



Search for Archaean basement in the Caledonian fold belt of North-East Greenland

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SHRIMP U-Pb isotope data on zircon crystals from a gneiss sample near Danmarkshavn, where the presence of Archaean rocks has earlier been documented, show that the rock has undergone a complex history of igneous and metamorphic zircon growth. At least three generations of zircon are present with ages of *c.* 3000 Ma, *c.* 2725 Ma and 1967 ± 8 Ma (2σ). Apparently the rock was formed from an Archaean protolith which underwent high grade metamorphism during the early Proterozoic. Another sample from the easternmost exposures of the Caledonian basement, collected further north, yielded only early Proterozoic zircons with an age of 1963 ± 6 Ma. Together with a SHRIMP U-Pb zircon age of 1974 ± 17 Ma reported earlier, these results give evidence of a major igneous and metamorphic event in North-East Greenland about 1965 Ma ago.

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Early Precambrian orthogneisses make up a major part of the crystalline basement of the Caledonian fold belt in North-East Greenland (Henriksen, 1991; Chadwick & Friend, 1991; Friderichsen *et al.*, 1991). Prior to GGU's 1988–90 mapping project in this region the only reliable age determination on these rocks gave *c.* 3000 Ma for a banded gneiss collected near Danmarkshavn (zircon U-Pb and whole-rock Rb-Sr data, Steiger *et al.*, 1976; Fig. 1). Isotopic data (Sm-Nd and Rb-Sr model ages and SHRIMP U-Pb zircon dates) collected in connection with GGU's recent work, however, showed that most of the crystalline basement of the Caledonian fold belt in North-East Greenland is of early Proterozoic age. No further evidence of the presence of Archaean rocks was found, although more than 30 localities were studied (Kalsbeek *et al.*, 1993). The present SHRIMP U-Pb zircon study had two aims: first, to seek confirmation of the Archaean age of the banded gneisses at Danmarkshavn; second, since the Danmarkshavn gneiss studied by Steiger *et al.* (1976) was collected in the eastern part of the exposed Caledonian basement (Fig. 1), to test whether more extensive units of Archaean gneisses existed in the easternmost parts of the investigated region. For the second purpose a sample was chosen from a site *c.* 110 km north of Danmarkshavn (Fig. 1), which possibly could belong to such an Archaean crustal block.

Banded gneiss from Danmarkshavn (GGU 365358)

This sample was taken from a locality near Danmarkshavn ($76^{\circ}46.1'N$, $18^{\circ}39'W$), 2 km along strike north of the site where the material studied by Steiger *et al.* (1976) had been collected, and in the same banded gneiss. The rock is a medium-grained tonalitic gneiss with a strong planar fabric, consisting of plagioclase, quartz, biotite (*c.* 10%) with some hornblende and subordinate garnet, apatite, zircon and opaque minerals. The gneisses are cut by numerous metabasic dykes at high metamorphic grade (amphibolite and granulite facies). The outcrop is characterised by alternating zones of high and low strain. Within the high-strain zones both the gneisses and the metabasic dykes are strongly deformed.

GGU sample 365358 yielded a diverse population of zircons. Grains are mostly prismatic and 200 to 300 μm long. All are distinctly rounded, and some have embayed prismatic faces, indicating metamorphic corrosion rather than sedimentary abrasion. Many grains have zoned, yellow or brown, partly metamict cores and clear, structureless overgrowths. Some cores are not located in the centre of their grains. Other grains are devoid of cores and consist entirely of clear, structureless zircon.

