GRØNLANDS GEOLOGISKE UNDERSØGELSE
BULLETIN No. 53

ISOTOPIC AGE DETERMINATIONS FROM SOUTH GREENLAND AND THEIR GEOLOGICAL SETTING

BY

DAVID BRIDGWATER

WITH 1 FIGURE IN THE TEXT, 7 TABLES
AND 1 PLATE

DANISH GEOLOGICAL CONTRIBUTION
TO THE INTERNATIONAL UPPER MANTLE PROJEKT

Reprinted from
Meddelelser om Grønland Bd. 179, Nr. 4

KØBENHAVN
BIANCO LUNOS BOGTRYKKERI A/S
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Abstract

A brief geological review of the area between Sermiligârssuk and Kap Farvel is given using the following five main divisions of the Precambrian of South Greenland: 1) pre-Ketilidian (? 2000–2700 m. y.), 2) Ketilidian (? 1700–2000 m. y.), 3) post-Ketilidian ≡ Kuanitic (? 1650–1700 m. y.), 4) Sanerutian (? 1500–1650 m. y.), 5) Gardar (1020–?1500 m. y.). In the area described these divisions are characterised by: 1) gneisses, 2) geosynclinal sedimentation and lava extrusion, metamorphism and plutonism, 3) basic and intermediate dyking, 4) renewed plutonism, and emplacement of synplutonic basic, intermediate and granitic rocks, 5) post-orogenic sedimentation, lava extrusion and a predominantly alkali suite of intrusive rocks.

Isotopic age determinations are available from the two youngest of the above divisions in South Greenland; dates for the three older divisions are suggested by comparison of the development of South Greenland with other fold belts together with sparse data from elsewhere in Greenland.

It is suggested that the pre-Ketilidian gneisses represent the remnant of an old fold belt formed approximately 2400–2700 m. y. ago which has been reactivated during the Ketilidian and Sanerutian plutonic episodes in South Greenland. It is further suggested that the Ketilidian, post-Ketilidian and Sanerutian episodes are phases in the evolution of one fold belt which started at approximately 2000 m. y. ago and represents the beginning of the Svecofennid chelogenic cycle in South Greenland. The Gardar magmatism is regarded as a typical post-orogenic alkali suite and it is thought that the Gardar activity at about 1200 m. y. may represent compensatory tensional conditions on the margins of the developing Grenville fold belt which probably passed south of Greenland.

Eight K/Ar age determinations (Geochron Laboratories) give the following results: Sanerutian hypersthene gabbro, 1645 m. y. (biotite) and 1700 m. y. (augite); Sanerutian granite, 1620 m. y. (biotite); early Gardar dolerite, 1435 m. y. (augite); Gardar syenite, 1128 m. y. (biotite) and 1355 m. y. (augite); inclusion of anorthosite fragment in a Gardar dyke, 1025 m. y. (biotite) and 1075 m. y. (augite).

Four Rb/Sr age determinations (Moorbath) give the following results: Ketilidian pegmatite affected by Sanerutian metamorphism, 1630 m. y; Sanerutian granite, 1615 m. y.; Sanerutian granite probably affected by Gardar event, 1220 m. y.; Gardar biotite granite, 1150 m. y.

Results from other areas in Greenland are discussed and it is suggested that a large part of the south-west coastal strip is pre-Ketilidian in age and that the Nagssugtoqidian fold belt was formed at approximately the same time as the Ketilidian-Sanerutian fold belt in South Greenland, that is at the beginning of the Svecofennid chelogenic cycle.

It is suggested that the main episodes described from South Greenland correspond to events in the Canadian shield as follows: pre-Ketilidian plutonism ≡ Kenoran; Ketilidian-Sanerutian and Nagssugtoqidian ≡ Hudsonian; Gardar ≡ post-Hudsonian, pre-Grenville igneous activity. Tectono-igneous cycles are used in conjunction with basic dykes and age determinations as a method of dividing the Precambrian.

CONTENTS

INTRODUCTION

This paper is an attempt to relate the most recent geological ideas about the chronology of South Greenland with the available isotopic age determinations. The conclusions reached are tentative because the number of age determinations is very small in relation to the complexity of the geological problems. Several of the determinations are of rather dubious value, either because the methods used were not refined enough or because the collection of specimens was made with insufficient knowledge of the geological background.

Geochron Laboratories Inc. provided the main impetus for this work when they determined eight K/Ar ages on five rocks supplied by the author as a result of their first annual competition. These determinations are gratefully acknowledged. S. MOORBATH of Oxford University kindly suggested that four unpublished Rb/Sr determinations should be included in this paper and has also offered many valuable comments during the initial drafting. Without Dr. MOORBATH's assistance the scope of this paper would have been considerably less.

All new K/Ar age determinations have been calculated assuming constants of:

$$\lambda_\beta = 4.72 \times 10^{-10}/\text{years}$$
$$\lambda_e = 0.585 \times 10^{-10}/\text{years}$$
$$K^{40}/K = 1.22 \times 10^{-4}\,\text{g./g.}$$

All Rb/Sr age determinations are given assuming the half life of Rb^{87} to be 4.7×10^{10} years (FLYNN and GLENDENIN 1959). Earlier Rb/Sr results have been recalculated using this constant. The initial ratio $(Sr^{87}/Sr^{86})_{t_0}$ is assumed to have been 0.710 for all rocks dated by the Rb/Sr method.

As this paper is essentially a summary of the most recent knowledge of the geology of South Greenland it contains many ideas current among members of the Geological Survey of Greenland (G. G. U.) which have not yet reached print. Reference is made where possible both to work in print and to forthcoming publications. A more detailed summary of the basement geology of the area between Kobberminebugt and Kap Farvel is being prepared by ALLAART (1964).

I. GEOLOGICAL REVIEW

South Greenland is a Precambrian area consisting of an old basement (formed largely under plutonic conditions), intruded by a younger, predominantly alkaline, series of magmatic rocks. The first modern account of the area was published by WEGMANN in his papers of 1938, 1939 and 1948 and his nomenclature stands as the frame of present-day work. WEGMANN proposed a three-fold chronological division of the Precambrian of South Greenland based on the recognition of rocks formed under stable (cratogenic) conditions separating rocks formed under regional conditions of high temperature and pressure (plutonic conditions). WEGMANN's divisions, which have been called "periods" by more recent authors, contain an unequal number of events. WEGMANN suggested that the Ketilidian probably could be divided by a series of basic dykes intruded during cratogenic conditions. These cut the early Ketilidian granites but are themselves affected by granites and pegmatites of the last stages of the Ketilidian (WEGMANN 1938 p. 49, 1939 p. 204). Recent work has confirmed this and the plutonic episode affecting these dykes has been called the Sanerutian (BERTHELSEN 1960, WATTERSON in press). The term Kuanitic has been used for the cratogenic episode separating Ketilidian plutonism from the Sanerutian (BERTHELSEN 1960) but as there is doubt about the age of some of the metadolerites from the type locality it is probably better not to use the term as a chronological division. The sequence of events shown in Table 2 is accepted by all the geologists working in South Greenland. There are, however, considerable differences of opinion about the distribution of the various divisions.

Table 1. *Division of the Precambrian of South Greenland* (WEGMANN).

3) Gardar	A series of supracrustal sediments and volcanics intruded by alkaline magmatic complexes and dykes.
2) Ketilidian	Sediments and volcanics lying unconformably on the pre-Ketilidian basement. These have been subsequently folded, metamorphosed and granitised in the Ketilidian episode.
1) pre-Ketilidian	An undifferentiated basement of gneiss and granites.

Table 2. *Terminology as used in this paper (G.G.U. 1964). Dates earlier than 1650 m.y. and those in parentheses are hypothetical or not obtained from South Greenland.*

Time	Event	Age
5) Gardar	Major alkali intrusions.	1020–1255 m. y.
	Basic and alkali dykes.	
	Early Gardar carbonatites.	(1450 m. y.)
	Sandstone deposition and lava extrusion.	
4) Sanerutian	Reactivation of earlier granite and some folding. Emplacement of	1500 m. y.
	"New granites".	1620 m. y.
	Intrusion of major basic masses under plutonic conditions.	1650 m. y.
3) post-Ketilidian (≡ Kuanitic)	Intrusion of basic and intermediate dykes.	
2) Ketilidian	b) Post tectonic granites.	1700 m. y.
	Folding, metamorphism and syntectonic granitic gneisses.	1800–1900 m. y.
	a) Sedimentation and lava extrusion.	2000 m. y.
1) pre-Ketilidian	b) Plutonic formation of granites and gneisses.	2500–2700 m. y.
	a) Original formation of material in Ivigtut region.	3000 m. y.

Description of the Major Geological Divisions of South Greenland

1) Pre-Ketilidian

WEGMANN defined the pre-Ketilidian as an older basement of gneiss and granites on which the sediments and lavas of the Ketilidian were deposited unconformably. He suggested that the pre-Ketilidian was represented by boulders in the Ketilidian quartzites near Tasermiut fjord and probably by the cores of structures within the Ivigtut gneisses (WEGMANN 1939, p. 205–206). BONDESEN (1962) has shown that a well preserved unconformity exists between the basal conglomerate of the Ketilidian sediments and a group of gneisses occurring along the ice margin at Grænseland to the north-east of Ivigtut. In this paper the unconformity is used as a datum line for defining the earliest Ketilidian rocks; thus the gneisses below the unconformity are by definition pre-

Ketilidian. Although it is now generally accepted in G. G. U. that these gneisses are pre-Ketilidian their extent is a matter of considerable controversy. The main points of this controversy are discussed in Section II.

Rock types recognised from the pre-Ketilidian

The gneisses below the Græenseland unconformity vary from homogeneous plagioclase quartz granodiorites with very little mafic material in the north to banded rocks with a higher proportion of hornblende in the south. No petrographic features have been described from these rocks which can be used to separate them from the rest of the Ivigtut gneisses. According to one interpretation most of the gneisses in the Ivigtut region are therefore pre-Ketilidian. The Ivigtut gneisses contain several lithological units which can be traced for considerable distances and which Berthelsen (1960) has used to build up a complex history of folding. Most of the gneisses are granitic; the units are separated by their different content of mafic material. One of the units, the "gabbro anorthosite" series, is of particular note as rocks of the same distinctive type have been reported from several places further north along the west coast of Greenland. Berthelsen (1961 p. 337) has used the presence of these rocks to suggest that rocks of a similar age to the Ivigtut gneisses are widespread. The "gabbro anorthosite" series consists of a group of gneisses in which there are enclaves, boudins, or bands of plagioclase-hornblende rock. Typically the rock shows a net structure, with slightly elongate lenses of basic plagioclase surrounded by hornblende. Bondam (1955) suggested that these rocks show a higher metamorphic facies than the surrounding gneiss as they acted as resisters to a subsequent period of granitisation.

South-east of Kobberminebugt some of the areas of gneiss within the granite may represent pre-Ketilidian rocks but it is impossible to be certain of their age relationships. Pre-Ketilidian rocks, represented in the conglomerates of the Ketilidian sediments in Tasermiut fjord, contain several varieties of granite which according to Wegmann range from syntectonic to post-tectonic types.

Age of the pre-Ketilidian

No direct determinations have been made on known pre-Ketilidian rocks. According to Slawson *et al.* (1963) and Kanasewich and Slawson (1964) the initial event in the Ivigtut region occurred between 3000 m. y. and 3520 m. y. ago. This date is based on the anomalous isotopic composition of the Ivigtut lead from the cryolite body emplaced approximately 1200 m. y. ago (Moorbath and Pauly 1962). Kanasewich and Slawson base their age calculations on a two stage model giving 3520 m. y. or a modified three stage model giving 3020 m. y. which allows for a metamorphism during a plutonic episode at 1600 m. y. Whether further modification of this date will either be necessary or possible will depend largely on the dating of the Ivigtut gneisses. Similar results from the Ivigtut lead have also been reported by ULRYCH (1964). The 3000 m. y. date from the Ivigtut region strongly suggests that some material has been derived from pre-Ketilidian sources in the area, either by resedimentation of pre-Ketilidian rocks, or by plutonic reworking of an older basement. If the lead is regarded as a primary mineral formed during the igneous activity at the beginning of the Ketilidian or by segregation during the Ketilidian plutonism then, a determination of the age of the gneisses below the Ketilidian unconformity would be very interesting.

2) The Ketilidian

a) Supracrustal rocks

Metamorphic rocks of sedimentary and volcanic origin exist in two main regions in South Greenland: surrounding the Ivigtut gneisses and around Tasermiut fjord. As they are separated by large areas of migmatites and granite there is no proof that they are contemporaneous. However, WEGMANN's 1938 correlation is still acceptable since rocks derived from the sediments in the two areas have both passed through a similar history including two plutonic episodes earlier than the Gardar.

The northern area of Ketilidian low grade metamorphic rocks is best preserved in the region mapped by BONDESEN (1962) to the north-east of Ivigtut. Here the supracrustals can be divided into three main units: a lower sedimentary unit with a well-defined basal conglomerate, quartzites, dolomitic limestones, pelitic schists and greywacke; a middle unit dominated by pillow lavas with a few sedimentary intercalations; and an upper unit consisting mainly of pyroclastics and related gabbroic rocks.

The southern area of presumed Ketilidian metamorphic rocks is divided by ESCHER (in press) into three main units: a lower unit of pelitic sediments, a middle unit of quartzites and an upper unit of pillow lavas and gabbroic rocks.

Both the northern and the southern supracrustal rocks seem to be geosynclinal deposits and therefore are suitable to define the beginning of the Ketilidian cycle.

b) Ketilidian plutonism

The supracrustal rocks laid down in the first phase of the Ketilidian were subjected to folding and metamorphism varying from slight in parts of the Ivigtut district, to extreme over a large part of the Julianehåb district with the formation of a more or less homogeneous gneiss. If the problematical Ivigtut gneisses are neglected, the only high grade metamorphism of the Ketilidian supracrustal rocks is seen towards the south and east where garnet pyroxene gneisses are developed. Fragmentary records from the east coast of Greenland suggest that high grade metamorphic rocks may extend for a considerable distance north from Kap Farvel (R. BØGVAD, unpublished diaries 1932, 7th. Thule expedition). Most of the supracrustal rocks north of Ivigtut are in the greenschist to epidote amphibolite facies. The Ketilidian granites show a variety of features, from those of syntectonic gneisses to post-tectonic homogeneous granites with intrusive contacts. In several areas large basic and ultrabasic bodies are found within the Ketilidian granites. The chronological position of these is rather controversial as in some areas they have been recorded cutting presumed Ketilidian gneisses while in others they are seen to be granitised before the intrusion of the post-Ketilidian series of metadolerites. It is possible that there are two episodes of ultrabasic intrusions or that they were synplutonic.

