New hornblende and muscovite ^{40}Ar/^{39}Ar cooling ages in the central Rinkian fold belt, West Greenland

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The Palaeoproterozoic Rinkian fold belt in West Greenland consists of reworked Archaean basement, mainly orthogneiss, and the unconformably overlying Palaeoproterozoic Karrat Group. Both parts were intensely deformed and metamorphosed at around 1.87 Ga, at which time the crustal anatectic Prøven igneous complex was emplaced into the northern part of the belt. Seven new hornblende and muscovite ^{40}Ar/^{39}Ar cooling ages are presented from the central–northern parts of the Rinkian fold belt. Four ^{40}Ar/^{39}Ar hornblende ages ranging from 1795 ± 3 to 1782 ± 3 Ma were obtained from amphibolite and hornblendite enclaves in the Archaean orthogneiss, and two from relict dyke fragments in the latter that may be of Palaeoproterozoic age. Three ^{40}Ar/^{39}Ar muscovite ages of 1681 ± 6 Ma, 1686 ± 3 Ma and 1676 ± 3 Ma were obtained from samples of Karrat Group metagreywacke, andalusite schist and metasiltstone. The new ^{40}Ar/^{39}Ar ages, from hornblende and muscovite respectively, are very uniform and probably unrelated to local metamorphic grade and structural history, and are interpreted as regional late orogenic cooling ages. The new hornblende ages are significantly older than those previously obtained from the central and northern parts of the adjacent Nagssugtoqidian orogen to the south, and point to different uplift histories, which may suggest that the orogeny was not synchronous in the two regions.

Keywords: Ar-Ar, geochronology, Rinkian, Palaeoproterozoic, West Greenland

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This paper presents seven new hornblende and muscovite ^{40}Ar/^{39}Ar cooling ages from the central part of the Palaeoproterozoic Rinkian fold belt in West Greenland. The new data set provides insight into the cooling history of the Rinkian fold belt and can also be used to address its temporal relationship with the adjacent Nagssugtoqidian orogen to the south, from which other ^{40}Ar/^{39}Ar cooling ages have previously been published.

Most of central and northern West Greenland consists of Archaean continental crust which was intensively reworked during the Palaeoproterozoic. This reworking was first recognised in central West Greenland between 66° and 69°N by Ramberg (1949), who established the Nagssugtoqidian mobile belt (now called the Nagssugtoqidian orogen) in this area. Escher & Pulvertaft (1976) subsequently proposed that a separate Palaeoproterozoic mobile belt, the Rinkian fold belt, existed in central and northern West Greenland between 69° and 75°N (see inset map of Fig. 1). They noted that the latter region was dominated by an overall flat-lying tectonic foliation with superimposed large domes, and considered that these structures were of a different nature from the generally steep foliations and tight folds that had previously been identified in the Nagssugtoqidian belt. In contrast to the collisional structures recognised within the Nagssugtoqidian orogen, it was thought that the Rinkian deformation had taken place without significant crustal shortening.

Furthermore, whereas the collisional Nagssugtoqidian

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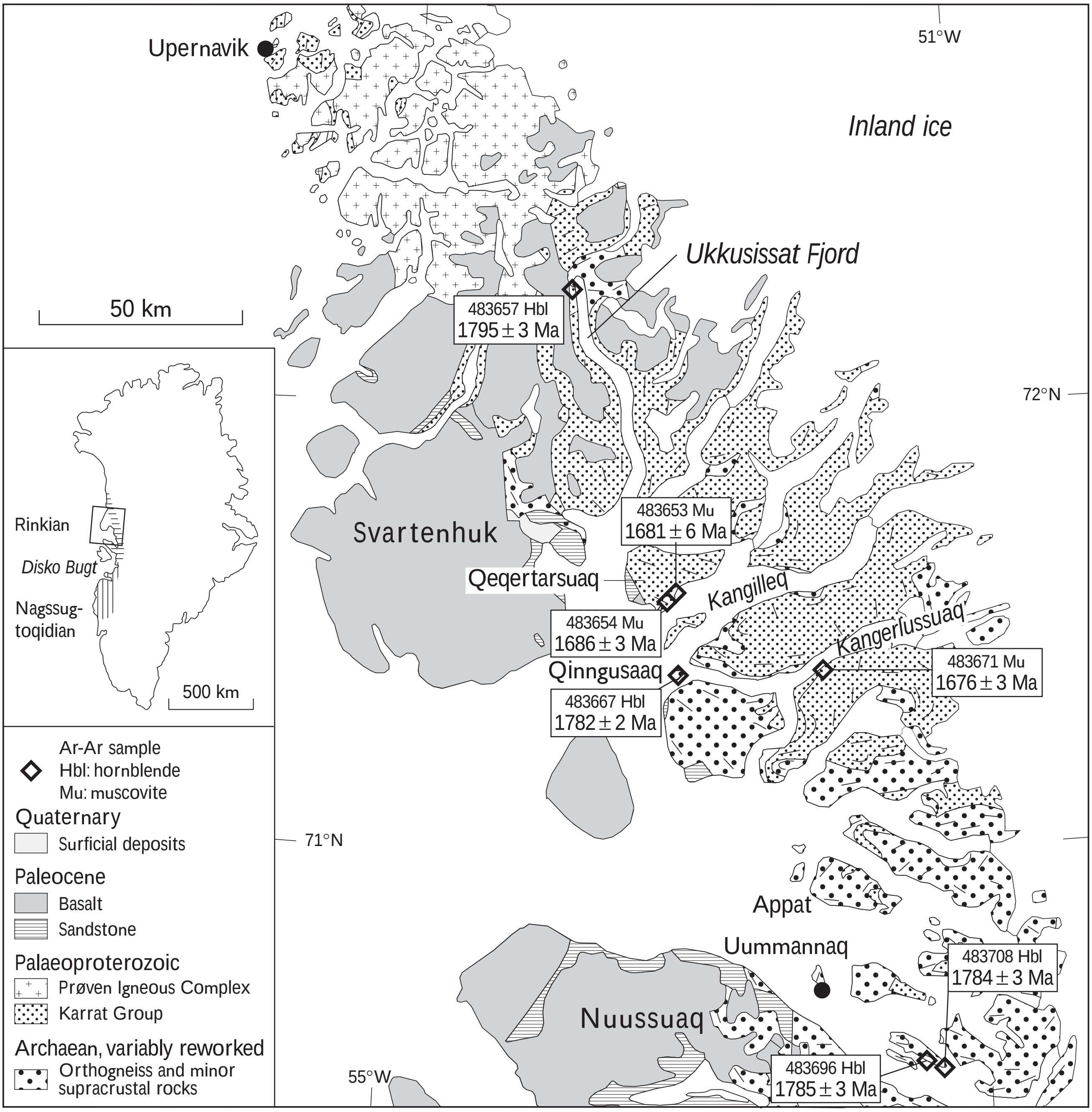

