U-Pb radiometric age of Nunarsuit pegmatite, Greenland: constraints on the timing of Gardar magmatism

ADRIAN A. FINCH, JOAKIM MANSFELD & TOM ANDERSEN

DGF

Finch, A.A., Mansfeld, J. & Andersen, T. 2001–06–28: U-Pb radiometric age of Nunarsuit pegmatite, Greenland: constraints on the timing of Gardar magmatism. *Bulletin of the Geological Society of Denmark*, Vol. 48, pp. 1–7, Copenhagen.

A precise U-Pb radiometric age of 1171±5 Ma has been obtained from zircons from a pegmatite in the Nunarsuit (previously spelt Nunarssuit) complex, Gardar Province, South Greenland. This age is slightly older than a corresponding Rb-Sr isochron determination. Since Nunarsuit is believed to be among the youngest Gardar centres, this radiometric age date more closely delimits the end of magmatism in the Gardar rift province. A comparison of our data with other published isotopic work may suggest that Gardar magmatism was a continuous rather than a punctuated process.

Key words: Nunarsuit complex, Gardar province, Mid-Proterozoic, alkaline rocks, zircons, cathodoluminescence.

Adrian A. Finch [*aaf1@st-and.ac.uk*], *Crustal Geodynamics Group, School of Geography and Geosciences, University of St Andrews, St Andrews, Fife KY16 9AL, UK. Joakim Mansfeld* [*joakim.mansfeld@ngu.no*] *Mineralogical-Petrological Museum, University of Oslo, Sars Gate 1, N-0562 Oslo, Norway, now at: Geological Survey of Norway, N-7491 Trondheim, Norway. Tom Andersen* [*t.h.andersen@toyen.uio.no*] *Mineralogical-Petrological Museum, University of Oslo, Sars Gate 1, N-0562 Oslo, Norway. 16 August 2000.*

The Gardar Province represents the products of continental rift-magmatism in the crust of South Greenland during the Proterozoic. Emeleus & Upton (1976) and Upton & Emeleus (1987) review Gardar geology and provide a location map of all the centers described in the present paper. Despite the worldwide importance of Gardar rocks, isotopic data for this province are surprisingly sparse, including radiometric age determinations. Blaxland et al. (1978) made the first attempt at systematic dating of Gardar centres using Rb-Sr whole rock isochrons. From their data it became clear that Gardar magmatism spanned some considerable time, since the earliest centres such as Grønnedal-Ikka (previously spelt Íka) are dated at circa 1300 Ma, in contrast to the youngest intrusions such as Klokken, Ilimmaasaq (previously spelt Ilímaussaq), Late Illerfigsalik (previously spelt Igdlerfigssalik) and Nunarsuit (previously spelt Nunarssuit), which are dated around 1170–1130 Ma. Despite the importance and high profile of many Gardar studies, and the advances in age determination methods since Blaxland et al. (1978), modern reliable dating of the Gardar centres has not been attempted in any systematic way. A few dates for individual centres (i.e. Early Motzfeldt, Qassiarsuk and Klokken, see Table 1) have been determined but there remains a need for a systematic reappraisal of Gardar geochronology. The present study will review radiometric age dates for Gardar centres and will present a new, precise radiometric age for a late-stage unit of the Nunarsuit centre, considered to be among the youngest Gardar rocks. Blaxland et al. (1978) showed that whole-rock Rb-Sr isochron ages for each unit of Nunarsuit were within error of the ages determined from other units, demonstrating that within error the whole complex represents the products of a single phase of magmatism.

Table 1. Published Gardar U-Pb age determinations. Sources: 1. Paslick et al. (1993). 2. Burgess et al. (1992). 3. This work.

Intrusion	Mineral Phase	Estimated Age	Ref.
Early Motzfeldt	Apatite	1350±10 Ma	1
Klokken	Baddeleyite	1166.6±1.2 Ma	2
Nunarsuit	Zircon	1171±5 Ma	3

Furthermore the Rb-Sr isochron of the whole intrusion suggested that Nunarsuit was the youngest centre in the Gardar province as a whole. A precise radiometric date of the Nunarsuit centre would therefore delimit the age of some of the youngest Gardar magmatism.

