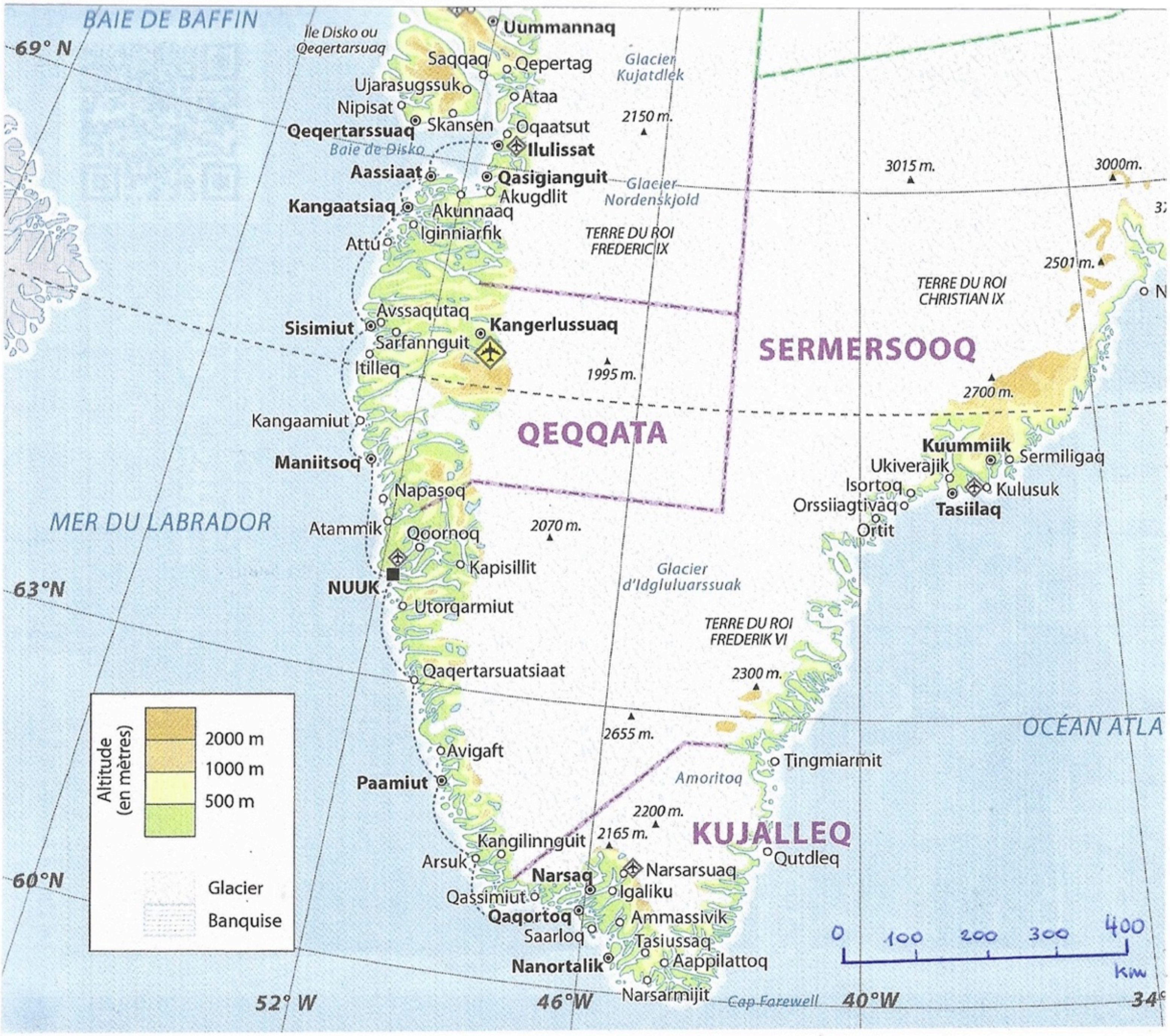
GROENLAND 2023

DOSSIER GEOLOGIQUE



Juillet 2023

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Summary of the geology of Greenland

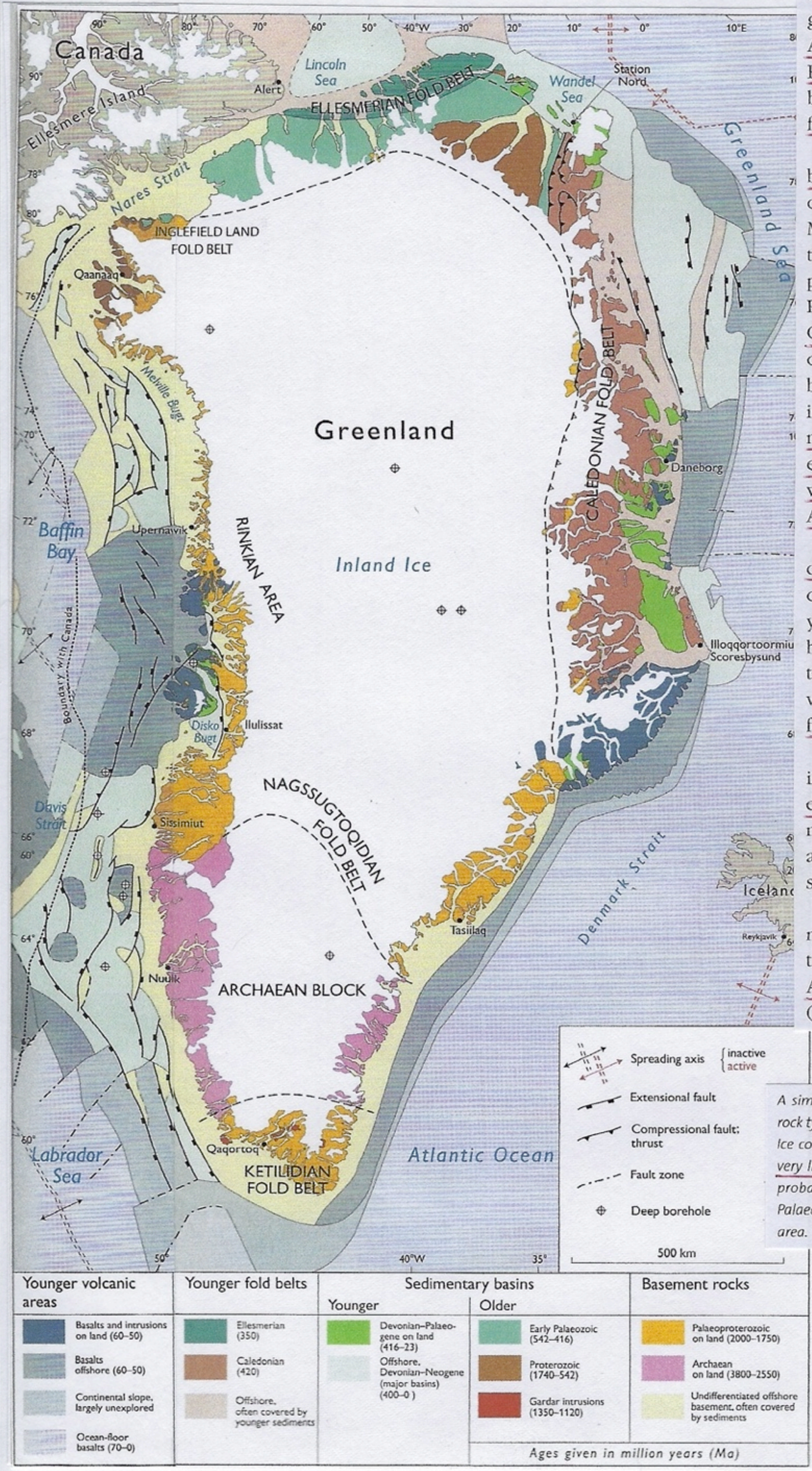
The island of Greenland, together with its offshore continental shelf, records a history of geological development that spans more than 3800 million years (Ma). The oldest areas constitute a basement shield composed of strongly folded gneissic rocks representing the root zones of Archaean (3800–3600 and 3000–2550 Ma) and Proterozoic (2000–1750 Ma) fold belts (orogenic belts). These belts are now welded together to form a stable coherent block.

The extensive basement shield is surrounded by sedimentary basins that developed in three discrete periods – the Proterozoic (1740–542 Ma), the Cambrian–Silurian (542–416 Ma) and the Devonian–Neogene (416–0 Ma). Two coast-parallel mountain chains formed in the Early Palaeozoic, one in North-East Greenland (the Caledonian fold belt about 420 Ma) and the other in North Greenland (the Ellesmerian fold belt about 350 Ma). Volcanic units occur locally in the Proterozoic sedimentary formations, but most of the exposed volcanic rocks were erupted much later as lavas formed in connection with continental break-up when the North Atlantic began to open about 60–55 Ma ago.

The offshore continental shelves can be perceived as a continuation of the land area. They comprise crystalline basement covered by younger sediments (400–0 Ma) and Palaeogene basalts. Farther away from the coast, continental rocks pass into ocean-floor rocks, comprising volcanic and associated sedimentary material formed in connection with sea-floor spreading.

Mineral resources within the land areas include gold, lead-zinc, diamonds and rare earth elements, as well as building and construction materials. Possibilities for oil and gas reserves are found in the younger sedimentary basins offshore North-East and West Greenland.

The ice-free land area comprises approximately 410 000 km^2, while the economic zone of the continental shelf is about 825 000 km^2. About 81% of Greenland is covered by ice (about 1 755 000 km^2).



A simplified geological map of Greenland with a classification of rock types in the ice-free land area and the offshore areas. The Inland Ice covers the whole of the central part of Greenland and there is very limited information on the geology beneath it. However, it is probable that most of the area comprises Archaean and Palaeoproterozoic basement rocks, similar to those in the ice-free area.

PLATE TECTONICS

Plate tectonics is the name for a concept, a geotectonic model, explaining large-scale geological phenomena such as fold belts, earthquake zones, ocean-floor formation and continental drift. The model is based on the interpretation of a series of geological and geophysical observations that have led to the following assumptions:

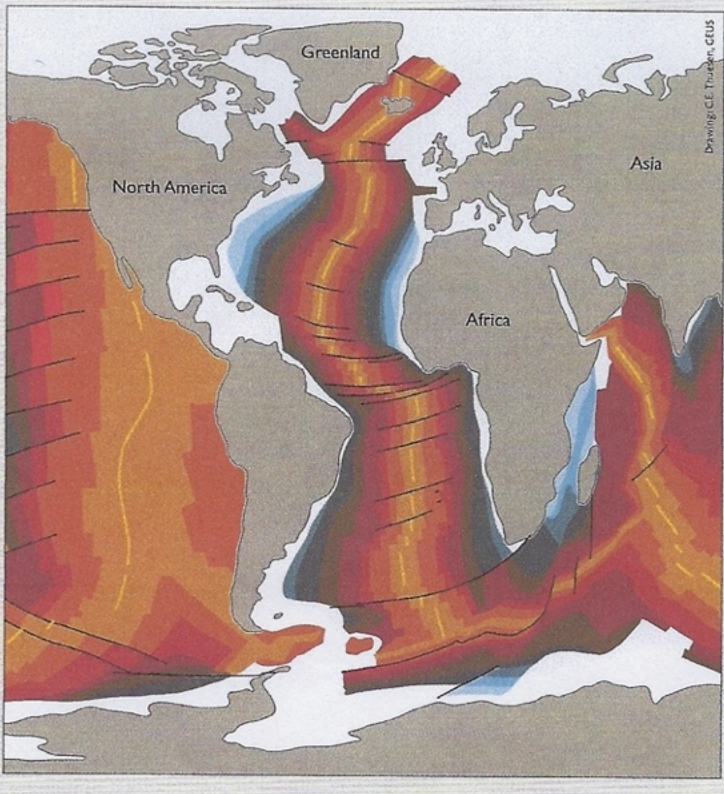
1) The Earth's outer shell, the lithosphere (see p. 20), functions as a rigid plate that rests on and can move across an underlying, more plastic part of the upper mantle, the asthenosphere.