There is no direct evidence for the date of the Ketilidian. A possible age of 1800 m. y. is suggested in Section II by comparing the development of South Greenland with other fold belts.

3) Post-Ketilidian dyke emplacement during cratogenic conditions

A return to more stable conditions at the end of Ketilidian plutonism is recognised by a series of metamorphosed igneous dykes cutting the Ketilidian structures. Most of the dykes belonging to this series are thin and have subsequently undergone considerable alteration, but primary structures, indicating that the dykes were intruded into cold brittle rocks, are locally preserved. The original composition of the dykes is not known accurately although relic ophitic texture suggests that most were dolerites, but locally there are dense swarms of intermediate rocks and composite dykes with less basic centres. Primary oligoclase phenocrysts in some of the dykes suggest that they were andesitic when intruded. Occasionally dykes with large xenocrysts of plagioclase are found. The feldspars are generally strongly altered but may be a lustrous black and opaque, when seen fresh. This feature is seen to a much larger extent in the Gardar dolerites which are described later. North of Ivigtut the gneisses are cut by a series of metadolerites (the Kuanitic dykes) (BONDESEN and HENRIKSEN in press). The chronological position of these dykes and their possible correlation with the dykes south of Kobberminebugt is discussed in Section II. No extrusive or sedimentary rocks equivalent in age to the dyke swarms have been recognised, although this probably reflects the level of erosion rather than an original feature.

4) Sanerutian plutonism

The pre-Ketilidian basement, the Ketilidian metasediments and granites and the post-Ketilidian dyke swarm have all been affected by the Sanerutian regional metamorphism. The exact distribution of the rocks affected by this activity is not easily defined, but there seems to be a decrease in the effect of the Sanerutian north of Ivigtut (Bondesen and Henriksen in press) and south of Sydprøven (P. Dawes personal communication).

In South Greenland major folding of the type and scale seen in the Ketilidian has not been recognised from the Sanerutian. The most common tectonic feature is a second movement along foliation planes already formed by the Ketilidian folding. This "structural reactivation" is concentrated in well-defined belts with intervening tracts of unaffected rock. It is quite possible that large scale simple structures, such as doming of the Ivigtut region, took place in the Sanerutian.

Rock types associated with the Sanerutian

a) Basic rocks. A noritic gabbro, hypersthene diorite, monzonite suite of igneous rocks was emplaced under plutonic conditions in the Sanerutian (Bridgwater 1963, Walton in press). These rocks show a complex relationship to a series of porphyritic, sometimes allochthonous, Sanerutian granites (the so called "New granites"), which often show intrusive contacts against the country rock. Generally the complexes consist of basic cores surrounded by granitic mantles. The granites remained active later than the basic rocks and formed a variety of contact features with them. These include agmatites, granitisation of original igneous layering and the widespread growth of feldspar megacrysts. Evidence is listed below to show that the two rocks were approximately contemporaneous and that the basic centres are not relics of an older generation of gabbroic rocks partially granitised by the "New granites".

i) The two rock types are intimately associated; the five main bodies of "New granite" already mapped in South Greenland all contain basic masses.

ii) The basic masses themselves contain inclusions of older granite cut by discordant amphibolite. Unless these represent rocks which have not been recognised locally this implies that the basic masses are later than the post-Ketilidian cratogenic period.

iii) Although generally the contacts between the two rock types suggest that the granite is later than the basic rock there are local features which show that the basic rock was still mobile when the granite was active. Considerable mixing is seen with the formation of mixed rocks as a belt surrounding the basic centres. Granite pipes and pegmatites cut the basic rock while the latter was still partially unconsolidated. Locally tongues of basic rock "intrude" into the granite with rounded chilled contacts.

A possible explanation of the relationship between these two rock types is the emplacement of basic magma into older rocks of granitic composition which were near to the melting point of granite due to their plutonic environment. Under these conditions the rheomorphic effect of a large basic mass on the surrounding rocks would be much greater than normal.

Minor basic intrusives of widely different types are common throughout the Sanerutian. Because of their plutonic environment these intrusions show a variety of curious features and have been extensively studied by members of G. G. U. in the last few years. Three main types have been recognised; late plutonic basic dykes intruded into hot shear zones (WATTERSON in press), net-veined diorites in which the intrusion of a basic sheet was rapidly followed by the intrusion of acid material in the same fissure (WINDLEY in press), and the intrusion of basic dykes into still mobile granites (BRIDGWATER 1963). The differences between the three types are probably due to the differences in local conditions during the Sanerutian. This may be either through lateral variation in the intensity of the episode or due to changes during the development of the Sanerutian. Using classical methods to divide the Precambrian it is vital that the basic dykes intruded during plutonic episodes should be distinguished from metamorphosed dolerites intruded under cratogenic conditions (WATTERSON in press).

Another group of minor intrusions of ultrabasic to granitic composition may be mentioned here. These rocks form very irregular lobate and sheet formed bodies and are found close to the "New granites". The mineralogy of these intrusions is remarkable for the number of different mafic minerals present within one body and often within one slide. It is common to see olivine, two pyroxenes, magnetite, orthite, garnet, hornblende and biotite in close association. The bodies are generally intensely layered and may grade from ultrabasic to granitic rock within five metres.

b) Sanerutian granites. Sanerutian granites range from those formed by a passive reactivation of pre-existing rocks to allochthonous granites discordant to earlier structures. The "New granites" which form a distinctive group within the Sanerutian, range from rocks with primary magmatic structures such as those described from Tigssaluk (EMELEUS 1963) to reactivated rocks preserving relics of pre-Sanerutian basic dykes (WALTON in press). One body, such as the Sydprøven granite, may show an almost complete range from replacement to crystal settling from a magma. The "New granites" are not confined to the main area of Sanerutian reactivation. Four of the five main bodies mapped are found in areas where the Ketilidian or pre-Ketilidian gneisses have been very little affected by general reactivation.

The Sanerutian reactivation of pre-existing granitic rocks has been extensively studied in the Julianehåb district by ALLAART (in prep.). The reactivation appears to be a highly variable phenomenon, ranging from slight recrystallisation to the forming of mobile granites with intrusive contacts. Because of the difficulties in delimiting areas of reactivation on a map the only Sanerutian granites shown on Plate 1 are those with very strong recrystallisation or discordant contacts. Occasionally considerable introduction of new material can be recognised where a Sanerutian granite is formed at the expense of pre-existing basic rocks (F. PERSOZ personal communication). Finally a group of fine to medium grained homogeneous granites with discordant contacts and few relic structures are concentrated in the area Qagssimiut to Sydprøven and NW of Tasermiut fjord. These are generally late Sanerutian and may be connected to the emplacement of the large swarms of pegmatites such as those described by WINDLEY (1963) and WINDLEY and BRIDGWATER (in press).

The end of the Sanerutian marked the close of plutonic activity in South Greenland. The change between plutonic and cratogenic conditions was probably gradual and may not have occurred at the same time at different places within the area over which Sanerutian activity has been recognised. It is often difficult to distinguish the last rocks formed under plutonic conditions and the first formed in the following cratogenic episode. A series of metadolerite dykes intruded later than the Sanerutian reactivation and the late plutonic basic dykes described by WATTERSON (in press) but earlier than the fresh Gardar dykes, are seen in the Julianehåb district (J. H. ALLAART personal communication). The most reasonable explanation for the metamorphism of these rocks is that they were affected by the country granites which were still at a relatively high temperature during the waning of plutonic conditions.

In the area north of the Igaliko syenite WALTON (in press) describes a series of late plutonic basic lamprophyres and carbonatitic sills and dykes which he suggests are the last phase of the appinitic suite of intrusions. These minor intrusions cut the late plutonic basic dykes emplaced in hot shear zones (WATTERSON in press) but have many features suggesting a similar structural control of their emplacement. These features include shearing parallel to their length during or immediately after intrusion and differentiation under stress. Somewhat similar rocks are described by WEIDMANN (1964 p. 83–89) from the area surrounding the Tigssaluk granite. WEIDMANN regards the lamprophyres as post-plutonic and representing the first phase of the Gardar cratogenic magmatism. In many areas the earliest dolerites of the Gardar cratogenic episode are slightly altered with sericitisation of the plagioclase and the formation of pyrite and hornblende.

At the end of plutonic activity in South Greenland there was considerable development of faulting. Some of the movement zones, especially the E-W wrench faults, may have been active before the end of plutonic conditions and continued intermittently throughout the following cratogenic episode (HENRIKSEN 1960).

Sanerutian plutonic conditions in South Greenland probably extended from 1650 m. y. to approximately 1500 m. y. The Rb/Sr date on the Julianehåb granite, recalculated as 1500 ± 70 m. y. from MOORBATH *et al* (1960), is the youngest date so far obtained from the Sanerutian. This date is slightly anomalous and is discussed on page 38.

5) The Gardar cratogenic episode

a) Chronology

The Gardar cratogenic episode is represented in South Greenland by the continental deposition of sandstones and lavas accompanied and followed by the emplacement of intrusive rocks. The Gardar rocks have been studied for a considerable time because of their great petrological interest, and a complete list of references is beyond the scope of this review. An exact chronology of the numerous events within the Gardar has yet to be worked out. The following scheme, which has been extended from UPTON (1962 p. 8), is probably applicable over the area from Ivigtut to Igaliko where the major igneous activity took place.

i) Early Gardar: Strong wrench faulting trending 90°–120°, probably considerable vertical faulting in other directions. Deposition of sandstone and extrusion of lavas. Intrusion of a nepheline syenite-carbonatite complex at Grønnedal (EMELEUS 1964), and a nepheline syenite-gabbro giant dyke on Tugtutôq (UPTON 1962). Intrusion of lamprophyric dykes in the Ivigtut region (BERTHELSEN 1962) and carbonatitic dykes, sills and plugs north of the Igaliko alkali complex (WALTON in press). Emplacement of a regional swarm of gabbroic dykes at approximately 90° to 120°, parallel to the wrench faults which continued active after the dyke emplacement.

ii) Mid-Gardar: Faulting with a general 50°–70° trend; several generations of NE dykes, ranging from dolerites to composite dykes with syenitic or granitic centres and gabbroic margins. Major period of dyke emplacement with anorthosite inclusions.

iii) Late Gardar: Emplacement of the Ivigtut granite (1255 m. y.)[1] and cryolite body (1190 m. y.). Emplacement of the major alkali complexes of Nunarssuit (1150 m. y., HARRY and PULVERTAFT 1963), Kûngnât (1170 m. y., UPTON 1960), Tugtutôq (UPTON 1962), and Ilímaussaq (1020 m. y., FERGUSON 1964). Intrusion of decreasing numbers of dykes. Local movement continued along faults until the end of the period.

The divisions above are somewhat arbitrary and it seems likely that events which some authors have placed in the late Gardar (for example the Ivigtut granite) may be contemporaneous with the mid-Gardar events of another area. The intrusion of one of the largest alkali complexes in South Greenland, the Igaliko syenite, is not included on the above scheme as no published work is yet available. It appears likely from the complexity of the body that it was intruded over a considerable period.

b) Summary of the Gardar rock types

i) Gardar supracrustal rocks.

The Gardar sandstones are thought to be among the oldest post-plutonic rocks as they are cut by carbonatite plugs and dykes. The sandstones and overlying lavas are mainly confined to the down faulted block trending NNE from Narssaq, although isolated outcrops and stoped blocks in younger intrusions suggest that they once extended over a much larger area. WEGMANN (1939 p. 208) and POULSEN (1964) have suggested that the major thickness of Gardar supracrustal rocks was deposited in a "graben" controlled by the 90°–120° wrench faults which had been active in the area before the beginning of the Gardar and which continued intermittently until the end of the episode. Both WEGMANN and POULSEN suggest that the sandstones were deposited in "desert" conditions. POULSEN has shown that the most common type of deposition is from torrential intermittent rivers similar to the violent floods which occur in the wadis of the North African desert. The sediments which were originally water-borne have been reworked by wind action. According to POULSEN explosive volcanic activity which preceded the major extrusion of lavas was concentrated along the wrench fault zones. WEGMANN compared the setting of the Gardar sedimentation to that of the Rhine rift valley; both were deposited in a "graben" formed at

[1] Dates with appropriate references are tabulated in Table 7.

an angle to the main trend of the preceding fold belt. If this analogy is correct then it seems quite probable that Gardar sedimentation followed quickly after the end of the Sanerutian plutonic episode.

ii) Gardar intrusive rocks.

The Gardar igneous province is dominated by the large alkali complexes. Two of these, Nunarssuit and Igaliko, are among the largest in the world, and local concentrations of alkali dykes and smaller bodies suggest that there may be other complexes beneath the present erosion surface. The complexes consist mainly of saturated or undersaturated syenites with lesser amounts of alkali gabbro. Granites are found in two of the complexes, Nunarssuit and Ilímaussaq. In both cases the origin of the major body of granite may not be by straight differentiation from an alkali magma. The province contains several unusual rock types, ranging from the carbonatites of Grønnedal to the more spectacular cryolite body at Ivigtut, and the agpaitic suite from the Ilímaussaq intrusion. No overall pattern can be seen yet in the Gardar intrusive rocks. Whether there is an important break between the intrusion of the agpaitic suite and the augite syenites of Ilímaussaq is not known at present.

One of the most interesting features of the province is the amount of layering present in the igneous rocks (Ferguson and Pulvertaft 1963). The significance of this may be more apparent when the tectonic setting of the Gardar is better understood. Large swarms of doleritic and syenitic dykes were emplaced in the early and mid-Gardar. The dykes extend outside the area in which the main concentration of major intrusions occurs and the interrelationship between various dyke generations and faults allows a rudimentary chronology to be built up. Some of the dykes carry large masses of labradoritic plagioclase, both as large single crystals and as coarse grained granular anorthosites (Bridgwater and Harry in prep.). The xenoliths may form 80 percent by volume of a dyke over a hundred metres wide and many kilometres long. The xenoliths are present in dykes occurring in an area of at least 12,000 square kilometres. Although the anorthosites have never been seen in place it is certain that the source from which the fragments were derived must have been very large. The xenoliths are concentrated in dykes emplaced at the end of the mid-Gardar, that is just before the major alkali complexes. They are not restricted to doleritic host dykes but are found in rocks ranging from lamprophyres to larvikitic syenites. They are however rare in the late Gardar major syenitic intrusions. Smaller amounts are found in early Gardar dolerites throughout the area and in Kuanitic dykes north of Ivigtut. Many of the feldspars show areas with a dense shiny black colouration and this feature is widespread. Chemically and mineralogically the anorthosites resemble the Gardar gabbros although texturally they appear to have been brecciated before inclusion into their present hosts. The resemblance to Gardar gabbros may only be superficial and it is possible that the xenoliths represent an older primary source of plagioclase which has been reworked in Kuanitic and Gardar magmas. The presence of anorthositic rocks in the sub-surface crust of South Greenland from post-Ketilidian to Gardar times must have considerable significance for the petrogenetic history of the area and is discussed later in Section II (p 29).

