Review of isotope data for Precambrian rocks from the Disko Bugt region, West Greenland

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Pb-Pb and Rb-Sr isotope data yield whole-rock isochron ages of *c*. 2800 Ma for two localities of granitoid rocks in the Disko Bugt region, with little evidence of strong later disturbance. Rb-Sr isotope data on Archaean metasediments from two localities, however, were strongly disturbed during the early Proterozoic. Sm-Nd whole-rock data for acid metavolcanic rocks within Archaean supracrustal sequences yield model ages of *c*. 2800 Ma. The early Proterozoic age of a younger sequence of supracrustal rocks (the Anap nunâ Group) is confirmed by Sm-Nd data, and Rb-Sr whole-rock data for albitised siltstones show that albitisation took place hundreds of millions of years after the peak of early Proterozoic orogenic activity.

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The Precambrian terrain of the Disko Bugt region (Fig. 1) consists mainly of grey migmatitic gneisses with units of supracrustal rocks (Henderson 1969; Garde & Steenfelt 1999, this volume). Most rocks in the region are of Archaean age, variably reworked during early Proterozoic orogenic activity (Kalsbeek 1981, 1994). In north-eastern Disko Bugt a sequence of low grade early Proterozoic metasediments, the Anap nunâ Group, unconformably overlies Archaean rocks.

Among the Archaean rocks the well-preserved Atâ intrusive complex (Atâ Tonalite on the 1:250 000 scale map of Garde 1994) in north-eastern Disko Bugt (Fig. 1; Kalsbeek & Skjernaa 1999, this volume) represents an important time marker because it has been emplaced into older gneisses and supracrustal rocks and is itself cut by younger granites. It has been dated at *c*. 2800 Ma (Kalsbeek *et al*. 1988; Nutman & Kalsbeek 1999, this volume), and one of the younger granites has yielded a date of *c*. 2760 Ma (Nutman & Kalsbeek 1999, this volume). Supracrustal rocks in the north-eastern Disko Bugt region cut by Atâ granitoids (Fig. 1) consist mainly of basic metavolcanic rocks (in part pillow lavas) with minor proportions of metasediments; acid metavolcanic rocks are also present.

The Proterozoic sedimentary sequence north-east of Arveprinsen Ejland (Fig. 1) consists mainly of sand- and siltstones (Garde & Steenfelt 1999, this volume) with local sheets and dykes of basic igneous rocks. Large parts of this sequence have been strongly albitised (Kalsbeek 1992).

A few well-preserved basic dykes, up to 100 m wide, cut Archaean and Proterozoic rocks in the easternmost part of the region. One of these has been dated at 1645 ± 35 Ma (Rb-Sr whole rock isochron; Kalsbeek & Taylor 1986).

The Disko Bugt region lies between two early Proterozoic orogenic belts: the Nagssugtoqidian belt to the south and the Rinkian belt to the north (Fig. 1). In both belts the rocks have been affected by high-grade metamorphism and deformation about 1850 Ma ago (Kalsbeek *et al*. 1984; Taylor & Kalsbeek 1990) which strongly disturbed Archaean Rb-Sr and Pb-Pb whole rock isotope systems (e.g. Kalsbeek *et al*. 1987). Rocks in the Disko Bugt region appear to have been less

