I.

ABSOLUTE AGE DETERMINATION IN SOUTH-WEST GREENLAND

THE JULIANEHAAB GRANITE, THE ILÍMAUSSAQ BATHOLITH AND THE KÛNGNÂT SYENITE COMPLEX

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CONTENTS

Abstract.

Rubidium-strontium age measurements for the Julianehaab Granite and for the Ilímaussaq Batholith give values of 1590 ± 70 m.y. and 1086 ± 19 m.y. respectively (using a value of 5.0 × 10^{10}y. for the half-life of rubidium). These represent the maximum and minimum values for the age of the Gardar Formation, which is thus Precambrian. The results furthermore show that the Ketilidian Basement rocks (pre-Julianehaab Granite) of South-West Greenland are themselves Precambrian.

A rubidium-strontium determination from the Kûngnât Syenite Complex also gives a Precambrian age (1240 ± 150) indicating possible contemporaneity with the Ilímaussaq Batholith.

Two potassium-argon age measurements are reported and are found to be in broad agreement with the rubidium-strontium data.

Introduction.

In the summer of 1957, one of the authors (S.M.) visited South-West Greenland under the auspices of GRØNLANDS GEOLOGISKE UNDERSØGELSE, (G.G.U.), in order to collect material for absolute geological age determinations. This paper describes the results of rubidium-strontium measurements on these and related samples carried out at the Atomic Energy Research Establishment, Harwell, prior to establishing the technique at Oxford. Some preliminary results obtained by the potassium-argon method are also presented which are in broad agreement with the rubidium-strontium figures. Further measurements by both techniques are in progress at Oxford on these, and other rocks from South-West Greenland localities and the results will appear in subsequent publications.

The results of rubidium-strontium measurements on five samples are described in this paper. Three of the samples are pegmatitic polylithionite (lithium mica) from different localities within the Ilímaussaq batholith near Narssaq. The two remaining specimens are biotite from a) the Julianehaab Granite, Julianehaab and b) the Kûngnât Syenite Complex, near Ivigtut. The areas mentioned are shown in figure 1.

Two potassium-argon ages are reported. One of these is for biotite separated from the Julianehaab Granite, the other for a pegmatitic polylithionite specimen from Ilímaussaq.

The ages of the Julianehaab Granite and of the Ilímaussaq batholith define, respectively, a maximum and minimum age for the Gardar formation, which is found to be Precambrian.

The biotite from Kûngnât also indicates a Precambrian age and, subject to the error of the measurement, possible contemporaneity with the Ilímaussaq batholith. The actual age is in serious disagreement with an earlier zircon lead-alpha age (Moorbath, Taylor and Upton, 1). Possible reasons for the disagreement are indicated later.

Experimental Methods.

Rubidium-strontium age-determinations were made by the isotope dilution method using a 6-inch radius of curvature, 60° sector, mass-spectrometer; the techniques have been described in detail elsewhere (Smales and Webster, 2; Loveridge, Webster, Morgan, Thomas and Smales, 3; Webster, Morgan and Smales, 4). For each sample, rubidium and strontium determinations were made on separate portions of the mineral.

The argon measurements were carried out in a total-volume apparatus, the volume of argon being measured in a calibrated McLeod gauge, (Thomson and Mayne, 5). The mineral samples were melted, without flux, by high-frequency induction heating. The correction for atmospheric argon contamination in the extracted gas samples was made by standard mass-spectrometric techniques at the Department of Geodesy and Geophysics, Cambridge University. Potassium analyses were carried out by a flame-photometric procedure on quadruplicate samples of finely-ground material.

Source and Description of Samples.

1) Julianehaab Granite. G.G.U. no. 39823. Collected by H. Sørensen M. Sc. at Julianehaab Quarries, Julianehaab Settlement. Coarse-grained rock with felspar, quartz, hornblende and biotite. Very "igneous" in appearance—no directional gneissic texture apparent. The mica was fresh and unaltered in thin section. It was separated electromagnetically from the crushed and sieved rock.