Analysis with the ion microprobe SHRIMP 1 followed

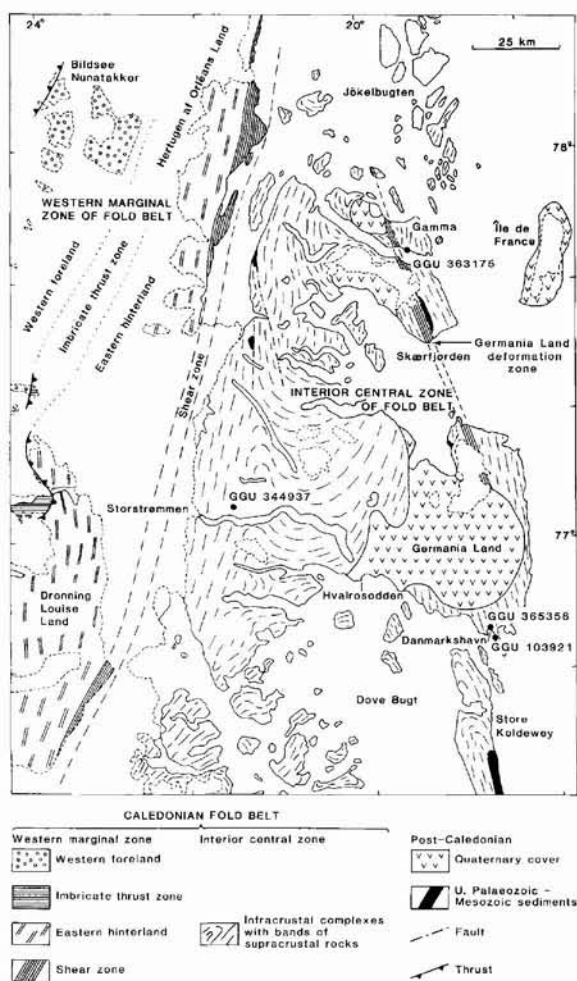


Fig. 1. Geological sketch map of the Dove Bugt - Jökelbugten region in North-East Greenland, with localities of samples mentioned in the text. GGU 103921 is the sample studied by Steiger *et al.* (1976).

routine analytical procedures (e.g. Compston *et al.*, 1984; Williams & Claesson, 1987). Thirty-six analyses were undertaken on 28 grains (Table 1A, Fig. 2A). Most of the analysed sites have moderate to high U content (typically 300–1000 ppm) but with highly variable Th/U ratios (0.02–0.8). $^{207}\text{Pb}/^{206}\text{Pb}$ ages range from *c.* 1900 to 3000 Ma. All analysed Archaean zircons yielded discordant ages, but some early Proterozoic zircons yielded concordant ages. The oldest zircons detected yielded $^{207}\text{Pb}/^{206}\text{Pb}$ ages between 2900 and 3000 Ma, and only occur as high U (900–2000 ppm) coloured, strongly zoned cores. Zircon with $^{207}\text{Pb}/^{206}\text{Pb}$ ages between 2600 and 2800 Ma is structureless or weakly zoned and forms overgrowths on > 2900 Ma zircon, whole grains and cores to Proterozoic overgrowths. The marked discordance of the Archaean zircon components (Fig. 2A) due to Proterozoic, Caledo-

nian and possibly modern Pb-loss precludes the possibility of reliable age determinations. However, the results clearly demonstrate that a *c.* 3000 Ma or slightly older component is present, and that in the late Archaean either a new igneous component was added or high grade metamorphism led to zircon growth in a *c.* 3000 Ma rock.

Analysed Proterozoic zircon is generally clearer and less zoned than Archaean zircon. A group of analyses which consist of both whole grains and overgrowths (commonly with low Th/U) on Archaean zircon are close to concordant at *c.* 1950 Ma, or discordant with slightly younger $^{207}\text{Pb}/^{206}\text{Pb}$ ages and scatter along a reference chord to 380 Ma (the U-Th-Pb age of titanite from this locality, Steiger *et al.*, 1976; Fig. 2B). The most concordant sites of this group yield a weighted mean $^{207}\text{Pb}/^{206}\text{Pb}$ age of 1967 ± 8 Ma (all precisions in this paper quoted at 2σ level), which is interpreted as the time of a high grade metamorphic event and possibly injection of new components. A few morphologically similar sites yield somewhat older ages, and indicate that a *c.* 2100 Ma component might also be present. No Caledonian zircon overgrowths were found. However, the Pb loss pattern of the 1967 ± 8 Ma zircons is consistent with some radiogenic Pb loss during the Caledonian orogeny.