2) The lithosphere is divided into a series of large plates that change their size and shape with time. The plates are in constant motion and their position on the surface of the Earth is continually very slowly changing.

The lithospheric plates contain both oceanic and continental crust. The mutual boundaries between plates are of two main types. Constructive plate boundaries form at mid-oceanic ridges (spreading zones) where new volcanic material is added from the mantle. Destructive plate margins occur where oceanic crust is forced underneath the adjacent plate (subduction) and partially melts.

Mountain belts form along subduction zones, where crustal material can become squeezed between two plates, and the rocks become deformed and folded. Frequently, fold belts occur where opposing continents, each on its own plate, collide and newly deposited sedimentary rocks between the continents are folded up and transported in over the margins of the adjacent, older continent.

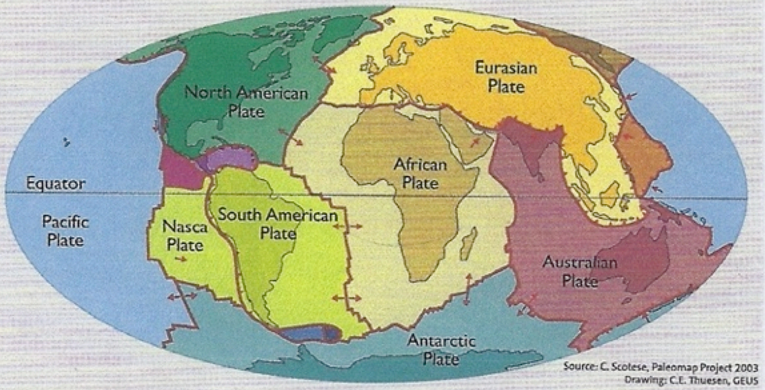
While old oceanic crust is continually descending into subduction zones, the less dense continents 'float' above, and progressively increase in size by addition of new mountain belts. There is thus a gradual increase in the amount of continental crust preserved at the surface of the Earth. Consequently, the oldest oceanic floor is only about 200 Ma old, but many continents have a core that is more than 3000 Ma old.



Drawing: C.E. Thuesen, GEUS

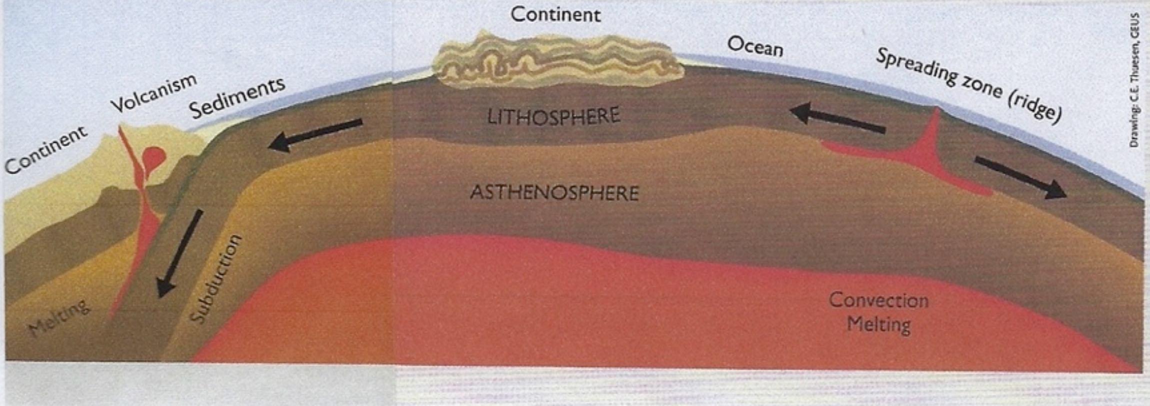
At the plate margins, along the mid-oceanic ridges, an extension of the ocean floor occurs which is described as sea-floor spreading. Here, basaltic magma from the mantle forces its way into the oceanic crust, and both sides of the ocean floor are forced apart. This spreading pattern can be traced back about 200 Ma. Due to the Earth's changing magnetic polarity with alternating north–south pole directions (see p. 113), these magnetic changes are preserved in the newly formed volcanic rocks and can be detected by the pattern of the magnetic anomalies on the ocean floor. The rates of spreading at the ridges are normally from 1 to 2 cm per year, but may be up to about 15 cm per year.

Rocks on the ocean floor
Age in million years.
🟧 0–20
🟧 20–40
🟥 40–60
🟥 60–80
🟫 80–100
⬛ 100–120
⬛ 120–140
🟦 141–160
🟦 160–200
— Spreading ridge



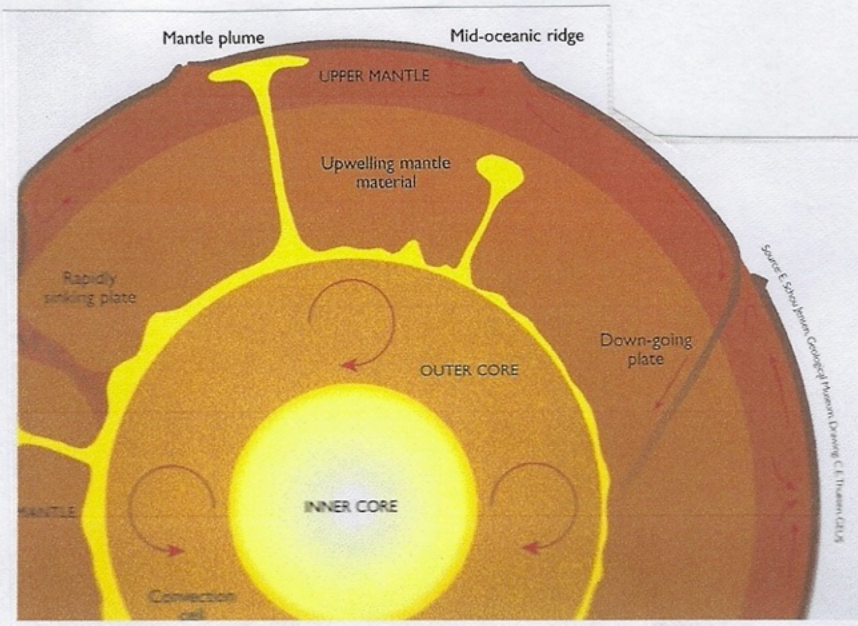
Source: C. Scotese, Paleomap Project 2003
Drawing: C.E. Thuesen, GEUS

Map showing the structure of the Earth's surface with seven large and a series of smaller lithospheric plates. Note that the single plates comprise both continental and oceanic crust.



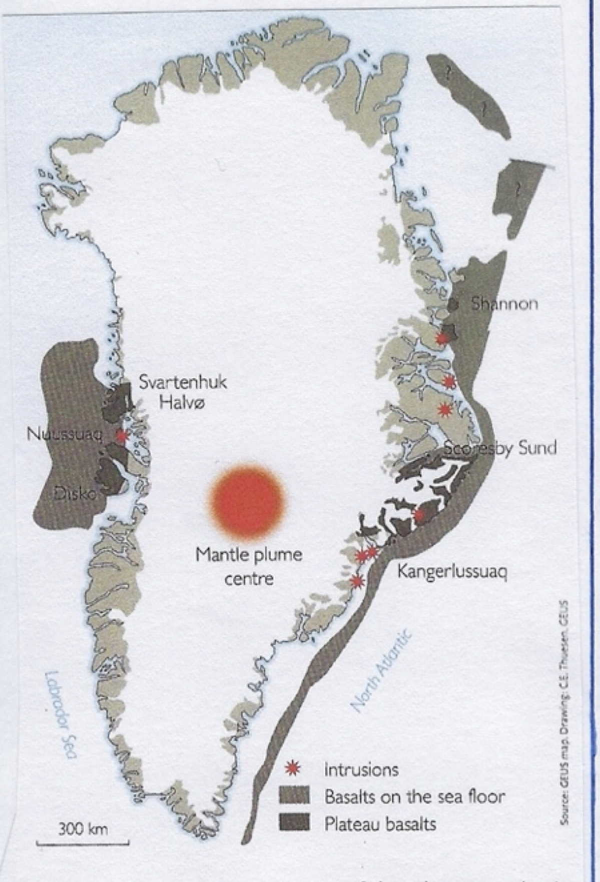
Drawing: C.E. Thuesen, GEUS

The principles of plate tectonics: In spreading zones (ridges), newly formed oceanic crust develops over a rising convection cell from the mantle. A lithospheric plate with oceanic crust sinks into the mantle by subduction underneath less dense continental crust. By this process, partial melting of the subducted lithosphere and overlying rocks causes volcanism at the surface and granitic intrusions at depth. The continent in the middle is part of the lithospheric plate that is moving left. Eventually, the two continents will collide, and a mountain belt will be formed in the collision zone.



