Isotopic re-equilibration of Rb-Sr whole rock systems during reworking of Archaean gneisses in the Nagssugtoqidian mobile belt, East Greenland

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Abstract

Samples from small vertical shear zones cutting retrogressed granulites near the northern margin of the Nagssugtoqidian mobile belt give an Rb-Sr whole rock age of 2660 ± 180 m.y. (I.R. 0.7016) indistinguishable from that of their country rocks in spite of massive alkali metasomatism along the shears. Regional samples of garnet gneisses formed during partial remelting of Archaean quartzo-feldspathic gneisses and pelites during Proterozoic contact metamorphism yielded points which scatter about a 1950 m.y. reference isochron (I.R. 0.7054). The scatter shows that re-equilibration has not occurred on a scale of kilometres when the gneisses were partially remelted. Samples from a single 10 × 20 m outcrop of highly deformed tonalitic gneiss with basic inclusions near the centre of the mobile belt yielded points which scatter about a 1875 m.y. reference isochron (I.R. 0.7039). Samples less than 500 g in weight yield points close to the reference isochron, while those from samples over 1000 g lie above the 1875 m.y. isochron suggesting re-equilibration has been on a scale of 5–10 cm. Samples from a post-tectonic pluton emplaced near the centre of the mobile belt give a whole-rock age of 1583 ± 27 m.y. (I.R. 0.7035). Regional low Rb-Sr ratios in the country gneisses do not permit use of the initial ratio to distinguish mantle from a lower crust source.

Introduction

In this paper we present the details of Rb-Sr whole rock studies from the Nagssugtoqidian mobile belt in East Greenland. The geological framework together with the ages obtained from the isotopic work described here have already been published (Bridgwater *et al.*, 1978; Bridgwater & Myers, this report), here we concentrate on a discussion of the processes which affect Rb-Sr systematics in a poly-metamorphic terrain.

One of the main problems confronting the geologist when interpreting isotopic data from high-grade gneisses is knowledge of the degree of re-equilibration which occurs to isotopic systems when rocks of one age are affected by deformation, recrystallisation, partial melting, and possible migration of some components during later geological events. There is a general tendency to treat Rb-Sr whole rock isochrons and U-Pb zircon concordia intercepts as giving ages close to original igneous events unless proved otherwise, even although the rocks from which samples have been collected may have little in common either physically or in some cases chemically with the supposed magmatic parents.

Parallel studies on the geochemistry of the samples used in this study have shown that Rb, Pb and U are all mobile elements during regional metamorphism. All three are found in lower concentrations in granulite facies gneisses than in their supposed amphibolite facies parents. All three increase to a variable extent during shearing and retrogression of the granulite facies rocks. In areas of high-grade gneisses in which there has been considerable movement of some elements straightforward interpretations of isotopic data may be misleading. Addition of Rb to a Rb-poor whole rock system 500–1000 m.y. after the formation of Archaean gneisses may mask the Sr initial ratio evidence of an extended crustal history (Bridgwater & Collerson, 1976, 1977). Loss of Pb from zircons during a second metamorphic event can destroy evidence of an early history still retained in the Rb-Sr systems (Baadsgaard *et al.,* 1979). The loss of Pb during granulite facies events and the addition of Pb during later retrogression can mean that the isotopic composition of the whole rock Pb studied does not represent the isotopic composition of the whole rock Pb of the original parents to the gneisses. U introduced 500 to 1000 m.y. after the original formation of a gneiss suite will produce a higher proportion of ^{206}Pb compared to ^{207}Pb than produced by the original U present in the rocks. If the rocks have an early history of depletion in both U and Pb (for example granulite facies gneisses) and a later history of U and possible Pb addition during retrogression then the isotopic early history of the rocks can be lost.

In the present study we examine changes in the Rb-Sr system of gneisses from three sets of samples representing different degrees of tectonic and metamorphic reworking of Archaean gneisses, and one set of samples from a young pluton which could represent remelted earlier crust. Further Rb-Sr, Pb-Pb whole rock and U-Pb zircon determinations are underway.

Geological setting

The Nagssugtoqidian mobile belt is an area of Archaean tonalitic and granodiorite gneiss with subordinate meta-sedimentary and basic meta-igneous rocks which has been affected by a series of tectonic and metamorphic events in the period from the end of regional Archaean metamorphism about 2800 m.y. ago through to about 1500 m.y. ago. Tectonic and metamorphic activity in the area correspond at least in part to the Hudsonian 'orogeny' of Baffin Island and western Labrador and to the post-Scourian events of the Lewisian gneiss complex of Scotland.