2) Polylithionite Mica, Ilímaussaq. G.G.U. no. 31708. From large, pegmatitic naujaite boulder on scree-slopes below Ilímaussaq Glacier. Altitude, 680 metres. All polylithionites were large, fresh hand-specimens

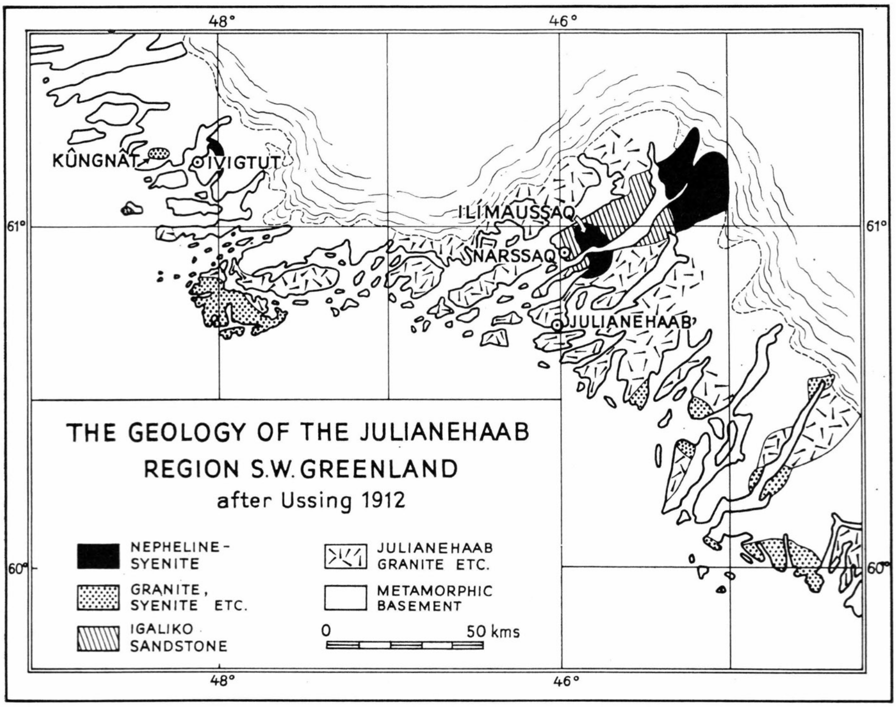

Fig. 1. Sketch map of the S.W. Greenland coastline.

of light green colour, which required no separation and were directly ground to the required mesh size.

3) Polylithionite Mica, Ilímaussaq. G.G.U. no. 31721. From pegmatite in Naujaite. About 1 km. due south of 1957 base-camp, in the Northwestern part of the area. Altitude, 520 metres.

4) Polylithionite Mica, Ilímaussaq. G.G.U. no. 31734. Collected by E. Hamilton from Kringlerne in the southern part of the area.

5) Lepidomelane Mica, in coarse-grained mafic rock, Kûngnât, nr. Ivigtut G.G.U. no. 26197. Collected by Dr. B. G. J. Upton. The Mica was separated electromagnetically from the crushed and sieved rock.

Results.

The rubidium-strontium results are presented in Table 1. The total rubidium content of the mineral is given in column 2. Column 3 gives the radiogenic strontium content in parts per million and column 4 shows the percentage of total strontium which is radiogenic. Column 5 gives the age of the mineral using a half-life value of 5.0×10^{10}y, for rubidium—87. This is the standard value used by many workers during the last few years, (ALDRICH, WETHERILL, TILTON and DAVIS, 6), and was obtained by comparison of rubidium-strontium ages with potassium-argon ages for micas and concordant uranium-lead ages on coexisting uranium minerals. Since this paper was submitted, FLYNN and GLENDENIN (1959, Phys. Phys. Rev. V. 116, pp. 744—748) have published a value of 4.7×10^{10} y. for the half-life of rubidium-87. The use of this value would lower the rubidium-strontium ages presented in this paper by 6 %.

The error quoted with each age is twice the overall standard error calculated from the standard errors (or standard deviations if only two observations were made) for the calibration of the rubidium and strontium tracers, and for the rubidium and radiogenic strontium determinations.