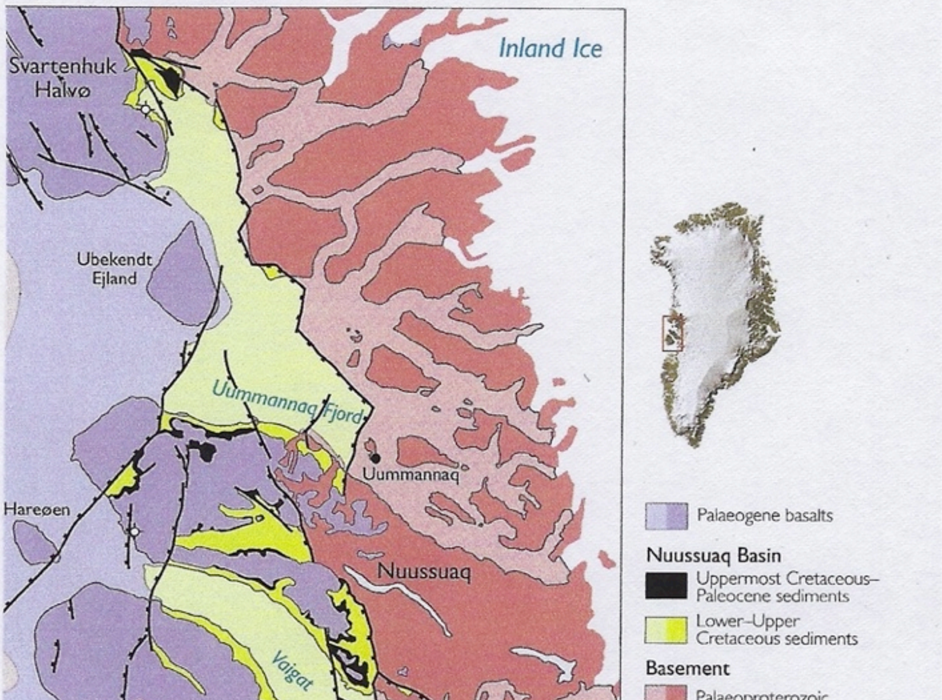
Source: E. Schou Jensen, Geological Museum. Drawing: C.E. Thuesen, GEUS

A cross-section of the Earth showing its internal structure and dynamic character. Convection cells (red arrows) in the outer core resulted in transference of heat energy upwards. At the boundary between the outer core and the lower mantle, bulges of hotter, more mobile material (yellow) formed. In some cases these grew and moved upwards to develop into 'mantle plumes'; ultimately these reached the upper mantle at the base of the crust (brown) forming mushroom-shaped structures. Such mantle plumes transferred vast amounts of heat energy into the overlying mantle, causing parts of the upper mantle to melt resulting in volcanism at the surface.



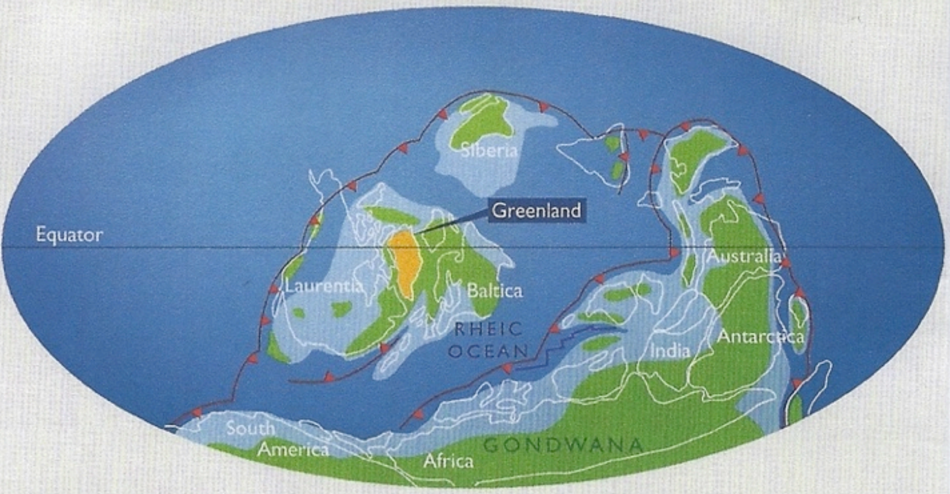
Source: GEUS map. Drawing: C.E. Thuesen, GEUS

Map showing the occurrences and extent of the Palaeogene volcanism and associated intrusions into the volcanic provinces in West and East Greenland. Volcanism in West Greenland began a little earlier than in East Greenland, but in both regions took place in the Paleocene and Early Eocene about 60–54 Ma ago. The map shows the postulated position of the 'hot spot' (the mantle plume, see p. 139), which reached the base of the crust and generated the magmas leading to the volcanic activity.



Map of the Nuussuaq Basin in West Greenland showing its Cretaceous to Paleocene sediments and the overlying Palaeogene plateau basalts.

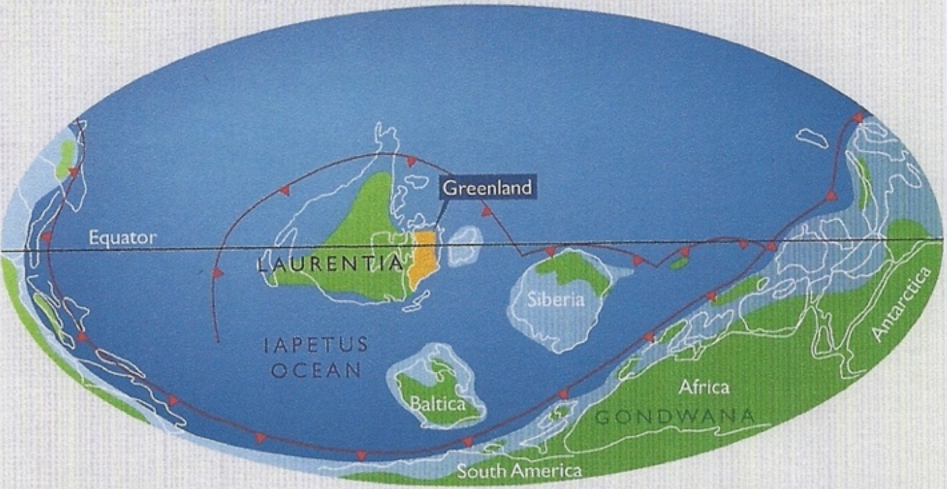
POSITION OF GREENLAND 425 Ma AGO



Source: C. Scotese, Paleomap Project 2003. Drawing: C.E. Thuesen, GEUS

The distribution of the continents in the Middle Silurian, after the closure of the Iapetus Ocean and the collision of North America/Greenland (Laurentia) and Scandinavia/Europe (Baltica) to form the Caledonian fold belt. In the southern hemisphere all the continents were assembled into a supercontinent, Gondwana, separated from the continents around the equator by the Rheic Ocean.

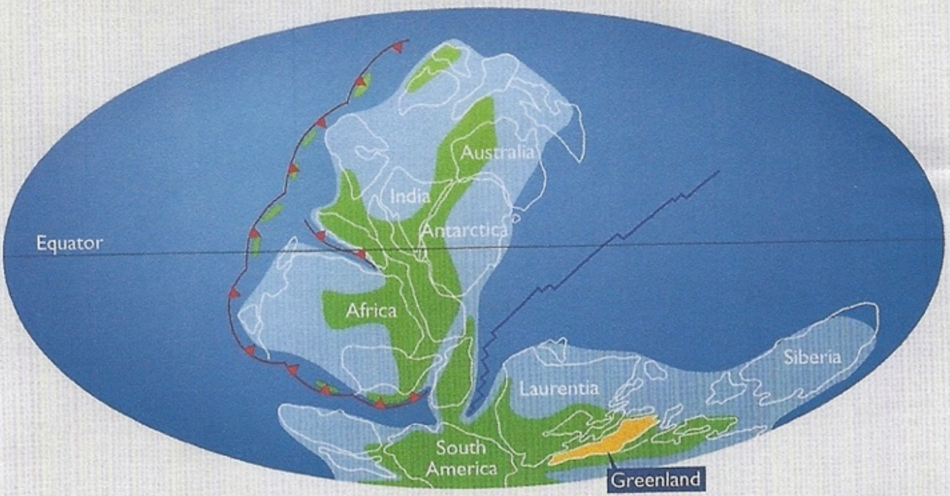
POSITION OF GREENLAND 514 Ma AGO



Source: C. Scotese, Paleomap Project 2003. Drawing: C.E. Thuesen, GEUS

The position of the continents in the Middle Cambrian, 514 Ma ago. The North American continent, 'Laurentia', with Greenland along its eastern part, was at that time located over the equator, separated from the other continents by wide oceans.

POSITION OF GREENLAND 650 Ma AGO



Source: C. Scotese, Paleomap Project 2003. Drawing: C.E. Thuesen, GEUS

Late in the Neoproterozoic, Greenland lay far to the south in the southern hemisphere, together with the adjacent part of North America (Laurentia) and in contact with continental blocks containing the future South America and Siberia. The oceanic areas formed an unbroken entity and several of the continents that today are found in the southern hemisphere then lay close to or north of the equator, in a large assembled block (a supercontinent).

POSITION OF GREENLAND 255 Ma AGO

Source: C. Scotese, Paleomap Project 2003. Drawing: C.E. Thuesen, GEUS

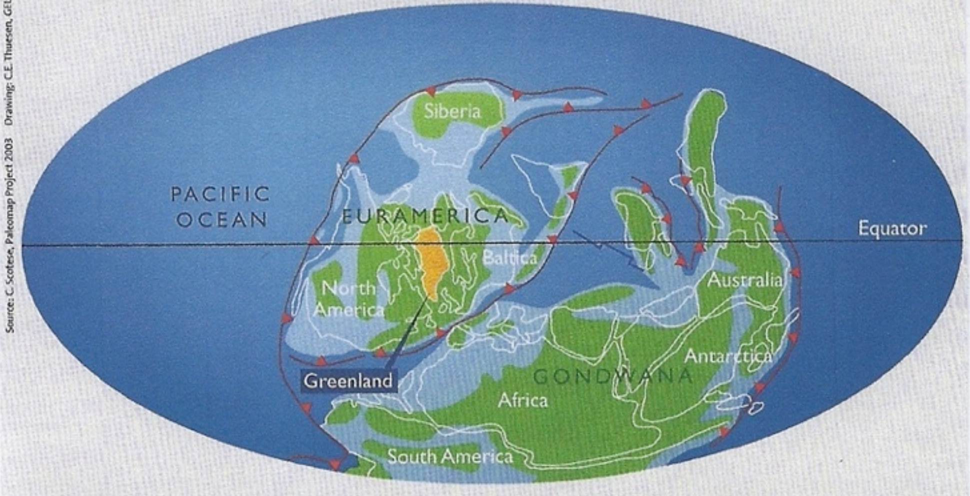
Palaeogeographic map showing the location of the continents during the Late Permian, 255 Ma ago. The continents were assembled into the supercontinent Pangaea and a narrow strait between Greenland and Scandinavia connected the marine basins in East Greenland with those in the North Sea.

POSITION OF GREENLAND 306 Ma AGO

Source: C. Scotese, Paleomap Project 2003. Drawing: C.E. Thuesen, GEUS

The supercontinent Pangaea formed at the end of the Carboniferous when all the continents in the southern hemisphere – Gondwana – united with all the continents in the northern hemisphere – North America, Baltica and Siberia. Greenland found itself within a land area that stretched from the South Pole to half-way up the northern hemisphere.