In East Greenland the Nagssugtoqidian (Bridgwater, 1976; Bridgwater *et al.,* 1977, 1978; Bridgwater & Myers, this volume) is restricted to a 240 km wide belt of metamorphic rocks flanked on either side by Archaean gneisses virtually unaffected by younger events (fig. 1). The belt was established at the end of the Archaean by the formation of vertical shear zones accompanied by the intrusion of basic dykes. Intrusion of syntectonic calc-alkaline plutons occurred at about 2350 m.y. in the central zone of the mobile belt (Pb-Pb whole rock age, Taylor *in* Bridgwater *et al.,* 1978) followed by intrusion of numerous basic dykes. A second major phase of tectonic activity dominated by thrusting from the north occurred about 1800–1900 m.y. ago and was accompanied by the emplacement of basic to intermediate igneous complexes under granulite facies conditions in the central part of the mobile belt. Uplift and the intrusion of post-tectonic granites occurred between 1500 and 1600 m.y. ago.

The timing of individual tectonic and metamorphic events within the mobile belt can only be obtained with certainty by dating igneous events associated with different phases of

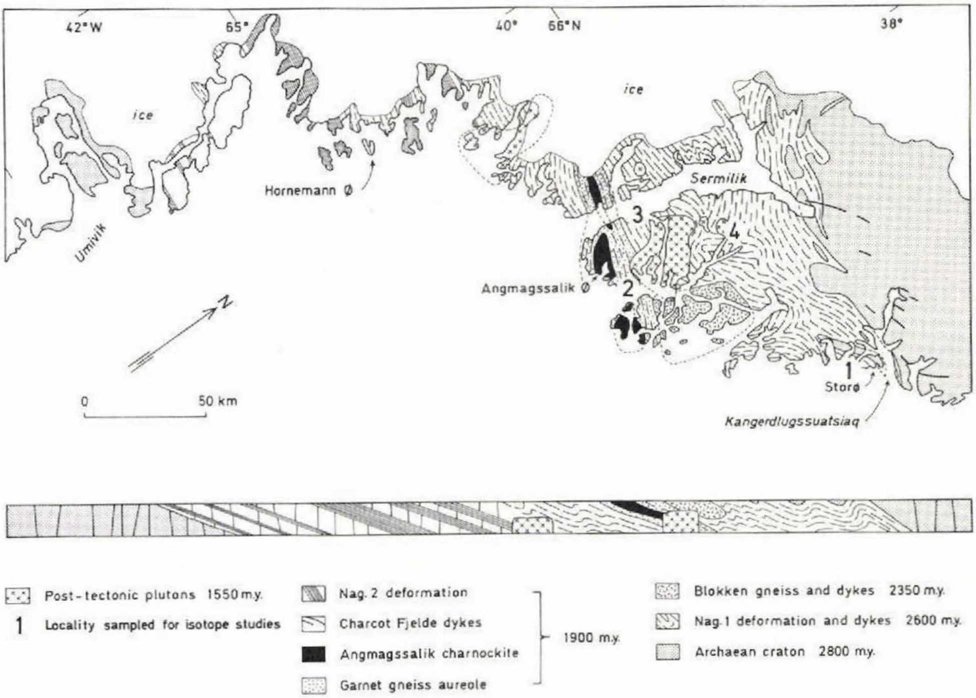

Fig. 1. Sketch map of the Nagssugtoqidian mobile belt, East Greenland, to show localities sampled.

deformation since, as will become apparent, the resetting of isotopic systems during metamorphism has been far from perfect (see also work on the west coast, Kalsbeek & Zeck, 1978; Hickman, this volume). In spite of this uncertainty there is now enough evidence both from Greenland and Scotland to allow us to assume that the two most important deformation episodes within the mobile belt occurred 2700 ± 100 m.y. and 1850 ± 150 m.y. ago. These ages correspond to the nearest fit isochrons (York, 1966) through the scatter of points we obtain for the gneiss suites described in this paper. We use these constructed lines as reference isochrons as a base to study the behaviour of individual samples. We have purposely not quoted errors for two of the 'isochrons' of the suites since we were specifically investigating the imperfections of the Rb-Sr system rather than trying to produce 'ages'.

Rb-Sr determinations on rocks from a metasomatised early Nagssugtoqidian shear zone

The earliest structures recognised as an integral part of the Nagssugtoqidian mobile belt are a series of vertical shear zones with a sub-horizontal stretching fabric. In the Nagssugtoqidian of East Greenland the majority of these vertical shears trend E–W and are interpreted as developed during transcurrent movements. Similar structures are found in confined belts within the Archaean cratons to the north and south, the distinction between craton and mobile belt being the marked concentration of movement zones in the latter. Within the mobile belt the E–W shear zones are irregularly distributed, the majority are concentrated in distinct zones a kilometre or so wide separated by islands of less deformed gneisses which preserve Archaean structures. The E–W shear zones controlled the injection of major swarms of basic dykes within the Nagssugtoqidian mobile belt. Many of the dykes are syntectonic (Bridgwater & Myers, this volume, fig. 2). Over most of the Nagssugtoqidian mobile belt in East Greenland the E–W shear belts are associated with retrogression of earlier granulite facies assemblages. Elsewhere similar structures are found in granulite facies. This is interpreted as reflecting the crustal depth now exposed in different areas. Where associated with retrogression the shear zones are seen to be surrounded by broader belts in which Archaean granulite facies rocks are bleached and show partial retrogression. The bleached areas finger into the surrounding brown weathering granulites apparently along small fractures.