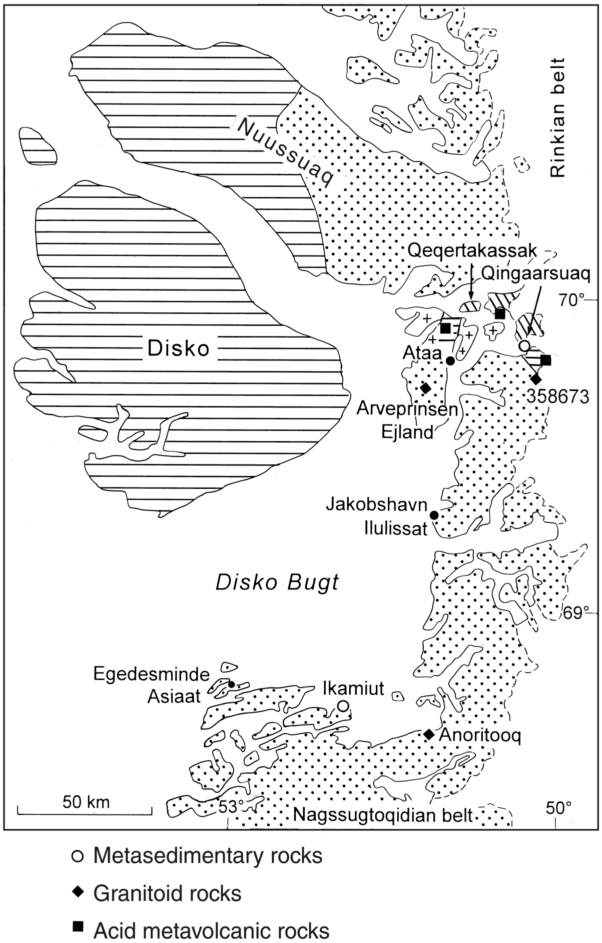

Fig. 1. Geological sketch map of the Disko Bugt region (from Kalsbeek 1991) with sample localities. Stipple: mainly Archaean gneisses. Wide horizontal ruling: mainly Tertiary basalts. In the Ataa area in north-eastern Disko Bugt Archaean gneisses and metavolcanic rocks (horizontal ruling) are intruded by the Atâ intrusive complex (Atâ tonalite, crosses), and unconformably overlain by an early Proterozoic sequence of sand- and siltstones, the Anap nunâ Group (oblique ruling; for a more detailed map of this area see, for example, Nutman & Kalsbeek 1999, this volume).

strongly affected by this orogenic event (Kalsbeek *et al.* 1988); nevertheless, K-Ar isotope data on biotite (Larsen & Møller 1968) and K-Ar and ^{40}Ar-^{39}Ar data on hornblende from different rock types (Rasmussen & Holm 1999, this volume) yield evidence of significant heating during the early Proterozoic.

In this paper we present Pb-Pb, Rb-Sr and Sm-Nd data on various rock units in the Disko Bugt region. Most are from the area around Ataa, recently investigated by the former Geological Survey of Greenland, see geological maps at 1:250 000 (enclosed in this volume) and 1:100 000; Garde 1994 and Escher 1995, respectively. For descriptions of the various rock units see Garde & Steenfelt (1999) and other papers in this volume. Also included are data for rocks from the southern part of Disko Bugt, mapped and described by Henderson (1969). No data are yet available from Nuussuaq.

Gneisses and granitoid rocks

Pb-Pb data for Archaean gneisses at Anoritooq, SE Disko Bugt

Pb-isotope data have been obtained from the regional grey gneisses at Anoritooq on the south-eastern coast of Disko Bugt (Fig. 1). Outcrops here consist of light grey biotite gneisses with variable proportions of pink K-feldspar augen and local remnants of anorthosite