POSITION OF GREENLAND 390 Ma AGO



Source: C. Scotese, Paleomap Project 2003   Drawing: C.E. Thuesen, GEUS

The distribution of the continents in the Middle Devonian, after the Caledonian orogeny had taken place, and the continents Laurentia and Baltica had joined together into a coherent block called Euramerica (after Europe and America). The supercontinent Gondwana that occupied a position in the southern hemisphere drifted northwards and later, together with Euramerica, formed the supercontinent Pangaea

POSITION OF GREENLAND 152 Ma AGO

Source: C. Scotese, Paleomap Project 2003. Drawing: C.E. Thuesen, GEUS

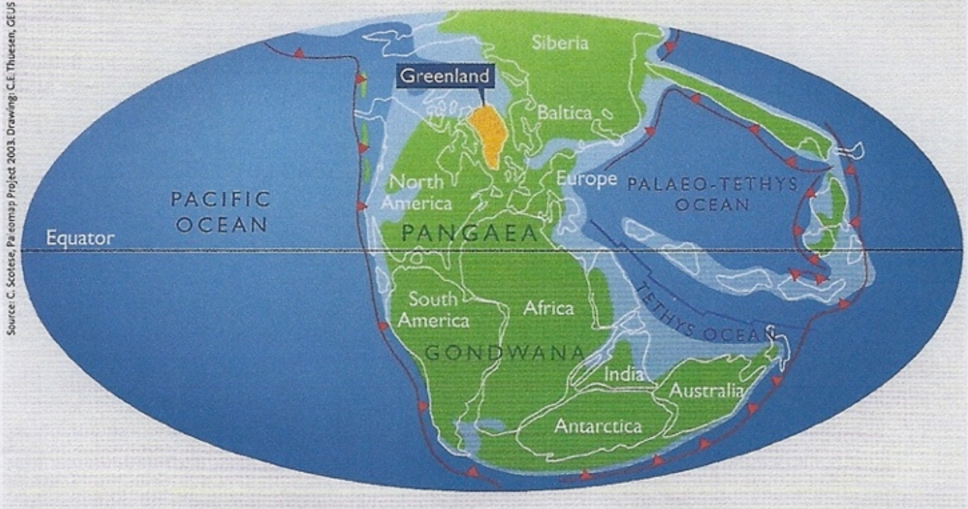
Palaeogeographic map showing the location of the continents during the Late Jurassic, 152 Ma ago. As Pangaea started to disintegrate, Africa and North America started to split and move away from one another, forming the earliest part of the Atlantic Ocean between them. A shallow shelf covered western Europe and eastern Greenland where various shaly sediments were deposited. These deposits were so rich in organic material in many places that they later formed one of the most important source rocks for oil and gas in the North Sea area.

POSITION OF GREENLAND 195 Ma AGO

Source: C. Scotese, Paleomap Project 2003. Drawing: C.E. Thuesen, GEUS

During the Early Jurassic, the supercontinent Pangaea was still contiguous but started to disintegrate soon after. The map shows that at this time there was a shallow sea between Greenland and North America on one side and western Europe on the other.

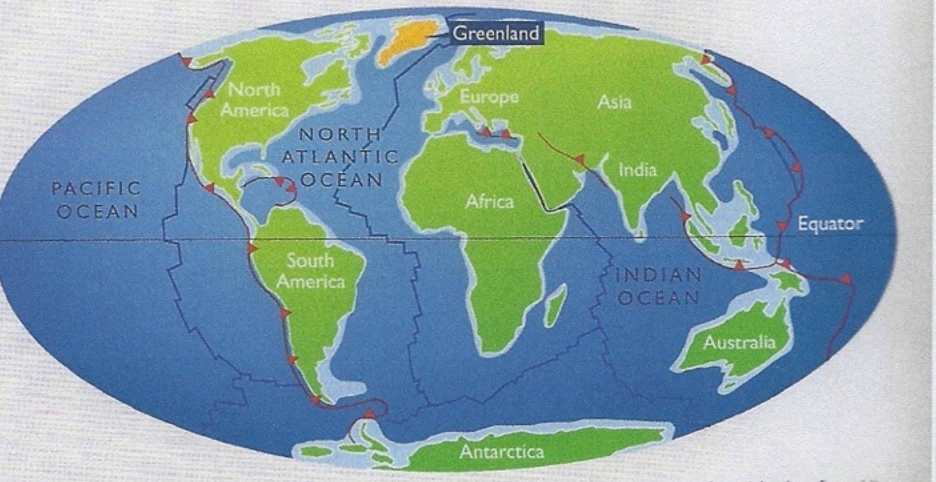
POSITION OF GREENLAND 237 Ma AGO



Source: C. Scotese, Paleomap Project 2003. Drawing: C.E. Thuesen, GEUS

Palaeogeographic map showing the location of the continents during the Middle Triassic, 237 Ma ago. At that time, North-East Greenland had a desert climate and was connected to most of the supercontinent Pangaea.

POSITION OF GREENLAND 14 Ma AGO



Source: C. Scotese, Paleomap Project 2003. Drawing: C.E. Thuesen, GEUS

Palaeogeographical map of the Middle Miocene, about 14 Ma ago. The mid-Atlantic spreading ridge has forced its way up between Greenland and North-West Europe and formed new ocean floor between Greenland and Norway. In the Alps and Himalayas large-scale mountain belt complexes were formed following continental collision. Along the Pacific coast of the Americas the Earth's longest mountain chain, the Cordillera–Andean orogen, developed at a plate boundary between the American continental plates and the oceanic plate to the west.

POSITION OF GREENLAND 65 Ma AGO

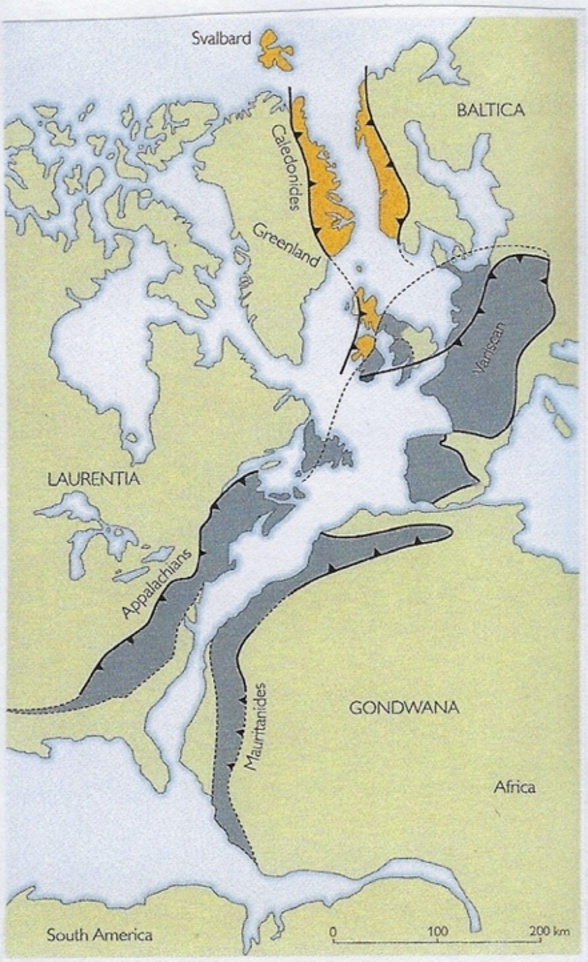
Source: C. Scotese, Paleomap Project 2003. Drawing: C.E. Thuesen, GEUS

Palaeogeographical map showing the position of the continents at the Cretaceous–Paleocene boundary, 65 Ma ago. The opening of the Atlantic Ocean initially formed a spreading zone between Greenland and Canada. At this point there was no ocean formation in the North Atlantic region between Greenland and North-West Europe. India was moving rapidly (at 13 cm per year) north-eastwards towards southern Asia.

POSITION OF GREENLAND 94 Ma AGO

Source: C. Scotese, Paleomap Project 2003. Drawing: C.E. Thuesen, GEUS

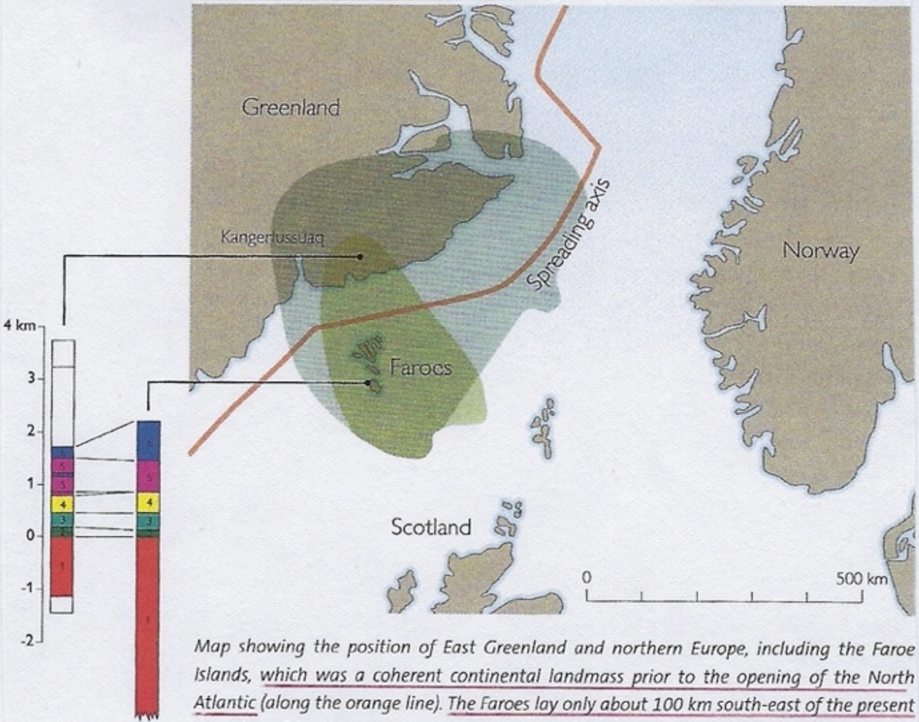
Opening of much of the Atlantic Ocean was underway by the middle of the Cretaceous. In the north, however, sea-floor spreading had not yet started along Greenland's margins. Tension within the crust was causing them to stretch and subside, forming basins between Greenland and Scandinavia on one side and Greenland and Canada on the other. Sea-floor spreading on both sides of Greenland began between 65 and 57 Ma ago, shortly after the beginning of the Palaeogene.



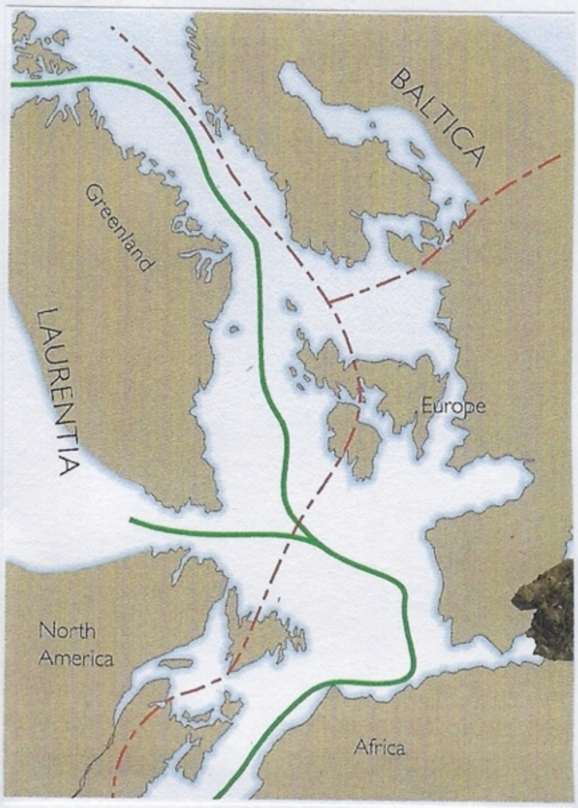
Map of the Palaeozoic fold belts around the Atlantic with the continents shown in their original relative position about 300 Ma ago, before the sea-floor spreading that created the present-day Atlantic Ocean. The Caledonian fold belt in the north, shown in orange, was formed by continental collision between Laurentia and Baltica in the Silurian. The other Palaeozoic fold belts, depicted in blue, reflect the collisions of Laurentia with various microcontinents and Africa in tectonic events lasting into the Carboniferous. The stable continental areas are buff coloured.

