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Greenland from Archaean to Quaternary
Descriptive text to the Geological map of
Greenland, 1:2 500 000

Niels Henriksen, A.K. Higgins, Feiko Kalsbeek
and T. Christopher R. Pulvertaft

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Archaean, Caledonides, Cenozoic, economic geology, geological map, Greenland, ice sheet, Mesozoic, offshore, orogenic belts, Palaeozoic, petroleum, Phanerozoic, Proterozoic, sedimentary basins.

Cover illustration

The cover design depicts mountains of the East Greenland Caledonian fold belt. The view, west of Mestersvig (located on map, page 4), is north over Bersærkerbræ and the northern part of the Stauning Alper to Kong Oscar Fjord with Traill Ø in the right background. The mountains up to 1800 m high are of the late Proterozoic Eleonore Bay Supergroup. The person shown is senior author Niels Henriksen, daily leader of geological mapping, and participant in field work in Greenland for more than 45 years. He retired in 2000.

Frontispiece: facing page

Major Caledonian syncline deforming reactivated Archaean basement gneisses containing amphibolite bands. Overlying rusty coloured middle Proterozoic metasediments (Krummedal supracrustal sequence) just visible in tight core of the fold. The intensity of deformation in the syncline clearly increases towards the core, where the basement gneisses become more strongly foliated. Some of the amphibolite bands were derived from cross-cutting basic intrusions, which are still discernable in the less severely deformed parts of the Archaean basement (Fig. 15, p. 24). The height of the section is c. 2000 m. South-west of innermost Nordvestfjord / Kangersik Kiatteq (c. 71°30'N), Scoresby Sund region, central East Greenland.

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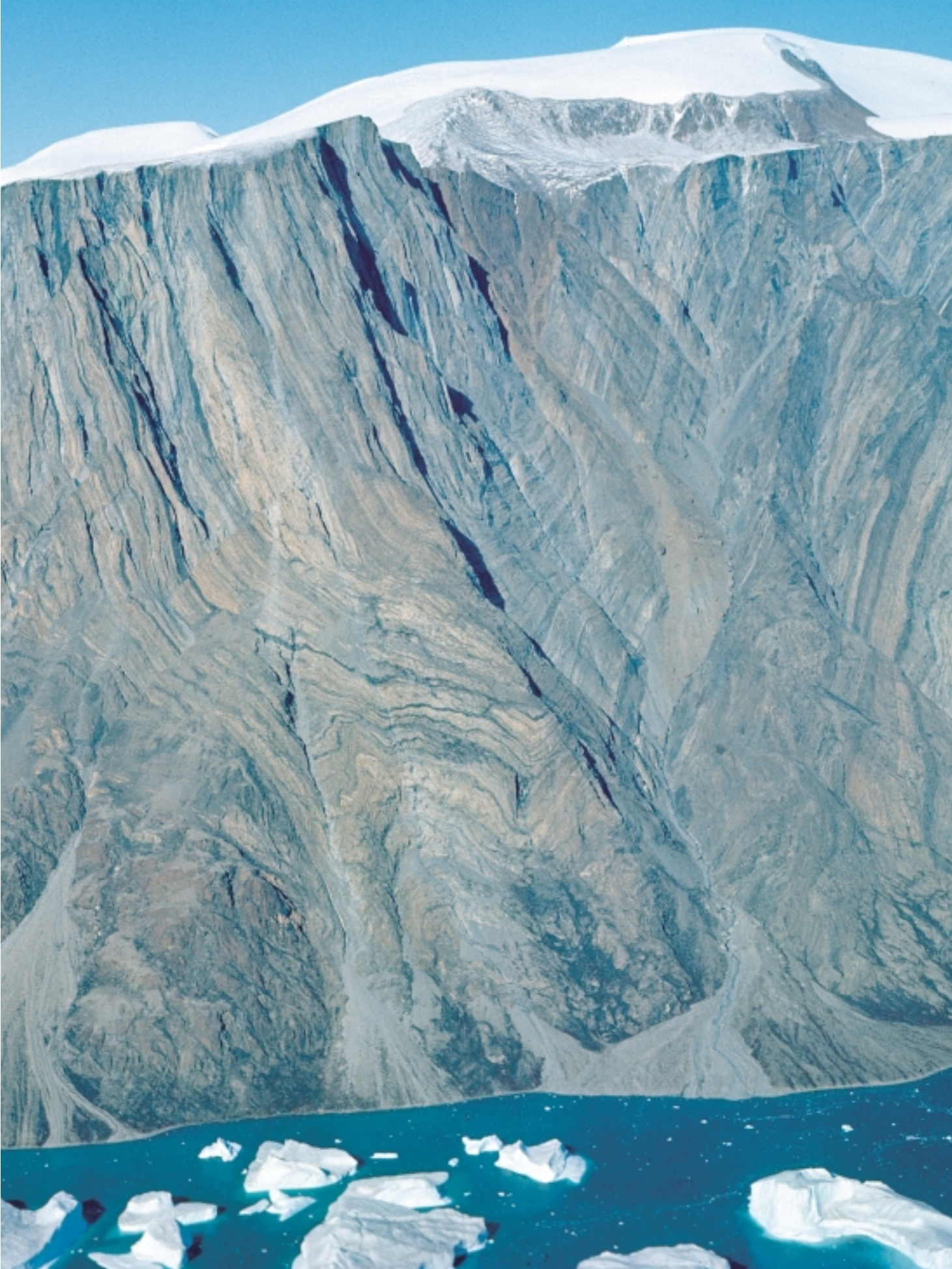
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Geographical subdivisions of Greenland used by the Survey

