GRØNLANDS GEOLOGISKE UNDERSØGELSE
RAPPORT NR. 42

The Geological Survey of Greenland
Report no. 42

U – Pb isotopic ages of zircons from Precambrian rocks of South Greenland

by

R. Chessex, A. Buchs, J. H. Allaart, M. Delaloye, P. Buttet and J. C. Landry

KØBENHAVN 1971

Grønlands Geologiske Undersøgelse

(The Geological Survey of Greenland)
Østervoldgade 10, DK-1350 Copenhagen K

Reports

No. 18 Preliminary account of the geology of the Kvanefjeld area of the Ilímaussaq intrusion, South Greenland. 1969 *by* H. Sørensen, J. Hansen and E. Bondesen. D. kr. 6.00.

No. 19 Report of activities, 1968. 1969. D. kr. 6.00.

No. 20 On the applicability of magnetic prospecting for chromite in the Fiskenæsset region, West Greenland. 1969 *by* M. Ghisler and P. Vallabh Sharma. D. kr. 3.50.

No. 21 Report on the 1968 geological expedition to Scoresby Sund, East Greenland. 1969. D. kr. 6.00.

No. 22 Oil and gas prospects in the Cretaceous-Tertiary basin of West Greenland. 1969 *by* G. Henderson. D. kr. 6.00.

No. 23 The Precambrian rocks of the Egedesminde-Christianshåb area, West Greenland. 1969 *by* G. Henderson. D. kr. 4.00.

No. 24 The mode of occurrence and petrogenesis of the sapphirine-bearing and associated rocks of West Greenland. 1969 *by* R. K. Herd, B. F. Windley and M. Ghisler. D. kr. 4.50.

No. 25 The chronology and petrography of the Gardar dykes between Igaliko Fjord and Redekammen, South Greenland. 1969 *by* J. H. Allaart. D. kr. 4.50.

No. 26 Preliminary report on the geology of Bjørneøer, Scoresby Sund. 1969 *by* F. Kalsbeek. D. kr. 4.00.

No. 27 Some observations on the structural and metamorphic chronology on Agto and surrounding islands, central West Greenland. 1970 *by* K. Sørensen. D. kr. 3.50.

No. 28 Report of activities, 1969. 1970. D. kr. 12.50.

No. 29 Bedrock geology of the nunataks and semi-nunataks in the Frederikshåbs Isblink area of southern West Greenland. 1970 *by* P. R. Dawes. D. kr. 20.00.

No. 30 Report on the 1969 geological expedition to Scoresby Sund, East Greenland. 1970. D. kr. 10.00.

No. 31 Preliminary account of kimberlite intrusions from the Frederikshåb district, South-West Greenland. 1971 *by* J. R. Andrews & C. H. Emeleus. D. kr. 6.00.

No. 32 Géologie d'un secteur situé entre les fjords de Sermiligârssuk et Arsuk (SW du Groenland). 1971 *par* L.-F. Bonnard.

No. 33 Beryllium mineralization in the Ilímaussaq intrusion, South Greenland, with description of a field beryllometer and chemical methods. 1971 *by* J. Engell *et alia*.

No. 34 Preliminary account of the geology of south-east Renland, Scoresby Sund, East Greenland. 1971 *by* B. Chadwick.

No. 35 Report of activities, 1970. 1971.

No. 36 Short explanation to the Quaternary map of Greenland. 1971 *by* A. Weidick. D. kr. 3.00.

No. 37 Report on the 1970 geological expedition to Scoresby Sund. East Greenland. 1971.

No. 38 Field observations on the kakortokites of the Ilímaussaq intrusion, South Greenland, including mapping and analyses by portable X-ray fluorescence equipment for zirconium and niobium. 1971 *by* H. Bohse *et al.*

No. 39 An electronic data processing system for geological field and laboratory data. The E.D.P. system Agto. (in press) *by* S. W. Platou.

No. 40 The composition of sands from the Fiskenæsset region, South-West Greenland, and its bearing on the bedrock geology of the area. 1971 *by* F. Kalsbeek.

No. 41 Holocene shore-lines and glacial stages in Greenland — an attempt at correlation. (in press) *by* A. Weidick.

GRØNLANDS GEOLOGISKE UNDERSØGELSE
RAPPORT NR. 42

U – Pb ISOTOPIC AGES OF ZIRCONS FROM PRECAMBRIAN ROCKS OF SOUTH GREENLAND

by

R. CHESSEX, A. BUCHS, J. H. ALLAART, M. DELALOYE, P. BUTTET, AND J. C. LANDRY

With 1 figure and 2 tables

1971

Abstract

Results of age determinations on zircons from samples of gneiss, granite, syenite and diorite from the Ketilidian mobile belt of South Greenland are presented. The lead isotopes were determined by a direct ionisation method.