Previous radiometric studies of Gardar rocks

Blaxland et al. (1978) estimated that Gardar magmatism spanned a period from circa 1300 to 1120 Ma, which was subdivided into three periods termed Early, Mid and Late-Gardar (Upton & Emeleus 1987). Previous Rb-Sr radiometric data are summarised in Table 2. Early Gardar magmatism seems to have spanned c. 1300 to 1270 Ma, with a period of apparent dormancy until the oldest Mid-Gardar rocks which date from about 1240 Ma. Mid-Gardar magmatism spanned c. 1240–1200 Ma, and followed by further dormancy before Late Gardar episodes (1160–1120 Ma).

Nature and origin of material analysed

The Nunarsuit complex is the largest intrusion in the Gardar province (Harry & Pulvertaft, 1963; Anderson, 1974; Butterfield, 1980; Parsons & Butterfield, 1981; Hodson, 1994; Finch et al. 1995. Hodson 1997). Much of the western part of the complex is submerged beneath the Davis Strait, being exposed only in skerries (Ydre and Indre Kitsigsut). The Nunarsuit complex intrudes the Julianehåb granite-gneiss basement, which is Ketilidian in age (circa 1.75 Ga old; van Breemen et al. 1974, Hamilton 1997). Nunarsuit is one of the youngest Gardar events, clearly post-dating the Mid-Gardar Nunarsuit-Isortôq dyke swarm. The earliest activity associated with Nunarsuit appears to have been the emplacement of alkali granite and

Table 2: Published Rb-Sr radiometric age dates for the Gardar Province. Major centres are in **bold**. One Pb-Pb date for the Qassiarsuk centre is also present. The centres are grouped into Early (top), Mid- and Late (bottom) Gardar events. The ages of the Østfjordsdal, Narsarsuaq and Tunulliarfik syenites are unknown but are believed to be either Mid- or Late-Gardar, and are grouped separately. Sources: 1. Blaxland et al. (1978). 2. Finch et al. (unpublished). 3. Andersen (1997). 4. Patchett (1977).

Name	Description	Rb-Sr age dates	Ref
Early Motzfeldt centre	Gabbro, Nepheline syenites & Lujavrite	1282±30 Ma	1
Grønnedal-Ikka	Nepheline syenites & carbonatite	1299±17 Ma	1
North Qôroq centre	Nepheline syenites & Lujavrite	1268±60 Ma	1
North Motzfeldt	Nepheline syenites	1240±20 Ma	2
Qassiarsuk volcanics	Trachytes & carbonatite eruptives	1205±12 Ma	3
	(Pb-Pb:	1176±8 Ma)	3
Ivittuut Peninsular dykes	Lamprophyres & basalts	1250±18 Ma to 1227±29 Ma	4
East Motzfeldt	Nepheline syenite	None	
Late Motzfeldt centre	Nepheline syenites	None	
Ivittuut	Alkali granite plus cryolite body	1222±24 Ma	1
Kuunnaat	Gabbro & quartz syenites	1219±16 Ma	1
Østfjordsdal syenite	Nepheline syenite	None	
Narsarsuaq* syenite	Nepheline syenite	None	
Tunulliarfik* syenite	Nepheline syenite	None	
South Qôroq centre	Augite & Nepheline syenites	1160±8 Ma	1
Tugtutôq OGDC		1150±9 Ma	1
Nunarsuit	Quartz syenite & granites	1124±47 Ma	1
Ilimmaasaq	Agpaites, alkali granite & augite syenite	1143±21 Ma	1
Tugtutôq YGDC	Basalt grading through to nepheline syenite & alkali granite	None	
Central Tugtutôq	Quartz syenites	1143±36 Ma	1
Early Illerfissalik centre	Augite & Nepheline syenites	None	
Fox-Bay dyke swarm		None	
Klokken	Gabbro & quartz syenite	1135±11 Ma	1
Late Illerfissalik centre	Gabbro, Augite & Nepheline syenites	1142±15 Ma	1

syenite intrusions (the *Helene granite* and the *Kitsigsut syenite*), followed by the intrusion of gabbro (the *Alángorsuaq gabbro*) and further granitic rocks (the *biotite granite*). The majority of the centre comprises a late syenite (the *Nunarsuit syenite*), sometimes quartz-bearing, which has been subdivided according to compositions of pyroxenes (P.B. Greenwood, personal communication, 1967). Some internal chilled contacts have been observed within this syenite (our unpublished field observations), but these appear localised. A final major intrusive event was the emplacement of the peralkaline *Kidtlavât granite* and there are a number of smaller alkali granite bodies and quartz-bearing pegmatites.