Several age determinations of Gardar rocks have been published, all of which are from late Gardar intrusions, (see MOORBATH *et al.* 1960, and MOORBATH and PAULY 1962). It can already be seen that the late Gardar alone is of considerable duration, from 1255 ± 20 m. y., the date of the Ivigtut granite, to 1020 ± 24 m. y. the date of the Ilímaussaq agpaitic rocks.

II. MAJOR GEOLOGICAL PROBLEMS IN SOUTH GREENLAND

In the first section of this paper an attempt has been made to present a simplified account of the geological information available from South Greenland without entering into the many controversies of interpretation of the events. In the following section a more interpretive approach is used in order to highlight the main problems in the area which might be "solved" by age determinations.

1) The distribution of the pre-Ketilidian rocks

Berthelsen (1960), in a review of the work done by G. G. U. in the Ivigtut region, suggested on structural grounds that the major part of the Ivigtut gneisses was formed by metamorphism of Ketilidian sediments. Berthelsen notes that a complete gradation exists between the low metamorphic supracrustal rocks south of Sermiligârssuk and the Ivigtut gneisses. He suggests that this represents a migmatite front between a central core of rocks highly metamorphosed in the Ketilidian orogeny (infrastructure) and a less metamorphosed cover (suprastructure). Berthelsen explains that the difference in structural pattern which exists between the two "stockwerke" is due to the difference in level within the fold belt. The original migmatite front between the infrastructure and suprastructure has generally been obscured either by late granitisation which used the contact as a structural control, or by movement along the plane of weakness between the two "stockwerke".

The discovery of a well defined basal conglomerate to the Ketilidian geosynclinal sediments resting on rocks which are indistinguishable from the main Ivigtut gneiss series (p. 7) has lead to a reappraisal of the problem. Three main possibilities exist:

a) The gneiss below the Ketilidian basal conglomerate is a wedge of rock older than the adjacent Ivigtut gneisses. It represents the only recognisable pre-Ketilidian rocks in the area, which have been preserved by faulting (Berthelsen 1962 Plate 7).

b) The supracrustal rocks surrounding the Ivigtut gneisses belong to two different periods of sedimentation. As the base of the Ketilidian is defined at the basal conglomerate from Grænseland then both the Ivigtut gneisses and the supracrustal rocks from which they were formed are pre-Ketilidian.

c) The infrastructure is an older pre-Ketilidian core of gneisses with a mantle of Ketilidian low metamorphic rocks comparable to the classic mantle gneiss domes described by Eskola (1949). The Grænseland unconformity is the only place where the original relationship is preserved. In other places the original unconformity has been destroyed by Ketilidian reactivation of the older gneisses.

The geological observations obtained from the area are not sufficient to warrant complete rejection of any of the above possibilities. One factor common to all three interpretations, however, is the recognition that pre-Ketilidian rocks exist as mappable units in South Greenland. This has considerable importance in the correlation of events noted further north along the west coast of Greenland with those described from South Greenland.

No isotopic age determinations have been made on pre-Ketilidian or Ketilidian rocks from South Greenland and this seems to be one of the most important problems to be attempted. Considerable difficulties may be expected because of the effect of the Sanerutian plutonic episode. This practically rules out the use of K/Ar determinations in South Greenland for rocks older than 1600 m. y. unless they can be shown to be unaffected by the Sanerutian. Rb/Sr isochron methods, such as those used by Giletti *et al.* (1961), may provide the best approach for dating the Ivigtut gneisses although reliable dating would require determination of several rocks in which there was an initial difference in the Rb/Sr ratios but which had similar Sr^{87}/Sr^{86} ratios when formed. These conditions would be difficult to demonstrate in gneiss terrains in which the source rocks varied and in which there has probably been considerable migration and introduction of material.

Perhaps the first stage of research should be the testing of the idea that the Ivigtut gneisses are *relatively* older than the suprastructure. A more accurate determination could then be made on rocks north of Sermiligârssuk where the metamorphic effects of the Sanerutian, and possibly the Ketilidian, are not so strong. Dating of stable minerals, such as zircons from the Ivigtut gneiss, may provide evidence that these rocks contain elements older than the surrounding suprastructure. This has been shown by Wetherill *et al.* (1962) for the Finnish gneiss domes. However, the interpretation of these results would require knowledge of the derivation of the zircons and the number of geological cycles they had been through before much emphasis could be placed on them.

2) The age of the Kuanitic dykes

The period of dyke emplacement following the formation of the Ivigtut gneisses has been used by BERTHELSEN (1960) to divide the Ketilidian and Sanerutian plutonic episodes. However, the possibility that the Ivigtut gneisses are pre-Ketilidian raises the question of the age of the metadolerites from the type locality at Kuánit fjord. As these dykes are of considerable significance in the extension of the South Greenland chronology northwards critical relationships between them and other rocks are described below.

a) The relationship between the Kuanitic dykes and the gneiss-suprastructure contact south of Sermiligârssuk

AYRTON (1963) and WEIDMANN (1964) have described the relationship between the gneisses and the overlying greenschists as a typical migmatite front which is generally parallel to the original lithological divisions of the suprastructure. The zone between the overlying low metamorphic and the typical Ivigtut gneisses varies in width between 1500 and 4000 metres. In this zone AYRTON traces a complex series of processes representing stages in the formation of the gneisses from the low metamorphic rocks. Both AYRTON and WEIDMANN divide the metadolerite dykes, intruded into the area after the formation of the gneisses, into two main phases separated by a period of faulting. Dykes crossing the boundary between the gneisses and the greenschists are rare and generally die out within the first hundred metres. However, members of both older and younger dyke swarms do cut the suprastructure for distances of up to 500 metres and both cut minor structures within the low metamorphic rocks (M. WEIDMANN personal communication). On this evidence some of the Kuanitic dykes are certainly later than the metamorphosed supracrustal rocks south of Sermiligârssuk fjord. If these supracrustal rocks are Ketilidian then the Kuanitic dykes must be post-Ketilidian and probably equivalent to the post-Ketilidian dykes south of Kobberminebugt. On the other hand, if the sediments and their granitisation are pre-Ketilidian, this need not imply that the Kuanitic dykes are also earlier than the Ketilidian plutonic episode.

b) The relationship between the Kuanitic dykes and the basal unconformity of the Ketilidian

BONDESEN in his description of the unconformity between the Ivigtut gneisses and the low grade metamorphic rocks of Grænseland gives a detailed account of the metadolerite dykes of the area. These may be divided into three groups according to their relationship with the unconformity and the structures affecting the supracrustal rocks. Intersections between dykes of the different groups have not been seen.

i) The first group of dykes, which consists of broad, strongly metamorphosed dolerites trending approximately east-west, do not cross into the suprastructure from the gneiss. They are folded and dislocated in the crush zone which locally forms the boundary between the suprastructure and the gneiss. The shearing along the contact runs parallel to the main direction of folding in the suprastructure and is thought by BONDESEN to be related to it. Post-Ketilidian reactivation of the shear zone may, however, have taken place.

ii) The second group of the dykes consists of two thin metadolerites, which cut both the gneiss-suprastructure unconformity, and a breccia zone in the gneisses thought to be the continuation of the shear zone affecting the first group of dykes. The dykes are unaffected by the main north-west Ketilidian folding which they cut almost at right angles, but they are affected by a (Sanerutian) reactivation of an early north-east fold trend.

iii) The third group of dykes consists of a swarm of metadolerites trending NW–SE and cutting the suprastructure. These cut the Ketilidian folding in the low metamorphic rocks but do not continue into areas affected by Sanerutian folding.

If, as BONDESEN suggests, the shearing affecting the first group of dykes is Ketilidian, then both these dykes and the gneisses they cut must be earlier than the Ketilidian folding. In this case a large part of the Ivigtut gneisses must be regarded as pre-Ketilidian while some of the Kuanitic dykes are probably feeders to the Ketilidian lavas.

c) The relationship between the Kuanitic dykes and the gneisses north of Sermiligârssuk

Recent field work in the summer of 1963 has shown that the effect of the Sanerutian plutonic episode is less towards the north. The major swarms of Kuanitic dykes in this region are locally unmetamorphosed and can only be distinguished from the later Gardar dolerites by the effect of a period of faulting and shearing equivalent in age to the Sanerutian plutonism further south. However, the gneisses of the area are cut by basic dykes which have been metamorphosed and folded before the injection of the Kuanitic dykes (W. S. WATT personal communication). Whatever age is accepted for the Kuanitic dykes this suggests that the gneisses north of Sermiligârssuk are pre-Ketilidian. If the Kuanitic dykes are post-Ketilidian then the folding and metamorphism affecting the earlier basic dykes is probably Ketilidian.

To sum up, it appears that either the Kuanitic dykes or the supracrustal rocks surrounding the Ivigtut gneisses must belong to more than one episode. In either case a considerable amount of the Ivigtut gneisses must be older than the basal Ketilidian conglomerate from Grænseland. The fact that some of the younger Kuanitic dyke generations can be traced for 40 km without folding and without granitisation in the area south of Sermiligârssuk fjord certainly suggests that they, at least, are post-Ketilidian.

Dating the Kuanitic dykes

If the Kuanitic dykes can be traced out of the area of Sanerutian metamorphism it should be possible to date them using the methods described by BURWASH *et al.* (1963). From a theoretical viewpoint it would be interesting to carry out a series of determinations on dykes of the same group as the change from dolerites in the north to amphibolites in the south and to relate the changes in the dates obtained to changes in chemistry and mineralogy.

3) The relationship between the Ketilidian plutonic episode and later events in South Greenland

The Precambrian chronology in South Greenland is based on the recognition of a sequence of plutonic and cratogenic events, of which two—Sanerutian plutonism and late Gardar magmatism—have been dated. However, until the age of the Ketilidian is accurately known, the interrelationship of these events will remain uncertain.

There are three principal views concerning the possible interrelationship between the Ketilidian and the later events.

i) The Ketilidian is an independent orogeny belonging to a very early tectono-igneous cycle (as used by TYRREL 1955). This view would assign the post-Ketilidian basic dykes to a major Precambrian cratogenic epoch which should be recognisable on a continental scale.

ii) The Ketilidian and Sanerutian are separate orogenies which represent different phases in the development of a fold belt, but belong to the same tectono-igneous cycle. On this assumption the post-Ketilidian dykes still mark an important hiatus in the Precambrian: the cratogenic conditions they represent could have extended over a considerable area, although locally such conditions might not have arisen due to a merging in time of the orogenies.

iii) The Ketilidian and Sanerutian are phases of the same orogeny. If this is the case the post-Ketilidian dykes either belong to a minor intra-orogenic phase, after which plutonism was resumed, or mark a general return to cratogenic conditions which was locally interrupted by a revival of late plutonism.

Armstrong (1963) subscribes to the first view when he suggests that the 2700 m. y. K/Ar biotite date of a gneiss from Godthåbsfjord represents Ketilidian plutonism. This follows Berthelsen's (1961) correlation of the gneisses of the Godthåb region with the Ivigtut gneisses which are in his opinion Ketilidian. If Berthelsen's view is correct then the Sanerutian at 1600 m. y. belongs to a separate period of mobility in the crust. However, with the recognition that pre-Ketilidian rocks may form a large part of West Greenland (p. 19) it is equally likely that 2700 m. y. is a pre-Ketilidian date, and the Ketilidian episode occurred at some time between this and 1600 m. y. ago.

There is in fact no conclusive evidence from South Greenland to show which view is correct. In the absence of adequate isotopic age determinations opinions vary according to individual geologist's evaluation of the significance of cratogenic episodes marked by the intrusion of basic dykes.

A fruitful line of enquiry might be to make use of experience gained in other parts of the world where the sequence of events is well chronicled and similar to that in South Greenland. For this purpose Table 6 has been prepared. Although some of the events listed occurred at the same time as their counterpart in Greenland, no correlation is intended. It is the *sequence* of events which is important for comparison.

Inspection of Table 6 prompts the suggestion that the four youngest episodes recognised in South Greenland are different phases of a single cycle of crustal evolution. This may be described as a tectono-igneous cycle consisting of either two related orogenies or one polyphase orogeny, followed by alkali magmatism, depending on the particular definition of orogeny used. Similar suggestions for a tectono-igneous cycle have been made for other fold belts; for example the Caledonides (Tyrrell 1955, Read 1961), the Precambrian of the Ukrainian shield (Vinogradov *et al.* 1960, Komlev 1958), and a more general case by Harpum (1960).

Certain aspects of the various episodes will now be examined in the light of this proposal.

a) The character of the Sanerutian plutonic episode

The Sanerutian is not a repetition of the same sequence of events described from the Ketilidian, but rather it has the character of a rejuvenation and supplement of the Ketilidian. The Sanerutian plutonic episode was not preceded by any recognisable geosynclinal sedimentation. Sanerutian movements were restricted to narrow belts within the area of Ketilidian activity where they involved a reaction of pre-existing structures along trends already defined in the Ketilidian or the production of a new foliation parallel to the main Ketilidian trend (WATTERSON in press). The style of the Sanerutian folding is different to that of the Ketilidian; whereas Ketilidian deformation was mainly plastic, the Sanerutian shows considerable shearing suggesting a change in tectonic conditions.

