

Greenland from Archaean to Quaternary
Descriptive text to the 1995 Geological map
of Greenland, 1:2 500 000.
2nd edition

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Keywords

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 Neoproterozoic Eleonore Bay Supergroup. To the right: first author Niels Henriksen, for many years head of geological mapping at GGU/GEUS, and participant in field work in Greenland for more than 45 years.

Frontispiece: facing page

Major Caledonian syncline involving reactivated Archaean basement gneisses containing amphibolite bands. Overlying rusty coloured Mesoproterozoic 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. 17, p. 31). 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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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, application of these subdivisions has not been rigorously applied in all parts of the text in order to avoid unwieldy phrases.

It should also be noted that 'West Greenland' and 'East Greenland' are used both as shown on the map (each with two subdivisions, viz. central and southern) and for the entire western and eastern sides of Greenland. 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. 110–112) and Index (pp. 117–126).

Editorial note

This bulletin is a revised 2nd edition of the descriptive text to the Geological map of Greenland 1:2 500 000. The description was first published in 2000 as *Geology of Greenland Survey Bulletin 185* by Henriksen *et al.* 2000. The map, compiled by Escher & Pulvertaft in 1995 and printed the same year, accompanies the present description.

Since the first edition of this work was published, large amounts of new data have been acquired, especially in the offshore regions, in relation to mineral prospecting and in connection with general geological research mainly in West Greenland. The present description aims at providing an updated overview of the geology of Greenland with reference to the enclosed geological map from 1995 that in general terms is still valid. The first edition included an extensive reference list designed as a key to the most relevant sources for the explanation of the Geological map of Greenland 1:2 500 000. In this second edition the reference list has been expanded with more than

200 new references to cited papers, to give the reader a possibility to follow up on new data and details in agreement with modern interpretations.

The 1:2 500 000 map presents a general overview of Greenland geology, but as a basis for this overview there also exists a wealth of more detailed published maps. A set of 14 geological maps at scale 1:500 000 covers the onshore areas of the entire country and a special map at scale 1:1 000 000 covers onshore areas in North-East Greenland. In addition to these maps more than 60 geological maps at 1:100 000 have been published, covering mainly areas in central and southern West Greenland. A wide range of special geological and geophysical maps has also been published covering both onshore and offshore areas. Details of all these publications can be obtained from the Survey's website.

For a catalogue of Greenland publications and data see: www.geus.dk/publications/publ-uk.htm. This list will be updated at intervals, when relevant new data become available.

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Abstract

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Geological Survey of Denmark and Greenland Bulletin 18, 126 pp. + map.

The geological development of Greenland spans a period of nearly 4 Ga, from Eoarchaeon to the Quaternary. Greenland is the largest island on Earth with a total area of 2 166 000 km², but only c. 410 000 km² are exposed bedrock, the remaining part being covered by a major ice sheet (the Inland Ice) 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 Palaeoproterozoic orogenic events and 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 (3200–2600 Ma old, with local older units up to >3800 Ma) that were almost unaffected by Proterozoic or later orogenic activity; (2) Archaean terrains reworked during the Palaeoproterozoic around 1900–1750 Ma ago; and (3) terrains mainly composed of juvenile Palaeoproterozoic rocks (2000–1750 Ma in age).

Subsequent geological developments mainly took place along the margins of the shield. During the Proterozoic and throughout the Phanerozoic major sedimentary basins formed, notably in North and North-East Greenland, in which sedimentary successions locally reaching 18 km in thickness were deposited. 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 Ocean in the late Paleocene. Sea-floor spreading was accompanied by extrusion of Palaeogene (early Tertiary) plateau basalts in both central West and central–southern East Greenland.

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

Mineral exploitation in Greenland has so far encompassed cryolite, lead-zinc, gold, olivine and coal. Current prospecting activities in Greenland are concentrated on gold, base metals, platinum-group elements, molybdenum, iron ore, diamonds and lead-zinc. Hydrocarbon potential is confined to the major Phanerozoic sedimentary basins, notably the large basins offshore North-East and West Greenland. While reserves of oil or gas have yet to be found, geophysical data combined with discoveries of oil seeps onshore have revealed a considerable potential for offshore oil and gas.