Tonalite from Gamma Ø (GGU sample 363175)

The sample was collected on Gamma Ø ($77^{\circ}44.6'\text{N}$, $19^{\circ}18'\text{W}$; Fig. 1), east of the Germania Land deformation zone (Hull & Gilotti, 1994). It represents a tonalitic gneiss with hornblende as the main mafic mineral, and is strongly deformed with a blastomylonitic texture. GGU sample 363175 yielded a uniform population of sub-hedral prismatic grains, typically 200–300 μm long. The grains are devoid of structure or only weakly zoned, colourless or pale brown or yellow. No clear evidence of structural cores or overgrowths could be seen optically.

Thirty-six analyses were undertaken on 24 grains (Table 1B) during two analytical sessions (see below). Even with duplicate analyses on many grains no older inherited cores were detected. All analysed sites had moderate U contents (mostly 100–250 ppm) and moderate Th/U ratios (mostly 0.2–0.4). On a concordia plot (Fig. 2C) all analyses form a single array in which most analyses are concordant at *c.* 1950 Ma, with the remainder slightly discordant, commonly with slightly younger $^{207}\text{Pb}/^{206}\text{Pb}$ ages. In the first session when 22 analyses were undertaken, there was a slight problem of overcounting ^{204}Pb , giving rise to over-correction for common Pb and slightly too young $^{207}\text{Pb}/^{206}\text{Pb}$ ages. On a $^{206}\text{Pb}/^{208}\text{Pb}$ versus $^{238}\text{U}/^{232}\text{Th}$ plot the data fall on a 1965 Ma reference line, indicating that use of the ^{248}Pb correction method for

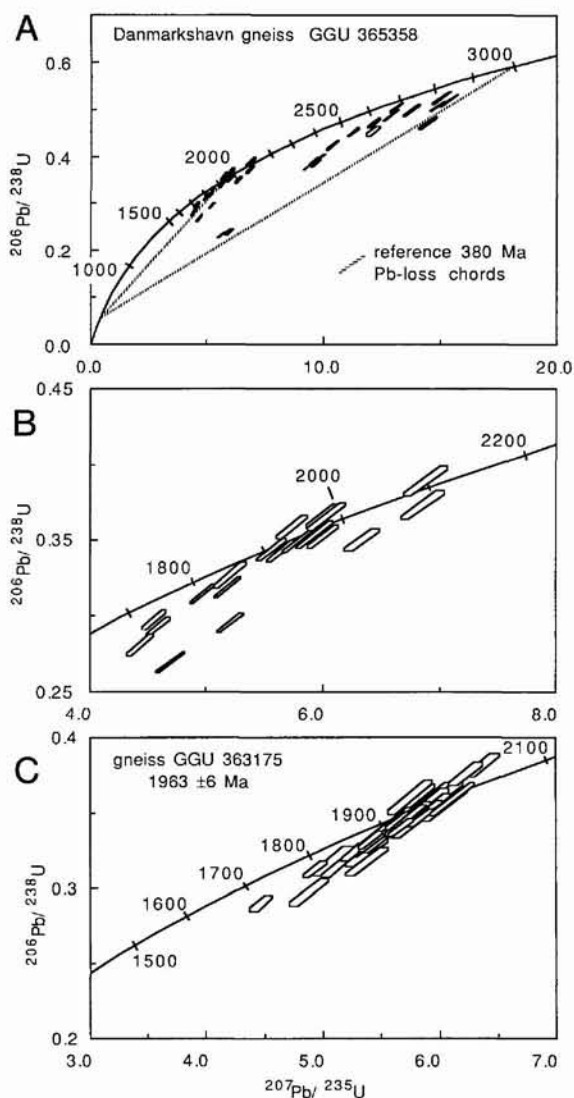


Fig. 2A-C. SHRIMP zircon U-Pb data for two gneiss samples from the Precambrian basement of the Caledonian fold in North-East Greenland.

common Pb (Compston *et al.*, 1984) is likely to be a valid procedure. By this method the analyses that are indistinguishable from each other yielded a weighted mean $^{207}\text{Pb}/^{206}\text{Pb}$ age of 1962 ± 9 Ma, agreeing well with the $^{206}\text{Pb}/^{238}\text{U}$ age of 1963 ± 26 Ma. For the second analytical session the ^{208}Pb and ^{204}Pb correction methods gave rise to weighted mean $^{207}\text{Pb}/^{206}\text{Pb}$ ages indistinguishable from each other (1963 ± 9 and 1953 ± 9 Ma, respectively), giving extra confidence to the reliability of the calculated age from the first session. When the results of both analytical sessions are pooled, data corrected for common Pb using the ^{208}Pb method give rise to a weighted mean

age of 1963 ± 6 Ma, interpreted as giving the age of crystallisation of the igneous protolith of GGU 363175.