Drawings: A. Andersen, GEUS

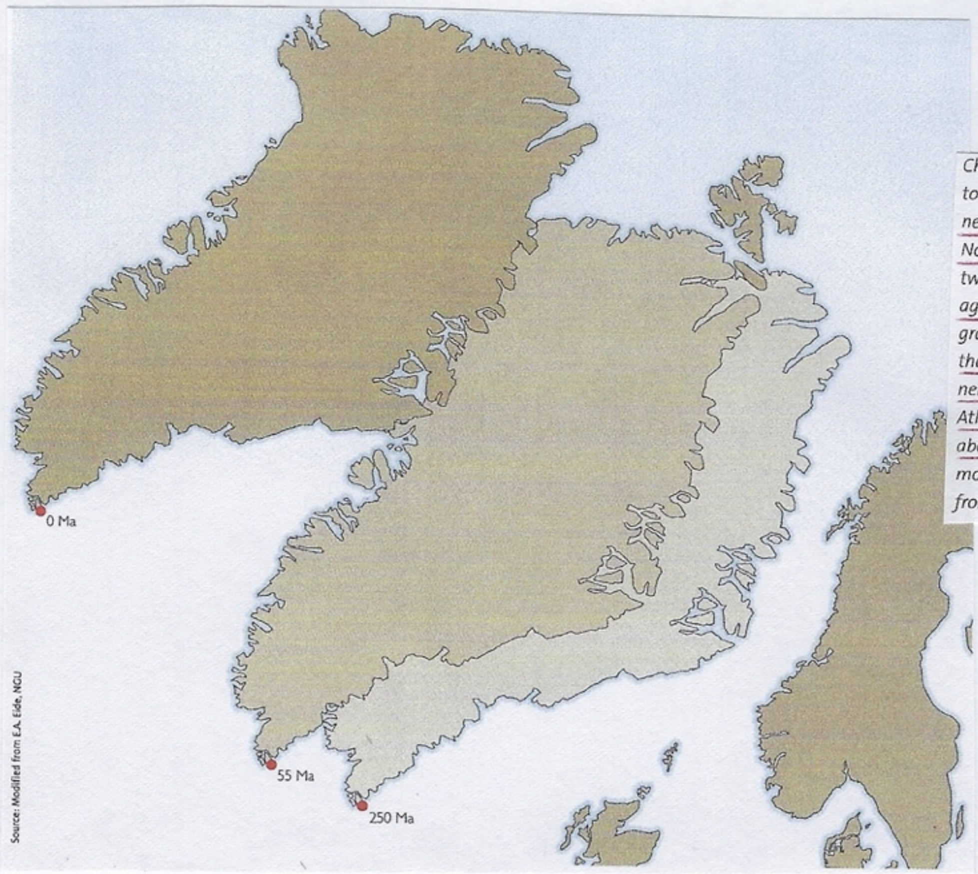
A globe showing the locations of the continents during the Middle Devonian about 390 Ma ago, after the formation of the Caledonian fold belts. The map shows how the various basins (in yellow) containing the Old Red Sandstone developed in a continuous land area at the margins of the continents of Laurentia and Baltica



Map showing the position of East Greenland and northern Europe, including the Faroe Islands, which was a coherent continental landmass prior to the opening of the North Atlantic (along the orange line). The Faroes lay only about 100 km south-east of the present coastline of South-East Greenland. The Palaeogene volcanism resulted in the formation of thick sequences of basalt that covered areas in both South-East Greenland and the Faroes. Measured profiles of the succession have shown that the lower and middle parts of the basalts in both areas are nearly identical and that it is possible to correlate a series of units. Today they are separated by the Atlantic Ocean and lie more than 1000 km apart.

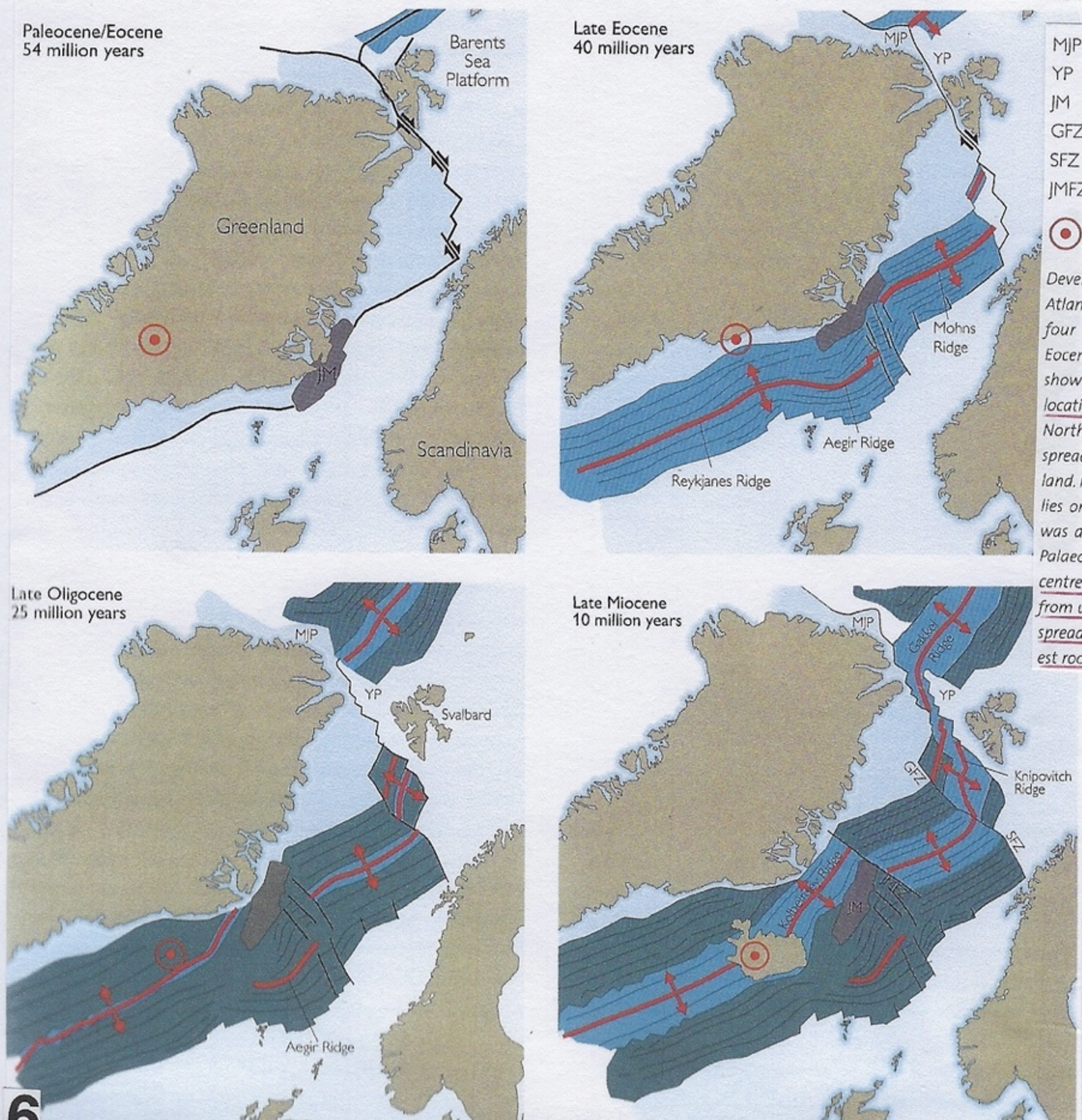


The present day North Atlantic Ocean developed gradually by continental spreading between Europe and North America/Greenland during a period of approximately 55 Ma. The figure shows how the two continental masses were situated in relation to each other before the opening began along the Atlantic spreading axis (green line). A similar oceanic development had taken place about 550 Ma earlier when the Iapetus Ocean opened along a different spreading axis (dashed red line). After this older opening, the continents drifted together again and collided about 420 Ma ago whereby the Caledonian mountain belt was formed



Source: Modified from E.A. Eide, NGU

Changes in the position of Greenland relative to Europe as a result of extension of continental crust and sea-floor spreading in the North Atlantic. The continental crust of the two areas was contiguous 250 million years ago, but extension of the continental crust gradually moved them apart, giving rise to the large sedimentary basins under the continental shelves on both sides of the North Atlantic ocean. Sea-floor spreading started about 55 million years ago resulting in much more rapid movement of Greenland away from Europe.



Paleocene/Eocene 54 million years

Late Eocene 40 million years

Late Oligocene 25 million years

Late Miocene 10 million years

MJP	Morris Jesup Plateau
YP	Yermak Plateau
JM	Jan Mayen microcontinent
GFZ	Greenland fracture zone
SFZ	Senja fracture zone
JMFZ	Jan Mayen Fracture Zone
⊙	Plume centre

Development of oceanic crust in the North Atlantic between Greenland and Europe at four different times from the Paleocene/Eocene boundary to the Miocene. The figures show how the spreading axis has changed location with time and how spreading in the North Atlantic has become connected to spreading in the Polar Basin north of Greenland. Note that the volcanic island Jan Mayen lies on a fragment of continental crust that was attached to the Greenland shelf in the Palaeogene. The figure also shows how the centre of the Iceland plume has moved out from under Greenland to lie today under the spreading axis, so forming Iceland, whose oldest rocks are about 14 Ma old.

PALAEOGEOGRAPHY – the changing positions of continents and oceans in the past

The distribution of land and sea we see today on our geographical maps is only a single frame in a moving picture of an ever-changing distribution of continents and oceans. Continental drift and the creation and destruction of oceans are the primary geological processes, collectively known as plate tectonics, that alter the Earth's crust and the constantly-changing geography on our maps.

The distance that continents move is very small during a human lifespan. Typically the crustal plates move only a few cm/year, although rates of up to 10–15 cm/year have been recorded. Even though such movements are very small, they accumulate to many thousands of kilometres during the long intervals of geological time. At a rate of 2–5 cm/year a continent will move 2000–5000 km over a period of 100 million years.

How do we know where the continents were in the past?