Fig. 1. Map of the central Rinkian fold belt showing the locations of samples collected for ^{40}Ar/^{39}Ar age determination. The index map shows the position of Fig. 1 and the approximate extent of Nagssugtoqidian and Rinkian reworking in West Greenland. Modified from Garde *et al.* (2004).

orogen was originally believed only to comprise Archaean supracrustal and infracrustal rocks, the Rinkian fold belt contains a widespread, metamorphosed and deformed cover sequence, the *c.* 2 Ga old Karrat Group, which was unconformably deposited on the Archaean basement gneisses (Garde & Pulvertaft 1976; Henderson & Pulvertaft 1987; Kalsbeek *et al.* 1998). The lowest parts of the Karrat Group consist of quartzite, marble and minor amphibolite (the Qeqertarsuaq and Marmorilik Formations), which are overlain by a very uniform sequence of metagreywacke, the Nukavsak Formation, which is several kilometres thick and occurs throughout most of the Rinkian belt (Fig. 1; Henderson & Pulvertaft 1987). The geochemistry of the Karrat Group and studies of its detrital zircons indicate that the Karrat Group was derived from a mixed source including Palaeoproterozoic magmatic arc rocks and Archaean basement rocks, and that it was deposited at around 2.0–1.9 Ga ago (Kalsbeek *et al.* 1998; Thrane *et al.* 2003).

The Rinkian fold belt also incorporates the Prøven igneous complex, a very large plutonic complex of granitic and microdioritic crustal melts that were emplaced under granulite facies conditions into the middle to upper crust in the Upernavik region of the Rinkian belt and is also found as the Cumberland batholith on adjacent Baffin Island, Canada. The pluton has previously yielded a Rb-Sr whole rock isochron age of 1860 ± 25 Ma with a high initial ^{87}Sr/^{86}Sr ratio (Kalsbeek 1981) and has recently also been studied by Thrane *et al.* (2005). The latter produced a more precise zircon U-Pb ion probe age of 1869 ± 9 Ma and obtained negative εNd values from the pluton (calculated at 1870 Ma) ranging between –5.2 and –4.3. In agreement with the previous Rb/Sr data this shows that the plutonic complex contains a large Archaean continental crustal component. It is therefore questionable whether the Prøven igneous complex – Cumberland batholith is subduction-related as has been proposed by Canadian workers. Thrane *et al.* (2005) suggest it represents a crustal melt, induced by upwelling hot asthenospheric mantle.

Pulvertaft (1986), Henderson & Pulvertaft (1987), Grocott & Pulvertaft (1990) and Garde & Steenfelt (1999b) have described the structural evolution in various parts of the Rinkian fold belt, and recognised large-scale thrusts in its southern part. Following new field work in 2002–2003, the structural evolution in the Uummannaq region is at present regarded as consisting of four main phases (briefly outlined by Garde *et al.* 2003, 2004). Deformation began with tight folding and possibly thrusting (D1), which developed prior to cleavage formation. This was followed by NE- to E-directed thrusting and ductile tectonic transport (D2) accompanied by formation of a penetrative schistosity, and then by NW- to W-directed tectonic transport (D3) and intensification of the pre-existing schistosity. Lastly, very large, upright to overturned, dome-shaped anticlines and tight synclinal cusps were developed during continued shortening of the now strongly tectonically layered crust; these large structures are only locally accompanied by a new tectonic fabric. The Prøven igneous complex was emplaced at a late stage of the main fabric-forming events and gave rise to a wide metamorphic aureole that was overprinted on rocks that were already regionally metamorphosed at high grade.