Discussion

The results for the Danmarkshavn sample (GGU 365358) show that this rock was formed from an Archaean protolith, in agreement with the findings of Steiger *et al.* (1976). These authors believed that the banded gneisses were of sedimentary origin, and it must therefore be considered whether the Archaean zircons could be clastic grains in an early Proterozoic sediment. Several observations argue against this possibility: (1) Whole-rock Rb-Sr isotope data for different layers of the banded gneiss scatter along an Archaean (*c.* 3000 Ma) isochron (Steiger *et al.*, 1976); (2) The investigated sample is of normal tonalitic composition and is not reminiscent of a paragneiss; (3) Zircon morphology does not suggest sedimentary abrasion (see above). We therefore regard the analysed sample as an orthogneiss, which because of the presence of Archaean zircons must be of Archaean origin. Early Proterozoic zircon apparently grew during high grade metamorphism around 1965 Ma ago. The presence of 1965 Ma zircons with high, 'igneous', Th/U ratios may indicate that the rock underwent incipient melting at that time. However, this is not evident from the sample, since no distinct quartzo-feldspathic sweats are present. Moreover, the rock as a whole cannot be the product of Proterozoic anatexis of an Archaean parent because it does not have the K-rich composition of an anatectic granite.

The tonalite (GGU 363175) collected further north (age 1963 ± 6 Ma) was emplaced at about the time when high-grade metamorphism took place at Danmarkshavn. Another tonalitic gneiss (GGU 344937) which has been studied earlier, yielded a comparable age (1974 ± 17 Ma; Kalsbeek *et al.*, 1993).

In summary, the data provide evidence of a major igneous and metamorphic event in North-East Greenland about 1965 Ma ago. The presence of Archaean rocks at Danmarkshavn was confirmed, but this is still the only place where such rocks have been documented in North-East Greenland. Caledonian metamorphism, documented by mineral isotope data (Steiger *et al.*, 1976; Brueckner & Gilotti, 1993; Dallmeyer & Strachan, 1994) is in this study only recorded by small degrees of Pb loss from parts of the analysed zircons.

Acknowledgements. The investigated samples were collected by N. Henriksen (GGU 365358) and J. D. Friderichsen (GGU 363175). The manuscript was reviewed by J. D. Friderichsen, J. A. Gilotti, N. Henriksen and A. K. Higgins.

