak of the Hauge Bjerge – 300 m higher than any other summit in eastern Hauge Bjerge (fig. 40). Choice of this

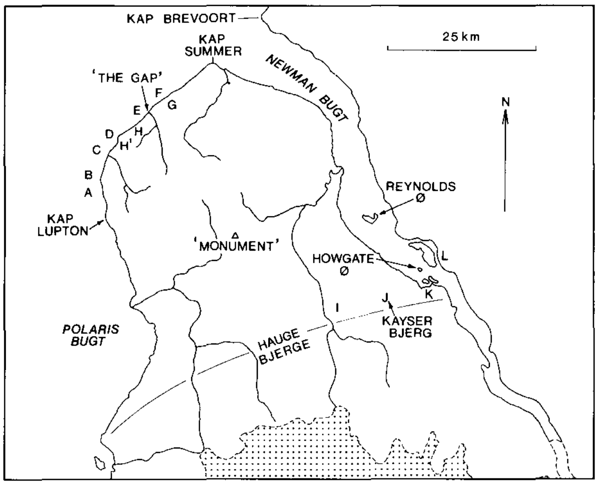


Fig. 90. Toponymic map showing localities A–L referred to in appendix and Table 6.

landmark by the expedition to honour H. C. Chester (1st Mate of the U.S.S. Polaris) rather than one of several other undistinctive summits to the west seems appropriate.

If these conclusions are correct, then on the basis of general spacing of the summits as shown on Davis' map, 'Left Hand Mt' must be situated in coastal Nyeboe Land, presumably at position L (fig. 90) – Nina Bang Bjerg on the AMS map (fig. 5C). This placing of 'Left Hand Mt' is compatible with the form of Newman Bugt shown on Davis' map, and also relative to the location of 'Three Mile Bluff'.

It should be noted that the actual peak in south-western Nyeboe Land to which Koch (1932) gave the name Nina Bang Bjerg is farther to the south-east than the mountain so named on the AMS map (cf. figs 5A–C, 40). Unfortunately Laursen (1972, plate IX) unaccountably transfers Nina Bang Bjerg, as well as 'Three Mile Bluff', to locations in north-western Nyeboe Land, 5 km and 20 km respectively distant from Kap Brevoort (fig. 90), while the latter locality is mistakenly described in the text (p. 351) as in 'E Hall Land'.

Howgate Ø

Howgate Ø is the smallest of five islands in Newman Bugt (fig. 12); on the present map the island is situated on the very edge of the northern sheet. Unfortunately the name has been misplaced and it appears on the southern sheet, suggesting Howgate Ø to be the eastern of a pair of islands close to the coast. This positioning has previously been given on the map published by Hurst & Surlyk (1982).

The name was given by the Hall Expedition; it is found on the map in Bessels (1879, fig. 4B) but not in the official account by Davis (1879, fig. 89). Only two islands, viz. Reynolds Ø, in mid-channel to the north, and Howgate Ø, are shown on early maps; the other three islands first appear on maps prepared from aerial photographs flown in 1947 (fig. 5B–C).

All maps indicate that Howgate Ø is of smaller areal extent than Reynolds Ø. Davis' and Bessels' maps indicate that Howgate Ø is located at the supposed head of the fjord at the eastern end of Hauge Bjerge; Koch (1932) was able to extend the fjord farther south but placed Howgate Ø too far north, as a continuation of the Reynolds Ø feature (fig. 5A).

No small islands or skerries occur near Reynolds Ø, and the only reasonable candidate for Howgate Ø is the small low-lying island in mid-channel (less than 25 m high) over 10 km to the south. The twin islands to the south are both smaller than Reynolds Ø but they are situated close to the mountainous coast. Despite their higher elevation – the eastern one reaches *c.* 100 m – it seems clear that these summits were not discerned as islands by the Hall Expedition or other early expeditions that viewed Newman Bugt from the north.