As three of the four zircon concentrates gave more or less discordant results, their interpretation is difficult. However, the data agree with the view that late Ketilidian granite emplacement took place roughly 1800 m.y. ago and not around 1600 m.y. age as the previously available K/Ar dates on pre-Gardar rocks seemed to indicate.

Authors' addresses: R. Chessex & M. Delaloye: Institute of Mineralogy, University of Geneva, Switzerland.

A. Buchs & J. C. Landry: Laboratory of Mass Spectrometry, University of Geneva, Switzerland.

J. H. Allaart: Geological Survey of Greenland, Copenhagen.

P. Buttet: Cimentaciones Especiales, Madrid, Spain.

CONTENTS

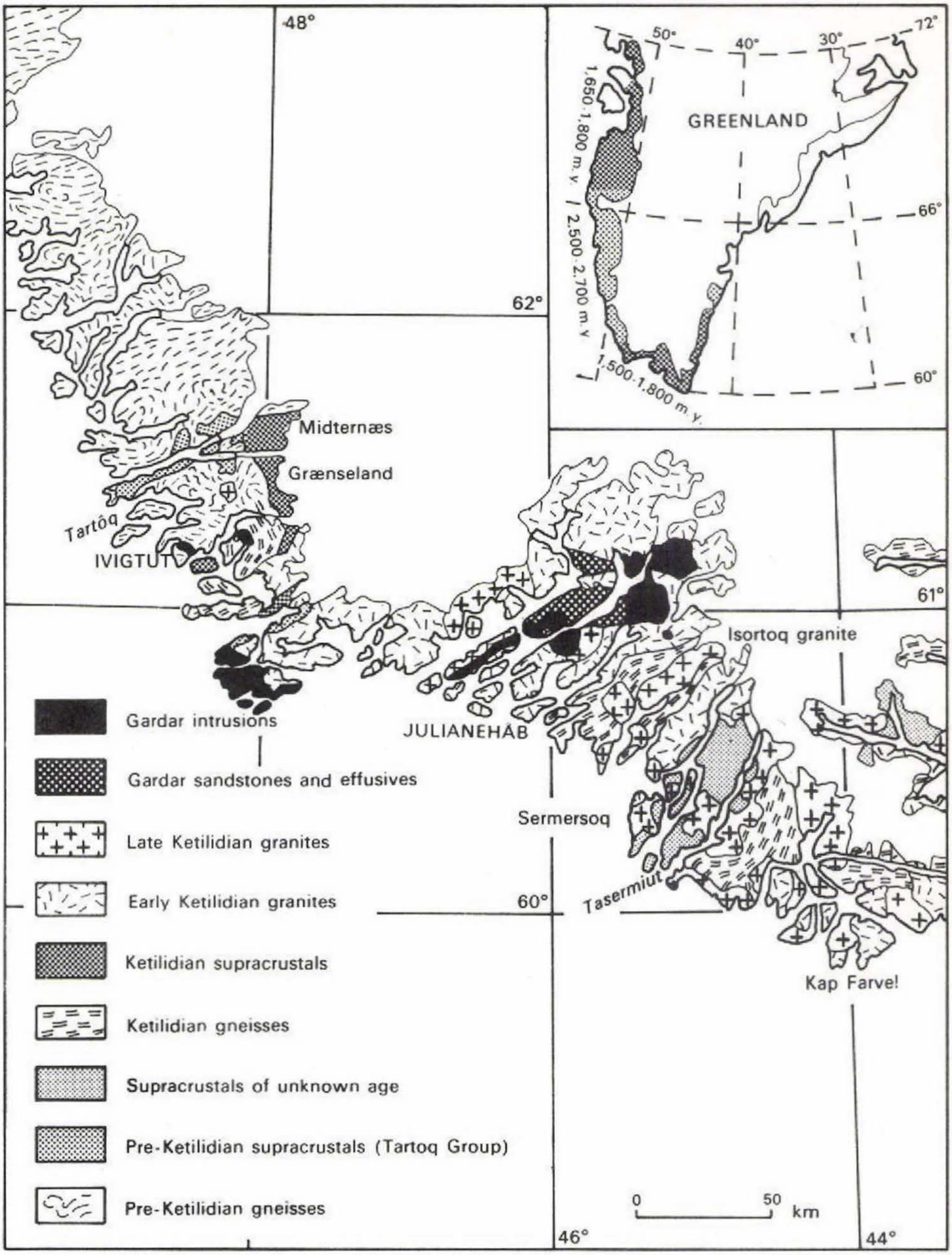

Fig. 1. Geological sketch map of southern Greenland.