A major series of quartz-bearing aplo-pegmatitic late-stage intrusives, which are the focus of the present study, are found in a roughly north-south line along the fjord of Eqadtliartarfik, and samples from the present study were taken from a point with latitude and longitude 48.023° W 60.740° N. These spectacular rocks are characterised by large (often 10 cm long) euhedral arfvedsonitic amphibole and microcline, interstitial quartz and occasional bizarre herring-bone twinned aegirines up to 1 m long. Monazites and rare-earth element-rich fluorapatites are common. At irregular intervals along the pegmatite, pods rich in zircon, astrophyllite and sporadic magnetite occur. Astrophyllite forms radial platy aggregates often 3 cm in diameter with magnetite in anhedral lumps. Euhedral zircons are commonly 1 cm long, lustrous red-brown, honey yellow or colourless and form such dense aggregates that hand specimens of what might be termed 'zirconite' can be collected. The unit fluctuates between coarsely pegmatitic and aplitic facies forming banded rocks alternating in mm- and cm-sized crystals (Fig. 1).

The aplo-pegmatites clearly postdate the Nunarsuit syenite, but the relative ages of these to the Kidtlavât granite are unclear. There is however unlikely to be a large age difference, and therefore the aplo-pegmatitic units discussed here are among the youngest rocks in the Nunarsuit complex and therefore in the Gardar as a whole. Samples for the present study (reference numbers AF/88/A22, AF/88/A23 and AF/88/A24) are taken from zircon-rich pods within pegmatites in the area around Tassiusaq (48° 03′ W, 60° 45′ N), in what appears to be an extension of the Eqadtliartarfik pegmatite zone. The samples are almost exclusively zircon and provide superlative material for age determination.

Characterisation of the zircons

Many recent studies stress the need for detailed characterisation of zircon before isotopic analysis, since older inherited cores have been recognised in some igneous rocks. In addition, zircons, which incorporate high levels of radioactive elements such as U or Th, may become periodically amorphous due to radiation damage (Salje et al. 1999) and therefore lose radiogenic Pb - these may yield unreliable radiometric age dates. The zircons of the present study are unlikely to be inherited due to their field relationships and abundance. Syenitic rocks of the Gardar are believed to have formed from fractional crystallisation of transitional basalt (Upton & Emeleus 1987), and therefore any older zircons may only derive from assimilation of wall rocks. The large number of zircons in the present study is consistent with fractionation to Zr-rich evolved residua in silica oversaturated syenitic rocks.

Sample preparation and zircon analysis were performed at the Mineralogical-Geological Museum in Oslo. Zirconite material was crushed lightly and euhedral zircon crystallites were selected by hand picking under ethanol. The majority of the material in the rock comprises deeply coloured crystals that were considered unreliable for dating. The concentration of zircons was such that magnetic or heavy liquid separation of zircon from other phases was not necessary. Zircons were separated into two similar fractions. The grains were picked in ethanol under a binocular microscope, only whole, transparent, and light coloured zircons without visible inclusions were selected.

The zircons of the rock have an ordinary magmatic appearance, although rather large (250–750 µm long in the material analysed). They vary from colourless to light reddish brown, and are transparent to translucent. The crystals have simple tetragonal prismatic habits with aspect ratios around 3. The edges and corners are sharp but the crystal surfaces are undulating, probably an effect of the restricted crystal growth in a rock composed mainly of zircon. There are no signs of internal textures under the binocular microscope, although most of the grains contain small fluid and mineral inclusions. Analysis by X-ray diffraction failed to show any other phases present other than zircon within the grains. Qualitative energy-dispersive X-ray microanalysis (EDXA) was performed on CamScan CS44 scanning electron microscope attached with a CamScan EDitor energy dispersive X-ray analyser at the University of Hertfordshire, UK. These spectra indicate substitution in the zircon structure by W, Y and Hf for Zr, but interferences between the Si Ka radiation with W Ma, Hf Ma, and between

Fig. 1. Banded nature of sections of the pegmatite with coarse- and fine-grained areas alternating. The lens cap is 52 mm wide.

the Zr Lα and Y Lα radiations makes reliable quantitative analysis difficult.