The Sanerutian granites differ from those of the Ketilidian. The two most important granite types from the Sanerutian are those generated by reactivation of Ketilidian rocks and the intrusive "New granites". The former are largely confined to the area of relatively homogeneous granite between Qagssimiut and Julianehåb: outside this area they occur sporadically, usually along belts of Sanerutian movement (WATTERSON in press). The relationship between the reactivated granites and the "New granites" is not clear. In the area north of the Igaliko syenite the reactivation shows many of the features of the "New granites" and the two processes appear to be coincident (WALTON in press). In the Sydprøven area the "New granites" are younger than the first phase of reactivation (BRIDGWATER 1963) but are followed by considerable tectonic activity and the emplacement of several generations of plutonic basic dykes and late granites (F. PERSOZ personal communication). In the Tasermiut area the "New granites" follow the reactivation and are one of the youngest plutonic rocks in the area (P. DAWES personal communication). A large number of age determinations will be necessary before the relationships are fully understood. The available age determination from the Julianehåb granite (1500 m. y.) suggests that there was some plutonic activity later than the "New granites" which have so far given ages of approximately 1620 m. y. From the descriptions furnished on p. 12 it can be seen that the "New granites" present many features typical or late or post-orogenic granites (cf. READ 1961, SIMONEN 1960). WEGMANN's comparison of the South Greenland "New granites" with the rapakivi granites of Scandinavia was based on lithological similarities. The comparison is even more appropriate if the "New granites" are accepted as the late orogenic granites of the Ketilidian. A parallel has been drawn by WALTON (in press) between the diorite-monzonite suite associated with the "New granites" and the appinitic suite in the Caledonian of Scotland and Ireland. This, as explained by READ (1961), followed the main Caledonian migmatisation and movement and is related to the late Caledonian granites. Similarly comparison might be made between some of the late plutonic minor basic intrusions (p. 12) and minor basic intrusions within the late Caledonian granites (PITCHER and READ 1960).

The Sanerutian differs from the typical late plutonic episode described by HARPUM (1960) as it shows the development of granites formed by the reactivation of earlier plutonic rocks, which in the intervening time had become sufficiently cool and brittle to allow the intrusion of dolerite dykes (p. 10). However, it can be seen from Table 6 that the Sanerutian is not unique in this and there seem insufficient grounds to ascribe it to a separate orogeny for this reason alone. In some fold belts the emplacement of late plutonic granites has been accompanied or followed by reactivation of the surrounding rocks and by a resumption of fold movements parallel to the trend of the main tectonic phase. In the Appalachian fold belt the term orogeny has been given by KING (1959) both to the two phases of plutonic activity in the main metamorphic area and to the late folding in the marginal area (the Taconic, Acadian and Allegheny orogenies).

With this usage of the term both the Ketilidian and the Sanerutian could be regarded as separate orogenies. However READ (1961) and SUTTON (1963 a) discussing similar events in north-west Britain prefer to regard the Caledonian fold belt as one orogeny which may then be subdivided into different phases. In the Svecofennian of Finland as in the Appalachian, Caledonian and South Greenland fold belts the late rapakivi granites are associated with the intrusion of basic rocks some of which act as loci for the emplacement of granite. However, in contrast to the other fold belts the Svecofennian shows reactivation of the main phase of plutonism before the emplacement of the rapakivi granites and separated from them by a series of unmetamorphosed basic dykes (SIMONEN 1960 and in press). Similarly the late granites accompanying basic intrusions in the Penokean of Minnesota (GOLDICH *et al.* 1961) are not associated with reactivation.

It is possible that the Sanerutian plutonic episode consists of two separate events; the late plutonic phase of the Ketilidian orogeny, characterised by the "New granites" and the appinitic suite of rocks; and a local resumption of the subcrustal processes which caused the Ketilidian plutonism, resulting in reactivation and renewed folding at approximately the same time as the "New granites". Detailed age determinations of the various events seen within the Sanerutian may help to solve the relationship between the regional reactivation and the "New granites". Field observations have not suggested any significant break within the Sanerutian.

Some of the variation between the accounts of the evolutionary history of different fold belts may be due to the present erosion level. Generally the less a fold belt has been eroded the more opportunity there will be to subdivide it into different episodes. It would therefore seem more useful to reserve the term "orogeny" to mean the complete evolution of a fold belt. The use of the term for individual plutonic events or fold phases may obscure differences in the various episodes which occur during the development of a fold belt. Similarly although in this paper the term cratogenic is used to mean conditions which allow the intrusion of dolerites it may be better to restrict the term to stable conditions of considerable duration, for example the Canadian shield after the completion of the Grenville orogeny.

b) The significance of the post-Ketilidian dykes

It does not seem that the emplacement of the post-Ketilidian dykes need imply a particularly long period of crustal stability. With the end of the main deformational phase of an orogeny and the attendant relaxation of compressional forces and isostatic uplift, the conditions become suitable for dyke emplacement, but not necessarily to the same degree at the same time everywhere within the domain of the orogeny. This could lead to a variation in the behaviour of post-plutonic dykes. Such a variation in the appearance of the (presumably) post-Ketilidian dykes has been described by BONDESEN and HENRIKSEN (in press). The youngest generation of these contain dykes up to 100 m thick and which can be traced continuously up to 40 km in the area north-west of Ivigtut, but to the south-east individual dykes are thinner and less persistent. South of Kobberminebugt, in the region of most pronounced Sanerutian activity, the post-Ketilidian dykes, even prior to deformation, seldom exceeded 10 m in thickness. Clearly post-Ketilidian cratogenic conditions at the time were less perfectly developed in the area where Sanerutian plutonism later attained its acme (see the schematic diagram fig. 1). This is consistent with the view that the Sanerutian plutonic episode is a late phase of the Ketilidian orogeny. In their study of the metamorphic facies along a single major dyke, BONDESEN and HENRIKSEN provide evidence that the Sanerutian metamorphism lasted longer towards the south-east than in the north-west.

c) The relationship between the Gardar igneous province and the preceding plutonic events

It can be seen from Table 6 that other areas in which a tectono-magmatic cycle has been recognised commonly show alkali magmatism in the closing phase. VOROBIEVA (1960) expressed this in her summary of the alkali rocks of the USSR where she states: "The appearance of alkali magmatism is ascribed to the late and last period of the development of one or another tectono-magmatic cycle. The periods of intrusion of alkali rocks coincide with the paroxisms of the disjunctive tectonic

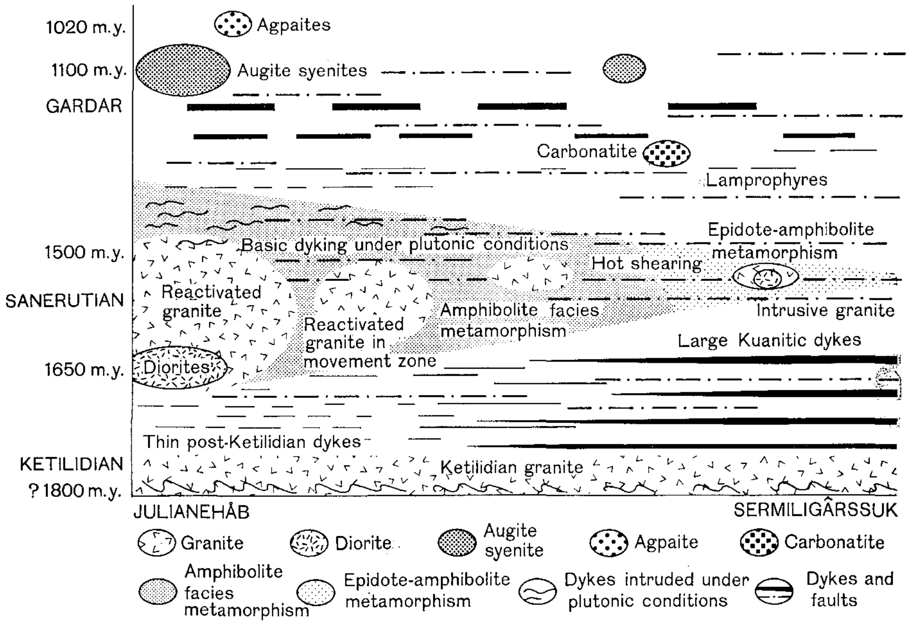

Fig. 1. A diagrammatic representation of the suggested relationship between the Sanerutian reactivation and the post-Ketilidian dyking. The reactivation is weakest in the north west (Sermiligârssuk) where the dykes are large and abundant. As the reactivation increases southwards the dyking decreases.

activity and their distribution is controlled by considerable ruptures of the Earth's crust (abysmal breakings)." (p. 7). The setting of the Gardar alkaline province agrees well with the general case described by Vorobieva. The Gardar could therefore be regarded as the final stage of the Ketilidian-Sanerutian cycle rather than the beginning of another cycle as suggested by Wegmann (1938), or as the marginal effects of the Grenville fold belt, as implied by Armstrong (1963).

The Gardar alkali province differs from those of Oslo and Kola, with which it has strong petrographic affinities, in that it was emplaced within the main area of the preceding plutonic activity instead of marginal to it. This does not seem to be an important distinction: all three provinces are thought to have been controlled by zones of weakness in the crust, represented on the surface by wrench faulting and the formation of graben. In South Greenland this zone of weakness occurs within the area of the old fold belt; its continuation outside the area is lost under the sea.

Whether there is an actual hiatus between the Gardar and the preceding plutonism is not known; it has been suggested (p. 13) that the earliest Gardar intrusives have some characters which might be due to their emplacement during the waning of plutonism. It is even possible that the emplacement of early Gardar complexes, such as the nepheline syenite-carbonite complex at Grønnedal, was contemporaneous with plutonism further south.

YODER and TILLEY (1962) have emphasised the importance of pressure in determining the initiation of an alkali trend in the differentiation of basaltic magma. They suggest that alkaline basalts may be derived from a greater depth than tholeiitic magma. This is in agreement with VOROBIEVA's association of alkali magmatism with "abysmal breakings" at the end of tectono-magmatic cycles. In the case of the Gardar, alkali magmatism lasted for 4–500 m. y. after the end of plutonism which suggests that the fractures developed at the end of the Sanerutian remained a fundamental zone of weakness during this time. It seems likely that while these fractures originated in the epeirogenic phase of the preceding orogeny they were activated at a later stage by readjustment of the crust corresponding to other events such as the development of the Grenville orogenic belt to the south.

4) Chelogenic cycles and the development of South Greenland

SUTTON (1963 b) has suggested that the history of the earth's crust may be divided into long term cycles, the last four of which began at approximately 3600 m. y. (Kola), 2900–2700 m. y. (Shamvian), 1900–1700 m. y. (Svecofennid) and 1200–1000 m. y. (Grenville). Each cycle consists of a phase of high thermal activity when a network of fold belts developed within the previously stable areas of the crust, and a cratogenic phase when the plutonic activity gradually declined with the simplification of the network of fold belts and their concentrations towards the margins of the developing cratons. These were in turn broken up by the first phase of the next chelogenic cycle. The high plutonic activity during the early phases of a chelogen causes the peaks which are seen when age determinations on a world wide scale are plotted on a time/frequency diagram (GASTIL 1960). The end of a cycle may be marked by the extrusion of large masses of basic lava.

If the period, from the beginning of the Ketilidian until the end of the Gardar, is regarded as one unit then South Greenland may be a good example of the development of a chelogenic cycle. In this case the Ketilidian-Sanerutian represents the early plutonic activity of the cycle while the Gardar represents the cratogenic late phase. The igneous activity of one cycle in South Greenland appears to overlap in time with the beginning of another (the Grenville) in Canada. A continuation of the Grenville fold belt north-east from Canada would pass just south of Greenland and would run approximately parallel with the main trend of the Ketilidian-Sanerutian structures and dyke emplacement in the

Gardar. This may be a case of the structural control of the first phases of a chelogen by lines of weakness developed in an earlier cycle.

Regarding the Ketilidian to Gardar period as one chelogen would imply that the Ketilidian plutonism took place approximately 1750 to 2000 m. y. ago, at the beginning of the Svecofennid cycle. This is consistant with the ideas expressed earlier in this section, but can only be established by isotopic age determinations.

5) The origin of the anorthosite xenoliths

Inclusions of labradoritic feldspar and olivine-augite-magnetite-bearing anorthosite are abundant in dykes belonging to the mid-Gardar swarm. Smaller amounts occur in the early Gardar dolerites and some in the Kuanitic dolerites (p. 16). The origin of these anorthosite xenoliths is controversial and it would be valuable to know the approximate date of their formation in order to relate them to their correct geological setting.

Anorthosites may be divided into three groups (modified after Harpum 1957):

a) Metamorphic anorthosites; concordant bodies in gneiss areas. These generally contain anorthite-rich plagioclase and show typical metamorphic textures. The gabbro anorthosite layers in the Ivigtut gneisses are probably representative of this group. It is unlikely that the plagioclase xenoliths in the Gardar dykes were derived from this source.

b) Orogenic anorthosites; major bodies dominated by andesine-labradorite feldspar rock. These may reach batholithic proportions and there is commonly a subordinate suite of noritic gabbros and hypersthene-bearing intermediate rocks associated with the anorthosites. Typical examples of this group of anorthosites occur in the Grenville province of the Canadian shield (Buddington 1939). The origin of orogenic anorthosites is controversial as they show contrasting characters suggesting both magmatic differentiation from a basic magma and an ultrametamorphic origin. This is probably due to convergence of two different phenomena under high metamorphic conditions (Michot 1955). Berrangé (1963) has given the name orogenic-plutonic anorthosites to this group to emphasise their setting within an actively developing fold belt under plutonic conditions.

c) Layered anorthosites; layers of anorthosite, sometimes of considerable thickness, occur within stratified basic igneous bodies such as Stillwater (Hess 1960). Gravity stratified complexes are more typical of tectonically stable areas and are thus mainly associated with post-orogenic igneous activity. Some layered complexes may be formed during relatively stable conditions between two tectonic phases of an orogeny, for example the Bays-of-Maine complex in the Appalachian fold belt (CHAPMAN 1962). Transitional types may be expected between groups b and c and it is probable that many "orogenic" anorthosites are relics of older layered bodies which have been affected by subsequent tectonic activity (KRANK 1961).

In their present state the xenoliths in the Gardar dykes have characteristics in common with the layered anorthosites. UPTON (1964) has suggested that they were derived from a layered olivine-gabbro anorthosite which differentiated from the same primary Gardar magma as the syenites. However xenoliths showing primary layering are rare and when they do occur, for example on the Assorutit peninsula, Tugtutôq, they contain inclusions of older brecciated massive anorthosite. The question of the ultimate origin of the feldspathic material is therefore still open; the xenoliths may have been derived from a partially layered Gardar body at depth, from a pre-Gardar orogenic anorthosite which has been partially reworked by the Gardar magmas, or even from a primary crustal layer below which the Gardar magmas accumulated.