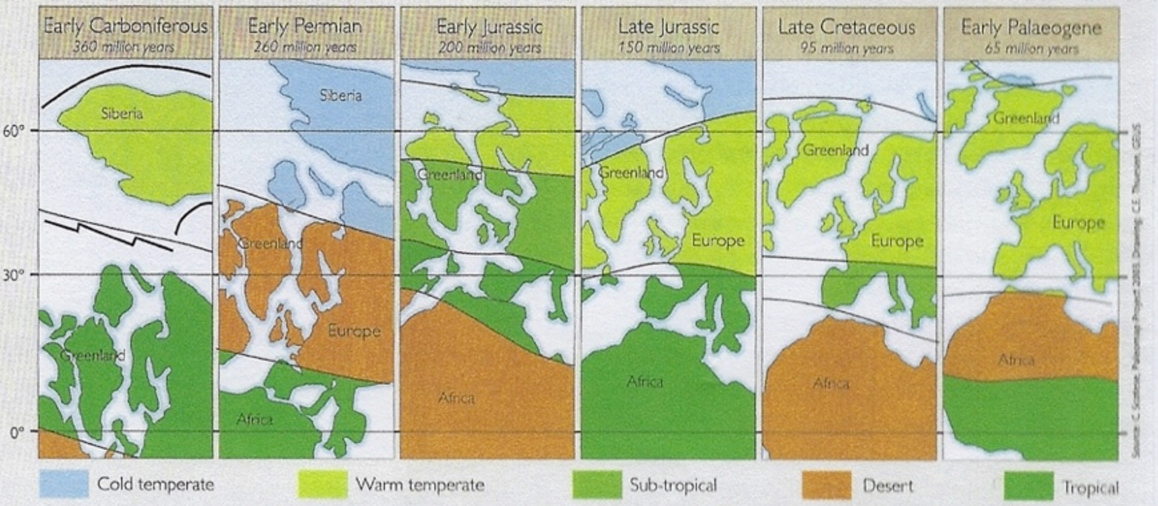
The past geographical locations of the continents and their relative positions are worked out using a whole suite of geological and geophysical measurements and observations. Primarily the palaeolongitude and -latitude of an area must be determined – this can be done by a number of methods. For older periods the most important method is palaeomagnetic measurements (see box on p. 113) that show how far north and south the continent lay at that time, and how it was oriented in relation to magnetic north–south. For developments during the last 150 million years the most important method is to reconstruct the palaeopositions of the continents by using the magnetic anomaly pattern in the oceans (see pp. 53 and 113).

The 'jigsaw method' is sometimes used to analyse the relative positions of continents in the past by seeing how their shapes fit together. The most well-known example is the close match between the west coast of Africa and the east coast of South America. These resemble two adjacent pieces of a jigsaw puzzle suggesting that they were once joined and have since separated. Other criteria used include the analysis of the distribution of fossil assemblages. An example is the distribution of some special 300 Ma old reptiles that originally must have lived in contiguous regions, but whose fossils are found today in regions of Africa and South America that were once adjacent.

Another method for determining how plates have moved is to use so-called 'hotspots', where rising bodies of high temperature material in the mantle (plumes) reach the surface and form volcanoes. If a hotspot stays stationary and the plate moves, a line of volcanoes forms, like pearls on a string, as the plate passes over the hot spot centre. The plate movement can be tracked in this way, back as far as the age of the volcanoes.

Maps showing the positions of the continents through time

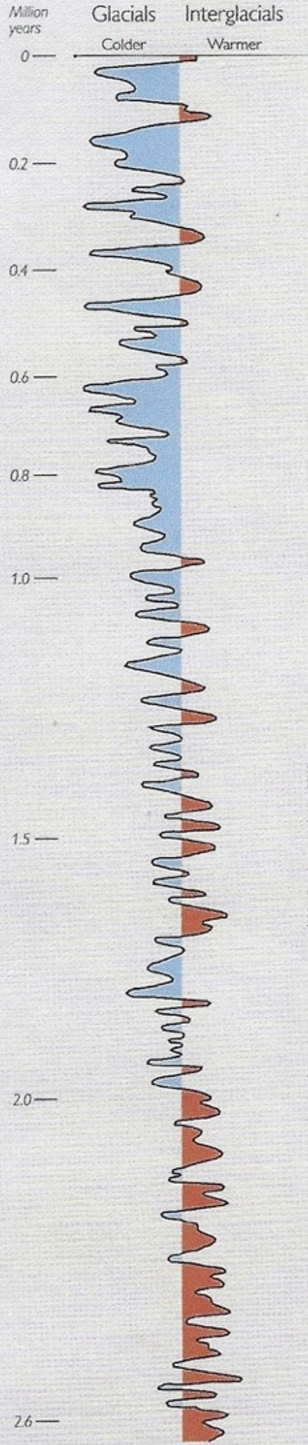
Palaeogeographic maps can be drawn successively back through time from the present. Geologists have excellent data that show the development back to the Middle Jurassic (about 170 Ma ago), when the present oceans started to open. Generalised maps can be drawn with reasonable certainty for times before this, back to the beginning of the Cambrian, about 542 Ma ago. Uncertainty grows further back in time and it is common to see different interpretations of the global geography during the Proterozoic. One of the problems with such ancient reconstructions is that the sizes and shapes of the continents have altered. Every additional mountain-building episode added to the older continents, and both their sizes and shapes changed. Greenland can often be recognised on palaeogeographic maps, however, because its shield area has remained essentially unchanged during the last 1750 Ma.



Source: C. Scotese, Paleomap Project 2003. Drawing: C.E. Thorsen, GEUS

Greenland's northward drift over 300 Ma. Continental drift caused Greenland's latitude to change during this period from just north of the equator to the northernmost third of the northern hemisphere. This movement alone has caused Greenland's climate to change from warmer to colder conditions. Variations in the climate of the whole Earth must be added to these changes, so during this long period Greenland's climate has altered substantially. The figure demonstrates the climatic shifts that Greenland has experienced through this 300 Ma period.

CLIMATE CHANGES DURING THE ICE AGE



Source: Modified from J.P. Steffensen, The Niels Bohr Institute, University of Copenhagen; J.F. McManus and IPCC. Drawing: A. Andersen, GEUS

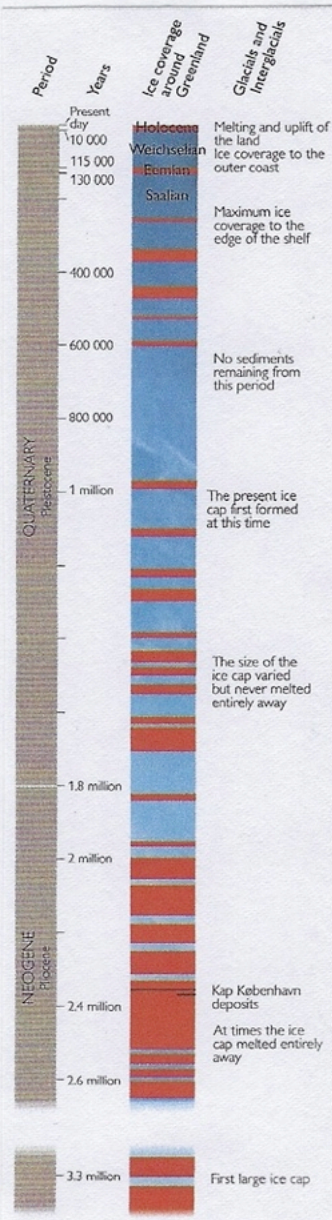
Simplified diagram showing temperature variations during the last 2.6 Ma, compiled from a variety of sources including ice cores and sediments recovered in deep-sea cores. Temperatures have varied rhythmically during that long interval of time creating 'glacial' and 'interglacial' conditions.

The glaciation of the northern polar regions began during the last part of the Cenozoic era, about five million years ago, whereas an ice sheet started to form over eastern Antarctica 20–30 million years earlier. Early glaciation caused a significant lowering of global sea level by about 50 m and the later expansion of the ice cover in the polar regions caused a further drop in sea level to about 130 m below its present level. The onset of glaciation is a clear sign of a fall in the average temperature of the Earth. Temperatures during the long period of glaciation have not been constant but have varied between colder and warmer intervals. This has caused the ice sheets to expand during cold periods (glacials) and retreat during the intervening warmer periods (interglacials). A total of about 20 oscillations between glacial and interglacial conditions has been recognised, during which the Earth's average temperature varied from about 10°C to about 20°C. Traces of the last four glacials are visible in the Alps, but in Greenland only limited evidence has been found of the very earliest glacials older than 2.4 Ma; much of the preserved record from Greenland concerns the most recent glacials and interglacials within the last 300–400 thousand years.

Our knowledge of the variations in the Earth's temperature during the last few million years comes primarily from drill cores from the deep oceans. Studies such as oxygen-isotope analysis of the shells of single-celled animals (foraminifera) show that the temperature of the oceans has oscillated during the last 5 million years in a fairly regular fashion. These variations in temperature must also have affected the land areas, but the sparse information has made it possible to find evidence of only a few of the swings. This is because more recent processes on land tend to erase traces of earlier events, especially in glaciated areas, where more recent ice erodes away the evidence of earlier glaciations.

The reasons for the variations in temperature are primarily astronomical. The Serbian astronomer Milutin Milankovich used detailed observations to show that the angle that the Earth's rotation axis makes with its orbit and the eccentricity of its orbit are not constant, but vary in three 'Milankovich cycles' that result in variations in the amount of sunlight falling on the Earth's polar regions. The three cycles are of different lengths. The main one is about 100 000 years long and determines the length of the glacials. The two other cycles are somewhat shorter: 41 000 years and 23 000 years.

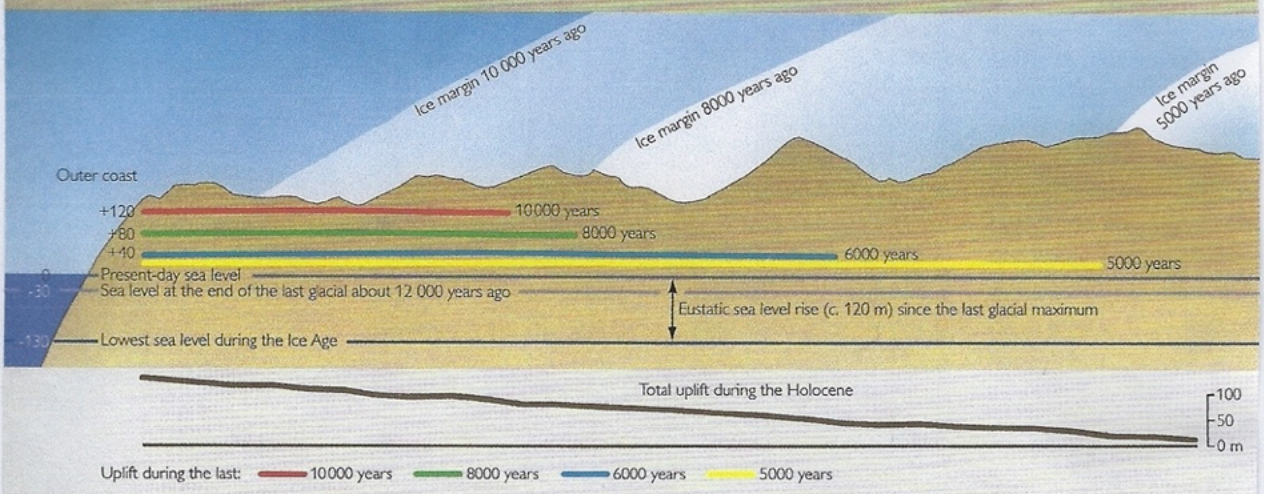
These slow variations do not explain all of the observed changes in the glacial record. The frequent and sudden variations in temperature that have been documented from studies of the Greenland ice cores are not explained by these astronomical cycles, and scientists have recently suggested that the abrupt changes are caused by sudden shifts in the circulation systems in the oceans. Further research is needed to identify the reasons and mechanisms behind these abrupt changes in climate.