INTRODUCTION

This paper reports the results of age determinations on zircons from samples of the Isortoq granite and the country rock all of which were formed or affected by thermal events related to the development of the Ketilidian mobile belt in South Greenland (see Fig. 1). These were collected by P. Buttet during field work for a Doctor's degree and left in Geneva. The determinations have been carried out in the Institutes of Mineralogy and of Mass Spectrometry of Geneva University.

GEOLOGICAL SETTING

The Ketilidian mobile belt can successively be subdivided from north-west to south-east, approximately across its main trend, as follows.

1) At *c.* 61° 30'N essentially unmetamorphosed Ketilidian lavas and sediments overlie the pre-Ketilidian (Archaean) Ivigtut gneisses and metamorphosed supracrustals of the Tartoq Group unconformably (Higgins & Bondesen, 1966).

2) In the southern part of the Ivigtut region between 61° 30'N and 61°00'N the Ketilidian supracrustal rocks and their underlying basement become progressively involved in Ketilidian metamorphism and deformation so that at the south and east of this region it is no longer possible to distinguish Ketilidian rocks and their reactivated basement with certainty in the field.

3) The Julianehåb granite shows intrusive contacts against the gneisses and supracrustals from the southern part of the Ivigtut region. It is a complex body with considerable field evidence for several phases of homogenisation, deformation and remobilisation. Here and there transformed pre-Ketilidian material can still be recognised (see table 1).

4) An area of gneisses and gneissose granites containing some supracrustal relics of unknown age and invaded by discrete bodies of granite.

5) Gneisses and migmatised supracrustals in amphibolite to cordierite granulite facies occur between Sermersoq and Kap Farvel. In this area, north-west of Tasermiut fjord, supracrustal rocks are especially well preserved.

In the area of gneisses and gneissose granites (see above under 4) between the Julianehåb granite and the Tasermiut supracrustals Persoz (1969) has mapped three large amphibolite masses which he interpreted to have originated from a series of basic lavas. The age of these rocks is unknown. They could be relics of Ketilidian supracrustals or equally well relics of still older rocks (Tartoq Group?). Each of these amphibolitic masses is completely surrounded by a body of granodiorite which according to Persoz has partially replaced the basic masses. Samples 110122, 110126 and 110127 have been taken from the largest of the granodiorite bodies, the Isortoq granite (see Fig. 1), the northern part of which is dioritic to syenitic in composition. Persoz places the granodiorite very late in the chronology. The field evidence is however not conclusive (Buttet, 1963). Sample 110125 has been taken from the country rock gneiss not far north-west of the margin of the Isortoq granite.

Table 1. Chronology of South Greenland

	Events		K/Ar ages (m.y.)
Phanerozoic	Coast-parallel olivine tholeiite dykes Carbonatitic lamprophyre dykes		164
Gardar	Alkaline igneous activity, dyking, faulting		1000–1150
	ESE-trending dolerites Sandstones and lavas Faulting (ESE-trending set)		1600 ?
Ketilidian	Rapakivi suite – Appinitic suite	Plutonic reactivation of earlier granites	
	Main plutonic episode	migmatisation metamorphism deformation	
	Extrusion of volcanics Sedimentation	(Ivigtut region and ? Tasermiut region)	
Pre-Ketilidian	Basic dykes (Kuanit fjord)		
	(formation of Julianehåb granite ?) Deformation, metamorphism, migmatisation		2500–2700
	Volcanism and some sedimentation (Tartoq Group)		
	? Older basement		

THE ISOTOPIC U-Pb METHOD

The available K/Ar and Rb/Sr mineral dates (see annual Reports of Activities of the Greenland Geological Survey and Allaart *et al.* 1969 for references) on rocks regarded as affected by Ketilidian thermal events cluster around 1600 m. y. and range down to 1500 m. y. These have been interpreted as a reflection of the effects of late-Ketilidian granite intrusion between 1500 and 1640 m. y. ago (Allaart *et al.* 1969: table 1).