The potassium-argon data are given in table 2. No errors are given for these ages, since only one argon analysis was carried out on each specimen. However, it is unlikely that the error exceeds $\pm$ 100 m.y. The potassium-argon age for the Julianehaab biotite agrees closely with the rubidium-strontium age for the same sample, whilst the two ages for the Ilímaussaq polylithionite differ by 8 % which is, nevertheless, considered to be within the experimental error of the potassium-argon analysis. Each potassium value is the mean of four analyses on separate mineral samples. The potassium-40 beta-decay constant used for calculating the ages is 0.476×10^{-9} year $^{-1}$ with a branching ratio of 0.123 (CARR and KULP, 7).

Discussion.

The Basement Complex in the Julianehaab—Narssaq region of South-West Greenland consists of the Julianehaab Granite, an extensive series of granitic rocks which extends as far north as the area to the south of Ivigtut. The nature and probable origin of these rocks, as well as their field relationships, have been discussed in detail by WEGMANN (8) in his classic study of the Geology of Southern Greenland.

The overlying, supracrustal, Gardar Formation rests unconformably on a deeply eroded peneplain of Julianehaab Granites. The basal member is the Igaliko Sandstone which is now found only in the Narssaq—Igaliko area, where it was preserved from later erosion by downfaulting of the Tunugdliarfik trough. Overlying the sandstones and quartzites is a thick series of lavas which are well exposed around Narssaq. Clearly, the age of the Julianehaab Granite defines the maximum age of the Gardar Formation. Although it is impossible to place too much reliance on absolute age-measurements on a single specimen from such a vast and complex formation, it is nevertheless assumed that the value

Table 1. Rubidium-Strontium Results.

1	2	3	4	5
Sample Locality and Specimen No.	Total Rubidium Content	Radiogenic Strontium Content	Radiogenic Percentage of of Total Strontium	Age in M.Y. (for Rb-87 Half-life $= 5.0 \times 10^{10}$ years)
Julianehaab Granite Biotite, Julianehaab, G.G.U. 39823	596, 583, 599 ppm. Mean 593 ppm.	3.76, 3.85, 3.61 ppm. Mean 3.74 ppm.	8 %	1590 ± 70 m.y.
Polylithionite, Ilímaussaq G.G.U. 31708	6640, 6710 ppm. Mean 6675 ppm.	28.96, 28.85 ppm. Mean 28.91 ppm.	97 %	1095 ± 24 m.y.
Polylithionite, Ilímaussaq G.G.U. 31721	9970, 10,080 ppm. Mean 10,025 ppm.	42.78, 42.66 ppm. Mean 42.72 ppm.	96 %	1077 ± 24 m.y.
Polylithionite, Ilímaussaq G.G.U. 31734	1980, 1980 ppm. Mean 1980 ppm.	8.54, 8.48 ppm. Mean 8.51 ppm.	92 %	1086 ± 20 m.y.
Kûngnât Biotite G.G.U. 26197	229, 206, 197 190, 202, 207 ppm. Mean 205 ppm.	0.97, 1.05 ppm. Mean 1.01 ppm.	11 %	1240 ± 150 m.y.

quoted in Tables 1 and 2 represent a good approximation to the true age of the Julianehaab Granite, at least in the area under discussion. The agreement between the rubidium-strontium age and the potassium-argon age furthermore indicates that the former is not a "relict" age from an older geological formation. The contacts of the Julianehaab Granite with the older Ketilidian formations (see below) are of two kinds a) intrusive contacts where the granite has intruded unconformably as a more or less molten mass, and b) all transitions from metamorphic formations to the granite, where preexisting rock has been converted into granitic rocks. In rocks of the mixed type, relict rubidium-strontium ages may occur. Much detailed age-work would, of course, be necessary to define clearly the relationship within the Julianehaab Granite itself and to the older Ketilidian formations.

According to Wegmann (8) the first great intrusive phase of the Gardar Cycle in the Narssaq Area is represented by the emplacement of the Essexite-series, a series of plutonic rocks which include Essexite-gabbro, Nordmarkite, Arfvedsonite—Granite, etc. These, in turn, are succeeded by large, plutonic Syenite massifs of alkaline type, of which the Ilímaussaq batholith is the best known example. The detailed geology and theories of origin of this unusual batholith have been described by Ussing (9), Wegmann (8) and Sørensen (10). It has been

Table 2. Potassium-Argon Results.

