Proterozoic basaltic magmatic periods in North-West Greenland: evidence from K/Ar ages

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This paper is the third of a series reporting on K/Ar whole rock ages of Proterozoic basaltic rocks of the Thule district, North-West Greenland. The dating programme is a co-operative venture between the Geological Survey of Greenland and The University, Leeds, U.K., and was set up in connection with a 1:500 000 mapping project of the region between 75°N and 78° 45′N (Melville Bugt – Inglefield Land, fig. 1). Field work by one of us (PRD) has shown that several episodes of unmetamorphosed Proterozoic basic igneous rocks can be distinguished stratigraphically in the region (see below). The routine K/Ar isotopic work, carried out concurrently with the field work, has aimed at dating these episodes, thereby providing minimum ages for deposition or consolidation of the host rocks.

The two earlier reports (Dawes *et al.*, 1973, 1982a) dealt with sills and dykes from the northern part of the region (Inglefield Land – Prudhoe Land); intrusions that have known or inferred stratigraphic relationships with the Proterozoic Thule Group. The present report gathers together all hitherto unpublished K/Ar dates – 18 in total on both extrusive and intrusive rocks – mainly from the central and southern parts of the region (Inglefield Bredning and Melville Bugt). Six of the samples represent cross-cutting intrusions in the Precambrian Shield that have uncertain age relationships with the overlying Thule Group.

Regional geology

North-West Greenland between 75° and 78° 45′N is composed of two geological provinces: Precambrian Shield containing both Archaean and Proterozoic elements and the overlying unmetamorphosed Proterozoic Thule Basin (figs 1 & 2). This basin occupies the outer coastal region; corresponding outcrops occur on the opposite side of Baffin Bay on eastern Ellesmere Island (Dawes *et al.*, 1982b; Frisch & Christie, 1982).

The Thule Basin succession is essentially undeformed but regional extension faults cut outcrops up into a number of fault blocks. Where preserved, the shield – Thule Group contact indicates that a major period of uplift, erosion, and in places peneplanation, occurred prior to subsidence and formation of the Thule Basin (fig. 2).

The Thule Group is composed of a thick and varied sedimentary sequence; one unit contains effusive strata. As presently defined the group is divided into three formations (from oldest to youngest): Wolstenholme Formation (multicoloured coarse clastics and volcanics), Dundas Formation (dark shales), and Narssârssuk Formation (cyclic red beds with evaporites). Age-diagnostic fossils are restricted to acritarch assemblages that indicate a Late Riphean age for the middle and upper parts of the Wolstenholme Formation and the Dundas Formation, and a Vendian age for the Narssârssuk Formation (?including uppermost Dundas Formation) (Vidal & Dawes, 1980; Dawes & Vidal, 1985). The lower Wolstenholme Formation has not yielded age-diagnostic fossils (only stromatolites), and the age of the basal strata can only be inferred from radiometric dating of basaltic rocks (reported on here),