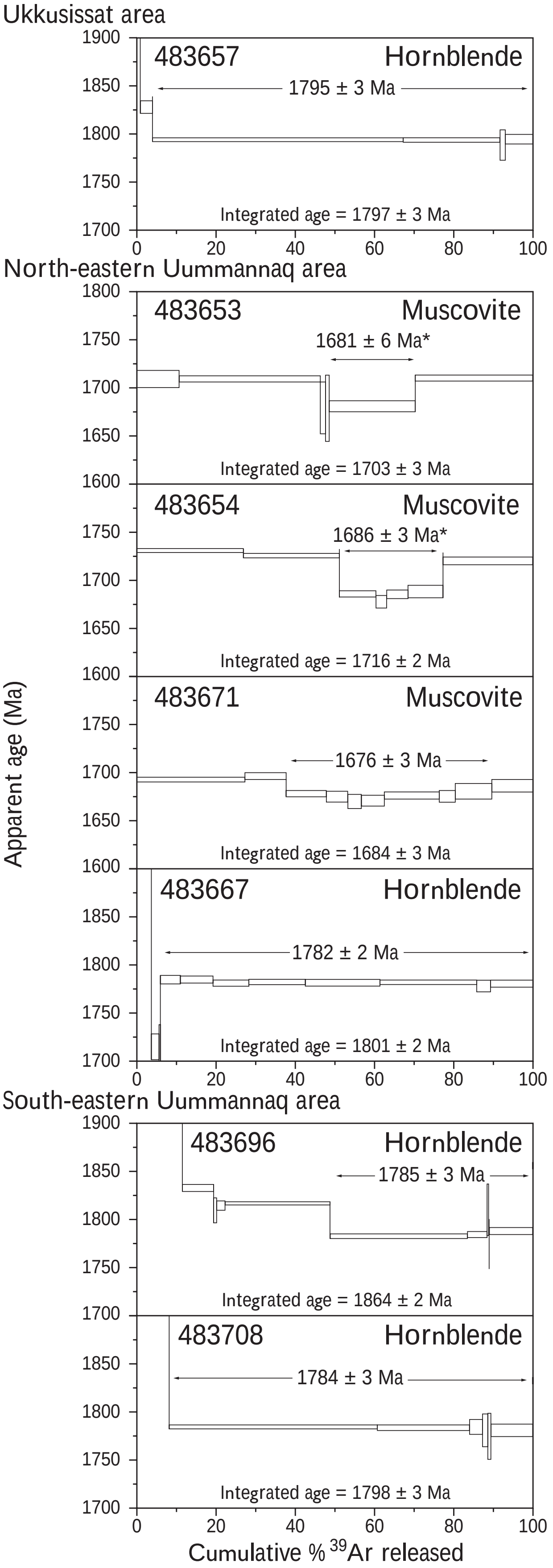

Fig. 2. ^{40}Ar/^{39}Ar plateau age spectra from the Rinkian fold belt. Ages with an asterisk (*): ^{40}Ar/^{39}Ar plateau age representing less than 50% of total ^{39}Ar release. Ages without an asterisk: ^{40}Ar/^{39}Ar plateau age.

Table 1. ^{40}Ar-^{39}Ar analytical data for step heating experiments on amphiboles and muscovites from the Rinkian fold belt

