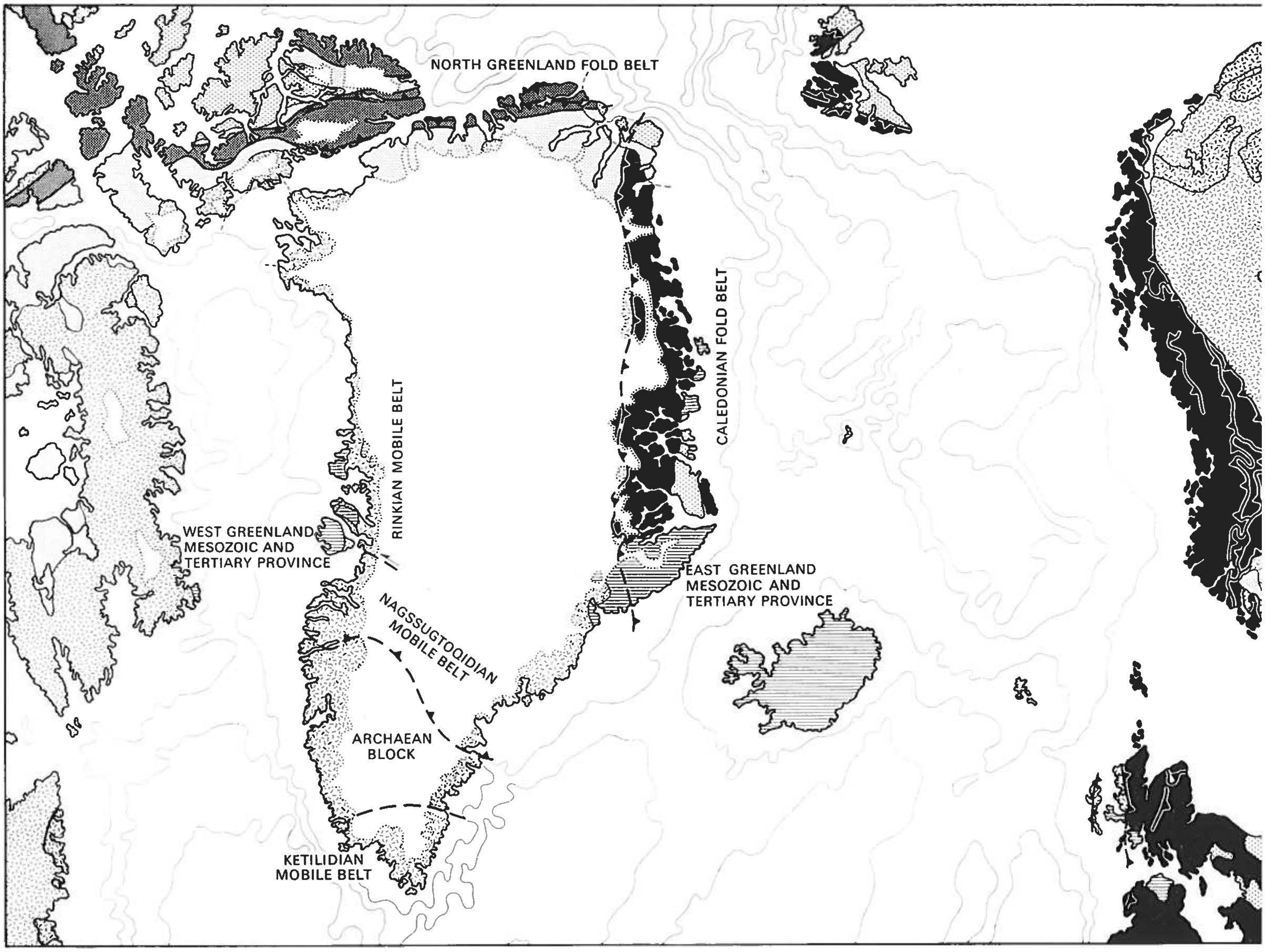

- Tertiary volcanic rocks, in Iceland includes Quaternary
- Mesozoic and younger platform deposits
- Palaeozoic and older platform deposits
- Innuitian and North Greenland fold belts
- Caledonian fold belt
- Mainly Proterozoic mobile belts
- Archaean mobile belts

Summary of the geology of Greenland

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Fig. 1. The structural divisions of Greenland in relation to the neighbouring land areas.