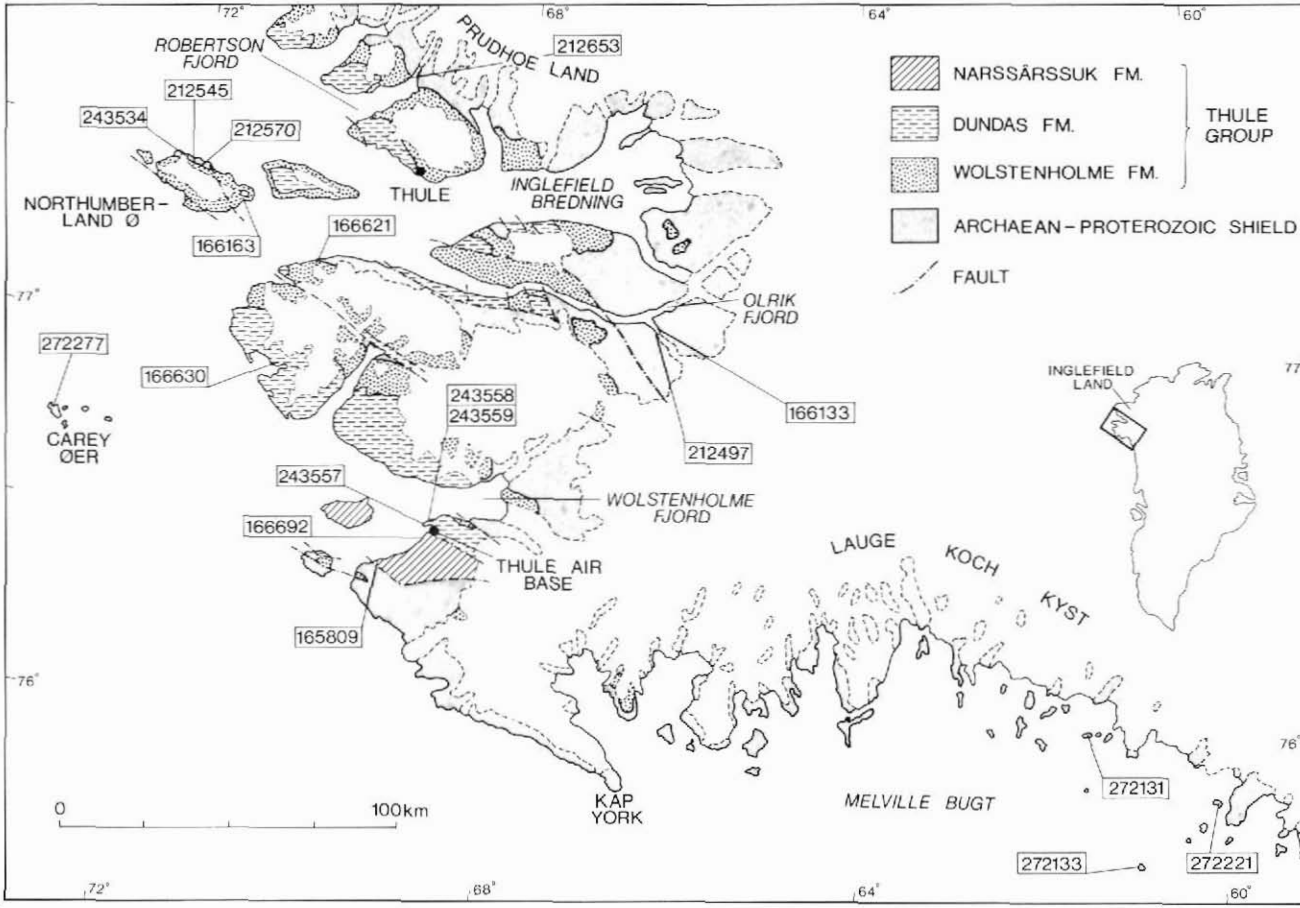

Fig. 1. Geological map of Thule district, North-West Greenland, showing locations of the 18 samples used in the K/Ar dating programme. Kap Trautwine (fig. 2) is at locality 166621; Dundas Fjeld (fig. 3) at locality 243557.