Step	Pwr/T°C	Ca/K	Cl/K	^{36}Ar/^{39}Ar	%^{36}Ar(Ca)	^{40*}Ar/^{39}Ar	Mol ^{39}Ar	% Step	%^{39}Ar Cumulated	%^{40*}Ar	Age (Ma)	± Age (2σ)
483653 Muscovite (J = 0.01071 ± 0.00001):												
C	1.4	0.00001	0.001	0.00011	0	147.485	0.093	10.9	10.9	100	1709.6	4.4
D	1.4	0.1461	0.004	0.00008	26.5	147.544	0.306	35.6	46.4	100	1710	1.7
•E	1.5	1.9453	0.021	0.00097	27.6	143.552	0.011	1.2	47.7	99.9	1679.9	13.4
•F	1.6	2.875	0.004	0.00041	96.1	143.488	0.009	1	48.7	100	1679.4	17.2
•G	1.9	0.4853	0.003	0.00010	68.7	143.739	0.187	21.7	70.3	100	1681.3	2.7
H	4	0.3402	0.004	0.00019	24.8	147.664	0.256	29.7	100	100	1710.9	1.6
Integrated (total fusion) age:											1703	3
(•) Plateau age:								23.9			1681	6
483654 Muscovite (J = 0.01071 ± 0.00001):												
A	1.4	0.005	0.003	0.00106	0.1	150.444	0.767	26.9	26.9	99.8	1731.6	1.0
B	1.5	0.006	0.005	0.00033	0.2	149.670	0.692	24.3	51.2	99.9	1725.9	1.2
•C	1.6	0.0499	0.009	0.00063	1.1	144.382	0.265	9.3	60.5	99.9	1686.2	1.5
•D	1.7	0.9006	0.020	0.00077	16.1	143.337	0.075	2.6	63.1	99.9	1678.2	3.3
•E	1.8	0.1521	0.007	0.00147	1.4	144.323	0.153	5.4	68.5	99.7	1685.7	2.2
•F	1.9	0.357	0.009	0.00015	32.9	144.706	0.251	8.8	77.3	100	1688.6	3.1
G	2.3	0.0741	0.003	0.00003	35.7	148.939	0.648	22.7	100	100	1720.4	2.1
Integrated (total fusion) age:											1716	2
(•) Plateau age:								26.1			1686	3
483657 Hornblende (J = 0.01071 ± 0.00001):												
A	1.8	11.847	0.123	0.04105	4	184.220	0.019	1	1	94	1965.7	11.4
B	1.9	11.642	0.027	0.00559	28.7	163.894	0.059	3.1	4.1	99.3	1828.5	3.3
•C	2	10.312	0.013	0.00193	73.5	159.127	1.198	63.2	67.3	99.9	1794.7	1.1
•D	2	10.03	0.014	0.00155	89	159.084	0.463	24.4	91.7	100	1794.4	1.3
•E	2.1	11.862	0.043	0.00182	90	158.317	0.028	1.5	93.2	100	1788.9	8.0
•F	2.6	11.62	0.018	0.00223	71.9	159.178	0.130	6.8	100	99.9	1795.1	2.3
Integrated (total fusion) age:											1797	3
(•) Plateau age:								95.9			1795	3
483667 Hornblende (J = 0.01071 ± 0.00001):												
A	1.8	14	0.277	0.08890	2.2	501.205	0.011	0.5	0.5	95.1	3339.8	25.5
B	1.9	8.88	-0.010	0.01236	9.9	166.723	0.006	0.2	0.7	98.1	1848.2	27.0
C	2	8.133	0.066	0.00845	13.3	196.061	0.068	3	3.7	98.9	2041	3.3
D	2	8.823	0.082	0.01454	8.4	148.220	0.042	1.8	5.5	97.4	1715.1	6.7
E	2.1	5.161	0.073	0.01482	4.8	146.685	0.009	0.4	5.9	97.2	1703.6	17.3
•F	2.2	8.525	0.054	0.00482	24.4	157.760	0.118	5.2	11	99.3	1784.9	2.3
•G	2.2	9.17	0.048	0.00241	52.4	157.782	0.188	8.2	19.2	99.8	1785.1	1.7
•H	2.3	8.683	0.050	0.00316	37.8	157.288	0.206	9	28.2	99.6	1781.6	1.6
•I	2.3	8.979	0.056	0.00234	53	157.382	0.328	14.3	42.5	99.8	1782.2	1.4
•J	2.4	8.623	0.055	0.00105	113.4	157.274	0.432	18.8	61.3	100	1781.5	1.9
•K	2.6	8.346	0.056	0.00150	77	157.395	0.561	24.4	85.8	99.9	1782.3	1.1
•L	2.8	9.598	0.067	0.00374	35.4	156.861	0.081	3.5	89.3	99.5	1778.5	3.0
•M	4	10.4	0.062	0.00273	52.5	157.231	0.246	10.7	100	99.8	1781.1	1.9
Integrated (total fusion) age:											1801	2
(•) Plateau age:								94.1			1782	2
483671 Muscovite (J = 0.01071 ± 0.00001):												
A	1.4	0.2482	0.005	0.00153	2.2	145.263	0.449	27.4	27.4	99.7	1692.9	1.2
B	1.5	0.7642	0.007	0.00189	5.6	145.703	0.168	10.3	37.6	99.6	1696.2	1.9
•C	1.5	0.3775	0.007	0.00197	2.6	143.327	0.168	10.2	47.8	99.6	1678.2	1.6
•D	1.6	0.4299	0.017	0.00377	1.6	142.856	0.089	5.4	53.3	99.2	1674.6	2.8
•E	1.6	1.5215	0.010	0.00180	11.7	142.234	0.057	3.5	56.7	99.7	1669.8	3.7
•F	1.7	0.9017	0.017	0.00144	8.7	142.377	0.093	5.7	62.4	99.7	1670.9	3.0
•G	1.7	0.2113	0.005	0.00004	79.6	143.047	0.230	14	76.4	100	1676	1.7
•H	1.8	1.123	0.015	0.00144	10.7	142.970	0.065	4	80.4	99.7	1675.4	23.0
•I	2	0.4492	0.005	0.00121	5.1	143.638	0.152	9.3	89.7	99.8	1680.5	4.2
J	2.3	0.2898	0.004	0.00172	2.3	144.357	0.169	10.3	100	99.7	1686	3.2
Integrated (total fusion) age:											1684	3
(•) Plateau age:								52.1			1676	3

J: irradiation parameter. ^{40*}Ar: radiogenic ^{40}Ar.
Steps marked with dot (•) are included in the plateau age for each sample.