The possibility that the xenoliths are derived from a pre-Gardar source means that it would be valuable to compare the date of their formation with pre-Gardar rocks which might be associated with anorthosite formation. As may be seen from Table 6 the "New granite"—noritic gabbro complexes from South Greenland occupy a similar position to the rapakivi granites in the Svecofennian fold belt. In Scandinavia the basic rocks associated with the rapakivi granites commonly contain anorthositic members and it is possible that a similar mode of occurrence could be expected in Greenland.

Mineralogically the anorthosites are rather unsuitable for age determinations as there is rarely enough fresh mafic material present. Furthermore the mafic minerals often appear to be younger than the feldspars, which were brecciated before the formation of the surrounding augites.

III. NEW K/Ar AGE DETERMINATIONS FROM SOUTH GREENLAND AND THEIR GEOLOGICAL SIGNIFICANCE

Eight K/Ar age determinations on five rocks from South Greenland selected by the author, were carried out by Geochron Laboratories Inc. and the results are given in Table 3. It is obvious that the major problems outlined in Section II present too many difficulties to be solved by a small number of K/Ar determinations. Therefore the five rocks chosen were restricted to give information which might help to solve the last problem mentioned in Section II, the origin of the anorthosites.

Discussion of results

Table 3 lists the analytical data determined by Geochron Laboratories Inc. With the exception of the anorthosite date the results are in agreement with the chronology erected by field work and have confirmed the earlier work by Moorbath *et al.* (1960). The significance of each determination is discussed below.

1) The age of the "New granites" and their associated basic rocks

Sydprøven biotite granite 1620 ± 50 m. y. (biotite).
Frederiksdal hypersthene gabbro 1645 ± 50 m. y. (biotite)
1700 ± 200 m. y. (augite).

Both these complexes give an age slightly older than that obtained by Moorbath *et al.* for the reactivation of the Julianehåb granite at 1500 ± 70 m. y. This is of great interest, firstly because it confirms the field evidence which suggested that some of Wegmann's "Younger granites" (Wegmann 1938) are pre-Gardar, secondly because it may mean that the "New granites" are not younger than the main reactivation of the Julianehåb block as implied by Bridgwater (1963). The significance of the latter will only be apparent when many more age determinations have been made on the reactivated granites. The present evidence gives some support to the idea that the "New granites" are late granites of

Table 3. *Potassium-Argon results.* (*Analyst Geochron Laboratories Inc.*).

Specimen and locality	Mineral	% K	Average	K^{40} ppm	Radiogenic Ar in ppm	Average	Radiogenic Ar/total Ar^{40}	Radiogenic Ar/K^{40}	Age in m. y.
Anorthosite inclusion	biotite	3.44		4.04	0.314		0.890	0.079_8	1025 ± 70
in Gardar dyke at			3.31			0.322			
Narssaq. G.G.U. 49320		3.18			0.330		0.395		
Anorthosite inclusion	augite	0.380		0.465	0.0383		0.328	0.084_6	1075 ± 50
in Gardar dyke at			0.381			0.0394			
Narssaq. G.G.U. 49320		0.382			0.0404		0.103		
Augite syenite	biotite	4.80		5.90	0.541		0.485	0.0902	1128 ± 30
Nunarssuit.			4.84			0.532			
G.G.U. 31097		4.88			0.522		0.453		
Augite syenite	augite	0.35_6		0.440	0.056_5		0.294	0.116	1355 ± 150
Nunarssuit.			0.36_1		0.048_5	0.051	0.725		
G.G.U. 31097		0.36_6			0.048		0.312		
Early Gardar dolerite.	augite	0.192		0.228	0.0303		0.301	0.126	1435 ± 80
G.G.U. 45297			0.187			0.028_8			
		0.182			0.0273		0.127		
Biotite granite (Sydprøven)	biotite	7.29		8.87	1.32		0.913	0.150_5	1620 ± 50
Tugtutuarssuk.			7.26_5			1.33_5			
G.G.G. 49195		7.24			1.35		0.917		
Hypersthene gabbro	biotite	5.74		7.15	1.08_4		0.937	0.154	1645 ± 50
Frederiksdal complex.			5.87			1.10			
G.G.U. 51304		6.00			1.11_6		0.931		
Hypersthene gabbro	augite	0.054		0.072	0.0115		0.312	0.161	1700 ± 200
Frederiksdal complex.			0.059			0.0116			
G.G.U. 51304		0.064			0.0117		0.072		

Constants used $\lambda_\beta = 4.72 \times 10^{-10}$/ year. $\lambda_e = 0.585 \times 10^{-10}$/ year. $K^{40}/K = 1.22 \times 10^{-4}$ g./g.

the Ketilidian orogeny which are accompanied by a minor resumption of plutonic conditions. The reactivation probably continued in the Julianehåb granite block and in isolated tectonically active areas for a longer period than it did in the gneiss areas to the north and south.

According to the available field evidence the Sydprøven granite and the Frederiksdal complex were emplaced contemporaneously and this is confirmed by the similarity of their radiogenic ages. Field work suggested that the granite shells to the "New granites" continued to be active later than the noritic gabbro centres although there was no large hiatus between them. This may be reflected in the slight difference between the two radiogenic ages although the difference is within the expected experimental error. There seems no reason to suspect that the date from the Frederiksdal noritic gabbro should have been affected by the emplacement of the surrounding granite, the specimen was taken over a kilometre from the nearest granite outcrop and was completely fresh. The biotite date for the Frederiksdal complex is taken as more significant than the pyroxene date for reasons which are discussed below.

2) The age of an early Gardar dolerite

1435 ± 80 m. y. (augite).

The date given by an early Gardar dolerite is in agreement with the suggestion made in Sections I and II of this paper that the Gardar igneous activity started soon after the end of the preceding plutonic episode. Several Gardar intrusions pre-date the early dolerites, for example the Grønnedal alkali complex and lamprophyric dykes in the Ivigtut area, but the dolerites are the first rocks to occur on a regional scale and thus would be the most useful as a stratigraphic marker. Unfortunately since the rocks were selected doubts have been raised about the use of pyroxenes for K/Ar age determinations, as augite is liable to contain excess radiogenic argon (see Aldrich *et al.* 1962) thus giving an older "date" than other minerals from the same rock. The date obtained from this dyke can therefore be regarded as provisional. Further work on these dykes using the methods suggested by Burwash *et al.* (1963) would seem of prime importance. However, a date between 1350 and 1450 m. y. might reasonably be expected for the early Gardar. So far age determinations have been restricted to the late Gardar complexes and these range from 1255 m. y. to 1020 m. y. (Moorbath and Pauly 1962, Moorbath *et al.* 1960). A similar period of time probably elapsed between the intrusion of the earliest Gardar rocks and the formation of the late complexes.

3) The date of the Nunarssuit syenite

1128 ± 30 m. y. (biotite), 1355 ± 150 m. y. (augite)

The occurrence of anorthosite and syenite as differentiates from the same primary magma has been seen in many parts of the world. In South Greenland the exact age relationships between the formation of the two rock types are not known, although the field relationships show that the intrusion of the syenites continued after the inclusion of the majority of the anorthosites. The Nunarssuit syenite was chosen because there are clear age relationships between this intrusion and anorthosite-bearing dykes. It is also one of the largest augite syenites in South Greenland and is probably representative of these rocks.

The K/Ar biotite date given by the Nunarssuit syenite is in close agreement with the Rb/Sr biotite date of the Alángorssuaq biotite granite (1150 ± 30 m. y., MOORBATH, in HARRY and PULVERTAFT 1963 p. 20) from the same complex. According to HARRY and PULVERTAFT (p. 118) the time separating the intrusion of the syenite and the biotite granite was short. The biotite date from the Nunarssuit intrusion also agrees with the Rb/Sr biotite date of 1170 ± 150 m. y. (revised from MOORBATH *et al.* 1960) from Kûngnât, another late Gardar augite syenite complex described by UPTON (1960).

The K/Ar pyroxene date from the Nunarssuit syenite is probably not so significant geologically for the reasons given in (2) above.

The date of an anorthosite xenolith

1025 ± 70 m. y. (biotite), 1075 ± 50 m. y. (augite)

The anorthosite xenolith dated occurs as a large inclusion in the Narssaq gabbro, which is regarded by UPTON (1962) as a continuation of the giant dykes of Tugtutôq. These dykes belong to the mid-Gardar period of dyke intrusion and pre-date the main syenite bodies. The mid-Gardar dykes were probably intruded about 1250–1300 m. y., they are certainly older than 1128 m. y., the age of the Nunarssuit intrusion and probably older than the Ivigtut granite dated at 1255 m. y. (MOORBATH and PAULY 1962). The dates obtained from the anorthosite xenolith are therefore rather surprising as they indicate a stage in the Gardar later than the formation of the syenites and contemporaneous with the agpaitic rocks of Ilímaussaq. Unless the complex chronology of dyking and faulting, which has been described for the Gardar, is incorrect the anorthosites must have been formed before 1128 m. y. and the younger date they give must therefore represent a thermal event which has affected the xenoliths. The most likely source of such an effect is Ilímaussaq (1020 m. y.) although the specimen dated was collected seven kilometres away from the nearest surface outcrop of this intrusion. A considerable zone of alteration surrounds Ilímaussaq and it appears that effects large enough to release radiogenic argon from both biotite and augite extend further than the effects visible in the field. In the case of biotite the release of argon appears to have been complete but the augite may have been slightly more retentive. Further work on dating the anorthosites is difficult because of the lack of fresh mafic material and the need for blocks large enough to minimise the effects of the host dykes. It is hoped that the olivine may prove a suitable mineral as its retentivity should be high although the potassium content is low.

No results have come from these age determinations which might directly help to solve the problem of the genesis of the anorthosites. However, the increase in understanding of the setting of the Gardar igneous activity which has been stimulated by the K/Ar ages determined by Geochron Laboratories Inc. has more than justified the experiment.

IV. Rb/Sr AGE DETERMINATIONS FROM SOUTH GREENLAND

Table 4 gives details of Rb/Sr age determinations made by S. MOORBATH at the University of Oxford and which he kindly suggested should be published here. Several of the age determinations have been briefly mentioned before by MOORBATH and PAULY (1962), but as no details of the analyses or the geological setting were given they are briefly discussed below.

Table 4. *Rubidium-Strontium results* (*Analyst* S. MOORBATH).

G. G. U. Sample Number	Description	Rb ppm	SrN ppm	Sr^{87}ppm	Age m.y.[1])
30173[2])	Biotite, Biotite granite. Alângorssuaq	870	29.6	4.22	1150 ± 30
31768[3])	Biotite. "Arsuk Storø" granite	1112	202	5.75	1220 ± 60
27729[4]) } 31674 }	Biotite. SE part of Tigssaluk granite	810	68.9	5.54	1615 ± 40
31767[3])	Biotite. Isa pegmatite	594	2.2	4.10	1630 ± 30

[1]) Half-life of Rb^{87} is 4.7×10^{10} years (FLYNN and GLENDENIN, Phys. Rev., (1959), 116, 744–748). Assume initial ratio $(Sr^{87}/Sr^{86})\ t_0 = 0.710$.

[2]) Collected by W. T. HARRY.

[3]) Collected by S. MOORBATH.

[4]) Collected by C. H. EMELEUS and S. MOORBATH.

1) Pegmatite from Isa

1630 ± 30 m. y. (biotite)

Large pegmatite swarms are found in the gneisses north-west of Ivigtut. These differ from the pegmatites south of Julianehåb (p. 13) as they are semi-concordant to the gneiss structures and are cut by the Kuanitic dykes. The pegmatites are thus almost certainly Ketilidian or pre-Ketilidian in age. If the 1630 m. y. date is taken as the date of the pegmatite formation then the difference in age between the (presumably) late Ketilidian, the post-Ketilidian dykes (Kuanitic) and the Sanerutian Tigssaluk granite (see (2) below) is too small to allow present age dating techniques to distinguish between them with certainty. However, it seems probable that the 1630 m. y. date is due to the superimposition of a Sanerutian "age" on an earlier rock. According to BONDESEN and HENRIKSEN (in press), Sanerutian metamorphism reached epidote-amphibolite to amphibolite facies in the area from which the sample was collected. This was probably high enough to "reset" the biotite. It appears that isochron work will be necessary before the age of these pegmatites can be settled with certainty.

2) Tigssaluk granite

1615 ± 40 m. y. (biotite).

The Tigssaluk granite (HARRY and EMELEUS 1960, EMELEUS 1963) is the most "magmatic" of the Sanerutian granites mapped so far in South Greenland, displaying good layering of mafic minerals by crystal settling and intrusive contacts against the Ivigtut gneisses. The date of 1615 m. y. however suggests that it belongs to the same group of granites as those of Sydprøven and Frederiksdal, with which it has many features in common. It is possible that its more allochthonous aspect may be due to the decrease in the regional metamorphism of the Sanerutian north of Ivigtut (p. 26).

3) "Arsuk Storø" granite

1220 ± 60 m. y. (biotite)

The "Arsuk Storø" granite has been described by WEGMANN (1938 p. 32) as an example of a Ketilidian intrusive granite because of its relationship to the (Ketilidian) metasedimentary rocks along its eastern contact. Since the subdivision of WEGMANN's Ketilidian (see p. 7) the "Arsuk Storø" granite and the neighbouring granites of Sánerut and Quiartorfik have been regarded as Sanerutian (BERTHELSEN 1962, Plate 6). The 1220 m. y. date, which suggests a late Gardar age, is therefore rather unexpected especially as the granite is cut by several generations of dykes including lamprophyres typical of the early Gardar in the Ivigtut region. Dykes, apparently similar to those cutting the "Arsuk Storø" granite, are cut by the Ivigtut granite on which several determinations have been made averaging 1255 m. y. (MOORBATH and PAULY 1962). According to field notes by MOORBATH, the specimen was taken from a locality in the granite which may have been affected by Gardar dyking and faulting. Thus the 1220 m. y. date may that be of a Gardar event rather than that of the original formation of the granite.

However, as the granite on "Arsuk Storø" is isolated from rocks of demonstrable age and as there are some granites of Gardar age which are not completely dissimilar further discussion of this result is better left until all the details of the petrography are published.

4) Alángorssuaq biotite granite

1150 ± 30 m. y. (biotite)

The geological setting of this granite has already been described by HARRY and PULVERTAFT (1963). It belongs to the Nunarssuit alkali complex mentioned on page 16 of this paper. The date is in agreement with other late Gardar alkali complexes.