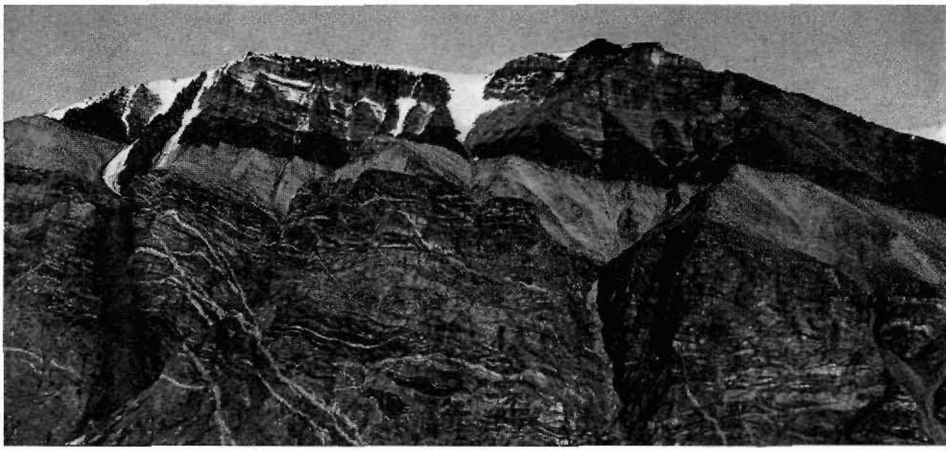

Fig. 2. Coastal section at Kap Trautwine (see fig. 1) showing Precambrian Shield (Aphebian–Palaeohelikian) overlain by the Proterozoic Thule Group (Wolstenholme Formation); the whole section is cut by a WNW-trending Hadrynian basic dyke. Dark unit near base of Thule succession is the volcanic-hypabyssal basalt unit (Neohelikian) from which sample 166621 was taken. Height of cliffs about 750 m.

and from regional correlation with other intracratonic basins of North America (Young, 1979).

Stratigraphic ages of basaltic rocks

Established and inferred field relationships of basaltic rocks with Thule Group strata, as well as intrusion intersections, demonstrate that four main episodes of Proterozoic magmatism affected North-West Greenland. These are (from oldest upwards):

(4) Basic dykes, mainly a WNW-trending swarm that cuts the Narssârssuk Formation.

(3) Basic sills that cut the Wolstenholme and Dundas Formations but are cut by dykes of group 4.

(2) Flows and sills in the lower part of the Wolstenholme Formation (unit 2 of Dawes *et al.*, 1982b).

(1) Basic dykes of various trends that cut the gneisses and associated crystalline rocks of the Precambrian Shield but are not seen in the overlying Thule Group.

Aim of study

Previous K/Ar ages fall into two ranges: 1200–1000 Ma and 800–600 Ma indicating a Neohelikian age for intrusions of group 2 and a Hadrynian age for groups 3 and 4 (Dawes *et al.*, 1973, 1982a). A single K/Ar age of 1563 ± 60 Ma on a dyke of group 1 suggests a Palaeohelikian age for the pre–Thule Group minor intrusions.

The material used in the present study was selected in an attempt to refine the K/Ar age intervals of the chronology, in particular to clarify three main aspects:

Table 1. K/Ar whole rock age and details of basaltic samples from North-West Greenland