1	2	3	4	5
Sample Locality and Specimen No.	Percentage K_2O	Volume of radiogenic Argon in ccs. at N.T.P.	Percent atmospheric argon contamination	Age in M.Y. ($\lambda_\beta = 0.476 \times 10^{-9} y^{-1}$ R = 0.123)
Julianehaab Granite Biotite, Julianehaab G.G.U. 39823	5.94, 6.05, 5.91, 6.18 Mean 6.02 %	2.05×10^{-3} ccs.	4.5 %	1597 m.y.
Polylithionite, Ilímaussaq G.G.U. 31708	9.56, 9.56, 9.58, 9.84 Mean 9.64 %	1.68×10^{-3} ccs.	4.2 %	1180 m.y.

clearly demonstrated by these authors that the intrusion of the Ilímaussaq complex occurred at the end of the Gardar Cycle. It follows, therefore, that the age of the Illímaussaq intrusion defines a minimum age for the Gardar Formation.

The three ages determined on Polylithionite, which are presented in table 1, are seen to be in extremely close agreement, giving an average value of 1086 ± 19 million years. The exceptional reliability of this age can be attributed to the following factors: a) large, fresh and completely unaltered, pegmatitic specimens of polylithionite, b) high rubidium content of polylithionite—in this respect the samples are exceptionally favourable, c) close agreement between specimens from three widely separated localities within the Ilímaussaq batholith, amongst which the rubidium content varies by a factor of 5.

The potassium-argon age from Ilímaussaq was obtained from one of the above samples of polylithionite and, subject to the limitations described in an earlier section, indicates broad agreement with the rubidium-strontium ages.

From the combined data presented above, it is clear that the Gardar formation is of Precambrian age and that the sedimentary and volcanic series accumulated in an interval between approximately sixteen hundred million and eleven hundred million years ago. Wegmann's cogent geological arguments (8) for a Precambrian age of the Gardar Formation are thus confirmed. The view held by a number of authors (including Ussing, Suess, Backlund, Bøggild) that the Igaliko Sandstone is Devonian and thus to be considered as formed within a late-Caledonian internal molasse basin cannot be maintained, nor the supposition that the Caledonides of East Greenland continue across the Julianehaab district, (Koch, 11). Furthermore, Wegmann (8) has already pointed out that the facies of the Ketilidian and of the Caledonides of East Greenland differ considerably and suggested that the Ketilides should be referred to one of the Precambrian orogenic cycles. This is, of course, supported by the data presented in this paper, since the Ketilidian Cycle is older than the Julianehaab Granite and represents the oldest known basement rocks in South-West Greenland.

The Precambrian age of the Gardar Formation indicates that the suggestion (quoted by WEGMANN, 8) of possible correlation with the Hoglandian—Jotnian Cycle of Fennoscandia and Keweenawan Formation on the North American Continent must be considered. Very few absolute age-determinations are available from these areas. POLKANOV (12) has determined potassium-argon ages of Micas from granites in the Jotnian—Hoglandian formation, which are given as 1500 million years. In Finland and Sweden the sediments of these formations are interbedded with a series of acid and basic rocks and are said to bear great resemblance to the Greenland rocks. Concerning the Keweenawan series of Red Sandstones and Volcanics, WILSON in his discussion on the Precambrian Classification of formations in the Canadian Shield (13) states; "A structural unconformity separates the Keweenawan rocks from Upper Cambrian sandstones, but this interval of erosion and deformation is probably not great enough (GROUT, etc., 14) for the Keweenawan Series to be more than 1600 million years old, as suggested by age-determinations of pitchblende in rocks mapped as Athabasca Group at Goldfields, Saskatchewan."

There are not nearly enough absolute age-determinations at the present time to draw any detailed or positive correlations between North America, Greenland and Fennoscandia, but as more data become available such correlation will permit the elucidation of some major geological problems.