5) Julianehåb granite

1500 ± 70 m. y., biotite (MOORBATH *et al.* 1960)

The amount of work done by G. G. U. on the Julianehåb granite area since the original publication of the age determination by MOORBATH *et al.* warrants a re-examination of the interpretation of the date. The Julianehåb granite is now regarded as consisting of two main units: Ketilidian granites and gneisses in which the post-Ketilidian dykes are metamorphosed but not strongly veined or broken; and reactivated granites in which the post-Ketilidian dykes are attacked, veined and even destroyed by the host granite which became active during Sanerutian plutonism. According to J. H. ALLAART (personal communication) the specimen of Julianehåb granite dated (from a blast site in Julianehåb town itself) is from an area of granite not showing strong reactivation, although it may be presumed to have been affected by the Sanerutian plutonism. Examination of specimens of granite from the same locality (kindly supplied by H. SØRENSEN) suggest that the rock dated was recrystallised during shearing probably under regional metamorphic conditions. This shearing has given the rock a faint but persistent laminar texture. The biotite is fresh but shows a green pleochroism atypical of the biotites from the Julianehåb granite elsewhere. The 1500 m. y. age is probably that of the shearing; whether this is contemporaneous with the general remobilisation of the Julianehåb granite during the Sanerutian plutonic episode is uncertain. Further work is thus needed to date the Sanerutian plutonic activity more exactly. The general agreement of dates between 1500 and 1650 m. y. suggests that the Sanerutian plutonism occurred at about this time but not enough is known to separate different events within the episode. Isochron work will be of great interest on the Julianehåb granite although the interpretation may be difficult. It is quite possible that new material was introduced during the Sanerutian or that recrystallisation has been so thorough that the rock can be regarded as having passed through a "magmatic" phase, at least with regard to the distribution of strontium and rubidium. In this case determination of the Ketilidian or pre-Ketilidian origin of the rocks may only be possible by inference from less affected enclaves or by zircon determinations.

V. CORRELATIONS IN SOUTH-WEST GREENLAND

Although the geology of South-West Greenland has been extensively studied in the last twenty years only the area described in Sections I and II of this paper has been studied in sufficient detail to allow a complex chronology to be built up. Even here the problems of Precambrian stratigraphy are so complicated that several interpretations are possible and thus it is premature to make firm correlations with the rocks further north. However, since some of the published correlations are, in the authors opinion, based on incorrect assumptions some brief comments are given below.

On the geological evidence so far obtained South-West Greenland may be divided into three main units from south to north.

1) The Ketilidian and younger rocks lying unconformably on pre-Ketilidian gneisses in South Greenland.

2) The gneiss area between Sermiligârssuk fjord and the Nagssugtoqidian fold belt, the boundary of which runs at approximately 110° from Holsteinsborg to the Inland Ice (see Noe-Nygaard and Ramberg 1961).

3) The Nagssugtoqidian fold belt consisting of a group of gneisses and some metasedimentary rocks. The metamorphism of the Nagssugtoqidian fold belt can be shown to be younger than the rocks to the south as it affects a regional swarm of basic dykes. These dykes are seen as fresh dolerites in the gneiss complex to the south but become metamorphosed, folded, granitised and finally obliterated as they are traced into the rocks involved in the Nagssugtoqidian fold belt.

1) The Ketilidian and younger rocks south of Sermiligârssuk fjord

These have been reviewed in Section I of this paper. Rocks demonstrably formed from Ketilidian sediments have not been reported for more than fifty kilometres north of this fjord although the metamorphic effect of the episode probably extended a considerable distance.

2) The gneiss area between Sermiligârssuk fjord and the Nagssugtoqidian fold belt

Although isolated areas in this 500 km coastal stretch are known in considerable detail no overall picture can be compiled for the region. Part of the area has been divided into a series of complexes by RAMBERG (1948) and NOE-NYGAARD and RAMBERG (1961). These divisions are mainly based on facies changes in the gneisses or structural unconformities. No major chronological divisions have been made, although it is probable that they exist.

Only one age determination of a rock of known provenance is available from this area. This is a biotite gneiss from Godthåbsfjord (No. 39, Plate 1) which gave a K/Ar biotite determination of 2710 m. y. ARMSTRONG (1963) has suggested that this date represents the Ketilidian, following BERTHELSEN's (1961) correlation of most of this region with the Ivigtut gneisses. However, as shown on p. 19, pre-Ketilidian rocks exist in the Ivigtut region and even if structural and petrological similarity can be used as a valid stratigraphical tool this does not mean that the gneisses north of Sermiligârssuk are Ketilidian. Other age determinations on rocks probably derived from this area or from the Nagssugtoqidian fold belt have been reported by DIBNER *et al.* (1963). Two determinations of approximately 2300–2400 m. y. may suggest that there is at least one other pre-Ketilidian plutonic event to be recognised along the west coast of Greenland, although the method used (K/Ar whole rock analysis) probably only gives minimum ages.

3) The Nagssugtoqidian fold belt

The term Nagssugtoqidian was given by RAMBERG (1948) to rocks between Søndre Strømfjord and Christianshåb. These form a younger fold belt separated by their effect on a series of dolerites from an older basement to the south (the Kangamiut complex). RAMBERG divided the Nagssugtoqidian into three, depending on the metamorphic facies of the rocks; a central complex of granulite facies and two outer complexes with epidote-amphibolite to amphibolite facies. NOE-NYGAARD (in press) has tentatively suggested that the Nagssugtoqidian fold belt extends further northwards and includes a group of highly folded and migmatized gneisses and metasediments north of Disko Bugt.

Much of the southern area of the Nagssugtoqidian fold belt consists of reactivated basement in which the original gneiss structures can be recognised and which contains granitised remnants of pre-Nagssugtoqidian dolerites.

The age of the Nagssugtoqidian fold belt

Dating of rocks of proven Nagssugtoqidian origin is limited to one K/Ar on a biotite from a gneiss collected at Søndre Strømfjord air-base (ARMSTRONG 1963), (No. 27 Plate 1). Another rock of probable Nagssugtoqidian origin giving a K/Ar date of 1620 m. y. is among the loose blocks trawled from the Banan Banke (DIBNER *et al.* 1963).

Table 5. *Succession of events in the Tasersiaq area* (TREVES 1963).

5) E-W trending dolerites	Typical post-orogenic dykes intruded into cold rocks, undeformed and unmetamorphosed.
4) Granites and gneisses	K/Ar determination on biotite 1890 m. y. Zircon determination on same rock 2990 m. y.
3) E-W trending dolerites	Metamorphosed to amphibolites.
2) Granulite facies metamorphism Syntectonic granites and gneisses	
1) Basic and ultrabasic igneous rocks, anorthosites, amphibolites and biotite schists	Inclusions and enclaves in granites and gneisses.

TREVES (1963 and personal communication) reports the succession of events shown in Table 5 from the Tasersiaq area (No. 33, Plate 1), which lies in line with the continuation of the Nagssugtoqidian boundary drawn by NOE-NYGAARD and RAMBERG (1961). Unfortunately the area so far mapped by TREVES is not large enough to be certain of the relationship between the succession in the Tasersiaq area and the Nagssugtoqidian fold belt. If the 1890 m. y. date is regarded as an early event in the development of the Nagssugtoqidian fold belt then it is possible that this activity may correspond in time to the proposed Ketilidian-Sanerutian fold belt in the south. If the 1890 m. y. date is earlier than the first phase of the Nagssugtoqidian then it may either represent a partial updating of an old pre-Nagssugtoqidian basement or an independent thermal event early in the Svecofennid chelogenic cycle which might correspond in time to the Ketilidian in the south. The 2990 m. y. zircon date from the same specimen suggests that the material from which these gneisses were derived was formed approximately contemporaneously with the material forming the Ivigtut gneisses (KANASEWICH and SLAWSON 1964). Two other rocks from the Banan Banke dated at 1800 m. y. and 1840 m. y. suggest that a thermal event at about this time may have been widespread in South-West Greenland. Recent work at the University of Oxford suggests that there was a marked thermal event about 1600–1800 m. y. in the rocks now forming the east coast of Greenland between Angmagssalik and Kangerdlugssuaq (Nos. 45–46, Plate 1) (E. I. Hamilton, personal communication). The prevalence of a thermal event between these dates in the Precambrian of Greenland gives some support to the ideas expressed in Section II of this paper.

Correlation of the Nagssugtoqidian fold belt with events in South Greenland

Before correlating the events in a fold belt in one area with events in a fold belt in a second area it is probably as well to define the terms used. So far in South Greenland the terms Ketilidian, Sanerutian etc. have been used both to mean a definite unit of time and also a particular type of event. This usage, although incorrect, raises no difficulties within the comparatively small area studied. However, a particular event in the evolution of a fold belt may occur at a different time from place to place. For example, the date of the main phase of folding in the Alpine fold belt can be shown to occur at a different time along the length of the mountain chain. If the Ketilidian and the Sanerutian are widely separated in time this double usage of the terms will probably cause no inconvenience. If however the suggestions made in Section II are correct the indiscriminate use of the terms may lead to confusion. It would, in this case, be possible to have a Ketilidian event occurring in Sanerutian time in the same fold belt away from the type area studied in South Greenland. The correlation between Nagssugtoqidian and the Sanerutian as suggested by Berthelsen (1961) can now be looked at more critically.

From the available information perhaps the only correct correlation which can be made is that thermal activity took place within the Nagssugtoqidian fold belt at approximately the same time that reactivation, accompanied by the emplacement of late plutonic granites, took place in South Greenland. This need not imply that the Sanerutian reactivation is due to the "deep-seated effects of a Nagssugtôqidian *contre coup*" (Berthelsen 1961). The single biotite K/Ar date of 1650 m. y. need not mean that the main thermal activity of the Nagssugtoqidian fold belt took place at this time; similar arguments in the South of Greenland would date the Ketilidian between 1650 and 1500 m. y., the age accepted for the Sanerutian reactivation.

If any correlation is to be made between the two fold belts then their whole evolution should be studied. If the gneiss dated by Treves at 1890 m. y. is early Nagssugtoqidian then it may be possible to compare the development of the Nagssugtoqidian with the proposed Ketilidian-Sanerutian fold belt in South Greenland. However, there is no need for similarity in dates from two areas separated by 500 km to indicate that they belong to the same fold belt. SUTTON (1963 b) pointed out that the period 1600 to 1800 m. y. was one of general thermal activity in the earth's crust in which an intersecting complex of fold belts developed. It is thus quite probable that the fold belts are only related by belonging to the same phase of the Svecofennid chelogenic cycle.

VI. COMPARISON OF SOUTH GREENLAND AND THE CANADIAN SHIELD

SLAWSON *et al.* (1963) show, on the basis of lead isotope studies, that the oldest rocks dated from both the North American mainland and Greenland were formed between 3000 m. y. and 3500 m. y. This probably indicates that isolated remnants of the Kola chelogenic cycle are present in the North American crust, although none have been recognised as forming major areas of the shield.

ARMSTRONG (1963) points out that age determinations from Greenland show that thermal events occurred concurrently with the main orogenic episodes of the Canadian shield, that is at 2300–2700 m. y. (Kenoran), 1600–1800 m. y. (Hudsonian) and 1200–800 m. y. (Grenville). These are also the main peaks of world wide thermal activity at the beginning of the Shamvian, Svecofennid, and Grenville chelogenic cycles. The compilation of available age determinations from Greenland (Table 7) supports this view, although dates from the Shamvian cycle are too sparse for any conclusions to be drawn. According to the arguments given in Section II of this paper the three groups of age determinations represent the pre-Ketilidian, the Ketilidian-Sanerutian, and the Gardar.

ARMSTRONG suggested that the Gardar igneous activity could be correlated with the Grenville plutonism between 1200 and 800 m. y. on the basis of the overlap in age determinations. However, the Gardar igneous province is typical of post-orogenic activity in a consolidated cratogen rather than the early phases of igneous activity of an orogenic cycle. Thus, in spite of the similarity of age, it is probably better to regard them as essentially independent phenomena. Possibly the crustal tension which characterised the Gardar in South Greenland occurred in the cratogen on the flanks of the developing Grenville geosyncline, parallel to the future direction of the Grenville fold belt.

Comparison of the Svecofennid chelogenic cycle in South Greenland and the Canadian shield.

The main thermal event of the Svecofennid chelogenic cycle in the Canadian shield was the Hudsonian "orogeny" at 1600–1800 m. y. Rocks showing this general age (the Churchill province) fall in a gentle arc swinging round the north of Hudson Bay to Labrador (LEECH *et al.* 1963). From the results described in this paper it appears that the Churchill province continues into Greenland, where it is represented by the Nagssugtoqidian and Ketilidian-Sanerutian fold belts and probably by a widespread metamorphic effect on the pre-Ketilidian basement.

The Canadian shield also contains several relatively restricted geosynclinal belts belonging to the Svecofennid chelogenic cycle, for example the Labrador trough and the Cape Smith fold belt, which were active between 1400 and 1600 m. y. (BEALL *et al.* 1963). How much activity there was in the shield at this time will not be known until more results are obtained from the Nairn province (LEECH *et al.* 1963). However, it is certain that it will not be as extensive as the Churchill or Superior (Kenoran) provinces. No activity has been reported from Greenland corresponding to these smaller fold belts unless some of the late Sanerutian events can be regarded as such.

The Canadian shield was intruded by a series of igneous rocks following the main Hudsonian episode and partly overlapping the development of the restricted geosynclines. These include at least three phases of dolerite dyke injection (FAHRIG and WANLESS 1963) some of which contain megacrysts of plagioclase feldspar (BARAGER 1960). Layered syenite-gabbro bodies, some of which are associated with anorthosites have been reported from Labrador which may correspond to the early Gardar intrusions (MORSE 1962, UPTON 1964). Igneous activity seems to have reached a peak immediately before the formation of the Grenville fold belt with the intrusion of large complexes many of which show spectacular layering (for example: the Duluth Gabbro, TAYLOR 1956; the Muskox intrusion, SMITH 1962; and the Lackner alkaline complex, PARSONS 1961). Except for the Lackner complex the Canadian igneous activity late in the Svecofennian chelogenic cycle was less alkaline than the contemporaneous Gardar intrusions.

The twin concepts of tectono-magmatic and chelogenic cycles may be useful from the purely chronological and from the economic viewpoint. For example the Sanerutian norites in South Greenland occur at the same time and in the same general geological setting as the Sudbury intrusion, Ontario. No mineralisation has been noted in connection with the Greenland norites but small hornblende peridotite bodies in close spacial association with the "New granites", which were possibly emplaced early in the Sanerutian episode, contain some nickel bearing minerals (J. BERRANGÉ personal communication). Further investigation of the South Greenland norites would be interesting.