In view of age results from the Svecofennian of Scandinavia and the Hudsonian of Canada and of the fact that the sealing against argon loss in the crust is known to take place at a temperature not higher than a few hundred degrees, the above interpretation is subject to doubt, and it is even thought possible that the K/Ar ages around 1600 m. y. represent a regional event of low intensity which took place clearly later than the intrusion of the late-Ketilidian granites.

As some zircons appear to be able to retain their radiogenic daughter elements under conditions at which regional loss of argon and redistribution of strontium have occurred the older ages to be expected from individual U-Pb results might give a minimum age closer to the dated major thermal event than either K/Ar or Rb/Sr mineral analyses.

The isotopic U-Pb method can be used on accessory zircons from granitic and gneissic rocks. One of the main difficulties in interpreting U-Pb isotopic ages is that in the majority of cases a discordant pattern is obtained (If the isotopic ages derived from the Pb^{206}/U^{238} and Pb^{207}/U^{235} ratios in a mineral differ by more than 5%, the results are said to be discordant, Catanzaro & Kulp, 1964; other authors permit a value of 10%). Discordant zircon ages generally show the following pattern: age Pb^{206}/U^{238} < age Pb^{207}/U^{235} < age $Pb^{207}/Pb^{206} \leqslant$ true age.

One of the most probable explanations for this kind of discordance is a loss of radiogenic lead, either by episodic loss (during a phase of reheating or weathering by ground water) or by continuous diffusion.

In the literature many authors have emphasised the great complexity of the geological and other processes which could lead to discordant ages. The exact mechanisms of the redistribution processes are not yet fully understood and may differ from case to case. As stated by Banks & Cain (1969): "discordance in zircons should probably be viewed as a complex function of both the chemical and mineralogical characteristics of the crystals and the detailed history of their environment".

ANALYTICAL PROCEDURE

The samples were crushed to a standard 80 mesh and zircon was separated and concentrated by conventional magnetic and heavy liquid techniques. Final purification was eventually made by hand picking under the binocular.

Uranium and lead contents were determined by X-ray fluorescence spectrometry by a procedure described by the second author (Buchs, 1962).

The isotopic analyses were made with a CH-4 Atlas mass spectrometer, without prior extraction of the lead from the zircons. The technique used will be fully described in a future paper (Buchs *et al.* 1971).

The decay constants used to calculate the ages are as follows: U^{238}: $1.54 \times 10^{-10} yr^{-1}$; U^{235}: $9.72 \times 10^{-10} yr^{-1}$; $U^{238}/U^{235} = 137.8$.

The isotopic ratios used for the common lead correction were $Pb^{206}/Pb^{204} = 15.0$; $Pb^{207}/Pb^{204} = 15.2$; $Pb^{208}/Pb^{204} = 35.0$.

(For the common lead correction the values given by Kouvo & Tilton (1966) for 1900 m. y. old minerals were used. As the zircons are very old and the common lead content relatively low, the possible errors introduced in the choice of common lead corrections are negligible).

The uncertainty in the concentrations given in table 2 is approximately ± 1-2% for the U and ± 3-4% for the Pb. The isotopic ratios are accurate within 0.5 to 3.5% (standard deviation) as far as mass spectrometer errors are concerned. The results are given in table 2.

Table 2. Analytical data and apparent ages

GGU No.	Rock	Concentration (ppm)		Isotopic abundance telative to Pb^{206}				Apparent ages, in m.y.		
		U	Pb	204	206	207	208	206-238	207-235	207-206
110122	Granodiorite	1302	333	0.030	100	10.87	9.88	1432	1557	1773
110125	Granitic gneiss	628	210	0.171	100	11.58	7.56	1802	1666	1496
110126.	Syenite	314	112	0.000	100	13.15	7.95	1924	2035	2155
110127	Diorite	497	169	0.000	100	11.06	8.39	1868	1854	1838

DESCRIPTION OF THE SAMPLES

In each sample the zircons show a great variation in shape. Most of the zircons are subhedral with slightly rounded pyramid faces without sharp edges. A prismatic habit is common, but many crystals are stubby (multifaceted bipyramidal). Some of the grains are well rounded, others are euhedral. Cores and overgrowths are not uncommon and many grains are metamict with expansion cracks.

It is clear that these zircons are neither definitely "igneous" nor definitely "detrital" in the terminology of Catanzaro & Kulp (1964), and it is difficult to determine with certainty the original character of the rock before it suffered the first metamorphic event in its history.

GGU 110122. *Biotite granodiorite.* This rock is medium-grained showing a subhedral granular texture and a weak orientation of the biotite crystals. Slightly zoned calcic oligoclase is the most abundant mineral. Microcline and quartz are late crystallisation products. Biotite shows slight alteration into chlorite.