Map showing the Survey's geographical subdivisions of Greenland, both onshore and offshore, used in this bulletin. Thus Nares Strait, the seaway separating Greenland from Ellesmere Island, Canada, borders North-West Greenland and western North Greenland. However, the strict application of all subdivisions is in places avoided in describing regional geology in order to avoid unwieldy phrases.

It should also be noted that the names West Greenland and East Greenland are used in two ways: in the sense as shown on the map (each with two subdivisions, viz. central and southern) and for the entire western and eastern sides of Greenland, respectively. In this broader sense, West Greenland covers the four western subdivisions, viz. North-West, central West, southern West and South-West Greenland whereas East Greenland covers the four eastern subdivisions, viz. North-East, central East, southern East and South-East Greenland.

The subdivisions are used throughout the text and also in the *Legend explanation* (pp. 79–81) and *Index* (pp. 87–93).

Editorial note

As mentioned in the *Preface*, this bulletin contains an extensive reference list designed as a key to the most relevant sources to the explanation of the *Geological map of Greenland* 1:2 500 000 (printed in 1995). The main text with reference list was compiled in 1998. Text revisions during 1999 included references to publications that were 'in press' in 1998. Subsequent additions in proof have been limited to results particularly relevant to the documentation and interpretation of the geology as presented on the map. No references to publications from 2000 have been included. For an update and listing of geoscientific Greenland literature published in 2000 the reader is referred to *Review of Greenland activities 2000*, to be published as Geology of Greenland Survey Bulletin 189.

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Abstract

Henriksen, N., Higgins, A.K., Kalsbeek, F. & Pulvertaft, T.C.R. 2000: Greenland from Archaean to Quaternary. Descriptive text to the Geological map of Greenland, 1:2 500 000.

Geology of Greenland Survey Bulletin 185, 93 pp. + map.

The geological development of Greenland spans a period of nearly 4 Ga, from the earliest Archaean to the Quaternary. Greenland is the largest island in the world with a total area of 2 166 000 km², but only c. 410 000 km² are exposed bedrock, the remaining part being covered by an inland ice cap reaching over 3 km in thickness. The adjacent offshore areas underlain by continental crust have an area of c. 825 000 km².