Table 1. SHRIMP zircon U-Pb data for two basement gneisses, North-East Greenland

Site	U (ppm)	Th (ppm)	Th/U	²⁰⁴ Pb (ppb)	Common ²⁰⁶ Pb(%)	²⁰⁶ Pb ²³⁸ U	²⁰⁷ Pb ²³⁵ U	²⁰⁷ Pb ²⁰⁶ Pb	Age (Ma)*	Disc. (%)
<i>A: GGU No 365358</i>										
1-1	664	149	0.22	9	0.07	0.344±07	5.64±0.13	0.1190±07	1942±11	-2
1-2	967	125	0.13	15	0.09	0.319±07	5.21±0.12	0.1184±05	1932±08	-8
2-1o	311	43	0.14	9	0.15	0.350±07	6.33±0.15	0.1313±11	2115±15	-9
3-1o	363	8	0.02	16	0.17	0.471±10	12.17±0.28	0.1876±10	2721±09	-9
4-1	839	193	0.23	22	0.16	0.296±06	5.20±0.12	0.1276±07	2066±09	-19
5-1	445	27	0.06	10	0.12	0.343±07	5.65±0.13	0.1197±09	1952±13	-3
5-2	532	42	0.08	14	0.13	0.366±08	5.95±0.14	0.1180±08	1926±12	4
7-1	477	279	0.59	27	0.27	0.387±08	9.65±0.22	0.1808±10	2660±09	-21
8-1	1167	209	0.18	<1	<0.01	0.315±07	4.97±0.11	0.1146±04	1873±07	-6
9-1	602	129	0.21	38	0.40	0.297±06	4.55±0.11	0.1110±08	1816±13	-8
10-1	418	197	0.47	21	0.18	0.504±11	13.13±0.29	0.1890±08	2733±07	-4
11-1	164	127	0.78	111	2.72	0.454±10	12.12±0.32	0.1936±24	2773±20	-13
12-1	600	29	0.05	29	0.25	0.359±08	5.73±0.13	0.1160±07	1895±11	4
13-1c	1185	410	0.35	7	0.02	0.507±11	14.88±0.32	0.2131±05	2929±04	-10
13-2o	757	64	0.08	26	0.19	0.349±07	5.73±0.13	0.1190±06	1942±09	-1
14-1	506	107	0.21	18	0.22	0.293±06	4.59±0.11	0.1135±09	1856±14	-11
15-1	867	186	0.21	18	0.10	0.380±08	9.34±0.20	0.1784±06	2638±05	-21
15-2	196	109	0.56	8	0.16	0.452±10	11.27±0.27	0.1809±14	2661±13	-10
16-1	214	74	0.34	11	0.24	0.392±08	9.60±0.23	0.1777±13	2631±12	-19
17-1	594	107	0.18	10	0.09	0.352±07	6.00±0.13	0.1235±06	2007±09	-3
18-1	580	40	0.07	4	0.04	0.353±09	5.94±0.16	0.1219±06	1984±09	-2
19-1	1727	105	0.06	18	0.07	0.270±07	4.69±0.12	0.1263±04	2047±06	-25
20-1c	1768	585	0.33	13	0.03	0.519±13	15.38±0.39	0.2148±04	2942±03	-8
20-2o	899	39	0.04	18	0.09	0.396±10	9.81±0.25	0.1797±06	2650±06	-47
21-2c	176	83	0.47	20	0.09	0.240±06	5.93±0.18	0.1790±25	2643±23	-47
21-2o	403	53	0.13	4	0.05	0.327±08	5.20±0.14	0.1154±08	1886±12	-3
22-1c	915	281	0.31	78	0.30	0.525±13	15.07±0.39	0.2080±06	2890±05	-6
22-2o	373	65	0.17	10	0.13	0.389±10	6.88±0.18	0.1283±08	2075±11	2
23-1	332	66	0.20	11	0.16	0.373±09	6.85±0.19	0.1332±10	2141±13	-5
24-1	1237	250	0.20	35	0.11	0.470±12	14.49±0.37	0.2235±05	3006±04	-17
25-1c	548	183	0.33	31	0.21	0.498±13	13.75±0.36	0.2003±08	2828±06	-8
25-2o	505	55	0.11	24	0.18	0.488±12	12.90±0.34	0.1918±08	2758±07	-7
26-1c	2310	412	0.18	29	0.10	0.234±06	5.62±0.14	0.1744±05	2600±05	-15
26-2o	608	156	0.26	30	0.32	0.281±07	4.43±0.12	0.1143±08	1868±13	-15
27-1	373	121	0.33	20	0.24	0.425±11	10.38±0.28	0.1774±10	2628±09	-13
28-1	288	21	0.07	21	0.38	0.364±09	5.91±0.17	0.1177±11	1921±17	4
<i>B: GGU No 363175**</i>										
1-1	227	73	0.32	17	0.38	0.359±07	5.94±0.14	0.1201±11	1958±17	1
1-2	208	61	0.29	10	0.25	0.351±06	5.81±0.12	0.1199±09	1954±13	1
2-1	135	34	0.25	11	0.44	0.337±07	5.50±0.14	0.1183±14	1931±21	-3
3-1	224	69	0.31	6	0.15	0.361±07	5.82±0.14	0.1168±11	1907±16	4
4-1	171	40	0.24	11	0.34	0.363±08	6.05±0.14	0.1208±12	1971±17	1
4-2	206	61	0.30	11	0.27	0.345±06	5.69±0.11	0.1197±09	1951±13	-2
5-1	212	71	0.34	17	0.39	0.376±08	6.22±0.15	0.1202±11	1959±16	5
5-2	217	76	0.35	8	0.22	0.313±06	4.93±0.10	0.1144±09	1870±15	-6
6-1	162	33	0.20	5	0.16	0.381±08	6.37±0.15	0.1211±12	1972±17	6
6-2	163	34	0.21	8	0.24	0.352±06	5.91±0.12	0.1216±08	1980±12	-2
7-1	380	148	0.39	19	0.26	0.352±11	5.90±0.19	0.1215±10	1979±14	-2
8-1	164	36	0.22	26	0.91	0.324±10	5.37±0.18	0.1203±15	1960±22	-8
8-2	269	77	0.29	11	0.22	0.333±06	5.40±0.10	0.1178±08	1924±12	-4
9-1	222	52	0.23	25	0.59	0.354±11	5.94±0.20	0.1217±12	1982±17	-1
9-2	173	58	0.33	14	0.44	0.324±06	5.26±0.11	0.1178±10	1923±16	-6
10-1	136	29	0.21	24	0.96	0.344±11	5.63±0.20	0.1189±15	1939±23	-2