VII. REMARKS ON THE SUBDIVISION OF THE PRECAMBRIAN

The geological review (Section I) shows that basic dykes intruded between two plutonic episodes provide the geologist with one of the best field criteria for the subdivision of the Precambrian. However, such divisions give no indication of the relative importance of each episode. It is possible that major divisions of the Precambrian have been proposed based on the occurrence of basic dyking which represented only a relatively local fluctuation in conditions. Thus a chronology based on periods of basic dyking alone may obscure the essential continuity of geological processes in a particular area by giving equal emphasis to short periods of local cratogenic conditions and long periods of crustal stability throughout a large area. An analogous situation in post-Cambrian stratigraphy would be the division of strata and their correlation over large areas using discordancies without palæontological evidence to show whether the breaks were of major significance.

Ideally isotopic age determinations should be able to control the divisions of the Precambrian made by the field geologist and to indicate the relative importance of any change of conditions. Unfortunately the 5% error which may be expected in isotopic age determinations may be critical in deciding the relative importance of a division. A large number of determinations are therefore necessary before complete reliance can be placed on the method. Further, although it is possible to obtain ages "through" a period of metamorphism interpretation of the results becomes increasingly difficult as the number of episodes which the rock has been through increases. Any process, such as migmatisation, affecting the rock to such an extent that complete redistribution of trace elements can be expected, will probably destroy isotopic records of an earlier event, although these may be recorded by the structures and lithology of the rocks involved. Finally, isotopic age determinations record thermal events, except in a few special cases. There is thus no reason why the age obtained from sediments should give a different age from the older basement from which they were derived, especially if both had been subjected to the same (later) metamorphism.

Geological cycles have been used in this paper as an additional basis for subdivision of the Precambrian, in combination with basic dykes and a relatively small number of age determinations. This is not a new method; the conclusions reached about the probable evolution of South Greenland are remarkably similar to those of WEGMANN in 1938. The method has the disadvantage of relying on subjective judgement rather than exact measurements, and opinions about what constitutes a geological cycle will differ from geologist to geologist. It also assumes that a pattern exists in the development of fold belts and that any particular example will agree broadly with the general case. However, it provides large enough divisions of the Precambrian to allow comparison between different areas with rocks of the same general age. It has the additional advantage of relating one geological process with another, a factor which is perhaps neglected when individual topics are treated in great detail.

CONCLUSIONS

The main conclusions of this paper must be that isotopic age determinations from South Greenland are inadequate to date most of the events recorded. Perhaps the most useful function of the available age determinations is in giving some ideas on which to base future work rather than providing an established time scale. Of the five episodes recognised in South Greenland only the two youngest (the Sanerutian 1650–1500 m. y. and the Gardar 1255–1020 m. y.) have been dated. Much more work is necessary to define the limits and to date individual events even in these episodes. A suggestion of approximately 1800 m. y. is made for the date of the Ketilidian plutonism, based on comparisons between South Greenland and other fold belts. A plutonic event at about this date was widespread in Greenland and the Canadian shield. The estimated 1800 m. y. date for the Ketilidian disagrees with previous estimates; part of the divergence of opinion is probably due to the definition of Ketilidian. In this paper the term Ketilidian is restricted to rocks which are of the same age or younger than the Grænseland basal conglomerate. On this definition the Ivigtut gneisses and many of the rocks north of Sermiligârssuk are probably reactivated pre-Ketilidian. It is also suggested that the Ketilidian and Sanerutian plutonic episodes are different phases of the same orogeny, and that the period of basic dykes which separate them is intra-orogenic.

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D. BRIDGWATER
Geological Survey of Greenland
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APPENDIX

Description of the five samples dated using K/Ar methods

1) Anorthosite inclusion, Narssaq, G. G. U. specimen 49320, collector D. B.

The anorthosite occurs as an inclusion containing at least 1000 cubic metres of rock within a Gardar gabbro on the north point of Narssaq Old Harbour. The inclusion is locally veined by host gabbro. Several specimens were taken from the block, the freshest were then crushed and biotite and augite were concentrated from approximately 100 kilograms of the rock. A bulk analysis of the crushed rock before separation is to be given in Bridgwater and Harry (in prep.).

Texture of the inclusion:

The anorthosite inclusion has a variable texture depending to a large extent on the proportions of the two main components present. These components are: a) rather crushed xenocrysts of plagioclase of variable size, and b) coarse grained anorthositic gabbro matrix. The relationship between the two components is complex; the xenocrysts of plagioclase are set in a mixture of augite, ilmenomagnetite and gabbro. Apparently the xenoliths have formed centres of crystallisation round which the augite and opaque minerals were precipitated until the rest of the interstices were filled with gabbro. Locally the gabbroic part of the anorthosite inclusions shows good layering with plagioclase laths aligned similar to those described by Upton (1961) from the Assorutit peninsula of Tugtutôq.

The main primary minerals are augite ($Ca_{40}Fe_{25}Mg_{35}$), olivine (Fa_{48}), ilmenomagnetite and plagioclase (An_{52-58}). No difference has been detected between the xenocryst composition and the groundmass feldspar although the total range shows a lower An content than seen in the xenocrysts. Some of the xenocrysts are lightly coloured purple, suggesting they may have belonged to the black feldspars described by Bridgwater and Harry. There is commonly a reaction rim between the xenocrysts and host anorthositic gabbro. Biotite occurs as a primary accessory mineral frequently surrounding the opaque minerals. Secondary alteration, with the formation of epidote and chloritic micas, has affected the anorthosite inclusion and the host dyke. An attempt was made to collect samples as far away from this alteration as possible.

2) Augite syenite, Nunarssuit, G. G. U. specimen 31097, collector T. C. R. Pulvertaft.

The specimen is from the main augite syenite of the Nunarssuit intrusive complex at the head of Amitsuarssuk fjord. For description of rock type see Harry and Pulvertaft 1963 p. 36–40. The specimen dated is a clean fresh rock consisting of interlocking feldspar grains with aggregates of subhedral pyroxenes and olivines. Opaque minerals and a reddish brown biotite are seen concentrated near the fayalitic olivines. The feldspars are vein and myrmekitic perthites; they sometimes show multiple albite twinning in the centre of the grains. Occasionally a rhombic shadow is present within the feldspars, suggesting that they were once phenocrysts before the final cementation of the rock. The pyroxenes are mushroom coloured, slightly iron-rich augite with some pale green, faintly pleochroic pyroxene near the margins. There is a very little alkali amphibole present.

3) Early Gardar dyke, Qaersuarssuk, G. G. U. specimen 45297, collector W. S. WATT.

The specimen was taken from the centre of a 80–90 m dyke trending 100° (W. S. WATT Ph. D. thesis, Durham University 1963). The dyke rock is a medium to fine-grained dolerite with occasional pegmatitic patches. The dolerite is generally sub-ophitic, with augite up to 3 mm in diameter partially surrounding plagioclase and granular olivine. In the pegmatitic patches the augites reach over a centimetre in diameter and there is considerable interstitial material containing a more sodic plagioclase than the normal dyke rock and probably a small amount of quartz and alkali feldspar. Near the pegmatite the olivines may show ophitic relationship towards plagioclase. Biotite is extremely scarce and a large amount of rock would be needed to concentrate it for age determination. The mineral compositions are as follows: augite $Ca_{38}Mg_{34}Fe_{28}$, plagioclase An_{55} zoning to An_{20} in the pegmatite, olivine Fa_{64} to Fa_{54}.

4) Biotite granite, Tugtutuarssuk, G. G. U. specimen 49195.

Specimen from one of the components of the Sydprøven granite (BRIDGWATER 1963).

In hand specimen a coarse-grained allotriomorphic biotite granite with porphyroblastic feldspars reaching 2 cm in diameter surrounded by patches of biotite which poikilitically enclose smaller feldspars and quartz grains. The feldspar porphyroblasts are a mixture of albite and microcline while most of the smaller groundmass feldspars are albite-oligoclase. Some of the plagioclases show a recrystallisation after an earlier sericitised plagioclase. Locally the rock contains small fine-grained patches of biotite, quartz, plagioclase and a little blue-green hornblende. Both the quartz and the plagioclase in the coarse-grained rock show signs of strain, the quartz is slightly opalescent in hand specimen while the plagioclase shows distorted twinning. The specimen is slightly atypical as most of the Sydprøven granite contains approximately equal amounts of poikilitic hornblende and biotite. No chlorite is visible in the biotite.

5) Hypersthene gabbro, Frederiksdal, G. G. U. specimen 51304, collector W. S. WATT.

A fresh olivine, augite, hypersthene gabbro from 1 km south of Frederiksdal village. Texturally the rock consists of interlocking, slightly stubby, plagioclase with patches of mafic minerals. Locally the olivine and augite surround the plagioclase ophitically; the olivine is more often granular. Many of the augites show a curious multiple lamella twinning, apparently due to the exsolution of hypersthene. Hypersthene may be seen either within the augite as lamellae or, more commonly, rimming the augite. Occasionally independant grains of hypersthene contain a grid of augite, generally confined to the centre of the host orthopyroxene. The twinning in the plagioclases is not always regular, some dislocations suggest strain. The plagioclase shows strong zoning with myrmekitic intergrowths towards the margins of individual grains. Original biotite is an abundant accessory surrounding ore grains and olivine. It has a marked pleochroism from reddish brown to colourless.

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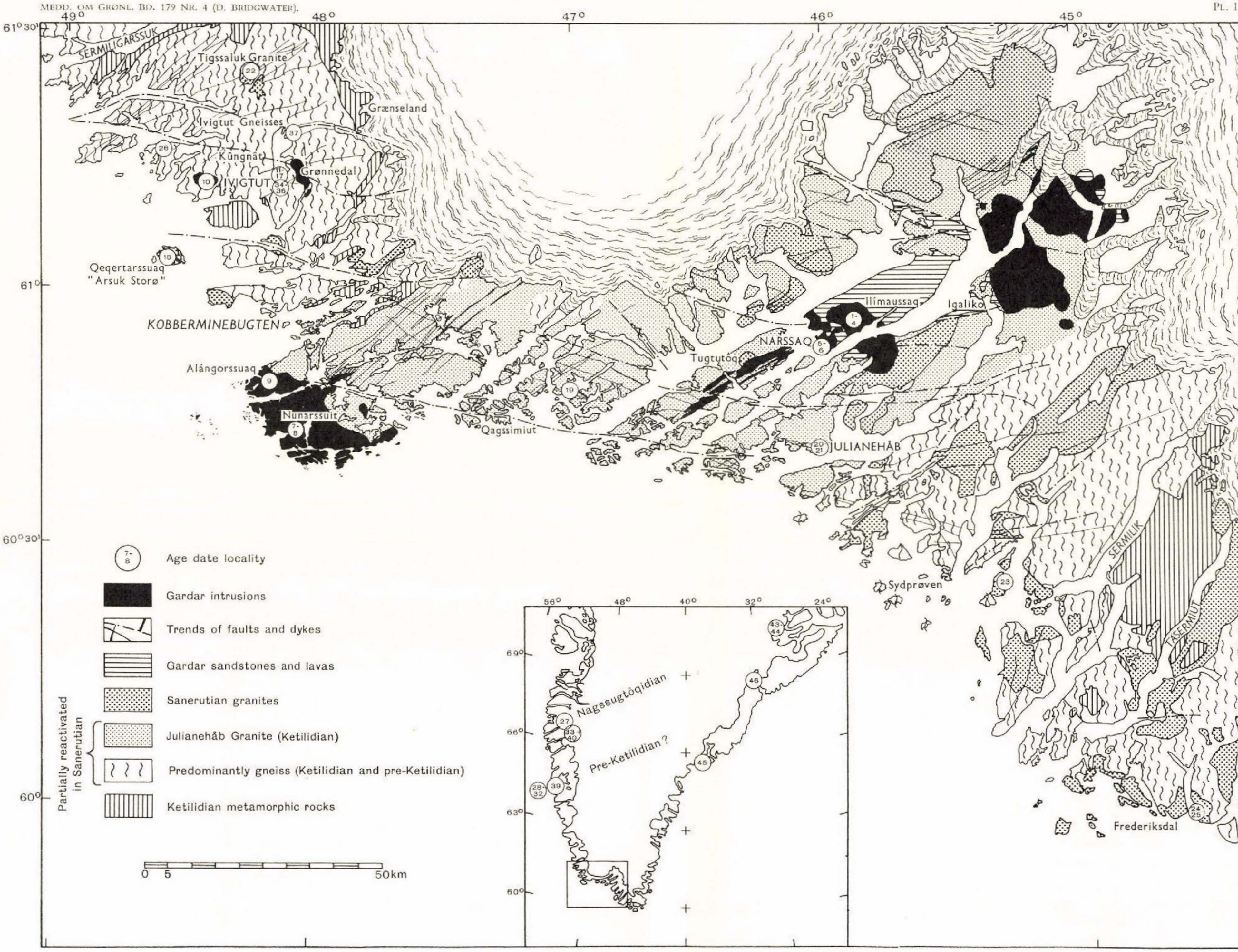
49°
48°
47°
46°
45°
61°30'
61°
60°30'
60°
SERMILIGÁRSSUK
Tigssaluk Granite
Grænseland
Ivigtut Gneisses
Kûngnât
Grønnedal
IVIGTUT
Qeqertarssuaq
"Arsuk Storø"
KOBBERMINEBUGTEN
Alángorssuaq
Nunarssuit
Qagssimiut
Tugtutôq
NARSSAQ
Ilímaussaq
Igaliko
JULIANEHÅB
Sydprøven
SERMILIK
TASERMIUT
Frederiksdal
Age date locality
Gardar intrusions
Trends of faults and dykes
Gardar sandstones and lavas
Sanerutian granites
Julianehåb Granite (Ketilidian)
Predominantly gneiss (Ketilidian and pre-Ketilidian)
Ketilidian metamorphic rocks
Partially reactivated in Sanerutian
0 5 50km
56° 48° 40° 32° 24°
69°
66°
63°
60°
Nagssugtôqidian
Pre-Ketilidian ?

Table 6.