K/Ar age group Dawes et al. 1973	GGU sample no.	Approx. coordinate position	Geological setting	Stratigraphic age inference	% K	Vol ^{40}Ar rad. cm^3 STP/g x 10^{-4}	% ^{40}Ar rad.	Age m.y.
	243534	77°26'N 72°10'W	Sill (?) in volcanic - red bed strata, Kissel Gletscher, Northumberland Ø	?Post-lower Wolstenholme Formation	0.814	1.5356 1.5469	90.0 86.0	431 $\pm$ 13
3. Hadrynian	165809	76°27'N 69°15'W	WNW dyke cutting red beds, Nungarutipaluk, Narssârssuk	Post-Narssârssuk Formation	1.451	0.4376	91.2	645 $\pm$ 26
	166630	76°56'N 70°45'W	Sill cutting siltstones and shales, Igánap timâ, Booth Sund	Post-Dundas Formation	0.510	1.5483 1.6148	81.2 78.6	661 $\pm$ 20
	166163	77°20'N 71°34'W	Sill cutting sandstones and shales, Qagssissalik, Northumberland Ø	Post-uppermost Wolstenholme Formation	0.643	2.0017 1.9982	88.4 88.6	662 $\pm$ 20
	243559	76°34'N 68°57'W	Lower contact of sill cutting shales, Dundas Fjeld	Post-Dundas Formation	1.17	3.6949 3.9532	96.1 95.0	688 $\pm$ 20
	243558		Sill cutting shales, Dundas Fjeld		0.734	2.4851 2.4402	91.8 92.4	705 $\pm$ 21
	166692	76°31'N 68°56'W	WNW dyke cutting red beds, Ivnag tugdleq, Thule Air Base	Post-Lower Narssârssuk Formation	0.778	0.2707	92.3	727 $\pm$ 30
	272277	76°44'N 73°14'W	Margin of sheet cutting gneiss, Nordvestø, Carey Øer	Post-faulting in Shield	0.412	1.4337 1.4424	87.1 86.7	729 $\pm$ 22
	212653	77°49'N 70°31'W	Vesicular lava (loose), Siorarssuaq, Robertson Fjord	?Syn-lower Wolstenholme Formation	0.455	1.6465 1.6359	91.3 90.6	749 $\pm$ 22
	243557	76°33'N 68°57'W	Dykelet cutting dolerite sill 243558-9	Post-Dundas Formation	0.542	2.2225 2.2072	85.8 86.0	828 $\pm$ 25
2. Neohelikian	212570	77°25'N 71°56'W	Extrusive (?) sheet in red beds, Robbins Gletscher, Northumberland Ø	Syn-lower Wolstenholme Formation	1.67	7.6551 7.7972	97.2 97.3	914 $\pm$ 27
	272221	75°52'N 59°48'W	Margin WNW dyke cutting gneiss & supra- crustals, Kivioq Havn, Melville Bugt	Post-faulting in Shield	0.865	4.5154 4.6545	95.8 95.4	1016 $\pm$ 30
	212545	77°25'N 72°02'W	Lowest sill in red beds, Parish Gletscher, Northumberland Ø	Post-lower Wolstenholme Formation	0.925	6.2950 6.1682	97.2 97.4	1205 $\pm$ 36
	166621	77°14'N 70°17'W	Extrusive sheet in red beds, Kap Trautwine, Hvalsund	Syn-lower Wolstenholme Formation	0.893	6.0514 6.0875	97.1 96.5	1222 $\pm$ 36
1. Palaeohelikian	212497	77°05'N 66°20'W	NE dyke cutting gneiss, Sermiarssupaluk, Olrik Fjord	Post-main plutonism of Precambrian Shield	0.428	3.2926 3.1362	93.9 92.5	1313 $\pm$ 39
	272133	75°44'N 60°37'W	Contact of NW dyke cutting gneiss and ironstone, Thom Ø, Melville Bugt		1.72	14.801 14.881	98.3 98.2	1450 $\pm$ 44
	166133	77°07'N 66°20'W	Contact of NW dyke cutting gneiss, Sermiarssupaluk, Olrik Fjord		1.705	15.879 16.201	98.1 97.9	1538 $\pm$ 46
	272131	76°04'N 61°15'W	Contact of NE dyke cutting gneiss, Balgoni Øer, Melville Bugt		1.22	13.003 13.015	98.0 98.6	1667 $\pm$ 50

(1) Age (and distribution) of the supposed pre–Thule Group basic dykes (group 1 above), thereby providing a minimum age for the establishment of the cratogenic conditions following Hudsonian plutonism.

(2) Age of the extrusive-hypabyssal rocks (group 2 above) thus providing a minimum age for the basal part of the Thule Group.

(3) Time relationship between sills of group 3 and dykes of group 4.

The material

Details of rock type and geological setting of the 18 samples are summarised in Table 1. The majority are minor intrusions, sills and dykes with chilled margins to host rocks, one (272277) is an inclined sheet. Two samples (166621, 212653) are undoubted effusives and two samples (212570, 243534) represent lava or sill rock. In the absence of well exposed contacts, precise distinction between flows and sills within the volcanic-hypabyssal unit is difficult.

The intrusive rocks are generally dark grey to brownish, less commonly, greenish weathering, ophitic to sub-ophitic dolerite and gabbro; some types contain olivine (e.g. 212545), others quartz (e.g. 243558). Opaque minerals, mainly magnetite and ilmenite, are common. Feldspar porphyritic types occur (e.g. 166133, 272131) but all the material dated is homogeneous fine to medium grained; chilled contacts were collected wherever possible. The dated extrusive material is similar in rock type to the associated sills, but all are vesicular and one sample (212570) is singled out by conspicuous red weathering. In thin section, all rocks dated show some degree of deuteric alteration but the majority are only slightly altered. Plagioclase is fresh to moderately saussuritised, clinopyroxene varies from fresh to moderately uralitised, but olivine can be completely replaced by antigorite, chlorite and oxides.