Zircons often emit yellow or green light emissions when subjected to electron beam excitation (cathodoluminescence, CL), and CL zoning can be used to recognize material with a polyphase history (see e.g. Götze et al. 1999). CL emissions are believed to relate to activation by trivalent rare earths substituting for Zr, consistent with our observation of significant Y using EDXA. A CL photomicrograph typical of the zircons of the present study is given in Figure 2. The crystals usually demonstrate fine oscillatory-zoning parallel to prism faces, reflecting magmatic growth. Some crystals have bright polycrystalline cores and suggest that some larger crystals form by coagulation of smaller crystallites. Older inherited zircons may be present in these polycrystalline materials. Zoning around prominent fractures may reflect interaction with very late-stage fluid phases but by selecting crystals without visible fractures for analysis these unrepresentative areas should not significantly contribute to the age determination.

Analytical methods

Of the two analyzed samples a selected subset of high quality zircons from sample 1 was abraded in air using the method of Krogh (1982). After washing, the zircons were weighed and transferred to small Teflon bombs and dissolved in an oven at c. 200°C in a con-

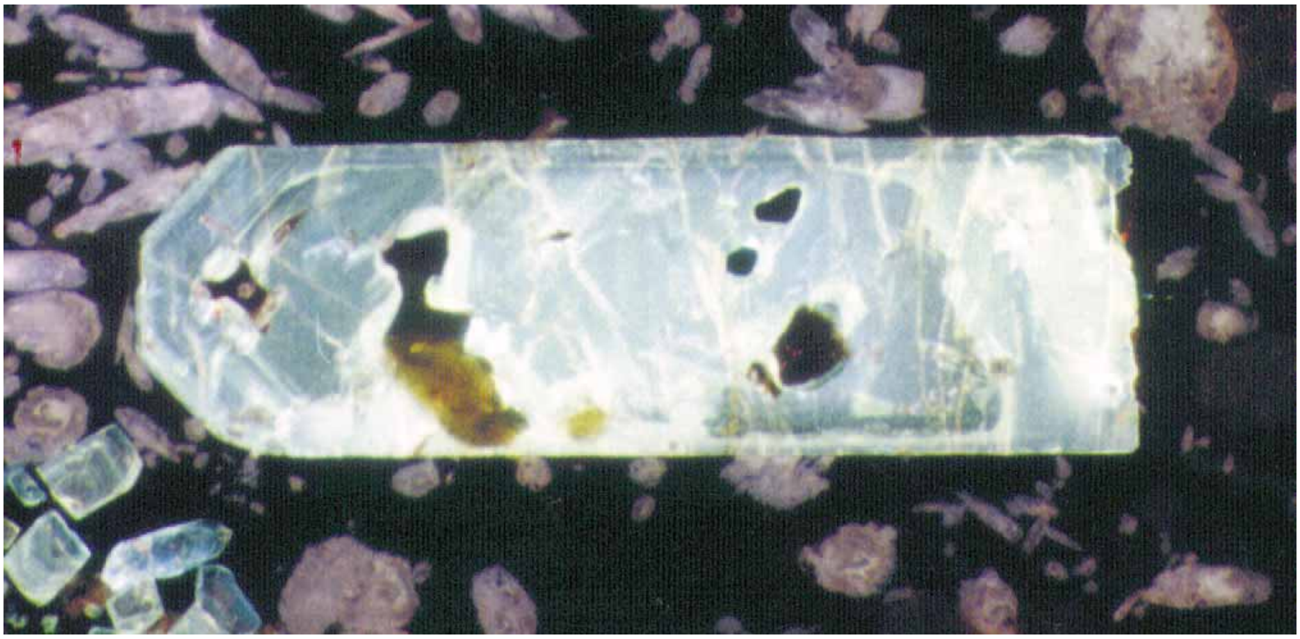

Fig. 2: Cathodoluminescence image of a zircon crystal (yellow-green emission). The field of view is circa 4 mm along the longest side. The crystal shows oscillatory zoning in the left of the image, in addition to luminescence following some fractures through the crystal.