Table 1 *(continued)*

Step	Pwr/T°C	Ca/K	Cl/K	^{36}Ar/^{39}Ar	%^{36}Ar(Ca)	^{40*}Ar/^{39}Ar	Mol ^{39}Ar	% Step	%^{39}Ar Cumulated	%^{40*}Ar	Age (Ma)	± Age (2σ)
483696 Hornblende (J = 0.01071 ± 0.00001):												
A	1.9	4.9568	0.167	0.02251	3	557.080	0.091	1.9	1.9	98.9	3501.9	4.4
B	2	5.6395	0.198	0.00248	31.3	176.447	0.447	9.5	11.5	99.7	1914.4	1.3
C	2.1	5.7159	0.202	0.00177	44.4	164.542	0.370	7.9	19.4	99.8	1833	1.7
D	2.2	5.9588	0.197	0.00468	17.5	161.233	0.042	0.9	20.3	99.3	1809.7	6.6
E	2.2	5.7368	0.198	0.00147	53.9	161.903	0.098	2.1	22.3	99.9	1814.5	2.5
F	2.3	5.3872	0.190	0.00107	69.3	162.278	1.212	26.4	48.8	99.9	1817.1	1.0
•G	2.3	5.3337	0.184	0.00097	75.5	157.503	1.620	34.6	83.4	100	1783.1	1.3
•H	2.4	5.3052	0.209	0.00097	75.2	157.732	0.242	5.2	88.5	100	1784.7	1.6
•I	2.6	6.2547	0.255	0.00436	19.8	161.354	0.017	0.4	88.9	99.4	1810.6	13.4
•J	2.9	7.1602	0.246	0.00815	12.1	156.396	0.009	0.2	89.1	98.7	1775.1	13.0
•K	4	5.4765	0.189	0.00181	41.7	158.216	0.511	10.9	100	99.8	1788.2	1.6
Integrated (total fusion) age:											1864	2
(•) Plateau age:								51.2			1785	3
483708 Hornblende (J = 0.01071 ± 0.00001):												
A	1.9	7.672	0.051	0.00834	12.7	181.053	0.134	8.2	8.2	98.8	1945	2.2
•B	2	9.5527	0.062	0.00197	66.7	157.766	0.855	52.6	60.8	99.9	1785	1.0
•C	2.1	9.6506	0.062	0.00317	42	157.637	0.376	23.2	84	99.7	1784.1	1.5
•D	2.2	8.7213	0.062	0.00050	241.2	157.711	0.054	3.3	87.3	100.1	1784.6	3.8
•E	2.3	10.597	0.109	0.00836	17.5	157.274	0.024	1.5	88.7	98.7	1781.5	8.4
•F	2.4	13.824	0.144	0.00502	38	156.401	0.012	0.7	89.5	99.4	1775.2	12.1
•G	2.7	10.368	0.067	0.00298	47.9	157.265	0.171	10.5	100	99.7	1781.4	3.3
Integrated (total fusion) age:											1798	3
(•) Plateau age:								91.8			1784	3

Whereas the tectonic model of Grocott & Pulvertaft (1990) operated with four contractional and three extensional events in an epicontinental marginal basin, four main phases of deformation that developed during progressive crustal shortening are now recognised. It has been debated in recent years whether the previous distinction between the Rinkian and Nagssugtoqidian belts in West Greenland is meaningful in tectonic terms (e.g. Garde & Steenfelt 1999a; van Gool *et al.* 2002), and it has now been proposed that the two belts represent the northern and southern parts of a common, more than 1100 km wide collisional orogen, separated by a suture located in the Disko Bugt region (Fig. 1; Connelly *et al.* 2005). The continuous crustal shortening in the Rinkian fold belt throughout its tectonic evolution is in agreement with a setting within the northern of two colliding plates at some distance from the suture, and thus in accordance with the proposed tectonic linkage to the Nagssugtoqidian orogen. However, the ^{40}Ar/^{39}Ar data presented in the following section may be interpreted to indicate that the tectonometamorphic events in the Rinkian and Nagssugtoqidian belts were not contemporaneous.

Descriptions of samples and results of ^{40}Ar/^{39}Ar age determinations

Four hornblende samples and three muscovite samples were collected at the head of Ukkusissat Fjord close to the Prøven igneous complex, between Svartenhuk and Uummannaq, and close to the north coast of Nuussuaq (Fig. 1). Sample numbers refer to the data base of the Geological Survey of Denmark and Greenland.

Ukkusissat Fjord near the Prøven igneous complex

A sample with hornblende was collected south of the Prøven igneous complex, within the high-grade contact metamorphic aureole where extensive partial melting has been observed, particularly within the Karrat Group (Grocott & Pulvertaft 1990). The sample (483657, Fig. 1) comes from a homogeneous, medium-grained, amphibolitic relict dyke within the regional flat-lying tonalitic orthogneiss basement. The amphibolite dyke is approximately one metre thick, a few metres long, and has been isoclinally folded. The sample is mostly composed of light to dark green hornblende between 0.5 and 1 mm in diameter, together with some plagioclase and minor phases such as biotite, titanite and zoizite. The biotite is intergrown with hornblende, and the plagioclase is partly altered to sericite. The obtained plateau age is 1795 ± 3 Ma (Fig 2; Table 1).