ISSN 0105 3507
AiO Print Ltd, Odense, Denmark

GRØNLANDS GEOLOGISKE UNDERSØGELSE
THE GEOLOGICAL SURVEY OF GREENLAND

GEOLOGICAL MAP OF HALL LAND, NORTH GREENLAND (northern part)

Geology map compilation by P.R. Dawes. Geology based on field work in 1965 by J.H. Allaart and P.R. Dawes and extensive aerial photo-interpretation by P.R. Dawes 1975-1978. Vertical aerial photographs at scale c. 1:54 000 by Greenarctic Consortium, Canada; oblique photographs by Geodætisk Institut, Denmark. Photogrammetric geological mapping of 76 stereo models at 1:50 000 was in Zeiss Planitop F-2 and computer-supported Kern PG-2 stereo-plotting instruments.

Photogrammetric operators: Ole Ørslev (Zeiss Planitop and Stecometer) and Olav Winding (Kern PG-2).

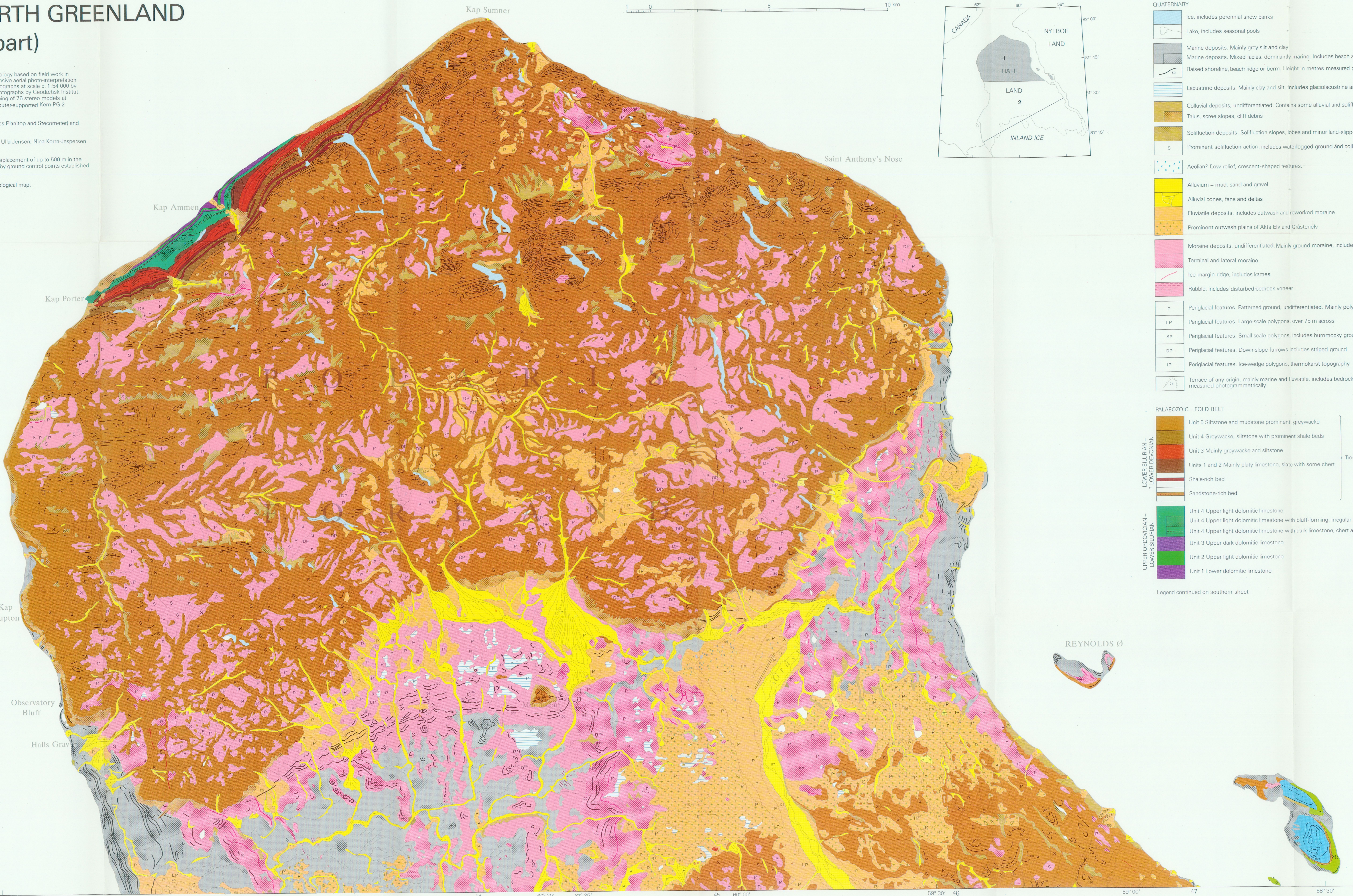
Draughtsmanship: Lis Duegaard assisted by Ulla Jensen, Nina Kerrn-Jespersen and Gurli Hansen.