The zircons vary from clear, pale violet to metamict brownish black. Crystals with prismatic habit and simple bipyramidal terminations [111] are strongly represented. 25% of the crystals have visible cores. The average length/width ratio is just over two; some grains are much more elongate.

GGU 110125. *Quartz-dioritic gneiss.* The rock is medium-grained and has a granoblastic texture. It shows a conspicuous but irregular foliation and is locally cataclastic. Oligoclase-andesine takes more than half of the rock volume and microcline about 5%. Green hornblende (*c.* 5%) is partly replaced by olive biotite (*c.* 10%) and epidote.

The zircon crystals vary from pale violet to dark brown or black. Most of them are more or less turbid. Prismatic habit is well developed, but most of the crystals are subhedral without sharp terminations. There are more stubby multifaceted zircons than in sample 110122. Some grains have cores, outgrowths and overgrowths. The average length/width ratio is between 1.5. and 2.0.

GGU 110126. *Syenite.* The rock is leucocratic, unfoliated and coarse-grained. It has a subhedral granular texture. Perthitic K-felspar and albite-oligoclase take more than 85% of the rock volume. The K-feldspar has partly been replaced by albite. Quartz (*c.* 3%) and dark brown biotite (*c.* 8%) are other important constituents.

The zircons vary from pale violet to brown, very clear and poor in inclusions. Most of the grains are subhedral and more than 50% have multifaceted bipyramids. Many grains have an irregular shape, as in sample 110127. The length/width ratio is moderate (*c.* 1.5).

GGU 110127. *Diorite.* This is a coarse-grained rock with a faint foliation. It has a grey white colour with clusters of dark minerals and a subhedral granular texture. Plagioclase (*c.* An_{35}) may be zoned and takes more than half of the volume. The other constituents are microcline, quartz, olive green biotite, green hornblende, epidote and titanite.

Zircon crystals vary from clear, pale violet to metamict, dark brown and often contain older cores. Some grains are clear and brown or milky and rounded. Most of the grains are subhedral, but many have an irregular shape. The population is less homogeneous than that of sample 110126.

DISCUSSION OF THE RESULTS

Although the results cannot be interpreted with the aid of a Concordia diagram, some preliminary conclusions can still be drawn. Zircon concentrates 110122 and and 110126 give discordant dates with a normal pattern. The granitic gneiss is clearly discordant with an abnormal pattern.

110122. *Granodiorite.* The age pattern suggests that the crystallisation of the zircons took place *c.* 1800 m. y. ago. The discordance between the dates cannot be related only with a thermal event of low intensity *c.* 1600 m. y. ago. As this zircon concentrate gives the most discordant pattern of the samples investigated, it has to be noted that it is also the most radioactive sample. This confirms the thesis that the degree of discordance of the zircon ages increases with increasing uranium content and consequently stronger metamictisation of the zircons (Catanzaro, 1968).

110125. *Quartz-dioritic gneiss.* The zircon ages of this rock show an abnormal pattern which is very uncommon for zircons, i. e.
$Pb^{206}/U^{238} > Pb^{207}/U^{235} > Pb^{207}/Pb^{206} \geqslant$ true age. It is often explained by loss of uranium. If the Pb^{207}/Pb^{206} age represented the last crystallisation event of high intensity in the gneiss, then the dates would be in clear contradiction to the field evidence which shows the gneiss to be earlier than the granodiorite. It is not possible to provide a reasonable explanation for this discrepancy and therefore the results have to be considered with some reservation.

110127. *Diorite.* These dates are concordant and it seems that the crystallisation of the zircons occurred roughly contemporaneously with that of the granodiorite (110122). Persoz (1969) has suggested that this rock is a product of granitisation of basic volcanics which still occupy a large area enclosed by the Isortoq granite. The concordant pattern of this diorite suggests that whatever the interpretation of the origin of the rock the basis material is not markedly older than the main episode of Ketilidian plutonism. An Archaean age of the basic rocks would probably have resulted in a clearly discordant pattern.

110126. *Syenite.* From the normally, relatively slightly discordant pattern the zircons of this rock may be considered as *c.* 2200 m. y. old. The discordancy might be explained as partial loss of radiogenic lead during Ketilidian plutonism between 1700 and 1900 m. y. This would be consistent with Persoz's (1969) interpretation that this rock originated by granitisation of earlier basic volcanics. However, the fact that basic volcanics are always very poor in zircon suggests that the syenite is either a recrystallisation or melting product of trachytic lavas, or an intrusion at least 2200 m. y. old emplaced before the Ketilidian main plutonic episode.