North-eastern Uummannaq

Four samples were collected in the Kangilleq–Kangerlussuaq area, 75–100 km north of Uummannaq (Fig. 1). This area was less intensely affected by Rinkian metamorphism than other areas investigated in this study, with chlorite schist locally preserved on the north coast of Qeqertarsuaq.

Samples 483653 and 483654, both from the Nukavsak Formation, were collected at two localities close to each other near the southern end of Qeqertarsuaq (Fig. 1). Sample 483653 (Fig. 1) is a greywacke consisting of biotite, sillimanite, quartz, muscovite and small amounts of tourmaline and zircon. It is a fine-grained rock, where biotite and muscovite together define the main tectonic foliation. Fibrolitic sillimanite occurs in broom-shaped clusters close to muscovite. It was difficult to obtain a good separate from this sample because the muscovite is very fine grained, intergrown with biotite, and sometimes has altered rims. This sample yielded a u-shaped spectrum, with a minimum which yields an age of 1681 ± 6 Ma and represents 24% of the total ^{39}Ar-release (Fig. 2; Table 1).

Sample 483654 (Fig. 1) is a fine-grained andalusite schist with centimetre-sized andalusite poikiloblasts in a matrix of biotite and quartz, minor tourmaline and muscovite. Partial recrystallisation of andalusite to fibrolite was observed. The biotite shows two different orientations implying growth both during D2 and D3 deformation. The muscovite crystals are very small and often occur close to biotite, but sometimes also in small separate clusters. This sample gave a u-shaped spectrum, with a minimum representing 26% of the total ^{39}Ar-release and yielding an age of 1686 ± 3 Ma (Fig. 2; Table 1).

Sample 483667 (Fig. 1) was collected from a decimetre-thick, boudinaged, homogeneous amphibolite band in tonalitic reworked orthogneiss on Qinngusaaq (Fig. 1). Folds, lineations, δ- and σ-shaped porphyroclasts and foliations representing both D2–D3 and D4 occur at the sampling locality. The light to dark brownish-green hornblende forms well-crystallised medium-grained aggregates with interstitial plagioclase partly altered to sericite. Small grains of pale green pyroxene, probably diopside, occur together with the hornblende. A hornblende plateau age of 1782 ± 2 Ma was obtained (Fig. 2; Table 1).

Sample 483671 (Fig. 1) consists of fine-grained metasandstone to metasiltstone from the Nukavsak Formation with quartz, biotite, muscovite and sillimanite as main minerals. Biotite, muscovite and sillimanite define the main tectonic foliation, where sillimanite often occurs in clusters containing small muscovite and biotite grains. At this locality, quartz pods display distinct asymmetries in two different directions. The asymmetric pods on rock faces with SW–NE orientations suggest top-to-NE tectonic transport (during D2), whereas rock faces with SE–NW orientations suggest transport to the NW (during D3) and contain biotite lineations with that trend. Muscovite from this rock, presumably grown during D3, gave a plateau age of 1676 ± 3 Ma (Fig. 2; Table 1).

South-east of Uummannaq

Two samples with hornblende were collected from the Archaean basement south-east of the Uummannaq area, close to the north coast of Nuussuaq (Fig. 1). Sample 483696 (Fig. 1) comes from a hornblenditic layer in a leucogabbro that occurs as enclaves in quartzo-feldspathic orthogneiss. The sample consists almost exclusively of light to dark green, medium- to coarse-grained hornblende. The hornblende plateau age is 1785 ± 3 Ma (Fig. 2; Table 1).

Sample 483708 (Fig. 2) comes from an amphibolite dyke that cuts the fabric of the surrounding augen gneiss and is probably Palaeoproterozoic in age. Both the amphibolite and the host gneiss are intensely deformed. This sample has biotite and hornblende growing together, feldspars partly altered to sericite, and minor amounts of quartz. The hornblende plateau age is 1784 ± 3 Ma (Fig. 2; Table 1).

Discussion and conclusions

The results from this study provide the first published constraints on cooling ages of hornblende and muscovite in the central Rinkian belt. Hornblende ^{40}Ar/^{39}Ar plateau age spectra from samples 483657, 483667 and 483708 yield ages between 1795 and 1782 Ma. These ages all form well-defined plateaus, and the plateaus represent more than 90% of total ^{39}Ar release. Sample 483696 yielded a plateau age of 1785 Ma for 51% of the total ^{39}Ar release, and is consistent with the other hornblende ages. Muscovite samples 483653 and 483654 both yield u-shaped age spectra with minima representing less than 50% of the total ^{39}Ar release, at 1681 and 1686 Ma respectively. Sample 483671 provides a plateau age of 1676 Ma defined by

52% of the total ^{39}Ar release. The muscovite plateau age spectrum for sample 483671 is consistent with the minima provided by samples 483653 and 483654. These taken together suggest a relatively consistent muscovite cooling age below 350°C of *c.* 1680 Ma in the central Rinkian belt.