Greenland is dominated by crystalline rocks of the Precambrian shield, which formed during a succession of Archaean and early Proterozoic orogenic events and which stabilised as a part of the Laurentian shield about 1600 Ma ago. The shield area can be divided into three distinct types of basement provinces: (1) Archaean rocks (3100–2600 Ma old, with local older units) almost unaffected by Proterozoic or later orogenic activity; (2) Archaean terrains reworked during the early Proterozoic around 1850 Ma ago; and (3) terrains mainly composed of juvenile early Proterozoic rocks (2000–1750 Ma old).

Subsequent geological developments mainly took place along the margins of the shield. During the later Proterozoic and throughout the Phanerozoic major sedimentary basins formed, notably in North and North-East Greenland, and in places accumulated sedimentary successions which reached 10–15 km in thickness. Palaeozoic orogenic activity affected parts of these successions in the Ellesmerian fold belt of North Greenland and the East Greenland Caledonides; the latter also incorporates reworked Precambrian crystalline basement complexes.

Late Palaeozoic and Mesozoic sedimentary basins developed along the continent–ocean margins in North, East and West Greenland and are now preserved both onshore and offshore. Their development was closely related to continental break-up with formation of rift basins. Initial rifting in East Greenland in latest Devonian to earliest Carboniferous time and succeeding phases culminated with the opening of the North Atlantic in the late Paleocene. Sea-floor spreading was accompanied by extrusion of Tertiary plateau basalts in both central West and central and southern East Greenland.

During the Quaternary Greenland was almost completely covered by ice sheets, and the present Inland Ice is a relic of the Pleistocene ice ages. Vast amounts of glacially eroded detritus were deposited on the continental shelves offshore Greenland.

Mineral exploitation in Greenland has so far mainly been limited to one cryolite mine, two lead-zinc deposits and one coal deposit. Current prospecting activities in Greenland are concentrated on the gold, diamond and lead-zinc potential. The hydrocarbon potential is confined to the major Phanerozoic sedimentary basins, notably the large basins offshore East and West Greenland. While proven reserves of oil or gas have yet to be found, geophysical data combined with extrapolations from onshore studies have revealed a considerable potential for offshore oil and gas.