Source: Compiled of data from S. Funder et al., Geological Museum, University of Copenhagen. Drawing: C.E. Thuesen, GEUS

Time column showing glacial conditions in Greenland. Glaciation had already begun before the end of the Pliocene, before the Ice Age proper started in the Quaternary. Note that our postglacial time, called the Holocene by geologists, consists of only the last 11 700 years of the Ice Age that has lasted more than 2 Ma. Blue: Glacials. Red: Interglacials.

LAND- AND SEA-LEVEL CHANGES AFTER THE ICE AGE



The diagram shows a hypothetical cross-section through part of West Greenland where the interplay between the melting of the ice cap, sea-level change and the consequent uplift of the land is shown schematically. Ten thousand years ago, the edge of the ice lay near the present day outer coast and sea level was about 30 metres lower than today. By 8000 years ago, some of the ice had melted and the ice margin had moved east. By 5000 years ago, the edge of the ice was even farther east. The oldest marine deposits, about 10 000 years old, are found at a height of about 120 metres near the outer coast. The upper limit of marine sediments descends eastwards and lies at 20 metres farthest to the east where the sediments are about 5000 years old. The diagram thus shows how much uplift there has been relative to present-day sea level, from 120 m near the coast to 20 m inland.

The huge volumes of water that were bound up in the ice sheets during the Quaternary glacial maximum caused global sea level to be about 130 m lower than it is today, so many of today's shallow seas (e.g. the North Sea) were dry land. If the ice that still forms the Greenland and Antarctic ice caps today were to melt, global sea level would rise about 60 m and extensive lowland areas of the world would be flooded. These changes in sea level, called eustatic changes, are absolute and can be measured globally in areas of stable continental crust.

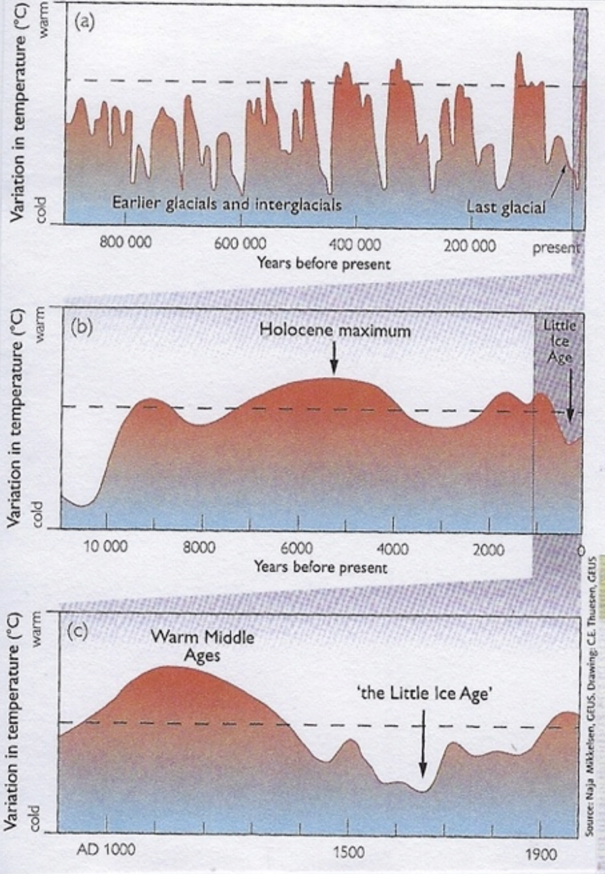
Glaciation of large areas of land during the Ice Age caused huge amounts of ice to accumulate to a thickness of 3–4 km. The weight of this ice-mass burdened the crust beneath and caused it to sink until it was in isostatic equilibrium (see p. 27). The weight of the Scandinavian ice cap, for example, caused the crust under its centre to sink about 300 m into the mantle and it has been calculated that the centre of Greenland under the Inland Ice has been pushed down about 800 m.

Melting of the ice during interglacials and during the Holocene happened rapidly, causing global sea level to rise in the space of a few thousand years, while it has taken much longer for the land to rebound after the weight from the ice was removed. The rise in sea level was therefore not synchronous with the uplift of the land and the effects of these processes were felt over different time spans. The combined effects of uplift and sea-level variations mean that it is possible to measure only relative sea-level changes in formerly glaciated areas. The only record left is where the sea encroached upon the land at a given time, and this was a balance between eustatic sea-level rise and post-glacial crustal rebound.

Geologists have used old raised beaches in Greenland to measure how the relative sea level changed during the last 10 000 to 14 000 years. Fossil shells found in these beach deposits give an accurate date for when sea level was in this position. Since then, isostatic rebound has caused the land to rise so that the old beach deposits are now found at various heights above sea level, from a few metres up to 140 m. There are, however, large local differences in the height of the raised beaches. The highest raised beaches are found where large amounts of ice have melted and thus the unloading of the land was greatest.

The gradual retreat of the ice combined with occasional advances and the formation of raised beaches in front of the ice have given geologists a fantastic dataset with which to evaluate the detailed relationships between melting of the ice and uplift of the land. These data, combined with data from lake deposits and their record of plant and animal remains, show how the landscape and climate have changed since the end of the last glacial 11 700 years ago.

Map showing the amount of uplift during the Holocene, since the end of the last glacial 11 700 years ago. Places where most uplift has taken place are now found at heights of 120–140 metres above present-day sea level and are close to the outermost coastline. The areas with the least glacial rebound lie close to the edge of the Inland Ice where the ice still depresses the land.



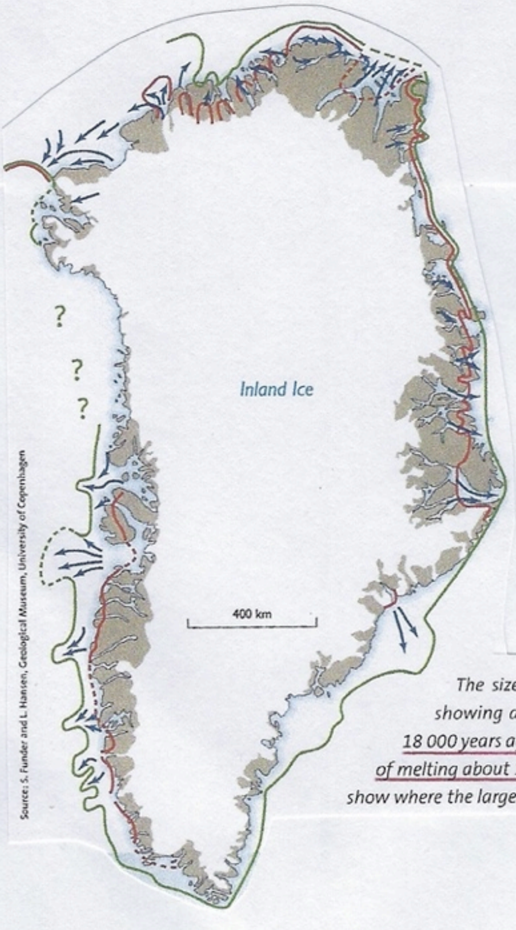
Source: Naja Mikkelsen, GEUS. Drawing: C.E. Thuesen, GEUS

Curves showing the temperature variations during the last 900 000 years. During the last (Weichselian) glacial, the average annual temperature was about 5–25°C colder than today and ice covered Greenland the whole time, even though the margins of the ice migrated back and forth as the temperature varied. The final retreat of the ice began about 11 700 years ago when there was a substantial rise in temperatures. The difference between highest and lowest temperatures shown on the upper curve (a), is about 20–25°C. The two lower curves (b and c) show details of the changes in temperature during the Holocene. The temperature during the Holocene maximum was about 2°C above today's average and in the 'Little Ice Age' the average temperature was about 1°C lower than today's.

ICE SHEETS DURING THE LAST GLACIAL

Source: C. Scotese, Paleomap Project 2003. Drawing: A. Andersen, GEUS

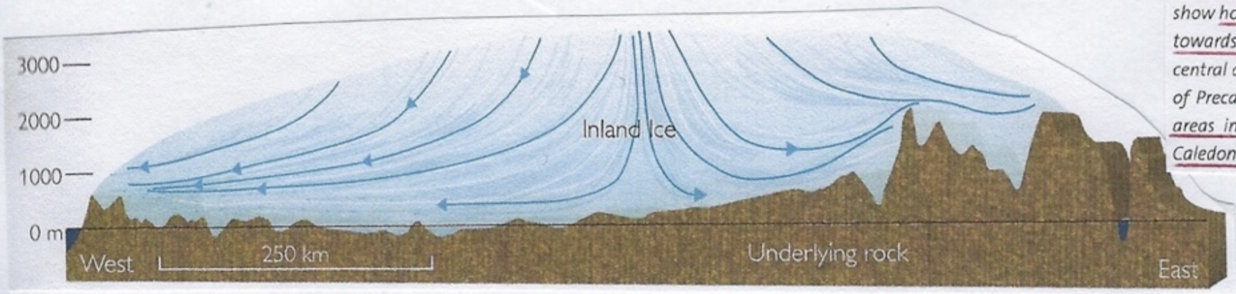
The large ice sheets during the last glacial about 18 000 years ago. Ice caps covered much of the land in both the north and south polar areas. The seas around them were partly covered by large contiguous areas of floating ice that probably resembled the ice shelves found today around Antarctica.