The localities sampled for the study on early Nagssugtoqidian shears occur on the southern end of Storø which lies close to the northern margin of the mobile belt (fig. 1, locality 1). The northern part of the island forms part of a major granulite facies enclave consisting of Archaean granulite facies gneisses dominated by tonalites and granodiorites with layers and rafts of supracrustal rocks and early basic intrusives. The granulite facies gneisses from the border zone of the Nagssugtoqidian have given a Pb-Pb whole rock age of approximately 2750 m.y. (Taylor *in* Bridgwater *et al.*, 1978) Rb-Sr ratios average less than 0.01 which is too low to obtain a reliable Rb-Sr age.

Locality 1A

Three kilometres from the southern tip of Storø the gneisses contain a 100 m wide layer of granulite facies basic supracrustal material veined by numerous pegmatitic sheets regarded as late K-rich phases of the surrounding tonalitic and granodioritic gneisses. The sheets contain amphibolite facies assemblages and show considerable range in Rb contents and Rb-Sr ratios (Table 1, locality 1A). There is no local evidence of strong deformation and retrogression and the amphibolite assemblage is regarded as primary, biotite crystallising rather than orthopyroxene because of the K-rich character of the rock (see Korstgård, 1979). Away from the contacts with the supracrustal unit the gneisses are less K-rich and contain granulite facies assemblages.

Locality 1B

The gneisses two kilometres south of locality 1A are medium to coarse-grained tonalites with moderate to low potassium. They are cut by occasional trondhjemitic veins which may represent local melts from the tonalites when these were subjected to regional high-grade conditions. The tonalites contain quartz, andesine with antiperthitic rectangular blebs of K-feldspar, Fe-Ti oxides with exolved ilmenite lamellae, colourless amphibole, hornblende, reddish-brown biotite and garnet. The mafic minerals are found in distinct clusters giving the rocks a characteristic 'blebby' appearence which has been regarded as typical of partially retrogressed granulite facies gneiss (Bridgwater *et al.*, 1974, 1977).

The massive gneisses at 1B are cut by three small zones trending 130/°V. These shears show central zones 10–20 cm wide in which the rock develops a new fabric. There is some irregular layering of light and dark material parallel to the margins of the central zone. Within a metre of the shear zone centres the regional mineral fabric in the country rock is intensified and rotated parallel to the central zone. The original rather homogeneous country rock becomes distinctly banded. The formation of the shears was accompanied by complete recrystallisation of the gneisses which extends for at least two metres away from the centre of the shear zones and at least one metre from the first signs in the field of rotational effects on the pre-existing fabric.

Table 1. Rb-Sr values and isotopic ratios from sheared tonalitic and granitic gneisses from the northern margin of the Nagssugtoqidian mobile belt, southern Storø

GGU No.	Rb(ppm)	Sr(ppm)	Rb/Sr	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$
Locality 1A, country rocks, K-rich granite sheets cutting granulite facies supracrustal rocks					
226801*	6	111	0.0526	0.152±15	0.7091±2
226802*	5	142	0.0307	0.089±11	0.7066±2
226804	15	837	0.0142	0.041±2	0.7035±2
226805	48	372	0.1387	0.402±4	0.7173±2
226806	93	483	0.2064	0.598±4	0.7242±2
226807	26	423	0.0667	0.193±3	0.7097±2
226808	59	468	0.1371	0.397±4	0.7171±2
226809	66	398	0.1732	0.502±5	0.7210±2
226810	85	480	0.1938	0.562±4	0.7230±2
Locality 1B, country rocks, tonalites and granodiorites, retrogressed from granulite assemblages					
226836	9	670	0.0140	0.041±2	0.7030±2
226837	24	658	0.0354	0.102±2	0.7054±2
226838	15	679	0.0224	0.065±2	0.7041±2
226839	9	658	0.0121	0.035±2	0.7029±2
Age, country rocks (loc.1 A & B) 2630±65 m.y., I.R. 0.7018±3					
Locality 1B, shear zones and country rocks within 1 m of shear centres					
226832	32	669	0.0474	0.137±2	0.7068±2
226840	33	674	0.0499	0.145±2	0.7068±2
226842	28	708	0.0390	0.1129±10	0.7061±2
226846	60	690	0.0899	0.260±2	0.7120±2
226848	64	583	0.1118	0.324±2	0.7141±2
226849A	61	551	0.1136	0.329±3	0.7140±2
226852	38	644	0.0603	0.175±2	0.7085±2
Age, sheared rocks (loc.1B) 2660±180 m.y., I.R. 0.7016±6					
Age, all samples (loc.1 A & B) 2635±55 m.y., I.R. 0.7017±2					

Rb/Sr ratios given are measured direct and need not correspond exactly to Rb/Sr ratios calculated from separate analyses.