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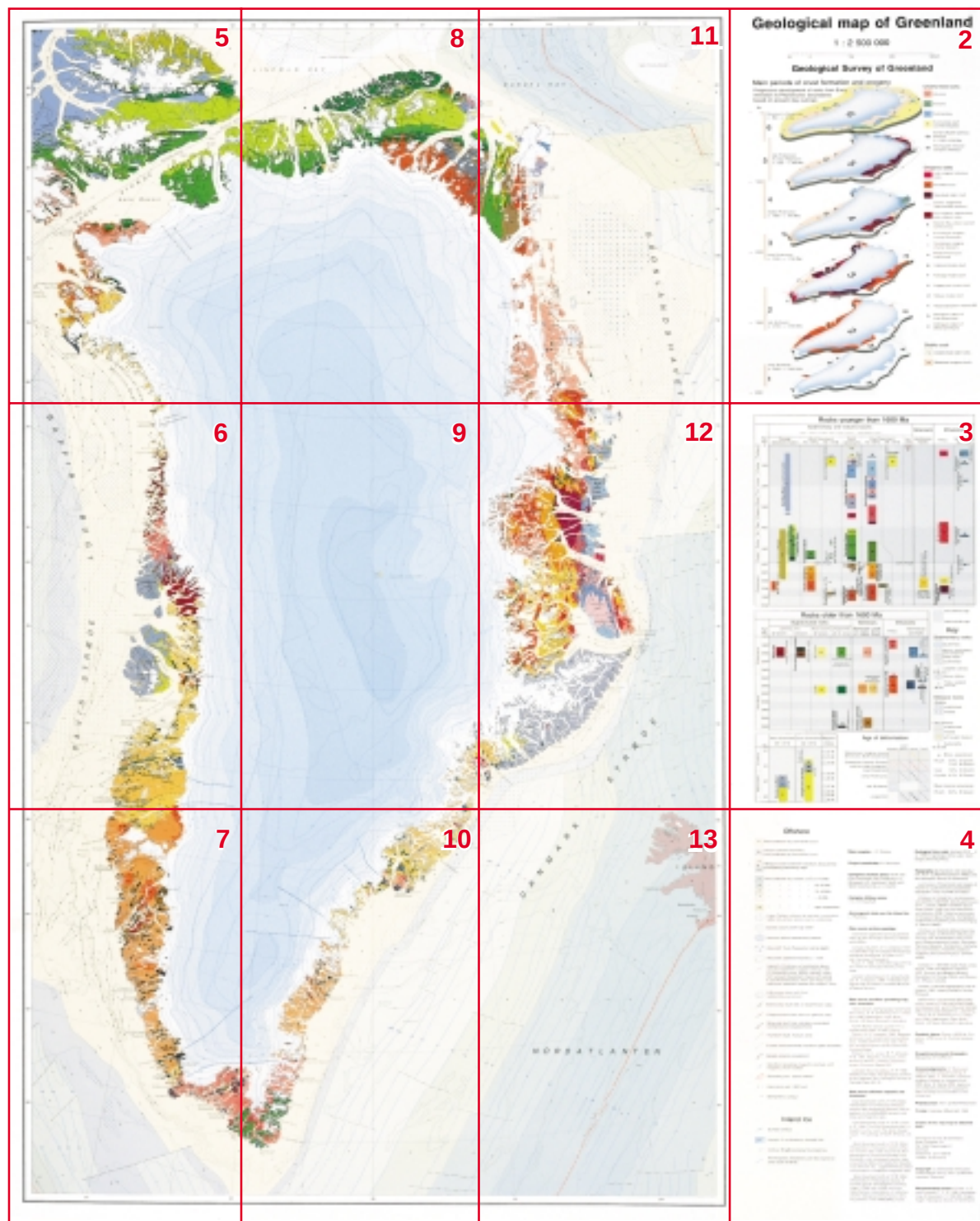


Fig. 1. Index map of the Geological map of Greenland, 1:2 500 000, showing segments 2–13, so numbered in the atlas version of the map (for atlas format, see p. 9). Segment 1 – the title page of the atlas – is not shown.

Preface

Greenland is the largest island in the world with a surface area of more than two million square kilometres. It is up to 1250 km from east to west and 2675 km from north to south, extending over almost 24 degrees of latitude; the northern extremity is the northernmost land area in the world. The Inland Ice, the large central ice sheet which covers c. 80% of Greenland, has a maximum thickness of c. 3.4 km. The ice-free strip of land surrounding the Inland Ice, in places up to 300 km wide, has an area of c. 410 000 km²; this is approximately 30% more than that of the British Isles. This ice-free zone is generally very well exposed and yields a wealth of geological information, notably in fjord walls and in mountainous areas; lowland areas have only a limited vegetation cover due to the arctic setting. The area of Greenland's offshore economic zone that is underlain by continental crust is estimated to be approximately 825 000 km².

Geological observations in Greenland began with the first scientific expeditions; these reached West and East Greenland in the early 1800s and North Greenland in the late 1800s and early 1900s. Systematic geological mapping commenced in East Greenland with Lauge Koch's 'Danish expeditions to East Greenland', which lasted from 1926 until 1958 and were mainly concentrated in the region 72°–76°N. In West Greenland systematic geological investigations began in 1946 with the foundation of Grønlands Geologiske Undersøgelse (GGU – the Geological Survey of Greenland); work was initially concentrated in West Greenland but was subsequently extended to all parts of Greenland. Comprehensive investigations by GGU expanded to include not only geological mapping, but a wide range of geochemical, geophysical and glaciological studies both onshore and offshore. In 1995 GGU was merged with Danmarks Geologiske Undersøgelse (DGU – the Geological Survey of Denmark) to form a new institute, Danmarks og Grønlands Geologiske Undersøgelse (GEUS – the Geological Survey of Denmark and Greenland). The broad range of geological activities in Greenland previously undertaken by GGU continue to be carried out by GEUS.