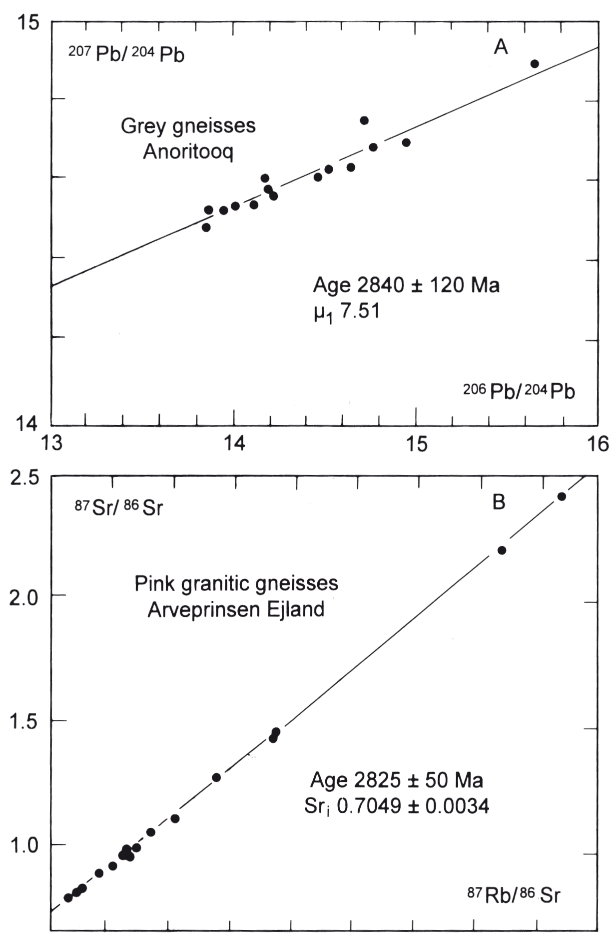

Fig. 2. **A**: Pb-Pb isochron diagram for grey gneisses from Anoritooq, south-east coast of Disko Bugt. **B**: Rb-Sr isochron diagram for pink granitic gneisses, Arveprinsen Ejland.

Table 1. Pb-isotope data for Archaean gneisses at Anoritooq, south-east coast of Disko Bugt

GGU sample no	$^{206}Pb/^{204}Pb$	$^{207}Pb/^{204}Pb$	$^{208}Pb/^{204}Pb$
298731	14.946	14.696	36.502
298732	14.645	14.633	35.261
298733	14.201	14.575	34.639
298734	13.874	14.526	38.166
298735	14.019	14.538	36.824
298736	14.530	14.627	37.699
298737	14.712	14.747	35.287
298738	14.769	14.682	37.068
298739	14.116	14.543	35.892
298740	14.216	14.563	35.388
298741	13.850	14.482	36.816
298742	14.464	14.611	36.638
298743	14.182	14.606	34.896
298745	15.652	14.891	45.333
298746	13.960	14.524	36.596

Analytical data from the Age and Isotope Laboratory, University of Oxford, UK. Pb-isotope ratios have been corrected for mass fractionation and have a precision of *c.* 0.1% (1σσ).

and leucogabbro. Fifteen samples were analysed (Table 1); 14 of these define an isochron with age 2840 ± 120 Ma (2σ), μ_1 (first stage $^{238}U/^{204}Pb$) 7.51, and MSWD 2.38 (Fig. 2A). The poor age resolution of the isochron is due to the limited range of Pb-isotope compositions. The reasonably good fit on the isochron, compared to Pb-isotope data from Archaean gneisses in the Nagssugtoqidian belt south of Disko Bugt (Kalsbeek *et al.* 1987), suggests that the rocks at Anoritooq have been less strongly affected by Proterozoic isotopic disturbance than in the Nagssugtoqidian belt.

Rb-Sr data for a pink granitic gneiss from central Arveprinsen Ejland

Rb-Sr data have been acquired for 16 samples of a *c.* 300 m wide granite sheet in central Arveprinsen Ejland (granitic gneiss ggn on the geological map of Garde 1994; see also Garde & Steenfelt 1999, this volume). This body consists of foliated, K-rich granite *sensu stricto*, and has gradational contacts with the surrounding grey gneisses. Field evidence shows that the granite is younger than the gneisses, of which it contains half-digested inclusions. The granite may have formed by anatexis of Archaean gneisses or metasedimentary rocks at depth.

Table 2. Rb-Sr isotope data on Archaean and Proterozoic rocks from the Disko Bugt region

GGU sample no	Rb (ppm)	Sr (ppm)	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$
(1) Pink granitic gneisses, Arveprinsen Ejland				
355163	125	76	5.53	0.92731
355164	142	17	18.16	1.45469
355165	121	63	6.35	0.96379
355166	128	50	8.61	1.05562
355167	154	13	41.62	2.42642
355168	139	45	10.40	1.12208
355169	107	55	6.46	0.97310
355170	166	16	36.87	2.21249
355171	125	57	7.20	0.99634
355172	140	70	6.58	0.96433
355173	132	32	13.81	1.28883
355174	142	26	18.28	1.46445
355175	62	103	1.95	0.78746
355176	101	114	2.91	0.82086
355177	88	65	4.39	0.88884
355178	93	111	2.76	0.81659
(2) Archaean metasediments, Qingaarsuaq				
355133	51	217	0.687	0.73323
355134	36	235	0.442	0.72661
355135	55	187	0.860	0.73842
355136	39	239	0.566	0.73094
355137	28	235	0.347	0.72476
355138	34	161	0.606	0.73367
(3) Archaean metasediments, Ikamiut				
298713	69	249	0.802	0.73246
298714	93	253	1.067	0.74241
298715	67	265	0.736	0.73056
298716	85	272	0.908	0.73689
298717	89	253	1.021	0.73982
298718	92	349	0.764	0.73441
298719	81	344	0.679	0.72966
298720	82	281	0.849	0.73517
298721	72	235	0.891	0.73782
298722	97	256	1.105	0.74285
298723	181	256	2.058	0.76591
298724	219	275	2.323	0.77585
(4) Proterozoic albite-rich rocks, Qeqertakassak				
355034	2.3	19	0.304	0.71979
355038	1.7	23	0.213	0.72090
355119	20	10	5.230	0.81012
355123	7.4	14	1.371	0.73072
355125	20	20	2.822	0.76804
355127	26	12	6.001	0.84060
355130	0.8	31	0.108	0.71454
355144	2.5	31	0.206	0.72089