Experimental procedure

The samples were processed and analysed in the geological laboratories of the Department of Earth Sciences, The University, Leeds. After crushing and sieving, the 60–90 mesh fraction was selected for analysis. Argon calculations were carried out following the method described by Rex & Dodson (1970). Potassium was determined by flame photometry; the percentages quoted in Table 1 are average values of three dissolutions.

For all but two samples (165809, 166692) Ar has been analysed in duplicate and the quoted ages are derived from an average of the two results. The errors are quoted at the 95 per cent confidence limit.

The K/Ar ages

The K/Ar dates given in Table 1 show a Proterozoic age range from 1667 ± 50 to 645 ± 26 Ma, with one sample outside this range at 431 ± 13 Ma (Early Silurian). This sample (243534) is an olivine dolerite sill from the volcanic-hypabyssal unit in the lower Wolstenholme Formation. No evidence exists to suggest that this sill represents a profoundly younger intrusion, and there is no other evidence for Palaeozoic magmatism in the region. Thus the sample is disregarded and it is concluded that the Silurian age expresses a fundamental disturbance of the K/Ar isotopic system.

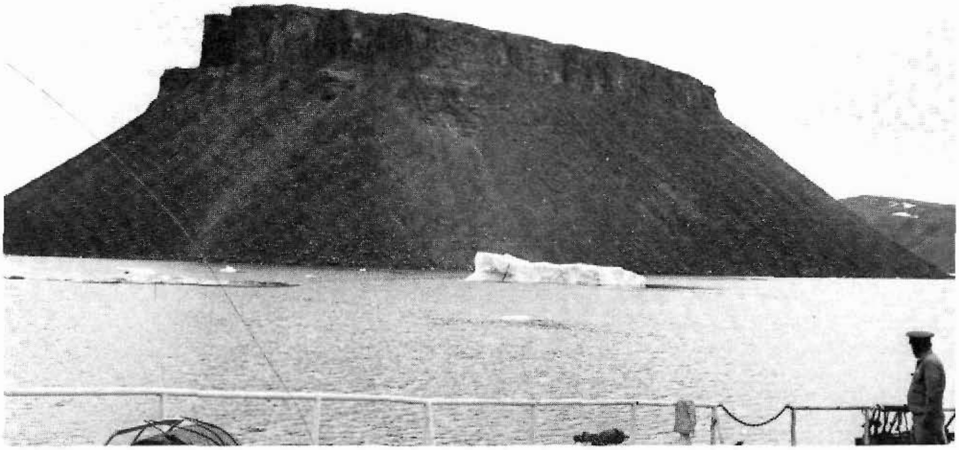

Fig. 3. Dundas Fjeld (see fig. 1) seen from the south, showing cap of Hadrynian dolerite (from which samples 243557–9 were taken) overlying shales of the Dundas Formation. Height of mountain is about 225 m.

The remaining K/Ar dates span the inferred age range of basaltic episodes 1 to 4 described above. Taken at face value the ages might suggest a more or less continuous generation of basaltic material from Middle through Late Proterozoic time. Available field control does not substantiate this. From the known limitations of the K/Ar method in general and the results of previous dating of basaltic rocks in North-West Greenland, little reliance can be placed on individual dates as indications of intrusion ages. Abnormally young ages may reflect post-consolidation disturbances and a fundamental redistribution of argon, during, for example, a faulting episode; high ages are presumably affected by considerable amounts of excess argon accumulated under 'abnormal' intrusion or crystallisation conditions or from migration during later disturbances.

Taken individually the K/Ar ages cannot be meaningfully related to geological events; however, as a batch, the results do confirm the field documentation for a wide age range of igneous activity and when suspect dates are discounted, major magmatic periods are reflected. Thus the oldest dates are those from dykes cutting the Precambrian Shield (group 1 above), while the youngest dates come from the sills and dykes that are known to cut the upper part of the Thule Group. Direct and indirect geological control indicate that two dates are anomalous, i.e. 828 ± 25 Ma (243557) and 749 ± 22 Ma (212653).