When GGU published the first general geological map of all of Greenland at scale 1:2 500 000 in 1970, representation of the geology was restricted to onshore

areas; relatively little was then known of the offshore geology. During the past 25 years the offshore areas surrounding Greenland have been investigated by airborne and shipborne geophysical surveys operated by the Survey, other scientific institutions and commercial companies, notably in connection with oil exploration activities. Sufficient is now known to enable an interpretation of the offshore geology to be presented on the new map, although it is emphasised that for some of the remote areas offshore North Greenland knowledge remains sketchy. There is considerable petroleum exploration interest in many of the offshore sedimentary basins, and geological knowledge of the offshore areas is expected to be considerably augmented in the near future as a result of commercial exploration.

The new Geological map of Greenland, 1:2 500 000, printed in 1995, is available in three formats:

1. A wall map (sheet size 96 × 120 cm).
2. A folded map sheet (24 × 20 cm, as in pocket of this bulletin).
3. An atlas of numbered segments (24 × 20 cm when closed). Fig. 1 is an index to 12 numbered segments of the map.

The description of the map has been prepared with the needs of the professional geologist in mind; it requires a knowledge of geological principles but not previous knowledge of Greenland geology. Throughout the text reference is made to the key numbers in the map legend indicated in square brackets [] representing geological units (see *Legend explanation*, p. 79), while a *Place names register* (p. 83) and an *Index* (p. 87) include place names, geological topics, stratigraphic terms and units found in the legend. The extensive reference list is intended as a key to the most relevant information sources. The text has been compiled by N. Henriksen. Principal contributors include: N. Henriksen (several sections and illustrations); A.K. Higgins (Lower Palaeozoic in North Greenland); F. Kalsbeek (Precambrian shield); T.C.R. Pulvertaft (offshore geology and petroleum potential). In addition, information and drafts for various sections were provided by colleagues (see *Acknowledgements*, p. 67).

Introduction

A general overview of the geology of the whole of Greenland in the form of a coloured map sheet, the Tectonic/geological map of Greenland, was published by the Geological Survey of Greenland (GGU) in 1970 at a scale of 1:2 500 000. Subsequently, a wealth of new information has become available as a result of new systematic geological mapping in the ice-free land areas, notably in North, North-East and South-East Greenland, while offshore areas have been investigated by a series of seismic, gravimetric and aeromagnetic surveys. The Inland Ice has also been intensely studied over the past 25 years, by regional satellite and airborne radar surveys as well as by ground studies and deep drilling through the more than 3000 m thick central part of the ice sheet. As a consequence of these developments the new Geological map of Greenland, 1:2 500 000, includes not only an up-to-date interpretation of the ice-free land areas, but as a new element summarises current knowledge of the geology of the offshore regions around Greenland. For the Inland Ice completely new representations of the upper and lower surface of the ice sheet are shown by contours, together with its calculated thickness.

To relate the geology of Greenland to neighbouring countries within the borders of the map sheet, the geology of the adjacent areas of Canada and Iceland has been included, based on recent published maps (see map legend).

The geology of the ice-free land areas on the new 1:2 500 000 map has been compiled as a conventional bedrock geological map, together with representations of the major tectonic features in the orogenic belts. The presentation of the geology of offshore areas follows a different concept, as interpretations are based on geophysical information. Onshore superficial deposits of Quaternary age have been shown only where extensive areas of bedrock are covered. In many regions dykes are a prominent element of the geology, but as they form only a minor proportion of the exposures they cannot generally be represented at the scale of the map. A compilation of dykes of different ages is shown in this volume as Fig. 18.

The Inland Ice and the many local ice caps and glaciers are shown as one unit. The sea ice which covers substantial parts of the oceans bordering North and East Greenland for much of the year, is not depicted on the map.