Sr-isotope ratios were acquired at the Danish Centre for Isotope Geology at the Institute of Geology, University of Copenhagen (1) and at the Age and Isotope Laboratory, University of Oxford, UK (2–4). Precisions *c.* 0.005% and 0.01% (1σ), respectively. At the Danish Centre for Isotope Geology a mean $^{87}Sr/^{86}Sr$ ratio of 0.710262 ± 16 (*n* = 12) was obtained on the NBS 987 Sr standard (accepted value 0.710248). Rb/Sr ratios were measured by X-ray fluorescence spectrometry at the Institute of Geology, University of Copenhagen. Rb and Sr ± *c.* 10%, for the Proterozoic albite-rich rocks ± *c.* 2%, but not better than *c.* 0.5 ppm; $^{87}Rb/^{86}Sr$ ± *c.* 1% (1σ).

The analysed samples have a wide range of $^{87}Rb/^{86}Sr$ ratios (1.95 to 41.6; Table 2-1), mainly due to very variable Sr: 13–114 ppm; Rb shows less variation: 62–166 ppm. In the $^{87}Sr/^{86}Sr$ *v.* $^{87}Rb/^{86}Sr$ diagram (Fig. 2B) the data fall in a well-defined linear array, but do not fit an isochron within analytical precision (MSWD 4.59). The errorchron yields an age of 2825 ± 50 Ma (2σ) with an initial $^{87}Sr/^{86}Sr$ ratio of 0.7049 ± 0.0034. Again, the reasonable fit of the data points on the isochron line compared to that observed for granitic rocks in the central Nagssugtoqidian belt (Kalsbeek *et al.* 1987) shows that disturbance of the Rb-Sr isotope systems was here less severe.

Sm-Nd model age for a homogeneous gneiss SE of Eqi

A Sm-Nd model age (T_{DM}; DePaolo 1981) of 2930 Ma (Table 3) has been obtained for GGU 358673 (for locality see Fig. 1), collected from a mappable unit of relatively homogeneous non-migmatitic gneiss east of Ataa (see Escher *et al.* 1999, this volume). This is significantly older than the Atâ intrusive complex, in agreement with field evidence that the Atâ complex locally has intruded into older gneisses. However, U-Pb data on single zircons from this sample did not yield ages older than *c.* 2835 Ma (Nutman & Kalsbeek 1999, this volume). The Sm-Nd data thus suggest that the rock in question may have incorporated older crustal material, which is not recorded by the zircons.

Archaean supracrustal rocks

Sm-Nd data on acid metavolcanic rocks

Three samples of acid metavolcanic rocks (Ac, Garde 1994; for localities see Fig. 1), associated with Archaean meta-pillow lavas, yielded T_{DM} values of 2770, 2780, and 2810 Ma (Table 3). With estimated precisions of the order of 40 Ma (2σ) these values are not significantly different from that obtained for a sample from the Atâ intrusive complex (2800 Ma, Kalsbeek *et al.* 1988). Field evidence suggests that the Atâ complex intruded at relatively high crustal levels (Kalsbeek & Skjernaa 1999, this volume) and it seems plausible that the acid volcanic rocks are the surface expression of emplacement of the complex into Archaean supracrustal rocks.