The obtained hornblende and muscovite ages at 1795–1782 and 1686–1676 Ma, respectively, are remarkably uniform, although they cover a distance of *c.* 200 km in chlorite to sillimanite grade amphibolite facies terrain across the entire central part of the Rinkian fold belt. This ^{40}Ar/^{39}Ar age study shows that the temperatures reached during the Palaeoproterozoic tectonothermal reworking were everywhere sufficiently high to reset the ^{40}Ar/^{39}Ar hornblende and muscovite systems in the rocks examined. The ages date the cooling below the closure temperature of Ar diffusion in hornblende and muscovite after the Palaeoproterozoic metamorphic event, and the data suggest a slow cooling rate of *c.* 1.5°C/Ma between *c.* 1780 and 1680 Ma, using closure temperatures of 500°C for hornblende and 350°C for muscovite (McDougall & Harrison 1999).

Due to recent recalculation of the primary and secondary standards used in ^{40}Ar/^{39}Ar geochronological experiments (Renne *et al.* 1998), the previously published ^{40}Ar/^{39}Ar ages from the Nagssugtoqidian belt (Rasmussen & Holm 1999; Williigers *et al.* 2001, 2002), which use the older standard age, have to be multiplied by 1.009 in order to compare directly with the new ^{40}Ar/^{39}Ar ages presented here from the Rinkian belt. In the northern part of the Nagssugtoqidian orogen, Williigers *et al.* (2001, 2002) obtained ^{40}Ar/^{39}Ar hornblende ages of 1756–1733 Ma (recalculated from 1740–1717 Ma) and muscovite ages of *c.* 1715 Ma (recalculated from 1700 Ma). In the central part of the orogen still farther south, their hornblende ages range between *c.* 1750–1700 Ma and muscovite ages between *c.* 1765–1715 Ma (recalculated from 1750–1700 Ma). In the Disko Bugt area (Fig. 1), where Connelly *et al.* (2005) proposed a suture between the two belts, a set of ^{40}Ar/^{39}Ar and K-Ar hornblende age data reported by Rasmussen & Holm (1999) scatter between Archaean ages and a K-Ar age of *c.* 1765 Ma, revealing that temperatures during the Palaeoproterozoic thermal event were not sufficiently high in all parts of this area to reset the K-Ar isotope system (Rasmussen & Holm 1999).

The uniformity of the new ^{40}Ar/^{39}Ar ages from the central and northern Rinkian fold belt suggests that the ages are largely unrelated to the metamorphic grade and to the structural history of the geographical locations of the samples, with the possible exception of sample 483657 from Ukkusissat Fjord (see below). Accordingly, the ^{40}Ar/^{39}Ar data are interpreted as regional, late orogenic cooling ages which are not directly related to the tectono-metamorphic history of the individual samples. This conclusion is supported by (in part unpublished) U-Pb zircon ages of syn- to late-kinematic Palaeoproterozoic pegmatites from the same region, which are older than 1800 Ma (Thrane *et al.* 2003; K. Thrane, personal communication 2004).

Williigers *et al.* (2002) reached the same conclusion from their ^{40}Ar/^{39}Ar studies of the central and northern Nagssugtoqidian orogen reported above, pointing out that their study area represents a section of middle to lower crust that was only slowly exhumed by erosion.

In preserved upper crustal levels of younger orogens it is commonly possible to date specific tectonic events using the ^{40}Ar/^{39}Ar method, because the dated units were either transported rapidly to these crustal levels and are not yet eroded away, or the minerals grew at temperatures near or below their closing temperature and thus constrain the age of the prograde tectonothermal event itself. The 1795 ± 3 Ma age of the hornblende from Ukkusissat Fjord (sample 483657, about 12 Ma older than the other hornblende ages) may point to early uplift of this particular area, which is a domain of early NE-directed D2 thrusting that was not affected by the subsequent NW-directed tectonic transport during D3.

The cooling rate of *c.* 1.5°C/Ma documented by this study (using hornblende and muscovite closure temperatures of 500°C and 350°C) is only slightly slower than the 2–3°C/Ma reported by Williigers *et al.* (2001, 2002) from the central Nagssugtoqidian orogen, but considerably slower than rates between 5° and 7°C/Ma reported by the latter authors from the northern Nagssugtoqidian orogen. Williigers *et al.* (2001, 2002) used less accepted closure temperatures of 580°C and 410°C for hornblende and muscovite, respectively, implying a difference of 170°C between hornblende and muscovite closure temperatures. The latter temperature gap is larger than the 150°C used in this study, but this makes little difference to the calculation of cooling rates.

The uniform ^{40}Ar/^{39}Ar hornblende ages resulting from the present investigation are significantly older than those in both the northern and central parts of the Nagssugtoqidian orogen (Williigers *et al.* 2001, 2002). As regards muscovite, the Rinkian muscovite ages are younger than muscovite ages in the northern Nagssugtoqidian belt, but older than those in the central Nagssugtoqidian orogen (Williigers *et al.* 2001, 2002). The fact that Rinkian hornblende ages are older than those in the Nagssugtoqidian orogen shows that cooling below 500°C took place earlier in the Rinkian fold belt than in both the central and northern parts of the Nagssugtoqidian orogen. It is therefore plausible that uplift began significantly earlier in the Rinkian belt but was slower than in the Nagssugtoqidian orogen, which may in turn suggest that the main phases of compression and peak metamorphism in the two belts were not synchronous.