Introduction

Greenland is the largest island in the world with a surface area of 2 186 000 km² about 80 per cent of which is covered by the Inland Ice. The ice-free marginal mountainous rim of well-exposed bedrock is up to 250 km broad and the highest peak is 3733 m. The major units of the geological column in Greenland can be matched with rocks of similar age and lithology in North America and northern Europe, and their character and distribution are consistent with the idea that Greenland represents a fragment of a single North Atlantic land mass.

The largest part of the ice-free area is made up of crystalline rocks of the Precambrian shield. Rocks from part of this shield in the Isua region of central West Greenland have given the oldest reliable isotopic ages of any terrestrial rocks. The shield acted as a stable block on which sediments accumulated at various times throughout the Precambrian and were deformed and metamorphosed.

In North and East Greenland sedimentation continued into the Palaeozoic and some of the deposits were involved, together with the underlying basement, in tectonic and metamorphic events in mid-Palaeozoic time. Folded Palaeozoic rocks are overlain by Upper Palaeozoic and younger platform sediments in North Greenland; in East Greenland Upper Palaeozoic continental and marine deposits followed by thick successions of mainly marine Mesozoic sediments lie on the folded Palaeozoic and Precambrian rocks.

Along the west coast of Greenland a sedimentary basin developed during the Mesozoic and is represented onshore by Cretaceous and Tertiary sediments. In both West and East Greenland there was considerable volcanic activity in the early Tertiary.

Precambrian shield

Four major structural provinces are recognised in the Precambrian shield of Greenland (fig. 1). An old Archaean block is flanked by the late Archaean and early Proterozoic Nagssugtoqidian mobile belt to the north and the Ketilidian mobile belt to the south. To the north of the Nagssugtoqidian mobile belt another early Proterozoic complex, the Rinkian mobile belt, occurs that contrasts strongly in character with the Nagssugtoqidian. Cratogenic conditions were established by middle Proterozoic time when sediments and volcanic rocks accumulated in the Garder province of South Greenland, and platform sediments were deposited in North Greenland.

Archaean gneiss complex

The Archaean gneiss complex, which extends from the west coast to the east coast in the southern part of Greenland, has remained unaffected by major metamorphic, tectonic or magmatic events during the last 2500 m.y. Similar complexes occur in north-west Scotland and Labrador (fig. 1). The Archaean block in Greenland is the largest and best exposed fragment of the Archaean craton in the North Atlantic region. Isolated remnants of similar Archaean rocks occur within the younger mobile belts to the north and south suggesting that the Archaean complex was once much larger and that an important part of it was reworked by younger tectonic and metamorphic events.

The main part of the Archaean complex consists of quartzo-feldspathic gneisses derived largely from igneous rocks. Metavolcanic amphibolites and minor amounts of metasedimentary gneisses are intercalated with the orthogneisses as concordant layers. Large concordant units of anorthosite and associated basic igneous rocks are abundant and are spectacularly developed. High grade polymetamorphic mineral assemblages, mainly in high amphibolite and hornblende granulite facies, are characteristic. The layered nature of the Archaean gneisses is thought to be due in part to extensive injection of igneous sheets and in part to intense deformation during which rocks of different type and provenance were interleaved and folded together.

Field and isotopic investigations have established that the Archaean gneiss complex is made up of various units ranging in age from 3750 m.y., or older, to 2500 m.y. old (fig. 2).

During late Archaean time a variety of igneous rocks were intruded and these were later cut by several swarms of basic dykes between 2700 and 2000 m.y. ago. These dyke swarms are particularly dense near the northern and southern borders of the old block.

Nagssugtoqidian mobile belt

The Nagssugtoqidian mobile belt consists mainly of Archaean gneisses which were reworked in a major tectonic zone about 300 km wide identifiable in both East and West Greenland. This zone is characterised by a pronounced regional planar fabric parallel to the boundary with the Archaean block, the so-called linear belts alternating with areas of less deformed rock.

Isotopic dates suggest that the main phase of Nagssugtoqidian deformation and metamorphism took place about 2700 m.y. ago although the belt was active until about 1700 m.y. ago.

Supracrustal rocks form thin layers interlayered and deformed together with the Archaean gneisses. The gneisses are mostly in amphibolite facies though granulite facies gneisses occur in the central part of the mobile belt. The strong deformation of Nagssugtoqidian rocks is probably partly due to horizontal shear movements associated with overthrusting of the Nagssugtoqidian block onto the Archaean block to the south. Deformation is not equally developed throughout the belt; islands of Archaean rocks occur which are almost unaffected by Nagssugtoqidian movements and show a complex pattern of dome and basin structures.