centrated HF:HNO_3 mixture for four days. After cooling an undissolved residue still remained in the two unabraded fractions. They were therefore evaporated and subsequently dissolved in a new batch of HF:HNO_3 for three days, which resulted in a clear solution without any visible solid remnants. After evaporation the samples were dissolved in 3.1 M HCl at ambient temperature for a day. U and Pb were analyzed with the isotopic dilution technique using a ^{235}U-^{208}Pb mixed spike. Ion exchange was performed in a continuous flow apparatus under slight overpressure using the chemistry adapted from Krogh (1973). Lead was loaded with a silica gel manufactured according to Gerstenberger & Haase (1997) onto single Re filaments, and U was loaded with graphite onto Re filaments in a double filament configuration. U and Pb were measured on a Finnigan MAT 262 equipped with multiple Faraday cups. Simultaneous measurements of the ^{204}Pb-signal were performed with a digital amplified secondary electron multiplier. Mass discriminations of 0.1%/AMU for Pb and 0.2%/AMU for U were determined with analysis of the NBS 981 Pb-standard and the NBS U-500 U-standard respectively. Blank levels were 20 pg for Pb and 10 pg for U. Calculation and regression analysis was done according to Ludwig (1993, 1994) with decay constants from Steiger & Jäger (1977), and a common lead composition at 1170 Ma calculated according to Stacey & Kramers (1975).

Results

The U–Pb results of the three zircon fractions are plotted in Fig. 3 and presented in Table 3. The two unabraded fractions form a discordia line that inter-

Table 3. U–Pb analytical data for the Nunarsuit pegmatite, AF/88/A24

	Concentration (ppm)		Atomic ratios						
Fraction	U	Pb_{rad}	Pb_{init}	$^{206}Pb/^{204}Pb^a$	$^{208}Pb/^{206}Pb^b$	$^{206}Pb/^{238}U^b$	$^{207}Pb/^{235}U^b$	$^{207}Pb/^{206}Pb^b$	Age
Sample 1	121	26.0	0.34	4300	0.138	0.2019±7	2.197±10	0.07893±22	1170± 6
Sample 1 abr	141	28.9	0.17	9780	0.143	0.1935±8	2.130±10	0.07984±17	1193± 4
Sample 2	123	24.5	0.26	5370	0.140	0.1879±7	2.049±13	0.07908±39	1174±10

Errors are given at the 2σ-level. abr = air abraded fraction, a = atomic ratio corrected for blank and mass discrimination, b = atomic ratios corrected for blank, mass discrimination and initial lead. Age is the ^{207}Pb/^{206}Pb age in Ma.

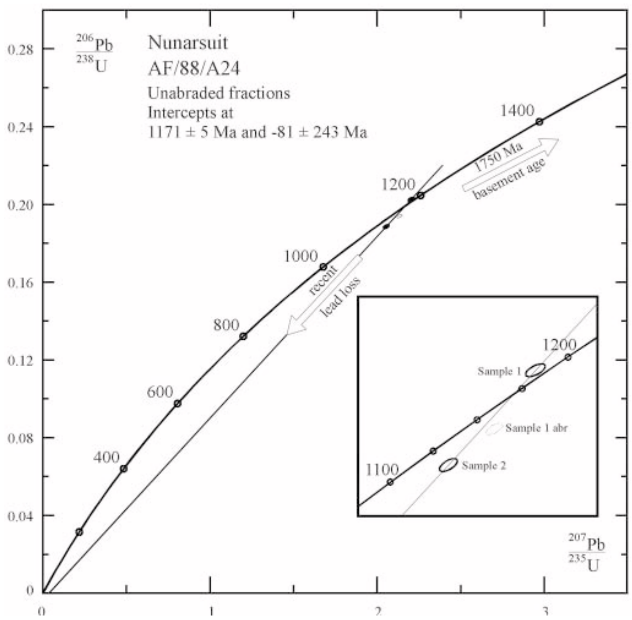

Fig. 3. U-Pb concordia diagram of the Nunarsuit pegmatite. Error ellipses and limits correspond to 2 σ. Arrows indicate the directions in which data points are influenced by processes of Pb loss and inheritance of Ketilidian zircons. Inset is an enlargement of the intercept between the Condordia and the discordia lines.