Finally, the age of the Biotite Sample from the Kûngnât Syenite Complex, near Ivigtut, (table 1) shows that this intrusion, too, is Precambrian. The age value has a rather larger experimental error than the other samples, due to the smaller rubidium and radiogenic strontium content of the sample. Subject to this error, the age is in broad agreement with that of the Ilímaussaq batholith. There was not sufficient biotite sample for a potassium-argon analysis.

The plutonic rocks of Kûngnât were intruded into a series of ancient, highly-folded and regionally metamorphosed rocks which are regarded as having once been a sedimentary sequence. The folding and metamorphism are attributed to the Ketilidian orogeny which affected a large part of the South Greenland basement in Precambrian times. Sandstones and lavas of the Gardar Formation, of post-Ketilidian age, were probably deposited over the whole region, although, as mentioned previously, they are now confined to the down-faulted zone of the area around Narssaq, about 100 kms. to the E.S.E. (see figure 1).

The geology of the Kûngnât Complex has been described in detail by UPTON (15), whilst the chronology of the Ivigtut area, deduced from field-evidence, is discussed in a preliminary report by BERTHELSEN (16). These, and other workers refer the intrusion of the Kûngnât Complex to late Gardar times on general geological grounds, and suggest probable contemporaneity with the rocks of Ilímaussaq.

The above Rubidium—Strontium age for the Kûngnât biotite is in profound disagreement with the lead-alpha age of zircon from the same Complex, reported in a previous communication, (MOORBATH, TAYLOR and UPTON, 1). The lead-alpha age (ca. 500 million years) was interpreted as indicating a Cambrian age for the Kûngnât Complex. Dr. B. G. J. UPTON, who collected both the zircon and biotite specimens, has kindly contributed the following note regarding their field relationships:

"The intrusive Complex of Kûngnât consists of three intersecting Syenite stocks which are virtually surrounded by a later ring-dyke of Olivine-gabbro and Olivine-diorite. The intrusions are believed to have succeeded one another in fairly rapid succession so that the late residual liquids from the earlier Syenites were still available for injection after consolidation of the ring-dyke."

"The previous age-determination (MOORBATH, TAYLOR and UPTON, 1) was made on zircons from such a late-stage pegmatitic vein within the Syenites."

"The lepidomelane used for the present rubidium-strontium dating was taken from a mafic rock (G.G.U. no. 26197) exposed on the south side of Kûngnât Fjeld. Although exceptional in being somewhat foliated, there can be no doubt that the rock is a mica rich marginal facies of the main ring-dyke."

"It is unlikely that there is any substantial age difference between the zircon and the biotite."

It must be assumed, therefore, that the observed discrepancy in ages is probably due to the uncertainties inherent in the lead-alpha method. This method yields an age from measurements of the total lead content of a mineral (spectrographic) and its alpha-activity, using the latter as a measure of the combined uranium and thorium content and assuming a uranium-thorium ratio typical of the mineral. Furthermore, the radioactive decay series must be assumed to be in radioactive equilibrium and all the lead contained in the mineral must be radiogenic. In a recent publication, TILTON and co-workers (17) describe a detailed investigation of isotopic ages of zircon from granites and pegmatites and present a comparison with non-isotopic ages, including lead-alpha ages. They conclude that of the non-isotopic ages, one-third to one-half are lower than the probable true age (obtained from coexisting minerals by the rubidium-strontium and potassium-argon methods) by more than ten per cent and that errors of as much as a factor of two can occur. It is clear, therefore, that complete reliance on any single non-isotopic zircon age is unjustified and can lead to serious error. It is only if a body such as a large batholith is sampled extensively and found to give zircon lead-alpha ages which agree throughout that it is probable that this result represents the true age. Tilton and co-workers do not give any valid diagnostic criteria for choosing zircons likely to give reliable lead-alpha ages.

Further rubidium-strontium and potassium-argon work is in progress at Oxford on biotites and feldspars from other areas in South-West Greenland including Ivigtut, Tigssaluk, Nunarssuit etc. A number of lead-isotope measurements on galenas are also being carried out.

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