Rinkian mobile belt

The Rinkian mobile belt lies to the north of the Nagssugtoqidian belt in West Greenland. It is considered as a separate structural province because it presents a striking contrast in tectonic style to the Nagssugtoqidian. The Rinkian is characterised by large-scale recumbent isoclinal folds and nappes, and large open gneiss domes which are often surrounded by rim synclines of metamorphosed supracrustal rocks. Corresponding structures and supracrustal successions are known from Baffin Island.

The supracrustal sequences overlie earlier gneisses and are particularly well developed in the Umanak region where a succession over 5 km thick of quartzites, pelites and flysch-like metasediments is preserved. These were metamorphosed together with remobilised basement gneisses under upper greenschist-amphibolite facies conditions during the formation of the dome structures.

To the north, near Upernavik, the supracrustal sequences are cut by a major igneous body, the Prø-

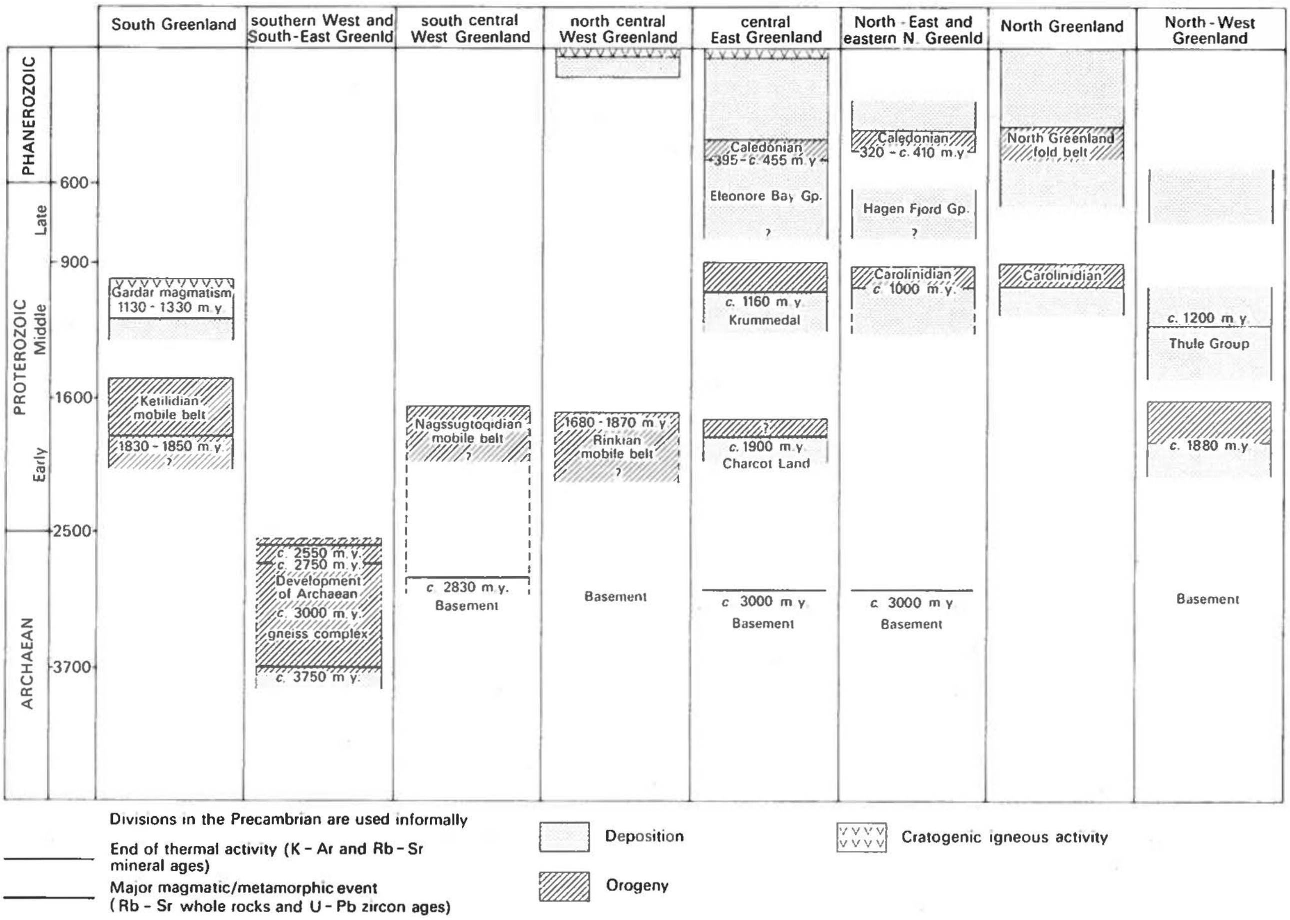

Fig. 2. Schematic chronological representation of the major geological events affecting Greenland.

ven granite, which locally resembles the Ketilidian rapakivi granites of South Greenland. The northern part of the granite and the adjacent gneisses contain granulite facies mineral assemblages.

K-Ar mineral ages from the Rinkian mobile belt range from 1870 to 1650 m.y.

Ketilidian mobile belt

The Ketilidian mobile belt occurs in the southern part of Greenland south of the Archaean block. It is characterised by numerous large late intrusive granite plutons. Isotopic ages range between 1850 and 1830 m.y. for the early granites, and between 1810 and 1740 m.y. for the intrusive rapakivi and other late granites.

At the northern margin of the Ketilidian mobile belt, sediments and volcanic rocks unconformably overlie the Archaean gneisses. Towards the south these supracrustal rocks and gneisses are progressively involved in Ketilidian metamorphism and deformation. The central part of the belt is dominated by a complex of gneissose granites, diorites and late intrusive granites, collectively known as the Julianehåb granite.

South of the Julianehåb granite there is an intricately folded zone of granites, gneisses and migmatised older metasediments and metavolcanics. Towards the southern tip of Greenland this migmatite complex shows high-grade mineral assemblages and is intruded by many large, late Ketilidian rapakivi-type granite intrusions of great areal extent.

Palaeozoic fold belts