These interpretations are consistent with the observation by Taylor & Kalsbeek (1990) that Pb-Pb whole-rock isochron ages of marbles in the two belts (interpreted as representing recrystallisation of the marbles during peak metamorphism) differ significantly from each other. Marbles collected on Appat island in the central Rinkian belt (Fig. 1) yielded a Pb-Pb isochron of 1881 ± 20 Ma, whereas an age of 1845 ± 23 Ma was obtained from marbles in the central part of the Nagssugtoqidian orogen. Our interpretations are also consistent with the fact that the ^{40}Ar/^{39}Ar data reported here show no signs of having been affected by a contact metamorphic aureole around the Prøven igneous complex. The intrusion age of the latter at 1869 ± 9 Ma is coeval with the youngest members of the Arfersiorfik complex and Sisimiut charnockite in the central Nagssugtoqidian orogen (Connelly *et al.* 2000; van Gool *et al.* 2002). The Prøven igneous complex has intruded rocks belonging to the Karrat Group that were already intensely deformed and metamorphosed prior to the intrusion, but before the last major deformation and peak metamorphism (Thrane *et al.* 2005); the Prøven igneous complex represents a crustal melt that was apparently not related to subduction processes. In contrast, the Arfersiorfik complex and Sisimiut charnockite in the south represent I-type magmas that were related to precollision subduction.

Notwithstanding the overall structural and geochronological evidence for a direct linkage between the Rinkian fold belt and the Nagssugtoqidian orogen, the age relationships outlined above may imply that collision-related deformation, metamorphism and magmatic activity took place in the northern Rinkian belt while subduction was still going on south of the recently proposed suture in the Disko Bugt region. It may be speculated that such diachronism is also reflected in the dissimilar ^{40}Ar/^{39}Ar cooling ages from the Rinkian and Nagssugtoqidian parts of the entire Palaeoproterozoic orogenic complex in West Greenland. Alternatively, the different Rinkian and Nagssugtoqidian cooling ages might relate to different depths of burial. However, this is not supported by the uniform hornblende ^{40}Ar/^{39}Ar cooling ages found within the Rinkian belt itself, regardless of geographical distance and metamorphic facies; further discussion of large-scale plate-tectonic implications is beyond the scope of the present paper.

Analytical procedure

Four hornblende and three muscovite separates from the central Rinkian belt have been dated with the ^{40}Ar/^{39}Ar-method. The hornblende separates were obtained from amphibolite and diorite, and muscovite from metasedimentary rocks, by crushing, sieving and handpicking. The hornblende and muscovite samples selected for ^{40}Ar/^{39}Ar geochronology were irradiated together with the DRA-2 sanidine standard (25.26 Ma; Wijbrans *et al.* 1995, recalculated following Renne *et al.* 1998), for 35 hours at the NRG-Petten HFR RODEO facility in Petten, The Netherlands. J-values (the irradiation parameter) were calculated with a precision of 0.5%.

The ^{40}Ar/^{39}Ar geochronology laboratory at the University of Lund employs a Micromass 5400 mass spectrometer with a Faraday cup and an electron multiplier. A metal extraction line, which contains two SAES C50-ST101 Zr-Al getters and a cold finger cooled to *c.* –155°C by a Polycold P100 cryogenic refrigeration unit, is also present. One or two grains of hornblende or muscovite were loaded into a copper planchette that consists of several 3 mm holes. Samples were step-heated using a defocused 50W CO^2 laser. Sample clean-up time was 5 minutes, using the two hot Zr-Al SAES getters and the cold finger. The laser was rastered over the samples to provide even heating of all grains. The entire analytical process is automated and runs on a Macintosh computer with software developed at the Berkeley Geochronology Center by Al Deino and modified for the laboratory at the University of Lund. Time zero regressions were fitted to data collected from 10 scans over the mass range of 40 to 36. Peak heights and backgrounds were corrected for mass discrimination, isotopic decay and interfering nucleogenic Ca-, K-, and Cl-derived isotopes. Isotopic production values for the cadmium lined position in the Petten reactor are $^{36}\mathrm{Ar}/^{37}\mathrm{Ar}_{(\mathrm{Ca})} = 0.000270$, $^{39}\mathrm{Ar}/^{37}\mathrm{Ar}_{(\mathrm{Ca})} = 0.000699$, and $^{40}\mathrm{Ar}/^{39}\mathrm{Ar}_{(\mathrm{K})} = 0.00183$. ^{40}Ar blanks were calculated before every new sample and after every three sample steps. ^{40}Ar blanks were between 5.0 and 3×10^{-16}. Blank values for masses 39 to 36 were all less than 7×10^{-18}. Blank values were subtracted for all incremental steps from the sample signal. The laboratory was able to produce very good incremental gas splits, using a combination of increasing time at the same laser output, followed by increasing laser output. Age plateaus were determined using the criteria of Dalrymple & Lanphere (1971), which specify the presence of at least three contiguous incremental heating steps with statistically indistinguishable ages and constituting greater than 50% of the total ^{39}Ar released during the experiment. Inverse isochrons yield ages statistically indistinguishable from those given by the plateaus and are not presented here. ^{40}Ar/^{39}Ar plateau age spectra are presented in Fig. 2 and the analytical data in Table 1.

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