The term 'Tertiary' and division of the Proterozoic into early, middle and late, have been retained in the text in order to be consistent with the map, which was published before the new conventions of Palaeogene/Neogene and Palaeo-, Meso- and Neoproterozoic were established. In the Precambrian descriptions the prefixes 'early', 'middle' and 'late' have generally been used for subdivisions of both Archaean and Proterozoic time and rock units.

Concept of the geological legend

Two different legend concepts have been used – one for the onshore ice-free areas and one for the offshore regions.

In the legend for the ice-free land areas a distinction has been made between rocks older and younger than 1600 Ma. In the older group, which mainly comprises crystalline rocks of the stable Precambrian Greenland shield, the rock units are distinguished according to their lithology and age; the extent of regional tectono-metamorphic provinces is also depicted. Rocks younger than 1600 Ma are shown in relation to the formation of sedimentary basins and orogenic belts along the margins of the stable shield. The principal subdivisions depicted on the map illustrate the general depositional environment, age and extent of the main sedimentary and volcanic basins and, in the Franklinian Basin in North Greenland, the overall depositional setting. Younger crystalline gneisses and plutonic rocks are distinguished by lithology and age of orogenic formation and emplacement. A schematic chronological representation of the geological units shown on the map is included in the map legend.

The structures and the age of deformation in the various orogenic belts are shown by structural trend lines and major tectonic features by appropriate symbols. Most orogenic belts are of composite origin and may incorporate older crystalline rocks and structures. It is often difficult, or impossible, to distinguish between the older and younger structural elements, and therefore only the signature for the youngest orogenic event has been used within a specific fold belt. Post-orogenic undeformed rocks can be recognised by the absence of overprints of structural symbols.

A schematic cartoon representation of the crustal evolution of Greenland is incorporated in the legend. Six stages of evolution are shown from the early Archaean to the Tertiary. These show the distribution in time and space of the orogenic belts and the step-wise growth of the stable crust. The post-orogenic development of sedimentary basins and volcanic provinces is also shown, together with the approximate extent of continental crust around Greenland.

The legend concept for the offshore areas is based on geological interpretation of the available geophysical data. Distinction is made between areas underlain by continental crust and areas underlain by oceanic crust; a transition zone is also recognised. Areas with oceanic crust are further subdivided into time slices of 15 Ma based on magnetic anomaly patterns. Magnetic anomaly lines with chron-numbers are shown, together with spreading axes and transform faults. Major sedimentary basins are indicated by isopachs showing the sediment thickness superimposed on a representation of crustal type. Volcanic rocks exposed on the seabed (mostly Tertiary in age) are also shown.

Topographic base

The topographic base for the new 1:2 500 000 geological map is completely new and it has been drawn on

the basis of fixed points established throughout Greenland by Kort & Matrikelstyrelsen, Denmark (KMS – the National Survey and Cadastre, which incorporates the former Geodetic Institute). The map is constructed as a UTM projection in zone 24 with WGS 84 datum; the central meridian is 39°W. Photogrammetric constructions by KMS and GGU have been combined and co-ordinated to produce the first geometrically correct topographic representation of all of Greenland. All previous maps have suffered to varying degrees from insufficient ground control, especially in North Greenland where errors in the location of topographic features of up to 25 km occur on earlier maps (Fig. 2). Height contours have been omitted on the ice-free land areas to avoid obscuring the geological detail, but they are shown on the Inland Ice.

Place names are indicated in both their Greenlandic and Danish form, the Greenlandic names with the new orthography as approved by the Greenland Place Names Authority. A register of place names used on the map is given at the end of this work.

The bathymetry of the offshore areas has been compiled from various sources. The available material is very heterogeneous, ranging from very detailed navigation maps by the Royal Danish Hydrographic Office (now part of KMS) to generalised small-scale international oceanographic maps. Information from the ice-covered regions off North and East Greenland is limited; hydro-



Fig. 2. Outline map of North Greenland showing misplacement of boundaries between land and sea on respectively old (black) and new (red) topographic maps. The new map outline in red is based on ground control points measured in 1978. Data from Kort & Matrikelstyrelsen, Copenhagen, Denmark.