Two major mid-Palaeozoic fold belts occur in Greenland: the Caledonian fold belt of East and North-East Greenland, and the North Greenland fold belt. In both regions the folded rocks are unconformably overlain by late Palaeozoic and Mesozoic sediments.

East Greenland fold belt

The East Greenland fold belt is part of a major Caledonian orogenic belt which occurs on both sides of the North Atlantic Ocean (fig. 1). In North-East Greenland the Caledonian fold belt is superimposed on the traces of a Carolinidian fold belt which may have formed about 1000 m.y. ago .

The Caledonian fold belt contains extensive areas of Archaean and Proterozoic gneisses, and at least two groups of early Proterozoic metasediments. Geosynclinal conditions were established in late Proterozoic time and sedimentation was almost continuous through the Cambrian and Ordovician until the onset of the Caledonian orogeny (fig. 2). The youngest sediments affected by the orogeny are carbonate sequences of Middle Ordovician age in central East Greenland, and Middle to Upper Silurian age in North-East Greenland. The older metamorphic complexes and younger geosynclinal sediments are variously involved in the Caledonian folding, thrusting and regional metamorphism, and are locally cut by late granites.

Devonian to early Permian continental sediments (molasse), periodically disturbed by minor movements, accumulated east of the fold belt and preserve a celebrated fish and tetrapod fauna.

North Greenland fold belt

The North Greenland fold belt lies between the northern flank of the crystalline shield and the Arctic Ocean. It is a continuation of the Innuitian orogenic system of Arctic Canada although it exposes a much narrower orogenic tract than in Canada. Geosynclinal conditions prevailed throughout the Lower Palaeozoic and continued into at least the early Devonian with the accumulation of a thick, dominantly clastic sequence, the upper part of which developed as a flysch facies. An early, southerly-derived detrital source from the craton was added to during the Ordovician, Silurian and Devonian by material derived from a northerly borderland.

Uplift and deformation occurred in the Devonian and may have continued into the early Carboniferous when an E–W trending mountain chain was formed in which the main direction of tectonic transport was northwards towards the Arctic Ocean. The effects of metamorphism and deformation progressively increase northwards within the fold belt resulting in high-grade sediments along the northern coast.