* not used in the regression analysis, granulite facies supracrustals.

The recrystallised rocks contain K-feldspar as an independent phase, hydrated ferric oxides, oligoclase, scapolite, muscovite, biotite (grey-brown) garnet and amphibole. The mineralogical changes are related to changes in bulk chemistry with a marked but sporadic increase in K, Rb, Cl and Pb. Rb increases to an average of 40 ppm (locally as high as 70 ppm) which compares to the average of circa 5 ppm in the Archaean tonalitic granulites and 15 ppm in the blebby gneisses surrounding the shear zones. As Sr remains essentially constant Rb-Sr ratios increase markedly in the recrystallised gneisses.

The isotopic results from this study (Table 1 and fig. 2) show that data points from locality 1A and from the shear zones, their immediate country rocks and the blebby gneisses at

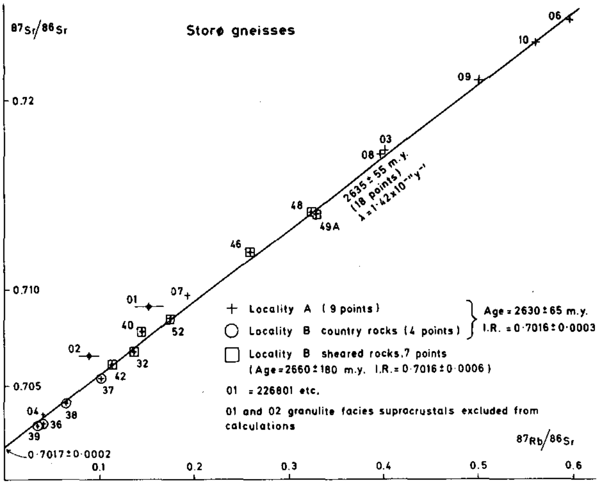

Fig. 2. Rb-Sr whole rock evolution diagram of Storø gneisses (locality 1, A & B, fig. 1).

locality 1B all lie close to an isochron of 2635 m.y. (I.R. 0.7017). The only two points lying significantly above this line are two samples of hypersthene-bearing supracrustal rocks from locality 1A which are not included in the age calculations.

There is good evidence of Rb addition to the shear zones and their immediate country rocks so that Rb-Sr ratios increase from 0.02 in the retrogressed granulites away from the shear zones at 1B to 0.07 in the sheared rocks. We suggest that this three to four fold increase in Rb is the main factor controlling the Rb-Sr system of the rocks in the shear zones and that the 2635 ± 55 m.y. age obtained must be close to that of the shearing (unless there has also been an influx of radiogenic Sr in the sheared rocks proportional to the increase in Rb shown by individual samples). As seen from fig. 2 the data points obtained from the shear zone lie on or close to the same isochron as the data points from the non sheared gneisses at B and the regional gneisses at A (individual age calculations yield 2630 ± 65 m.y. (I.R. 0.7018 ± 3) for the country rocks at A and B and 2660 ± 180 m.y. (I.R. 0.7016 ± 6) for the sheared rocks at B, see Table 1). This implies that shearing took place at or soon after the time at which the Rb-Sr system began development in all the amphibolite facies gneisses from southern Storø. Field and textural evidence suggest that the tonalitic gneisses were formed by retrogression from earlier granulites and that retrogression was intimately connected with shearing on a regional scale (Bridgwater & Myers, this volume). Direct geochemical comparison to establish regional changes between the granulite and retrograde granulite facies rocks is difficult since it cannot be proven that the retrograde rocks developed from the same suites as those which retain their granulite facies mineralogy. However, if the comparison is restricted to tonalites with similar major element chemistry a marked increase in Rb can be seen in the retrogressed rocks so that Rb-Sr ratios in the granulite facies tonalites average less than 0.01 while retrogressed tonalites from Storø average 0.02. The general agreement between the Pb-Pb whole rock age on the granulite facies rocks, the Rb-Sr age on the pegmatitic phases cutting the supracrustals at locality 1A and the results from both the retrogressed granulites and the sheared rocks suggest to us that shearing must have occurred within a maximum of 200–300 m.y. of the regional high grade metamorphism in the Archaean gneiss complex. It is hoped that U-Pb determinations on zircons will give more precise control of the timing of individual events.