cepts the Concordia at 1171±5 Ma. This age is also the same within errors as the $^{207}Pb/^{206}Pb$ ages of these fractions. One of the fractions plots just above the Concordia, the other is c. 6% discordant. The lower intercept points towards the origin with an intercept of –81±243 Ma. The abraded fraction is c. 5% discordant and has a $^{207}Pb/^{206}Pb$ age of 1193±4 Ma. Since the abraded fraction is more discordant than the most concordant non-abraded fraction, it is suggested that the older age of the abraded fraction is due to a very small contribution of radiogenic lead from inherited cores. The Nunarsuit complex intruded into rocks c. 1.75 Ga old and furthermore is located about 50 km south of the Archaean domain. Contamination by zircons from the country rock is common in rocks intruding old continental crust, and only a very small amount of old radiogenic lead is needed to account for the slight deviation from the discordia. Although the peculiar composition of the rock makes this assumption less likely, the most probable explanation for the deviating $^{207}Pb/^{206}Pb$ age and discordance of the abraded fraction is an extra contribution of old radiogenic lead to the abraded fraction. Therefore, in view of the simple magmatic appearance and the near concordant results for the unabraded fractions, the upper intercept age of 1171±5 Ma is considered to be the crystallisation age of the Nunarsuit pegmatite.

The Rb-Sr isochron age for Nunarsuit by Blaxland et al. (1978) has a large error (1124±47 Ma) and only constrains the age of the complex to within 100 Ma. The mean age of 1124 Ma is the youngest of any Gardar center. Our zircon U-Pb age is just within the uppermost error of the Rb-Sr isochron. Such discrepancies are not uncommon when the relatively inaccurate Rb-Sr data are compared with precise U-Pb dates from phases such as zircon. Feldspars and micas, usually the sites of Rb in the rock, are commonly hydrothermally altered in Gardar rocks allowing significant opening of the system to isotopic exchange. With the exception of some zoning along fractures in the zircon seen by CL, which were avoided by selecting unfractured grains, zircons in the present study are fresh. The present age determination is presented alongside other published precise U-Pb age dates for the Gardar province in Table 1. U-Pb dates are not usually within error of equivalent Rb-Sr isochron dates, even though the 2σ errors of many of the latter are large. The Klokken and Nunarsuit intrusions appear synchronous within error. All the U-Pb data provide older mean ages than corresponding Rb-Sr isochrons suggesting that some Rb-Sr open system behaviour has occurred in all those centres. Furthermore our precise date suggests that the end of Gardar magmatism (certainly in the Nunarsuit area) was some 40 Ma earlier than the mean Rb-Sr age suggests. From the data of Blaxland et al. (1978), it was inferred that Gardar activity resolved into distinct magmatic episodes (Early-, Mid- and Late-Gardar). However, new isotopic data show little distinction between Mid-Gardar events such as Qassiarsuk (dated by a Pb-Pb isochron at 1176±8 Ma; Andersen 1997) and Late-Gardar intrusions such as Nunarsuit (now dated at 1171±5 Ma). It may be that Gardar magmatism is more truly modelled by a continual process. Further precise dating is clearly required to clarify the exact chronology of the remainder of these important igneous centres.

Acknowledgements

AF collected samples for the present study during tenure of a NERC-funded PhD studentship at the University of Edinburgh. Subsequent visits to Greenland have had the support of the Carnegie Trust for the Universities of Scotland, the Mineralogical Society of Great Britain and Ireland, The Royal Geographical Society and the Percy Sladen Fund. AF and TA would like to thank the British Council for subsistence and travel expenses to perform the preparative work. The manuscript benefited from the reviews of Eirik Krogstad and Feiko Kalsbeek.