The fold belt has been subjected to late Phanerozoic (Jurassic? to Tertiary) folding, faulting, thrusting and metamorphism. Strong, northerly-directed thrusting in mid-Tertiary times resulted in the transport of the fold belt over a suite of mainly rhyolitic volcanic rocks of Devonian or younger age. This tectonism accentuated the northerly overturned mid-Palaeozoic tectonic grain of the fold belt.

Platform areas

The shield areas and the adjacent fold belts are overlain in places by younger sedimentary sequences.

Southern Greenland

In southern Greenland eroded granites of the Ketilidian mobile belt are overlain by continental sandstones intercalated with basaltic lavas of the Middle Proterozoic Gardar period. These are mostly preserved in fault-bounded outliers but are thought to have been originally more extensive. The extrusion of basaltic rocks was accompanied by intrusive dyke activity and faulting that affected much of southern Greenland, and a major suite of alkaline igneous rocks was emplaced about 1330–1140 m.y. ago.

The complexes are predominantly composed of alkaline to peralkaline rocks, and fall naturally into two categories: those involving granites and quartz syenites, and those involving syenites and nepheline syenites. Only one complex comprises rocks from both categories. Troctolitic gabbros, and syenogabbros and augite syenites occur within both oversaturated and undersaturated complexes and hence have come to be regarded by various authors as having played some parental role in the petrogenesis of the more salic magmas.

Igneous layering is conspicuous in most of the intrusive units of this province, which is one of the most notable alkaline igneous provinces of the world.

North and North-West Greenland

During the late Middle Proterozoic, unfossiliferous predominantly clastic sediments with a composite thickness of 4500 m were deposited in the Thule basin (77°N). Quartzite, sandstone and conglomerate at the base grade upwards into mainly black shales followed by dolomite and arenaceous rocks with some limestone and gypsum. Outside the Thule basin a strip of Middle to Late Proterozoic sandstones and quartzites outcrops in a narrow belt across North Greenland from Inglefield Land (78°N) to Kronprins Christian Land (80–81°N). In North Greenland these deposits are up to 1300 m thick and were intruded by doleritic dykes and sills which have given radiometric minimum ages of 1000 m.y. In a few places on the platform, the arenaceous rocks are overlain unconformably by Eocambrian tillites.

From Inglefield Land in a strip eastwards across North Greenland, the arenaceous deposits are overlain unconformably by a composite 4500 m sequence of fossiliferous dolomites and limestones with minor sandstones and shales, of Cambrian, Ordovician and Silurian age. Gypsiferous beds are present in the Lower Ordovician of western North Greenland, while a conspicuous east–west reef belt characterises the Silurian. To the north the Lower Palaeozoic carbonate sequences pass into clastic facies involved in the folding of the North Greenland fold belt.

In eastern North Greenland a 1300 m thick succession of limestones, sandstones and shales was deposited in a new sedimentary basin formed after the mid-Palaeozoic diastrophism. This sequence began with a Carboniferous marine transgression over the eroded remnants of the North Greenland fold belt and reaches up into the Paleocene.

East Greenland

In East Greenland the Caledonian molasse deposits were followed by an Upper Permian transgression with deposition of limestone, gypsum and shale on down-faulted and tilted blocks along the eastern border of the fold belt. Triassic sediments mostly comprise marine and continental clastic rocks whereas the succeeding Jurassic clastic sequence mostly accumulated in a shallow marine shelf environment and is highly fossiliferous. Cretaceous sediments are marine and predominantly clastic, consisting of conglomerates, sandstones and shales. The composite thickness of the whole sequence approaches 7000 m. Cretaceous and early Tertiary sandstones are known further south at Kangerdlugssuaq (68°N) immediately below the Tertiary basalts.

The Jurassic rocks provide one of the most complete sequences bordering the North Atlantic Ocean and are thus of special interest for studies of the evolution of the early Atlantic Ocean. Faulting was active throughout the Mesozoic and into the Tertiary, and has been related to crustal widening; the intense faulting in the late Jurassic may be related to the initial spreading between the North American and European continents.

West Greenland

In central West Greenland a sequence of clastic sediments ranging in age from Lower Cretaceous (Barremian–Aptian) to Lower Tertiary (Danian) overlies the eroded remnants of the Rinkian mobile belt. The Nûgssuaq embayment, in which the beds occur, is part of an extensive sedimentary basin – the West Greenland basin – whose major part is present offshore, fringing the coast of West Greenland from Kap Farvel in the south to Melville Bugt in the north. The embayment was the site of a slowly subsiding delta. A sandstone–shale facies of fluviatile deltaic origin in the south gives way to a prodelta marine facies in which shale predominates in the north. There was a gradual marine transgression from the north during sedimentation. Coal seams, some of which are thick enough to have been worked, are common in the southern part of the embayment, but disappear northwards.