Rb-Sr determinations on Archaean rocks partially remelted during Proterozoic high grade metamorphism

The central area of the Nagssugtoqidian mobile belt in East Greenland was affected by high grade metamorphism associated and following the second major phase of tectonic activity. The overthrusting from the north which characterised this tectonic phase caused considerable crustal thickening and the rocks in the central part of the mobile belt now exposed represent a deep level of the Proterozoic crust. The tectonic activity was accompanied by the injection at depth of syntectonic basic to intermediate magmas which now form sub-concordant sheets of leuco-norite and basic charnockite in the area around Angmagssalik (fig. 1). Attempts to date the intrusion of this body using Rb-Sr whole rock methods have been unsuccesful due to extremely unfavourable Rb/Sr ratios. A preliminary U-Pb zircon age of 1800 m.y. (R. Chessex, personal communication) is in agreement with the regional evidence for a major thermal event in the Nagssugtoqidian at 1850 ± 150 m.y. and is accepted as a close approximation to the age of intrusion. The norite-charnockite complex is surrounded by an aureole of garnet gneisses outcropping up to 10 km away from the exposed contacts of the igneous rocks and estimated to be 2–3 km in true thickness. Metamorphic assemblages in the garnet gneisses range from upper amphibolite to granulite facies, the main control being the chemistry of the parent rocks. On a regional scale the pre-existing stratigraphy of the Archaean gneiss complex is retained in the garnet gneisses. The basic complex was injected within a major unit of Archaean supracrustal rocks dominated by pelites with subordinate calc-silicates, quartzites and occasional layers of earlier basic intrusives including gabbroic anorthosites. The supracrustal rocks alternate with more homogeneous tonalitic gneisses. On an outcrop scale the garnet gneisses show an almost complete destruction of the pre-existing fabrics. The degree of recrystallisation increases as the contacts of the norite-charnockite sheet are approached. Original resistant layers within the supracrustals are broken up and transported in a leucocratic matrix which at least locally acts as an intrusive rock. Many outcrops appear as a complete mélange of disoriented fragments of different origin set in a more homogeneous light coloured matrix of garnet-bearing granite.

Samples were taken from four sites (221651 to 221658, Table 2) over a distance of approximately 5 km on the SE coast of Angmagssalik Ø (fig. 1, locality 2); 221651 at approximately 8 km away from the nearest outcrop of norite-charnockite, 221658 about 3 km from the exposed contact. All the rocks in this area show complete recrystallisation. Experience from other areas, for example West Greenland (see the isotopic work quoted by Bridgwater *et al.,* 1976), shows that most components in the Archaean gneiss complex, undisturbed by younger events, yield Rb-Sr ages of circa 2800 m.y. (I.R. 0.701) irrespective of whether the units are supracrustal rocks, intrusive tonalites or remnants of early basic intrusives. This is either interpreted as showing that the differentiation of mantle to form the major part of the Archaean continental crust took place at 2800 ± 200 m.y. or that there

Table 2. Rb-Sr values and isotopic ratios from garnet gneisses in the thermal aureole of a norite-charnockite complex, eastern Angmagssalik Ø

GGU No.		Distance from norite. km	Rb/Sr	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$
221651*	Migmatised semipelite	8	0.031	0.090±2	0.7068±1
221651A*	Migmatised psammite		0.157	0.453±6	0.7191±2
221651B*			0.094	0.272±4	0.7141±2
221652	Biotite-poor garnet gneisses of unknown origin		0.0085	0.025±3	0.7062±2
221652A			0.0050	0.0194±11	0.7060±2
221652B			0.0073	0.021±3	0.7058±2
221654A	Biotite garnet gneisses of unknown origin		0.114	0.330±3	0.7145±2
221658A			0.126	0.364±9	0.7153±2
221658B		3	0.209	0.606±5	0.7225±2

Reference isochron using best least squares fit: 1950 m.y.
I.R. 0.7054
* Not used in the regression analyses.

was sufficient redistribution of Rb and ^{87}Sr at that time to mask differences in age and origin. We assume in our study of the garnet gneisses that their parent rocks were isotopically homogeneous at 2800 m.y. and that any differences now seen are due to differences in Rb-Sr ratios and lack of perfect equilibration during subsequent events. The original rocks from which the garnet gneisses formed vary considerably from Archaean tonalites and anorthosites with low Rb-Sr ratios to pelitic metasediments with higher Rb contents and moderate Rb-Sr ratios. The data points from all the samples (Table 2, fig. 3) scatter about a 1950 m.y. reference line (I.R. 0.7054) supporting the suggestion that there has been a major Proterozoic event in the area at 1850 ± 150 m.y. The scatter of points about the reference line indicates that there has not been perfect homogenisation of the Sr isotopes on a scale of 5 km even although all the rocks have been close to or slightly above the melting tempera-

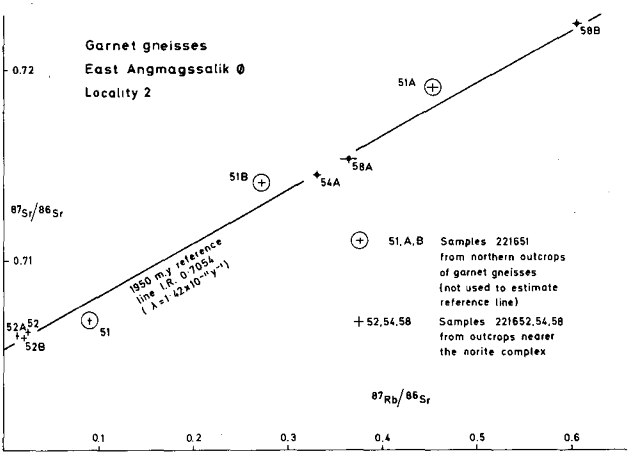

Fig. 3. Rb-Sr whole rock evolution diagram of garnet gneisses, east Angmagssalik Ø (locality 2, fig. 1).