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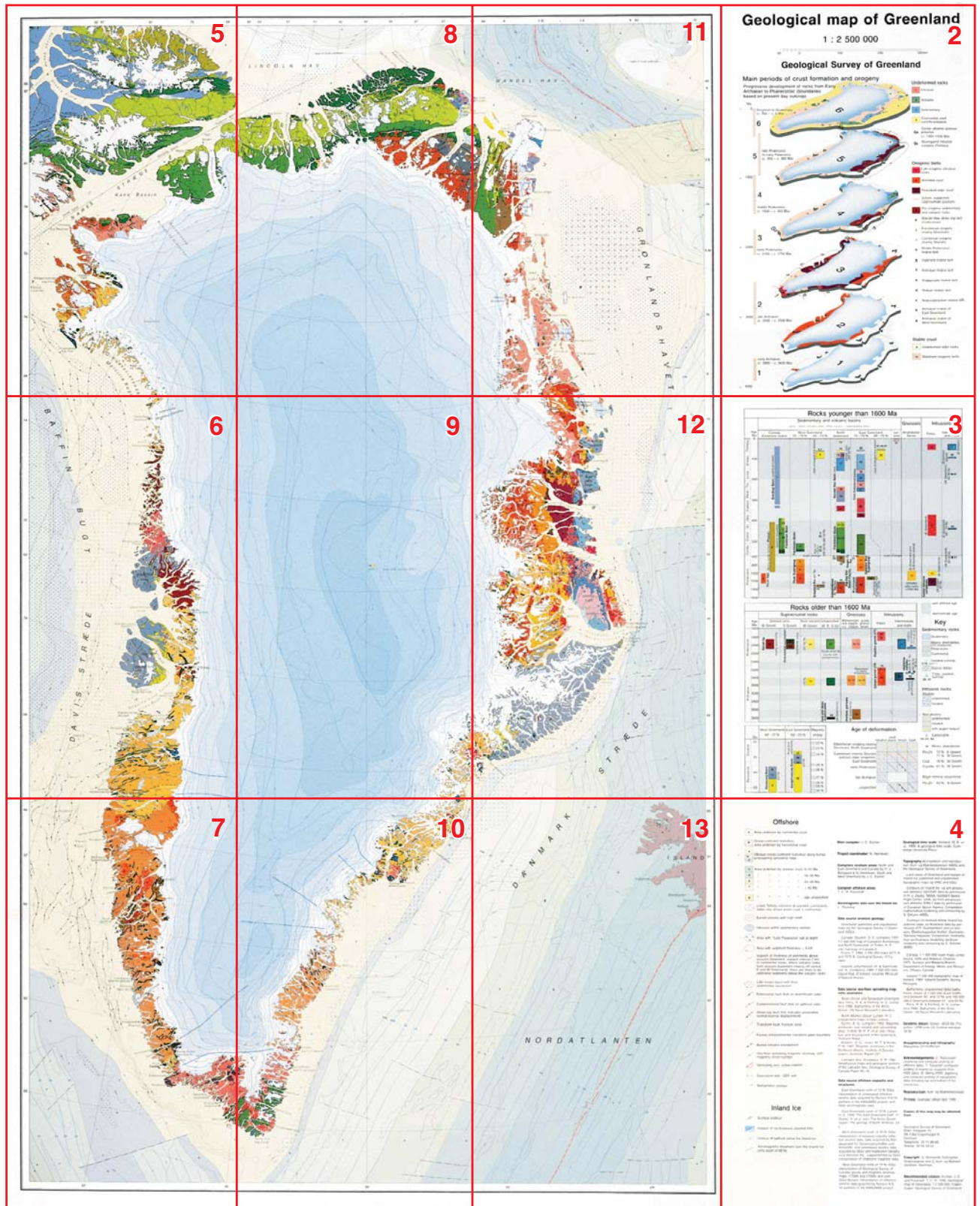


Fig. 1. Index map of the Geological map of Greenland, 1:2 500 000, showing segments 2–13, so numbered in the atlas version of the map (for atlas format, see p. 11). Segment 1 – the title page of the atlas – is not shown.