South Greenland		Svecofennian Fold Belt (Scandinavian and Kola peninsula) References 5, 6 and 7		Caledonian Fold Belt (Britain and Scandinavia) References 1, 2, 3, 4 and 5		Appalachian Fold Belt (New England and the Maritime provinces). References 8, 9 and 10	
EVENT	EPISODE AND DATES	EVENT	APPROXIMATE DATE	EVENT AND LOCALITY	APPROXIMATE DATE	EVENT	APPROXIMATE DATE
Intrusion of agpaitic syenites. Gradual decrease in fault activity. Intrusion of major augite syenite complexes, emplaced mainly by stoping, some late granites. Intrusions of major dyke swarms of gabbro, trachy-dolerites and alkali rocks. Inclusion of anorthosite fragments in dykes at maximum. Considerable normal faulting. Intrusions characterised by good layered structures formed mainly by gravity accumulation of minerals. Intrusion of carbonatite-nepheline syenite complex, lamprophyric and carbonatitic dykes and sills followed by early dolerites. Considerable movement of normal and transcurrent faults. Extrusion of (mainly) basaltic lavas. Deposition of sandstones in fault-controlled basins.	End of Gardar magmatism 1020 m. y. 1100–1200 m. y. Late Gardar intrusives. Not dated accurately; probably 1200–1400 m. y. Mid-Gardar intrusives. Early Gardar intrusions, not dated accurately. Possibly 1400–1450 m. y. Probably some overlap between formation of early Gardar intrusions and deposition of sandstones.	Widespread dolerite dyke emplacement. Composite syeno-gabbro giant dykes and some dolerites with plagioclase masses. Jotnian sandstone sedimentation. (Development of Gothian fold belt on margins of Svecofennian cratogen). Alkaline rocks, nepheline bearing basic rocks, ægerine granites emplaced in fault zones in Kola and Karelia. Post-orogenic rapakivi granites (6) intruded into rigid country rocks, some syngranitic basic dykes. Anorthositic gabbros and dolerites. Rapakivi granites discordant, sometimes sheet formed.	1100 m. y. 1270 m. y. (7) 1420–1660 m. y. (7) 1600 m. y. (5) 1650–1700 m. y.	Intrusion of agpaitic rocks in Kola associated with marginal fault zone following Caledonian orogeny. Intrusion of carbonatites (Kola). Formation of Oslo graben, with extrusion of alkali lavas, and the intrusion of alkali rocks, ranging from carbonatites to augite syenites and agpaitic pegmatites. Inclusions of anorthositic material. Midland valley graben (Scotland) with extrusion of alkali, trachybasaltic and basaltic lavas. Accumulation of plagioclase rich rocks in dykes and sills. (3) Deposition of continental sandstones. Emplacement of "Last granites" (Read) by cauldron subsidence etc. (1).	266–280 m. y. (4) 340 m. y. (4) 230 m. y. (5) 270 m. y. 340 m. y.	Eugeosynclinal area. White Mountain alkali magma series, Alkali granites (Rhode Island and Massachusetts). Continental sandstone deposition in fault controlled basins. Faulting gradually decreasing.	 180–190 m. y. (8) 230–260 m. y. 250–180 m. y. (Carboniferous to Trias).
Considerable faulting and crustal instability. Some faulting probably under semi-plutonic conditions. Formation of aplitic granites and large pegmatite swarms. Emplacement of minor basic intrusions under late plutonic conditions. Reactivation of earlier granites and gneisses often associated with shear movements. Emplacement of "New granites" in association with intrusion of norites, diorites and monzonites. Most of the "New granites" are discordant, often sheet formed bodies. Several show rapakivi texture.	End of Sanerutian plutonic episode. 1500 m. y. "New granites" 1620 m. y.	Late orogenic granites. (5,6). Reactivation, metasomatic granitisation.	Probably about 1750 m. y. Not separable from earlier rocks of the orogeny by age *determinations*.	Folding outside main metamorphic zone. Local formation of migmatites and "reactivated granites" connected with "Newer Granites". "Newer Granites" are generally discordant, often sheet formed. Some minor basic intrusives intruded in "plutonic conditions". Appinitic suite of noritic gabbros and monzonite rocks associated with "Newer Granites".	365 m. y. (Britain).	Sedimentation under waning unstable conditions. Local areas with compressional movements continued until approximately 270 m. y. Some *extrusion* of volcanic rocks. Acadian "orogeny", a period of folds parallel with the general trend of the fold belt accompanied by the formation of concordant granites and gneisses (Oliverian magma series). Rapakivi granites emplaced as *discordant stocks cutting* granite-granophyre, norite-gabbro series of layered rocks intruded under unstable conditions (Bays-of-Maine). Granodiorites, monzonites, and calc-alkaline suite (Deboullie) (10). Metamorphism of post-Taconic dykes.	250–300 m. y. (Carboniferous) (Devonian, early Carboniferous) 325–370 m. y. (9)
Intrusion of post-Ketilidian dyke swarms, dolerites and some intermediate rocks. Some composite dykes. Possibly emplacement of some large basic and ultrabasic layered bodies. Outside main Sanerutian metamorphic area emplacement of larger Kuanitic dolerites.	Post-Ketilidian "cratogenic" episode, (nor dated).	Basic dykes intruded in rigid crustal conditions, (6) amphibolitised by late orogenic granites.		Intrusion of olivine gabbro sheets with some differentiation to alkali gabbros and syenites. Intrusion of basic sills outside metamorphic belt. (1)		Basic and intermediate dykes intruded in conditions varying from cratogenic to partly plutonic according to erosional level and locality. Andesitic lavas, basalts and *rhyolites*.	Post-Taconic dykes (Silurian).
Emplacement and formation of homogeneous potash megacryst granites and granodiorites. Homogenisation of gneisses with introduction of potash feldspar in infrastructure. Formation of large semiconcordant pegmatites in suprastructure. Formation of late and syntectonic granodiorite gneisses. Several phases of folding under regional metamorphism.	Ketilidian plutonism (not dated). Possibly 1800 m. y.	Synorogenic diorites and granodiorites, (6); regional metamorphism and folding; oligoclase gneisses, micaceous schists.	Probably began approximately 1800 m. y.	Syn-and late tectonic concordant granites, gneisses and migmatites. Polyphase folding and regional metamorphism.	Approximately 480 to 395 m. y. (2)	"Taconic" orogeny, formation of "granitic batholiths", gneisses and regional metamorphism. Intrusion of ultrabasic rocks. Reactivation of Precambrian basement.	(Ordovician) 390–450 m. y.
Extrusion of basic lavas, some as pillow lavas. Intrusion of basic sills. Sedimentary sequence of pelites, quartzites and some limestones lying unconformably on gneissose pre-Ketilidian basement. Formation of late syntectonic granites, gneisses and metamorphic rocks probably belonging to more than one episode. Initial formation of rocks in Ivigtut region.	Ketilidian sedimentation (unknown date). pre-Ketilidian plutonic episodes one of which probably approximately 2400–2700 m. y. Possibly about 3000 m. y.	Argillaceous sediments. Basic volcanics, pillow lavas intercalated sediments. Greywackes and arkoses.	Not earlier than 2300 m. y. (6)	Basic intrusions, extrusives, pillow lavas and gabbroic sills. Moine, Torridonian and Dalradian sedimentation on older basement. (2) Basement to Caledonian fold belt variable and belongs to at least three tectono-igneous cycles. (1)	Probably between 1000 m. y. and 500 m. y.	Sedimentation and lava extrusion.	Approximately 600–450 m. y. (Late Precambrian to Ordovician) The geological Periods quoted above are those given by the various authors to the particular events described. They need not agree with the isotopic age quoted as the time scale has been altered since they were published.

1 READ (1961)
2 SUTTON (1963 a)
3 TYRREL (1955)
4 VOROBIEVA (1960)
5 POLKANOV and GERLING (1960)
6 SIMONEN (1962 and in press)
7 MAGNUSSON (1960)
8 KING (1959)
9 CHAPMAN (1962)
10 BOONE (1962)

G E U S
Report File no.
22205
Enclosure (2/2)

Table 7.

Precambrian isotopic age determinations from Greenland

No. on map	Rock type and locality	Specimen number	Mineral	Reference	Method	Date in m.y.	Comments
South and South-West Greenland.			GARDAR				
1	Late Gardar pegmatite from Ilímaussaq	31721	polylithionite	1	Rb/Sr	1012 ± 24*	
2	Late Gardar pegmatite from Ilímaussaq	31734	polylithionite	1	Rb/Sr	1021 ± 20*	
3	Late Gardar pegmatite from Ilímaussaq	31708	polylithionite	1	Rb/Sr	1030 ± 24*	
4	Late Gardar pegmatite from Ilímaussaq	31708	polylithionite	1	K/Ar	1180	Measurement probably erroneous (S. MOORBATH)
5	Anorthosite fragment in mid-Gardar dyke	49320	biotite		K/Ar	1025 ± 70	Probably affected by Ilímaussaq (page 34)
6	Anorthosite fragment in mid-Gardar dyke	49320	augite		K/Ar	1075 ± 50	Probably affected by Ilímaussaq
7	Augite Syenite Nunarssuit	31097	biotite		K/Ar	1128 ± 30	
8	Augite syenite Nunarssuit	31097	augite		K/Ar	1355 ± 150	Probably unreliable (page 33)
9	Biotite granite Alángorssuaq	30173	biotite	3	Rb/Sr	1150 ± 30	Same complex as 7–8
10	Augite syenite Kûngnât	26197	biotite	1	Rb/Sr	1170 ± 150*	
11	Pegmatite from Ivigtut granite	B-2	biotite	2	Rb/Sr	1230 ± 40 1180 ± 30	
12	Pegmatite from Ivigtut granite	B-2	biotite	2	K/Ar	1188 ± 30 1185 ± 30	Measured by M. H. DODSON and N. SNELLING
13	Pegmatite from Ivigtut granite	B-1 c	biotite	2	Rb/Sr	1160 ± 40	
14	Pegmatite from Ivigtut granite	B-1 a	biotite	2	Rb/Sr	1190 ± 50	
15	Pegmatite from Ivigtut granite	B-1 b	biotite	2	Rb/Sr	1210 ± 30	
16	Transition rock between granite and greisen	B-3	biotite	2	Rb/Sr	1150 ± 30 1190 ± 30	
17	Fine-grained granite Ivigtut granite	Ddh J 4-W.R.	whole rock	2	Rb/Sr	1250 30 1260 ± 30	
18	"Arsuk Storø" granite	31768	biotite	(2)	Rb/Sr	1220 ± 60	Possibly local effect of Gardar (page 37)
19	Early Gardar dolerite	45297	augite		K/Ar	1435 ± 80	See page 33
			SANERUTIAN				
20	Julianehåb granite	39823	biotite	1	Rb/Sr	1500 ± 70*	Sanerutian reactivation of Ketilidian (p. 38)
21	Julianehåb granite	39823	biotite	1	K/Ar	1597 ± 100	Measurement unreliable
22	Tigssaluk granite	31764	biotite	(2)	Rb/Sr	1615 ± 30	See page 37
23	Sydprøven granite	49195	biotite		K/Ar	1620 ± 50	See page 31
24	Frederiksdal noritic gabbro	51304	biotite		K/Ar	1645 ± 50	See page 31
25	Frederiksdal noritic gabbro	51304	augite		K/Ar	1700 ± 200	See page 31
26	Isa pegmatite	31167	biotite	(2)	Rb/Sr	1630 ± 30	Probably the effect of Sanerutian
27	Granodioritic gneiss Søndre Strømfjord	YAG I	biotite	4	K/Ar	1650 ± 80	Nagssugtoqidian
28	Biotite granite-gneiss Banan Banke	140 N	whole rock	5	K/Ar	1620	Nagssugtoqidian See 29–32 below
			PRE-SANERUTIAN				
29	Biotite granite-gneiss Banan Banke	140 b_1	whole rock	5	K/Ar	1800	Loose blocks trawled up west of Godthåbsfjord
30	Quartz metadiabase Banan Banke	147 A	whole rock	5	K/Ar	1840	
31	Biotite granite-gneiss Banan Banke	140 b	whole rock	5	K/Ar	2330	
32	Biotite-muscovite granitic gneiss Banan Banke	140 A	whole rock	5	K/Ar	2450	
33	Granitic gneiss, 66°15′ N 51°15′ W Tasersiaq	5862	biotite	6	K/Ar	1890 ± 5 %	See 40 below
34	Galena from cryolite ore body, Ivigtut	G I	galena	2	lead isotopes	2150 ± 50	Further work on the anomalous lead isotopes from Ivigtut galena given in 38, 41 and 42 below
35	Galena from cryolite ore body, Ivigtut	G 2	galena	2	lead isotopes	2140 ± 60	
36	Galena from quartz feldspar-biotite pegmatite, Ivigtut	G 3	galena	2	lead isotopes	2160 ± 70	
37	Galena from vein at Laxebunden, 12 km NE of Ivigtut	G 4	galena	2	lead isotopes	1970 ± 0.6	
38	Galena from Ivigtut		galena	7	lead isotopes	2400	
39	Granodioritic gneiss Godthåb	YAG 2	biotite	4	K/Ar	2710 ± 130	Probably represents pre-Ketilidian
40	Granitic gneiss 66°15′N 51°15′W	5862	zircon	3	lead alpha	2990 ± 340	Same specimen as 33
41	Galena from Ivigtut and Laxebunden	See 34–37	galena	8 & 9	lead isotopes	3520 3020	(2 stage model) (modified 3 stage model)
42	Galena from Ivigtut and Laxebunden	See 34–37	galena	10	lead isotopes	2980 1100	(multistage model) (emplacement)
East Greenland							
43	Alkali granite	GAA-135	biotite	11	K/Ar	1900 ± 50	Same specimen
44	Alkali granite	GAA-135	feldspar	12	Rb/Sr	2290 ± 70	
45–46	Kangerdlugssuaq and Angmagssalik. Rb/Sr determinations of rocks from these two areas give results suggesting high thermal conditions between 1600 and 1800 m. y. (E. I. HAMILTON personal communication). See WAGER, L. R. and HAMILTON, E. I. (1964) Nature, Lond., Vol. 204.						

1 MOORBATH *et al.* (1960),* denotes that the date has been modified due to the use of new constant.
2 MOORBATH and PAULY (1962)
(2) MOORBATH and PAULY. Additional information pertaining to 2 and given in Table 4.
3 MOORBATH *in* HARRY and PULVERTAFT (1963)
4 ARMSTRONG (1963)
5 DIBNER *et al.* (1963)
6 TREVES (1963)
7 BATE and KULP (1956)
8 SLAWSON *et al.* (1963)
9 KANASEWICH and SLAWSON (1964)
10 ULRYCH (1964)
11 KULP *et al.* (1962 a)
12 KULP *et al.* (1962 b)
No reference number means that it is a new date.