tures of their quartzo-feldspathic components. Material from the three localities nearest the norite show less scatter about the reference isochron than samples from site 221651 which suggests the degree of homogenisation at 1950 m.y. increases as the thermal effects of the intrusive body become more pronounced. Although the scatter about the reference isochron is large we do not consider that there is a large error in the initial ratio quoted since many of the points lie close to the Sr axis (fig. 3). The average Rb/Sr ratio of the garnet gneisses studied is 0.084. Tarney *et al.* (1972) give an average of 0.065 for 56 garnet gneisses from this area. Assuming that our figure is correct the initial ratio of the source rocks at 2800 m.y. must be in the range 0.7030–0.7035. This is higher than most measured initial ratios for rocks of this age from the Archaean of Greenland except for material in the Nagssugtoqidian of West Greenland (Kalsbeek & Zeck, 1978; Hickman, this volume).

Archaean tonalitic gneisses from the central zone of the mobile belt

On the north-west coast of Angmagssalik Ø the main rock unit is strongly banded gray gneiss with inclusions of basic material elongated within the regional foliation at approximately 90°/V. The main structure predates the intrusion of regional swarms of basic dykes which are concentrated in zones in the gneisses which have developed a marked flaggy texture. The dykes and their host gneisses have been affected by later metamorphism during which the dykes recrystallised with garnet amphibolite centres and amphibolite margins. Many of the dykes are disrupted tectonically and veined by numerous pegmatites. Pelitic units from the same area contain kyanite and sillimanite oriented parallel to post-dyke fold structures. Five kilometres south of the outcrops studied the gneisses develop hypersthene possibly in response to the thermal effects of the norite-charnockite complex. The grey gneisses are regarded as Archaean rocks which received their dominant structural character during early deformation within the Nagssugtoqidian mobile belt (corresponding to the shearing on Storø 2600 m.y. ago) but later affected by amphibolite facies metamorphism and partial recrystallisation during the 1850 ± 150 m.y. period of thermal and tectonic activity in the mobile belt.

The major part of the grey gneiss is tonalitic with oligoclase, quartz, hornblende, biotite and sphene as rock forming minerals. Chlorite and epidote develop in some layers suggesting partial retrogression. Between 5 and 10 per cent of the outcrops consist of slightly coarser-grained granodioritic layers averaging 1–5 cm in width. Basic material occurs irregularly distributed through the grey gneisses as concordant layers a few centimetres to tens of centimetres in width and as pods and schlieren. On some outcrops the basic material is seen to be derived from layered basic igneous rocks ranging from ultramafic to gabbro-anorthositic in composition. The basic rocks are now hornblende rich, some contain clinopyroxene, many contain biotite. There is frequently a gradation between basic material and the surrounding tonalites over 1 to 2 cm. We interpret the gneisses as derived from Archaean tonalitic intrusions possibly with minor granodioritic components which were intruded into a layered igneous complex. These rocks were later strongly deformed under high grade conditions with the formation of granodioritic veins and some interchange between the host tonalites and the basic inclusions.

Chemically the tonalitic gneisses are similar to the retrogressed granulite facies gneisses from Storø. They contain relatively low Rb and high Sr and Ba contents which are a

Table 3. Rb-Sr values and isotopic ratios from Archaean grey gneisses partially affected by younger metamorphism, north-west Angmagssalik Ø

GGU No.	Rock type	Weight	Rb (ppm)	Sr (ppm)	Rb/Sr	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$
226879A	Layered tonalite	1.0 kg	29	681	0.0507	0.1467±16	0.7090±3
226881A	Layered tonalite	1.5 kg	12	570	0.0235	0.0680±16	0.7068±2
$226881B_I$	Layered whole rock	0.5 kg	20	251	0.0768	0.222±4	0.7102±2
226881_{II}	Dark layer	0.18 kg	21	158	0.1409	0.408±8	0.7147±2
$226881B_{III}$	Light layer	0.11 kg	12	369	0.0367	0.106±3	0.7067±2
226881D	Tonalite	1.8 kg	15	586	0.0203	0.0588±16	0.7067±2
226881G	Layered whole rock	0.5 kg	5	457	0.0099	0.0286±24	0.7049±2
$226881G_{II}$	Coarse light layer	0.13 kg	3	567	0.0046	0.0133±20	0.7047±2
$226881G_{III}$	Medium light layer	0.12 kg	9	513	0.0183	0.053±2	0.7055±2
$226881G_{IV}$	Dark layer	0.06 kg	1	248	0.0086	0.025±6	0.7050±2
226881H	Thick dark layer	0.75 kg	4	116	0.0217	0.063±13	0.7067±2
226881I	Light layer	0.85 kg	9	539	0.0171	0.0494±11	0.7053±2