Sample 243557 is a fine-grained dolerite dykelet, 20–40 cm wide, that cuts the conspicuous sill forming the resistant cap of Dundas Fjeld, from which samples 243558 (705 ± 21 Ma) and 243559 (688 ± 20 Ma) were taken (fig. 3). The dykelet is one of several that have only been seen within the outcrop of the sill. The dykelet clearly post-dates the crystallisation of the sill rock; the K/Ar ages suggest it to be older. According to microfossil evidence, the uppermost part of the Dundas Formation is latest Riphean-Vendian in age; the K/Ar ages of 688 ± 20 Ma and 705 ± 21 Ma on the Dundas Fjeld sill are in general agreement with this. The age of 828 ± 25 Ma for the dykelet is regarded as too high.

Sample 212653 is a loose block of vesicular lava from Robertson Fjord. Although not collected *in situ*, this sample is almost certainly derived from the volcanic-hypabyssal unit in the lower Wolstenholme

Formation, outcrops of which occur in the cliffs above the sample site. If so the K/Ar age of 749 ± 22 Ma is too low.

When the two above mentioned anomalous ages are discounted, the remaining 15 ages fall into age groups that can be correlated with the K/Ar age groups derived from earlier work (Table 1).

Palaeohelikian (pre–Thule Group) magmatism

Four intrusions in the Precambrian Shield show a K/Ar age range of 1667 ± 50 Ma to 1313 ± 39 Ma; the previously reported age of 1563 ± 60 Ma falls into this range. Two other intrusions cutting gneisses, a dyke from Melville Bugt and an inclined sheet on Carey Øer, give 1016 ± 30 Ma and 729 ± 22 Ma respectively. No geological control exists to determine whether these intrusions are profoundly younger than the rocks they cut (i.e. associated with Thule Group magmatism) or whether the ages should be treated as anomalous.

K/Ar ages on hornblende and micas from gneisses and supracrustals indicate regional metamorphism at *c.* 1900–1750 Ma, with a cooling history perhaps as late as 1600 Ma (Larsen & Dawes, 1974). Field evidence, supported by K/Ar ages in the range 1650–1300 Ma, suggest that widespread Palaeohelikian basic dyking affected the region following the main Hudsonian tectonometamorphism but prior to the Thule Basin sedimentation.

Neohelikian (syn–Lower Thule Group) magmatism

Lavas and related sills in the lower Wolstenholme Formation of Northumberland Ø and Kap Trautwine show a K/Ar age range of 1222 ± 36 Ma to 914 ± 27 Ma; six previously reported ages from group 2 intrusions in the north fall into this range, viz. 1190 ± 40 – 1070 ± 40 Ma (Dawes *et al.*, 1973, 1982a). The date of 914 ± 27 Ma (212570) is perhaps the least reliable.

Sample 212570 is a peculiarly red-weathering vesicular lava from near the base of the volcanic-hypabyssal sequence on Northumberland Ø; it is a correlative of volcanic rock at Kap Trautwine (fig. 2), i.e. sample 166621 that gives a K/Ar age of 1222 ± 36 Ma. The variance in K/Ar ages of these two samples indicates disturbance in the isotopic system of one or both samples. However, in view of the fact that available K/Ar ages of sills from the lower Wolstenholme Formation fall in the age range 1200–1000 Ma, the date of 914 Ma on lava from near the base of the igneous unit is regarded as anomalously low.

There is good agreement between the age range of the Thule samples with that of lava-sill material from equivalent strata in adjacent Ellesmere Island, where four samples show a K/Ar age range of 1284 ± 37 – 978 ± 46 Ma (Frisch & Christie, 1982).