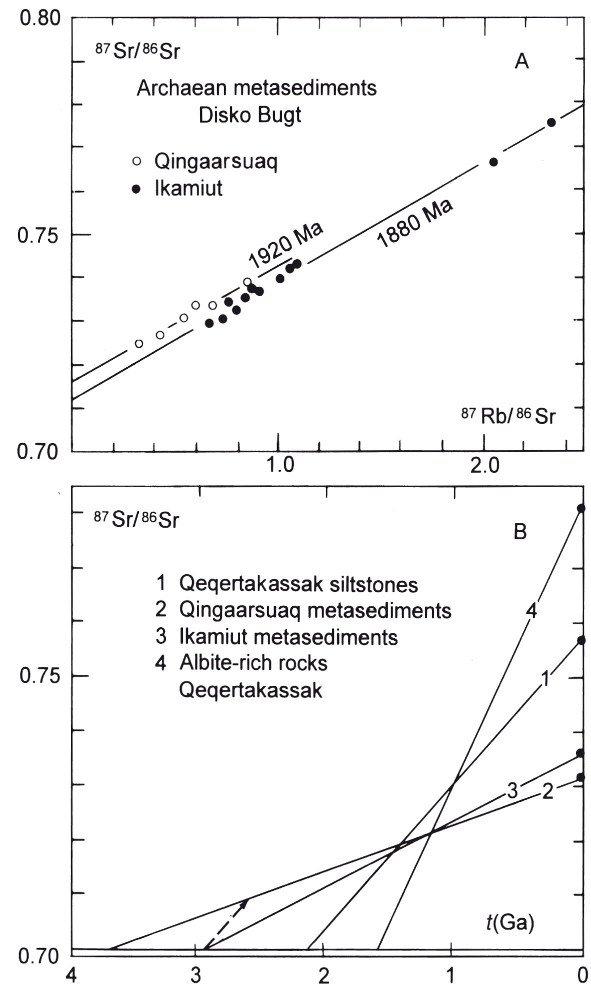

Fig. 3. **A**: Rb-Sr isochron diagram for samples of Archaean metasediments. **B**: Sr-evolution diagram based on measured mean $^{87}Sr/^{86}Sr$ ratios (t = 0, heavy dots) extrapolated backward in time with the help of corresponding mean $^{87}Rb/^{86}Sr$ ratios, see text. The dashed line shows that the Qingaarsuaq metasediments could be *c.* 2800 Ma old if their mean Rb/Sr ratio was significantly reduced during Archaean metamorphism.

Rb-Sr data for Archaean metasediments from Qingaarsuaq

Rb-Sr isotope data have been obtained for six samples of metasediments from within the Archaean supracrustal sequence on Qingaarsuaq east of Ataa (Fig. 1; for description see Garde & Steenfelt 1999, this volume). The analysed rocks are dark grey, fine-grained, biotite-rich gneisses, without aluminosilicate minerals. With 28–55 ppm Rb and 160–240 ppm Sr (Table 2-2) $^{87}Rb/^{86}Sr$ ratios are relatively low for metasediments. The rocks probably represent metagreywackes rather than metapelites.

Table 3. Sm-Nd isotope data and model age calculations for rocks from the Ataa area, north-east Disko Bugt

GGU sample no	Sm (ppm)	Nd (ppm)	$^{147}Sm/^{144}Nd$	$^{143}Nd/^{144}Nd$	T_{DM} (Ma)
Archaean gneiss					
358673	2.726	13.313	0.1237	0.511321	2930
Archaean acid metavolcanic rocks					
355006	2.122	12.201	0.1051	0.511045	2810
355055	1.667	9.669	0.1042	0.511053	2770
355056	2.905	17.481	0.1004	0.510977	2780
Proterozoic metasediments					
298790	5.722	30.754	0.1125	0.511411	2450
355053*	3.572	18.038	0.1197	0.511528	2460

Isotope data from the Age and Isotope Laboratory, University of Oxford, UK. Analytical uncertainties estimated at *c.* 0.1% for Sm and Nd concentrations, 0.2% for $^{147}Sm/^{144}Nd$, and 0.000010 for $^{143}Nd/^{144}Nd$ ratios (1σ).
* sample 355053 is a strongly albitised siltstone.
T_{DM} values represent model ages calculated according to the depleted mantle model of DePaolo (1981); they have a precision of *c.* 40 Ma (2σ).