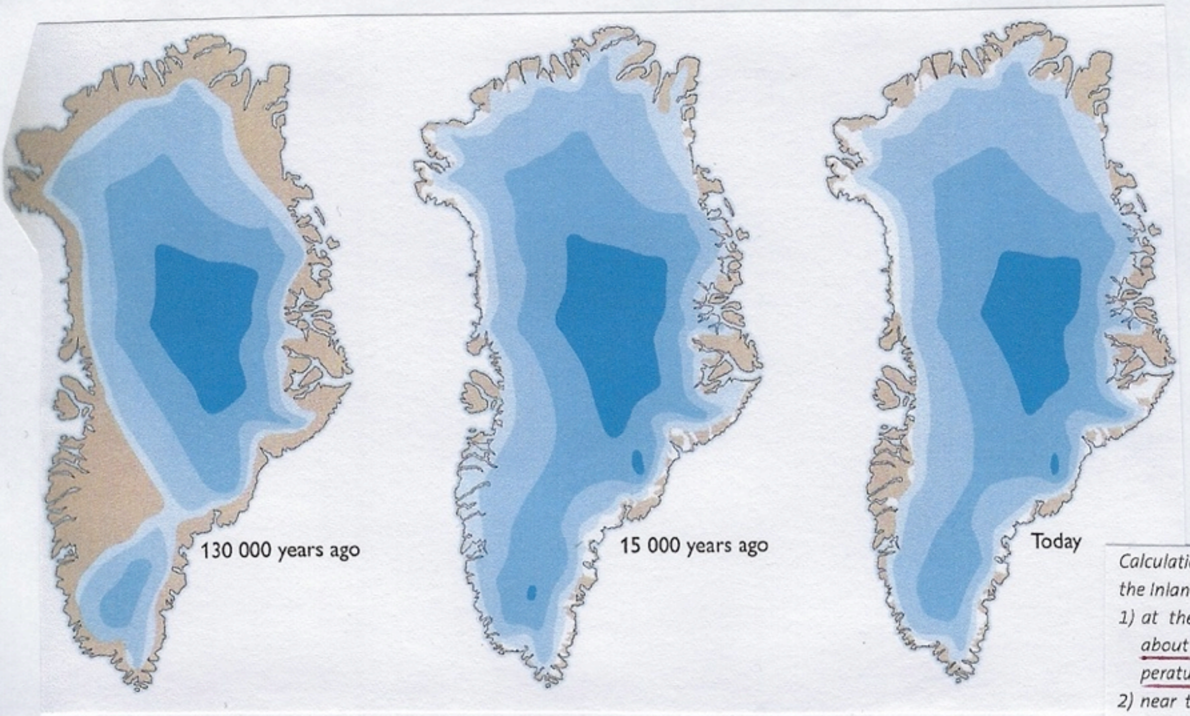
Source: S. Funder and L. Hansen, Geological Museum, University of Copenhagen

The size of the Inland Ice during the last glacial, showing an estimate of its maximum extent about 18 000 years ago (green line) and its extent after the onset of melting about 10 000 years ago (red line). The blue arrows show where the largest glacier streams flowed out.

The first ice cap probably formed about 3 Ma ago and ice caps must have melted completely and reformed several times during the following million years. The ice cap was entirely missing at the time the Kap København deposits were laid down, about 2.3 Ma ago when the interior of Greenland was probably covered by coniferous forest (dark green) and deciduous trees were found only near the coast in South Greenland (light green). The mountainous areas at that time were covered by heath (brown) with local ice caps (white). The size of the ice cap has varied substantially since the start of the Pleistocene, 1.8 Ma ago, but has never melted away entirely since then.



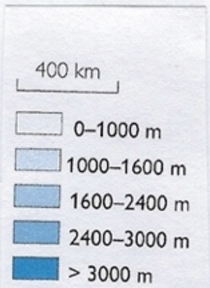
Cross-section through Greenland showing that the Inland Ice is more than 3 km thick in the centre. Note that the deepest part of the ice lies below sea level. The flow lines show how the ice moves from its centre out towards its margins. The rocks under the central and western parts consist primarily of Precambrian basement, while the high areas in the east consist of rocks in the Caledonian fold belt.



130 000 years ago

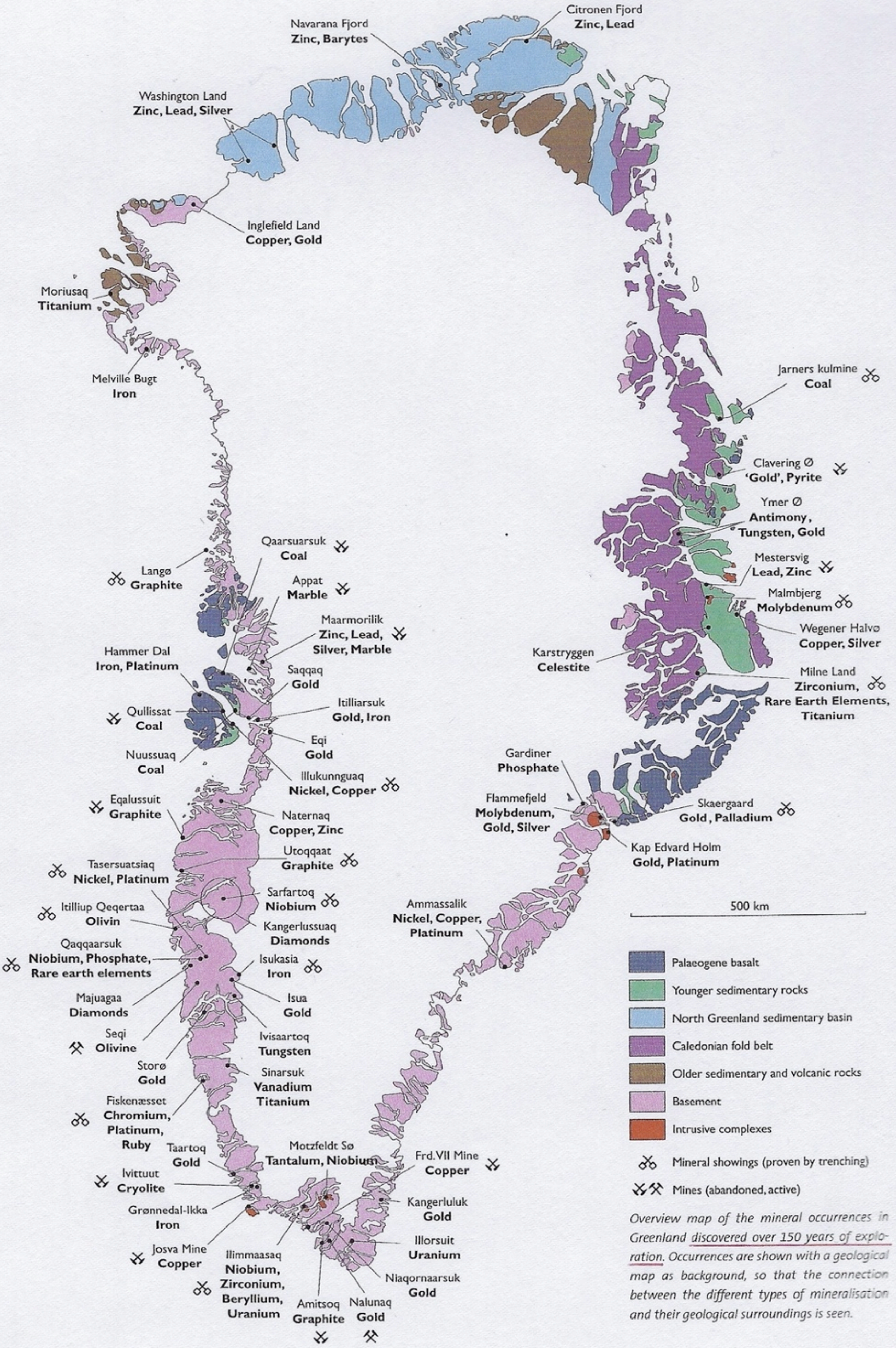
15 000 years ago

Today



Calculations of the thickness and extent of the Inland Ice at three different times:

1) at the start of the Eemian interglacial about 130 000 years ago, when the temperature was 4–5°C higher than today,
2) near the end of the last glacial 15 000 years ago, when the temperature was 10–12°C lower than today, and
3) the present extent of the ice.



Overview map of the mineral occurrences in Greenland discovered over 150 years of exploration. Occurrences are shown with a geological map as background, so that the connection between the different types of mineralisation and their geological surroundings is seen.

Source: Department of Economic Geology, GEUS

MAIN ROCK GROUPS

Rocks occur as aggregates of minerals with a grain size that spans from less than a millimetre up to several centimetres. Mineral grains are the smallest building block of the Earth's crust. The rocks are classified by their origin and their composition into the following main groups.

Rocks at the Earth's surface
- Sedimentary rocks
- Volcanic (extrusive) rocks

Rocks formed in the deeper parts of the crust
- Plutonic (magmatic) rocks
- Metamorphic rocks
- Migmatitic (partially melted) rocks

Examples of commonly occurring rock types from each group are shown on this page. The compositions of the rocks with their mineral components are described in the glossary (see p. 246-265).

SEDIMENTARY ROCKS

Siltstone
Fine-grained

Conglomerate
Coarse-grained

Sandstone
Medium-grained

Sediments are accumulations of mineral grains that are deposited by water or wind at the surface of the Earth. Examples are sands, gravels and conglomerates. Other types include rocks that are formed by chemical or biological precipitation in water such as rock salt and limestone.

VOLCANIC ROCKS

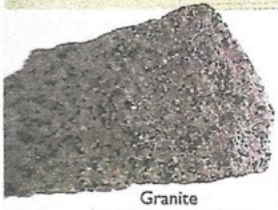
Vesicular basalt
Rock with holes from former gas bubbles

Ignimbrite
Rock formed from an incandescent ash cloud

Basalt
Solidified lava flow with flow structures

Extrusive volcanic rocks formed at the surface of the Earth by cooling of lavas (melted rock) or other eruptive products such as ash. Examples are basalt, pillow lava (magma erupted under water) and tuff (solidified ash).

PLUTONIC ROCKS



Granite
Reddish, medium-grained

Syenite
Pale, medium-grained

Gabbro
Dark, medium-grained

Plutonic rocks are formed by the solidification of a magma beneath the Earth's surface, commonly in the deeper parts of the crust. They are usually medium- to coarse-grained and have homogeneous textures. Examples are granite, quartz-diorite, gabbro, syenite and peridotite.

METAMORPHIC ROCKS

Gneiss
Grey, banded with pale veins

Augen gneiss
Gneiss with feldspar veins and 'eye' structures

Gneiss
Dark grey, folded

Marble
White, weakly banded

Amphibolite
Grey-black, banded

Metamorphic rocks and crystalline schists are formed by the transformation of other rocks through the effects of pressure and temperature. These rocks form typically in connection with fold belt formation or heating associated with magmatic intrusions. Examples are gneiss, quartzite, mica schist, amphibolite and marble.

MIGMATITES (Mixed rocks)

Migmatitic gneiss

Migmatitic amphibolite

Migmatitic rocks contain two different components; an older one (the palaeosome) and a younger component (the neosome) that occurs as pale veins permeating the palaeosome. The neosome usually forms by partial melting of material in the rock itself or from rocks nearby. The melted material mainly comprises quartz and feldspar and has a composition close to that of granite. Migmatites are very widespread in the deeper parts of mountain belts where temperatures are sufficiently high to mobilise components and melt parts of the rock.

Tous les documents de ce dossier géologique sont extraits de : Niels HENRIKSEN (2008): Geological History of Greenland, Four billion of Earth evolution, edition GEUS, Copenhagen (DK).

Sauf ceux des pages 18 (bas), 19 et 20, tirés de : Tom ANDERSEN, C. Henry EMELEUS, Karsten SECHER, Brian G. J. UPTON, Anker WEIDICK (2016): Geological guide South Greenland, The Narsarsuaq – Narsaq – Qaqortoq region, edition GEUS, Copenhagen (DK).