It is striking how each of the investigated rock types shows its own type of age pattern. The granodiorite is discordant, but with a normal pattern; the granitic gneiss is abnormally discordant; the syenite shows high ages; the diorite is completely concordant. Therefore it is difficult to believe that all the rocks from the Isortoq area have been closed systems throughout their evolution. As long as the nature of the redistribution processes of the elements and isotopes are not fully understood and consequently the meaning of each date is not completely clear only preliminary conclusions can be drawn from the presented results.

CONCLUSIONS

In view of the uncertainty of the isotopic ratios the dates of the Isortoq granodiorite (110122) and the diorite (110127), roughly 1800 m. y., can be considered as contemporaneous. These might represent a rough minimum age for the late Ketililidian major thermal events of granite emplacement and are clearly higher than the K/Ar ages of the pre-Gardar rocks of the area.

The date of 110125 is a surprise. It might either mark the emplacement of a syenite intrusion, or extrusion of trachyte lavas at an early stage of the Ketilidian period.

The concordant age pattern shown by the zircons of the diorite might suggest that the basic masses mapped by Persoz (1969) within the Isortoq granodiorite and the two other granodiorite bodies are relics of basic to intermediate rocks of Ketilidian age and not older.

Systematic work on zircons and with the Rb/Sr whole rock method is needed to get more precise dates of the successive major events in the Ketilidian and pre-Ketilidian crust of South Greenland.

REFERENCES

Allaart, J. H., Bridgwater, D. & Henriksen, N. 1969: The pre-Quaternary geology of South-West Greenland and its bearing on problems of correlation in the North Atlantic. *Mem. Am. Ass. Petrol. Geol.* **12,** 859–882.

Banks, P. O. & Cain, J. A. 1969: Zircon ages of Precambrian granitic rocks, north-eastern Wisconsin. *J. Geol.* **77,** 208–220.

Buchs, A. 1962: Dosage de l'uranium, du thorium et du plomb dans les zircons par la fluorescence des rayons X. *Helv. chim. Acta* **45,** 741–748.

Buchs, A., Chessex, R., Delaloye, M., Landry, J. C., Bertrand, J. & Vuagnat, M. 1971: U-Pb and Th-Pb age determinations on zircons. Some comments about a direct ionization method with application to the dating of two zircon samples. *Bull. suisse Minér. Pétrogr.* **51.**

Buttet, P. 1962: Géologie de la région de Qagdlumiut, Agdluitsoq fjord. Internal GGU report, 15 pp.

Buttet, P. 1963: Géologie de la région de Qagdlumiut, Agdluitsoq fjord. Internal GGU report, 12 pp.

Catanzaro, E. J. 1968: The interpretation of zircon ages. *In* Hamilton, E. I. & Farquhar, R. M. (edit.) *Radiometric dating for geologists.* London, New York: Interscience Publ. 225–258.

Catanzaro, E. J. & Kulp, J. L. 1964: Discordant zircons from the Little Belt (Montana), Beartooth (Montana) and Santa Catalina (Arizona) Mountains. *Geochim. cosmochim. Acta* **28,** 87–124.

Higgins, A. K. & Bondesen, E. 1966: Supracrustals of pre-Ketilidian age (the Tartoq Group) and their relationships with Ketilidian supracrustals in the Ivigtut region, South-West Greenland. *Rapp. Grønlands geol. Unders.* **8,** 21 pp.

Kouvo, O. & Tilton, G. R. 1966: Mineral ages from the Finnish Precambrian. *J. Geol.* **74,** 421–442.

Persoz, F. 1969: Evolution plutonique et structurale de la presqu'île d'Akuliaruseq, Groenland méridional. *Bull. Grønlands geol. Unders.* **72** *(also Meddr Grønland* **175,** 3) 202 pp.

Grønlands Geologiske Undersøgelse 1966: Report of activities, 1966: *Rapp. Grønlands geol. Unders.* **11.**

Grønlands Geologiske Undersøgelse 1968. Report of activities 1967. *Rapp. Grønlands geol. Unders.* **15.**

Grønlands Geologiske Undersøgelse 1969: Report of activities, 1968. *Rapp. Grønlands geol. Unders.* **19.**

Grønlands Geologiske Undersøgelse 1970: Report of activities 1969. *Rapp. Grønlands geol. Unders.* **28.**