Preface

Greenland is the largest island on Earth 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 about 1 756 000 km² (c. 81%) 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; even lowland areas only have a limited vegetation cover due to the arctic setting. The area of Greenland's continental shelf 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 the present Survey, De Nationale Geologiske Undersøgelser for Danmark og Grønland (GEUS – the Geological Survey of Denmark and Greenland). The broad range of geological activities in Greenland previously undertaken by GGU continues 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 almost 40 years the offshore areas surrounding Greenland have been investigated by airborne and ship

borne geophysical surveys operated by the Survey, by other scientific institutions and by commercial companies. When the new edition of the geological map was printed in 1995 enough was known to enable an interpretation of the offshore geology to be presented on the map, although it was emphasised that for some of the remote areas offshore North Greenland knowledge was very limited. Since 1995 a considerable amount of new information has been collected from the offshore areas. The new knowledge is reported in the chapter on offshore geology in the present description. There is a high petroleum exploration interest in many of the offshore sedimentary basins, and geological knowledge of the offshore areas has been considerably augmented as a result of commercial exploration.

The 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 the pocket of this bulletin).
3. An atlas of numbered segments (24 × 20 cm when closed. An index to the 12 numbered segments of the map is shown as figure 1.

The description of the map has been prepared with the needs of the professional geologist in mind; it requires 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 representing geological units and indicated in square brackets [] (see *legend explanation*, p. 110), while a *place names register* (p. 113) and an *index* (p. 117) 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 (Neoproterozoic – Lower Palaeozoic in North Greenland and Palaeozoic fold belts in North and North-East Greenland); F. Kalsbeek (Precambrian shield and Palaeo– Mesoproterozoic deposits in North Greenland); T.C.R. Pulvertaft (offshore geology). Chapters which have been much revised have been externally reviewed (Precambrian shield by C.R.L. Friend; offshore geology by G.N. Oakey and mineral deposits and petroleum potential by H. Stendal).

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, much new information became 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 were investigated by a series of seismic, gravimetric and aeromagnetic surveys. The Inland Ice was also further investigated in the period 1970–1995 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. At the time of compilation in 1995 the map therefore included much new information from the ice-free land areas, and the offshore regions were represented for the first time on a map at this scale. For the Inland Ice new representations of the upper and lower surface of the ice sheet were shown by contours, together with its calculated thickness. However, between 1995 and 2009 much additional information has been collected especially from the offshore regions, and as a consequence the enclosed geological map of Greenland, 1:2 500 000 does not represent a fully up-to-date expression of the present knowledge on the geology. The 1995-depiction of the ice-free land areas is in general terms still satisfactory, as well as the representation of the Inland Ice. It is mainly in the offshore regions that new information has been added since 1995, and these developments are described in the chapters on offshore geology and petroleum potential of Greenland. Another field with new developments is that of mineral occurrences, which are addressed in the chapter on mineral deposits.

In order 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 published maps (see map legend).

The geology of the ice-free land areas on the 1:2 500 000 scale 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 only form 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. 20 (p. 37).

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, was used in the legend on the printed map in accordance with the standards of the early 1990s. In the present revised edition of the map description the current conventions of Palaeogene/Neogene and Palaeo-, Meso- and Neoproterozoic are introduced. In the Precambrian descriptions the prefixes ‘early’, ‘middle’ and ‘late’ have been modernised to the subdivisions Eo, Palaeo, Meso and Neo for 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 forms the basic division of the map legend.

The structures and the ages 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 cartoon of the crustal evolution of Greenland is shown above the legend. Six stages of evolution are shown from the Eoarchaeon to the Cenozoic. These show the distribution in time and space of the orogenic belts and the stepwise 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 was based on geological interpretation of the available geophysical data. Distinction is made between areas underlain by continental and oceanic crust, respectively; 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 Palaeogene in age) are also shown. An updated overview map of the offshore regions is shown on pp. 68 and 85.

Topographic base

The topographic base for the 1:2 500 000 geological map 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 older maps. 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 forms, 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 on p. 113.

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; hydrographic representations from these areas should therefore be viewed with reservation.

A topographic map of Greenland at a scale of 1:2 500 000 was published by KMS in 1994 (KMS 1994). The enclosed Geological map of Greenland at the same scale uses an identical topographic base map with the same projection; the only significant topographical difference is the omission of contour lines on the land areas. Based on the digital data for the topographic map, the size of Greenland and its ice cover has been computed by Weng (1995). The area figures are:

Ice-free land area	410 449 km ²
Ice-covered area	1 755 637 km ²
Total area	2 166 086 km ²