Hadrynian (syn?/post–Thule Group) magmatism

Sills and dykes that cut strata of the upper Thule Group show a K/Ar age range of 729 ± 22 – 645 ± 26 Ma. The oldest age in this range is of the inclined sheet on Carey Øer already mentioned; the youngest age, 645 ± 26 Ma, is of a member of the WNW-trending dyke swarm that cuts the upper Narssârssuk Formation – the youngest strata of the Thule Group. Sample 166692, taken from a 3 m wide dyke cutting the lower Narssârssuk Formation and giving an older age of 727 ± 30 Ma, is also a member of this swarm. Previous K/Ar ages on WNW-trending dykes have given 676 ± 25 Ma and 672 ± 25 Ma (Dawes *et al.*, 1973, 1982a); ages that are in general accordance with the Vendian age of the Narssârssuk Formation suggested by microfossils.

The field distinction between an early episode of sill intrusion (group 3 above) and the later WNW dyke swarm (group 4) is not reflected in the K/Ar age data; neither was it by previous results that showed sills to have K/Ar ages of 764 ± 30, 610 ± 24 and 592 ± 20 Ma (Dawes *et al.*, 1973). Thus, while it is known that some minor intrusions certainly post-date the entire Thule Group it is uncertain if there was a distinct period of magmatism associated with the late stages of Thule Basin deposition.

The period of Hadrynian magmatism indicated by the K/Ar age range from North-West Greenland corresponds to the known ages of the Franklin intrusions of adjacent Canada, where dykes do not penetrate the overlying Lower Palaeozoic cover. On northern Baffin Island, the most reliable K/Ar ages are concentrated between 700–650 Ma (Jackson *et al.*, 1978); on eastern Ellesmere Island age determinations fall between 800 and 600 Ma (Frisch & Christie, 1982).

References

Dawes, P. R., Rex, D. C. & Jepsen, H. F. 1973: K/Ar whole rock ages of dolerite from the Thule district, western North Greenland. *Rapp. Grønlands geol. Unders.* **55,** 61–66.

Dawes, P. R., Peel J. S. & Rex, D. C. 1982a: The Kap Leiper basic dyke and the age of dolerites of Inglefield Land, North-West Greenland. *Rapp. Grønlands geol. Unders.* **110,** 14–19.

Dawes, P. R., Frisch, T. & Christie, R. L. 1982b: The Proterozoic Thule Basin of Greenland and Ellesmere Island: importance to the Nares Strait debate. *In* Dawes, P. R. & Kerr, J. W. (edit.) Nares Strait and the drift of Greenland: a conflict in plate tectonics. *Meddr Grønland, Geosci.* **8,** 89–104.

Dawes, P. R. & Vidal, G. 1985: Proterozoic age of the Thule Group: new evidence from microfossils. *Rapp. Grønlands geol. Unders.* **125,** 22–28.

Frisch, T. & Christie, R. L. 1982: Stratigraphy of the Proterozoic Thule Group, southeastern Ellesmere Island, Arctic Archipelago. *Pap. geol. Surv. Can.* **81–19,** 13 pp.

Jackson, G. D., Iannelli, T. R., Narbonne, A. M. & Wallace, P. J. 1978: Upper Proterozoic sedimentary and volcanic rocks of northwestern Baffin Island. *Pap. geol. Surv. Can.* **78–14,** 15 pp.

Larsen, O. & Dawes, P. R. 1974: K/Ar and Rb/Sr age determinations on Precambrian crystalline rocks in the Inglefield Land – Inglefield Bredning region, Thule district, western North Greenland. *Rapp. Grønlands geol. Unders.* **66,** 4–8.

Rex, D. C. & Dodson, M. H. 1970: Improved resolution and precision of argon analyses using an AEI MS10 mass spectrometer. *Eclog. geol. Helv.* **63,** 275–280.

Vidal, G. & Dawes, P. R. 1980: Acritarchs from the Proterozoic Thule Group, North-West Greenland. *Rapp. Grønlands geol. Unders.* **100,** 24–29.

Young, G. M. 1979: Correlation of middle and upper Proterozoic strata of the northern rim of the North Atlantic craton. *Trans. R. Soc. Edinb.* **70,** 323–336.

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