Table 1 continued

Site	U (ppm)	Th (ppm)	Th/U	²⁰⁴ Pb (pp ^b)	Common ²⁰⁶ Pb(%)	²⁰⁶ Pb ²³⁸ U	²⁰⁷ Pb ²³⁵ U	²⁰⁷ Pb ²⁰⁶ Pb	Age (Ma)*	Disc. (%)
11-1	260	53	0.21	25	0.50	0.355±11	6.04±0.20	0.1234±11	2006±15	-2
11-2	212	45	0.21	8	0.19	0.347±06	5.84±0.11	0.1221±08	1988±11	-3
12-1	217	62	0.28	6	0.17	0.318±10	5.37±0.18	0.1226±12	1995±18	-11
12-2	223	72	0.32	16	0.36	0.350±06	5.78±0.11	0.1199±08	1954±11	-1
13-1	185	39	0.21	15	0.50	0.298±09	4.88±0.16	0.1189±13	1940±20	-13
13-2	317	84	0.27	18	0.28	0.345±06	5.64±0.11	0.1184±07	1932±11	-1
14-1	196	39	0.20	26	0.73	0.334±10	5.50±0.18	0.1195±12	1949±18	-5
14-2	144	42	0.29	13	0.50	0.313±06	5.10±0.11	0.1181±11	1928±17	-9
15-1	255	97	0.38	18	0.38	0.344±10	5.78±0.19	0.1218±12	1983±17	-4
16-1	159	42	0.27	14	0.46	0.359±11	5.93±0.20	0.1199±13	1954±20	1
16-2	164	53	0.32	12	0.39	0.347±06	5.78±0.12	0.1208±09	1968±13	-2
17-1	111	23	0.21	17	0.90	0.325±10	5.36±0.19	0.1195±15	1948±23	-7
18-1	100	19	0.19	15	0.88	0.318±10	5.09±0.18	0.1161±17	1898±26	-6
19-1	152	38	0.25	34	1.23	0.331±10	5.40±0.18	0.1183±14	1930±21	-5
19-2	212	63	0.30	15	0.37	0.330±06	5.41±0.11	0.1188±09	1938±13	-5
20-1	247	52	0.21	23	0.49	0.345±10	5.71±0.19	0.1200±10	1956±15	-2
21-1	226	62	0.28	26	0.59	0.360±11	5.75±0.19	0.1157±11	1890±16	5
22-1	488	125	0.26	23	0.24	0.359±11	6.11±0.19	0.1234±07	2006±10	-1
23-1	233	64	0.27	10	0.23	0.341±06	5.66±0.11	0.1206±07	1965±11	-4
24-1	149	49	0.33	35	1.41	0.290±05	4.47±0.10	0.1118±12	1828±19	-10

Notes: ²⁰⁷Pb/²⁰⁶Pb ages corrected for very small amounts of common lead. Uncertainties are given at the 1 σ level. ²⁰⁸Pb correction method employed instead of ²⁰⁴Pb method, see text for explanation. o and c, visible structural overgrowths and cores, respectively. Disc. (%): discordance calculated as $100 \times [(^{206}\text{Pb}/^{238}\text{U} \text{ age}) / (^{207}\text{Pb}/^{206}\text{Pb} \text{ age}) - 1]$.

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