Reference isochron using best least squares fit: 1875 m.y. I.R. 0.7039

characteristic feature of the Archaean grey gneisses from South-East Greenland. In our samples Rb contents range between 1 ppm and 30 ppm (average 13 ppm), Sr from 130 ppm in an ultrabasic layer to between 450 and 840 ppm in the tonalites, Rb/Sr ratios range from 0.0004 to 0.13 (average 0.036). This is in agreement with regional studies over a wider area of Archaean rocks retrograded from granulite facies in East Greenland. Tarney *et al.* (1972) report an average Rb/Sr ratio of 0.076 for 41 grey gneisses from East Greenland. Their figure includes a high proportion of samples from 2350 m.y. post-Archaean tonalites east of Angmagssalik which show no evidence of early granulite facies metamorphism.

In the grey gneisses studied for this work Rb shows no correlation with the major element chemistry of the rocks, the highest Rb content is found in an amphibolite layer with high MgO, Ni and Cr derived from an ultramafic inclusion. This irregular distribution of Rb is taken to mean that there was considerable movement of this element during the post-magmatic history of the gneisses (cf. Bridgwater & Collerson, 1977).

The samples each weighing over 5 kg were taken from one outcrop (226881 a–j) (fig. 1, locality 3) within an area of approximately 10 × 20 m. One large sample was collected from the same grey gneiss unit 1 km north along the coast (226879). Samples with marked lithological differences between constituent layers were then halved at right angles to the foliation, one half was analysed as a single 'whole-rock' the second half split parallel to the foliation planes into light and dark layers. The resulting slices varied from 2 kg to 100 g. Twelve powders were selected on the basis of their spread in Rb/Sr ratios for isotopic analysis (Table 3, fig. 4). Most of the data plots close to a 1875 m.y. reference isochron (I.R. 0.7039) suggesting that there was re-equilibration of Sr isotopes in the grey gneisses on a scale of 5–10 cm at about 1900 m.y. Samples of gneiss weighing more than 1 kg yield data points above the reference line. There is no consistent relation between the petrology of the samples and the position of the data obtained relative to the reference isochron. We therefore consider the scatter to reflect lack of Sr isotope homogenisation over distances more than 10 cm in these rocks rather than reflecting inhomogeneities in the source material at an

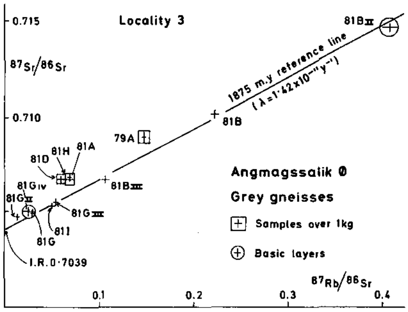

Fig. 4. Rb-Sr whole rock evolution diagram of grey gneisses, north-west Angmagssalik Ø (locality 3, fig. 1).

earlier point in their history. As with the garnet gneisses, while there is considerable scatter about the reference isochron leading to considerable uncertainty about the age of partial homogenisation of these rocks, there are sufficient well defined points close to the Sr axis of the Rb-Sr diagram for us to consider the initial ratio of 0.7039 to be reasonably precise (fig. 4). Using the initial ratio of 0.7039 and an average Rb-Sr ratio of 0.04 we calculate an initial ratio for the source rocks of 0.7024 at 2800 m.y. This like the figure obtained from the garnet gneisses is higher than initial ratios obtained from the majority of Archaean gneisses in Greenland and from the Storø shear zone. An apparent high initial ratio at 2800 m.y. could be explained by either loss of Rb or fractional removal of ^{86}Sr at 1900 m.y.

Post-tectonic intrusions in the Nagssugtoqidian mobile belt

A belt of late to post-tectonic intrusions was emplaced in the central high grade zone of the mobile belt during the final phases of thermal activity. The intrusive forms and petrology of these rocks show that they were emplaced at shallow depth and that there must therefore have been major uplift in the area following the high grade metamorphism at circa 1850 m.y. The intrusions are composite bodies with relatively small volumes of basic material enclosed in much more voluminous granodiorites and K-rich granites. Relations between acid and basic parts of the individual intrusions are complex and suggest comtemporaneous acid and basic magmas. Basic material is found as brecciated early phases, rounded inclusions with alkali-feldspars growing in place and as irregular pillowed material with chilled margins. Local hybridisation is seen. Composite dykes with acid margins and centres of basic material pillowed against the marginal granites cut the acid–basic mixtures seen in the main intrusion showing that both acid and basic magmas were available over an extended period. Both field relations and available chemical data suggests that the acid rocks are not developed by fractional crystallisation from the basic rocks seen at the present erosion level. It is reasonable to assume that the basic rocks are derived by partial melting of mantle material beneath the thickened crust in the centre of the mobile belt during a period of uplift. The origin of the acid portions of the intrusions is not known. They could represent earlier basic material emplaced at depth and partially remelted during continued thermal activity in the area or they could at least in part be derived from earlier sialic crust melted during intrusion of basic magmas at depth.