UTM - grid: Zone 21. There is a maximum displacement of up to 500 m in the overall geographical position as determined by ground control points established in 1979 by the Geodætisk Institut.

A computer-supported photogrammetric geological map.

Printed 1985

c. 1:66 500



QUATERNARY

- Ice, includes perennial snow banks
- Lake, includes seasonal pools
- Marine deposits. Mainly grey silt and clay
- Marine deposits. Mixed facies, dominantly marine. Includes beach and lacustrine deposits
- Raised shoreline, beach ridge or berm. Height in metres measured photogrammetrically
- Lacustrine deposits. Mainly clay and silt. Includes glaciolacustrine and seasonal lake deposits
- Colluvial deposits, undifferentiated. Contains some alluvial and solifluction deposits
- Talus, scree slopes, cliff debris
- Solifluction deposits. Solifluction slopes, lobes and minor land-slipped masses
- S — Prominent solifluction action, includes waterlogged ground and colluvial mantle
- Aeolian? Low relief, crescent-shaped features.
- Alluvium – mud, sand and gravel
- Alluvial cones, fans and deltas
- Fluviatile deposits, includes outwash and reworked moraine
- Prominent outwash plains of Akta Elv and Gråstenelv
- Moraine deposits, undifferentiated. Mainly ground moraine, includes glaciofluvial drift
- Terminal and lateral moraine
- Ice margin ridge, includes kames
- Rubble, includes disturbed bedrock veneer
- P — Periglacial features. Patterned ground, undifferentiated. Mainly polygons
- LP — Periglacial features. Large-scale polygons, over 75 m across
- SP — Periglacial features. Small-scale polygons, includes hummocky ground
- DP — Periglacial features. Down-slope furrows includes striped ground
- IP — Periglacial features. Ice-wedge polygons, thermokarst topography
- Terrace of any origin, mainly marine and fluviatile, includes bedrock bench. Height in metres measured photogrammetrically

PALAEOZOIC – FOLD BELT

LOWER SILURIAN – ? LOWER DEVONIAN (Trough and slope facies)

- Unit 5 Siltstone and mudstone prominent, greywacke
- Unit 4 Greywacke, siltstone with prominent shale beds
- Unit 3 Mainly greywacke and siltstone
- Units 1 and 2 Mainly platy limestone, slate with some chert
- Shale-rich bed
- Sandstone-rich bed

UPPER ORDOVICIAN – LOWER SILURIAN (Shelf facies)

- Unit 4 Upper light dolomitic limestone
- Unit 4 Upper light dolomitic limestone with bluff-forming, irregular bedded carbonate buildups
- Unit 4 Upper light dolomitic limestone with dark limestone, chert and shale
- Unit 3 Upper dark dolomitic limestone
- Unit 2 Upper light dolomitic limestone
- Unit 1 Lower dolomitic limestone

Legend continued on southern sheet

Trykt ved Geodætisk Institut 1985

Enclosure (2/4)

THE GEOLOGICAL SURVEY OF GREENLAND

Report File no.
22296
Enclosure (3/4)

GRØNLANDS GEOLOGISKE UNDERSØGELSE
THE GEOLOGICAL SURVEY OF GREENLAND

G E U S
Report File no.
22296
Enclosure (4/4)

GRØNLANDS GEOLOGISKE UNDERSØGELSE
THE GEOLOGICAL SURVEY OF GREENLAND

Trykt ved Geodætisk Institut 1985.