The maximum thickness of sediments in the onshore area has been shown by field mapping and geophysical surveys to be about 3500 m. Much greater thicknesses are known from geophysical evidence to be present offshore, up to 10 km in Melville Bugt, 5 km west of the Nûgssuaq embayment, and over 5 km south of Egedesminde.

The marine faunas from the Cretaceous shales show strong North American affinities whereas those from the Danian have strong European affinities.

Tertiary volcanic province

In the early Tertiary there was considerable magmatic activity in both central East and central West Greenland which form part of the Brito-Arctic or North Atlantic volcanic province. The two areas lie more than 700 km apart and the geology of each area is quite distinctive.

In West Greenland the first indications of volcanism are intercalations of tuffs in Danian (lowest Tertiary) marine sediments. The basal unit of thick basalt breccias and pillow lavas of submarine origin is succeeded by a thick sequence of subaerial picritic and olivine rich basalts, and an upper unit of variable types dominated by tholeiites. Non-marine clastic sediments intercalated in the upper part of the volcanic sequence have yielded fossil plants of late Eocene age. The composite thickness of the lava pile approaches 8000 m. Dykes and sills are known, and some can be shown to be feeders of the lavas, but only one relatively small intrusive complex is known.

In East Greenland, by contrast, there are many central igneous complexes varying in composition from mafic and ultramafic to syenitic, nepheline syenitic and granitic. Where time relationships are known the central complexes penetrate a cover of basaltic rocks. The basalts form an extensive continuous cover in the southern part of the area of volcanism, but further north the basalts are now discontinous. The basalt succession is a monotonous series of tholeiitic flood basalts up to 7000 m thick. These overlie sediments in the Kangerdlugssuaq region which have given a Paleocene (lowest Danian) age; they are overlain by marine sediments of Middle to Upper Eocene origin.

The massive extrusion of basaltic lavas in both West and East Greenland is linked to the pronounced rifting and spreading in the early Tertiary. In West Greenland this was associated with the opening of Baffin Bay and the Labrador Sea and in East Greenland with the opening of the North Atlantic Ocean.

Quaternary and glaciation

A period of climatic deterioration followed the warm temperate climate in the early Tertiary recorded by a rich flora in West Greenland. This led to the formation of an ice sheet that at its maximum extent virtually covered the whole of Greenland with the exception of a few nunatak areas. Climatic oscillations led to shrinkage of the ice sheet and formation of interglacial deposits around the coasts.

Considerable evidence suggests that the extent of the ice sheet during the last glacial advance was less than that at the maximum extent during the Wisconsin-Weichsel.

The amelioration of the climate in the postglacial period (Holocene) caused shrinkage of the ice sheet and a climatic optimum can be traced in the Holocene fauna and flora around 6000 B.P. when the ice sheet was apparently much smaller than now. The subsequent more severe climate during the last millenia established the ice margins close to their present positions.

Economic geology

There has been active prospecting on the gneiss areas of the shield in recent years, principally on the more accessable west coast, and many mineral deposits are known. Small deposits of copper and graphite were formerly mined, as was the important cryolite deposit at Ivigtut which was worked out in 1962. In 1973 extraction of lead-zinc ores was begun from a new mine at Mârmorilik. Large deposits of iron ore, chromite and uranium are also known in West Greenland but have not yet been exploited.

In central East Greenland mineralisation is associated with alkaline intrusive activity. A deposit of lead-zinc sulphides near Mesters Vig (72°) was mined between 1956 and 1963 and is now exhausted. In the same area molybdenite is known from the alkaline intrusion of Werner Bjerge.

The presence of flat-lying sediments of Mesozoic age in East and West Greenland and of Palaeozoic and Mesozoic sediments in North Greenland has encouraged oil exploration. In West Greenland onshore sediment thicknesses are small but geophysical investigations suggest considerable thicknesses offshore. The first concessions for oil and gas exploration in offshore areas were given in 1975.

The Greenland ice sheet covers 80 per cent of Greenland and although the general form of the subglacial surface is just becoming known, the distribution and nature of the rocks below it are a matter of extrapolation from the ice-free rim.