Rb-Sr studies on one intrusion from Qíngorssuak (fig. 1, locality 4; Table 4, fig. 5) give an

Table 4. Rb-Sr values and isotopic ratios from a post-tectonic intrusion Qíngorssuak, inner Angmagssalik Fjord

GGU No.	Rock type	Rb (ppm)	Sr (ppm)	Rb/Sr	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$
226862	K-rich granite	219	100	2.28	6.68 ± 3	0.8538 ± 2
226862D	Basic diorite	57	632	0.090	0.261 ± 2	0.7091 ± 2
226862E	Al_2O_3-rich basic	3	924	0.0041	0.0119 ± 15	0.7033 ± 2
226862H	Qtz monzonite	144	328	0.451	1.309 ± 6	0.7343 ± 2
226862J	K-rich granite	287	50	5.77	17.36 ± 16	1.0967 ± 5
226862K*	K-rich granite	390	28	13.90	44.1 ± 6	1.6770 ± 5
226862L	K-rich granite	297	114	2.67	7.86 ± 4	0.8820 ± 2
226862N	Qtz monzonite	87	503	0.170	0.494 ± 2	0.7151 ± 2

* not used in the regression analyses
Age: 1583±27 m.y. I.R.: 0.7035±6

age of 1584 ± 27 m.y. (I.R. 0.7035 ± 6). The rocks studied range from plagioclase-rich and mafic-rich cumulates through basalts and basic diorites to K-rich granites. There is a clear gap between the basic end of the suite with silica contents between 49 and 55% SiO_2 and the acid end of the suite with silica contents between 61 and 74% SiO_2. There is no evidence from the isotopic work that the two groups are derived from different sources. However, there is a surprising amount of scatter in the data from both most acid and most basic parts of the suite, and we cannot exclude the possibility that we are dealing with two groups with slight differences in the initial ratios of their source rocks connected by a series of hybrids. The initial ratio obtained is compatible either with mantle derivation of the whole suite at or shortly before 1584 m.y. or with a mantle derivation of the basic rocks contaminated by remelted Archaean crustal material with a low initial Sr ratio and low Rb/Sr ratio such as characterises the regional gneiss complex.

Conclusions

Our main conclusion is that while tectonic reworking accompanied by amphibolite facies metamorphism may disturb Rb-Sr isotope systems the degree of re-homogenisation is small and the isochrons produced during the younger event are poorly defined. In the absence of partial melting or massive transport of alkalis along shear planes Sr isotopic re-homogenisation in the Nagssugtoqidian is on the scale of a few centimetres across lithological boundaries. In gneisses which have been partially remelted the scale of homogenisation may be on the scale of hundreds of metres but even in these rocks the isochrons produced show considerable scatter. Where there is regional movement of alkalis either along shear zones or during retrogression we suggest the major control on the age obtained and the fit of data points to the isochron is the degree and timing of Rb addition. On Storø Rb addition was concentrated in shear zones at approximately the same time as the Rb-Sr systems began to evolve in the surrounding retrogressed country rocks.

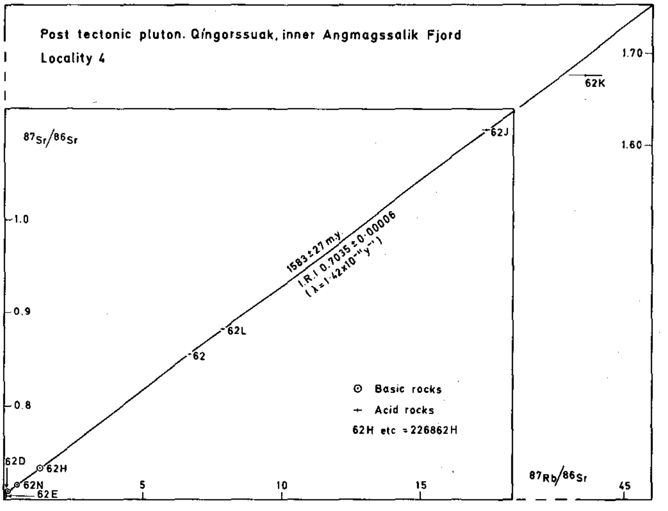

Fig. 5. Rb-Sr whole rock evolution diagram of a post-tectonic pluton, Qíngorssuak, inner Angmagssalik Fjord (locality 4, fig. 1).

Sr isotope studies do not give a definite answer about the origin of post-tectonic intrusions in areas of deeply eroded continental crust with low Rb-Sr ratios such as exposed in East Greenland.

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