In an isochron diagram the Rb-Sr data plot in a poorly defined linear array (Fig. 3A). A line of best fit corresponds to an age of *c.* 1920 Ma with Sr_i *c.* 0.715. It is apparent that partial Sr-isotopic homogenisation has taken place during the early Proterozoic, and the *c.* 1920 Ma age is probably a coarse approximation of the time of high-grade metamorphism.

Backward extrapolation of the mean $^{87}Sr/^{86}Sr$ ratio of the analysed samples in the Sr-isotopic evolution diagram (Fig. 3B) shows that, with the present mean $^{87}Rb/^{86}Sr$ ratio, the metasediments from Qingaarsuaq could have existed as far back as *c.* 3.5 Ga. However, reduction of Rb/Sr ratios during Archaean or early Proterozoic metamorphism (cf. Fig. 3B) would reduce this maximum age (for a more detailed discussion, see Kalsbeek 1993). For comparison the Sr-isotopic evolution of early Proterozoic siltstones from Qeqertakassak (Kalsbeek *et al.* 1988) is also shown. With their much higher $^{87}Rb/^{86}Sr$ ratios these sediments cannot have been deposited much earlier than 2 Ga ago. Fig. 3B illustrates the distinctly different Sr-isotopic evolution of the two metasedimentary units.

Rb-Sr data for metasediments from Ikamiut, south Disko Bugt

Kilometre-wide units of supracrustal rocks dominated by mica schists and pelitic gneisses are prominent along the coasts of south-eastern Disko Bugt (for description see Henderson 1969). Similar rocks east of Ilulissat/Jakobshavn (Fig. 1) are shown on the 1:250 000 geological map (Nms, Garde 1994) and have been described by Garde & Steenfelt (1999, this volume). Twelve samples have been analysed from a locality near Ikamiut on the south shore of Disko Bugt (Fig. 1; Table 2-3). In the isochron diagram they scatter about a line of best fit with a slope corresponding to an age of *c.* 1880 Ma and Sr_i *c.* 0.712 (Fig. 3A). Backward extrapolation in the Sr-evolution diagram (Fig. 3B) shows that, with their present $^{87}Rb/^{86}Sr$ ratios, these rocks may have existed for about 2.8 Ga, and it appears likely they represent sediments deposited during the late Archaean and isotopically strongly reset during early Proterozoic metamorphism.

Sm-Nd and Rb-Sr data for Proterozoic rocks and their alteration products

Sm-Nd data for siltstones from the Anap nunâ Group

The Proterozoic sedimentary sequence on the island Qeqertakassak (Fig. 1) consists mainly of dark siltstones which in part have been very strongly altered into albite-quartz-carbonate rocks (Kalsbeek 1992). Locally sheets

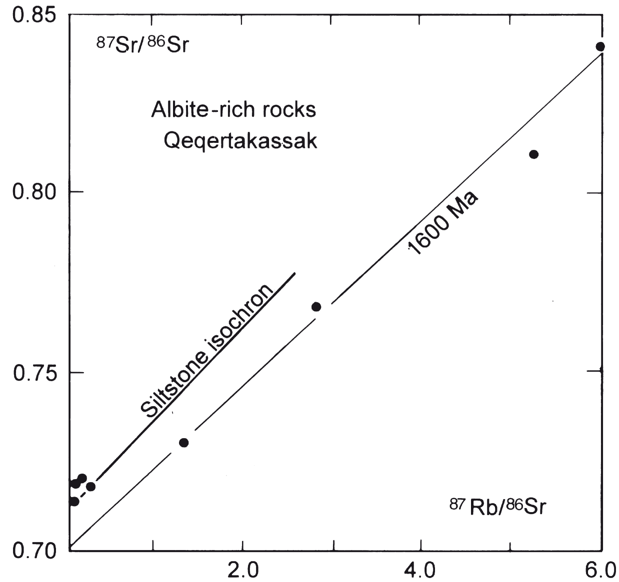

Fig. 4. Rb-Sr isochron diagram for albitised siltstones from Qeqertakassak, compared with the isochron obtained for non-albitised siltstones by Kalsbeek *et al.* (1988).

of metadolerite occur, and these may also be strongly albitised (Kalsbeek 1991). The Proterozoic age of these rocks was based on indirect evidence (Kalsbeek *et al.* 1988), and although later field evidence has revealed the presence of an unconformity towards the underlying Archaean rocks, a few Sm-Nd analyses were acquired to test their age.

Sm-Nd data for GGU 298790 (Table 3), a dark siltstone from Qeqertakassak, give a T_{DM} value of 2.45 Ga. This is much lower than T_{DM} values obtained from Archaean rocks in the area, and it is thus clear that Archaean rocks cannot have been the only source of clastic material for the sediments. If detrital material of Archaean origin is present at all (from the regional geology of the region this would appear to be very likely), then the sediments must also have contained a significant proportion of material that was derived from the mantle during the Proterozoic, later than 2.45 Ga ago. The Sm-Nd data thus strongly support a Proterozoic origin of the sediments.

GGU 355053 (Table 3) is an albitised siltstone. It yielded a T_{DM} value of 2.46 Ga, not significantly different from the non-albitised siltstone 298790. Apart from confirming the Proterozoic age of the rock this result illustrates the robustness of Sm-Nd isotope systems during alteration.

Age of albitisation

The age of the pervasive albitisation of the sediments on Qeqertakassak is not well constrained from field evidence. It may have started shortly after deposition, because albite-rich rocks commonly form conformable layers within less altered sediment, but there is also a clear relationship with late fracture zones (Kalsbeek 1992). There is ample evidence of mobility of Rb and Sr during albitisation, and, since the alteration must have been caused by massive percolation of fluids, it was thought that Sr-isotopic homogenisation might have taken place during the process, and that Rb-Sr isotope data therefore could give an indication of the age of albitisation. This is only partly the case.

The albite-rich rocks have a wide range of $^{87}Rb/^{86}Sr$ ratios (Fig. 4; Table 2–4) because variable proportions of Rb and Sr were leached from the siltstones during albitisation (Kalsbeek 1992). However, the samples do not yield an isochron. Of four samples with low $^{87}Rb/^{86}Sr$ (< 0.4) two plot close to the best-fit isochron line obtained for the Qeqertakassak siltstones, and two fall significantly above this line. Four samples with $^{87}Rb/^{86}Sr$ ratios > 1 plot very significantly below the Qeqertakassak siltstone isochron. Model age calculations for these samples (cf. Fig. 3B) indicate they must have acquired their present Rb/Sr ratios several hundred million years after deposition of the sediments, and much later than the peak of orogenic activity in the Nagssugtoqidian and Rinkian mobile belts (*c.* 1850 Ma, Kalsbeek *et al.* 1984, 1987; Taylor & Kalsbeek 1990). Even with a $^{87}Sr/^{86}Sr$ ratio as low as 0.7000 at the time of albitisation these samples cannot have existed much longer than *c.* 1600 Ma, unless significant later disturbance of the isotope systems has taken place. It is possible that the igneous event registered by the 1645 Ma basic dykes in the eastern part of the region triggered the hydrothermal activity that gave rise to a late phase of albitisation. The dykes themselves, however, appear to be totally unaffected.

Conclusions

1. Pb-Pb and Rb-Sr isotope data confirm that most of the Precambrian basement in the Disko Bugt region is of Archaean origin.

2. Pb-Pb and Rb-Sr systematics in granitoid rocks have been less strongly disturbed by early Proterozoic metamorphism than in the Nagssugtoqidian belt to the south.

3. Rb-Sr data for Archaean metasediments yield evidence of strong disturbance during early Proterozoic metamorphism.

4. Sm-Nd data for acid metavolcanic rocks yield model ages (T_{DM}) of *c.* 2800 Ma, similar to that of a sample from the Atâ intrusive complex.

5. Sm-Nd data confirm earlier considerations that the low-grade supracrustal rocks of the Anap nunâ Group are of early Proterozoic age.

6. Rb-Sr data show that massive albitisation of Anap nunâ Group metasediments took place hundreds of million years after deposition, and much later than high-grade metamorphism in the Nagssugtoqidian and Rinkian mobile belts.

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