Dansk sammendrag

Zirkoner fra en pegmatit fra Nunarsuit komplekset (tidligere stavet Nunarssuit) i Gardar provinsen i Sydgrønland er dateret til 1171±5 milioner år ved uranbly metoden. Denne alder er ubetydeligt ældre end en publiceret rubidium-strontium isokronalder fra samme kompleks (1124±47 millioner år). Siden Nunarsuit anses for at være blandt de yngste magmatiske centre i Gardar, giver denne alder et godt skøn for afslutningen af den magmatiske aktivitet i Gardar Provinsen. En sammenligning af data publiceret her med andre publicerede aldersbestemmelser antyder, at Gardar-magmatismen var en kontinuerlig snarere end en episodisk proces.

References

Andersen, T. 1997: Age and petrogenesis of the Qassiarsuk carbonatite-alkaline silicate volcanic complex in the Gardar rift, South Greenland. Mineralogical Magazine 61, 499–514.

Anderson, J.G. 1974: The Geology of Alángorssuaq, Northern Nunarssuit complex, S. Greenland. Unpublished PhD thesis, University of Aberdeen, UK.

Blaxland, A.B., Van Breemen, O., Emeleus, C.H. & Anderson, J.G. 1978: Age and Origin of the Major Syenite centres in the Gardar province of South Greenland: Rb-Sr studies. Geological Society of America Bulletin 89, 231–244.

Burgess, R., Kelley, S.P., Parsons, I., Walker, F.D.L. & Worden, R.H. 1992: ^{40}Ar-^{39}Ar analysis of perthite microtextures and fluid inclusions in alkali feldspars from the Klokken syenites, South Greenland. Earth and Planetary Science Letters 109, 147–167.

Butterfield, A.W. 1980: The Geology of the Western part of the Nunarssuit alkaline complex, S. Greenland. Unpublished PhD thesis, University of Aberdeen, UK.

Emeleus, C.H. & Upton, B.G.J. 1976: The Gardar period in southern Greenland. In: Escher, A. & Watt, W.S. (eds.) The Geology of Greenland, Grønlands Geologiske Undersøgelse, Copenhagen, 152–181.

Finch, A.A., Parsons, I., & Mingard, S.M., 1995: Biotites as Indicators of Fluorine Fugacities in Late-Stage Magmatic Fluids: the Gardar Province of South Greenland. Journal of Petrology 36, 1701–1728.

Gerstenberger, H. & Haase, G. 1997: A highly effective emitter substance for mass spectrometric Pb isotope ratio determinations. Chemical Geology 136, 309–312.

Götze J., Kempe U., Habermann D., Nasdala L., Neuser, R.D. & Richter D.K. 1999: High-resolution cathodoluminescence combined with SHRIMP ion probe measurements of detrital zircons. Mineralogical Magazine, 63, 179–187.

Hamilton, M.A. 1997: Synopsis of new U-Pb geochronological results from the Ketilidian orogen, South Greenland. In Wardle, R.J. & Hall, J. (eds.) Eastern Canadian Shield Onshore-Offshore Transect (ECSOOT). University of British Columbia, Lithoprobe Secreteriat Report 61, 118–134.

Harry, W.T. & Pulvertaft, T.C.R. 1963: The Nunarssuit Intrusive complex, south Greenland. Part I, General description. Meddelelser om Grønland 169, No.1, 136 pp.

Hodson, M. 1994: Igneous Layering in the Syenites of Nunarssuit and West Kûngnât, South Greenland. Unpublished PhD thesis, University of Edinburgh, UK.

Hodson, M. 1997: Post-crystallisation modification of the igneous layering in the Nunarsuit and West Kûngnât syenites, South Greenland. Mineralogical Magazine 61, 467–484.

Krogh, T.E. 1973: A low-contamination method for hydrothermal decomposition of zircon and extraction of U and Pb for isotopic age determinations. Geochimica et Cosmochimica Acta 37, 485–494.

Krogh, T.E. 1982: Improved accuracy of U-Pb zircon ages by the creation of more concordant systems using an air abrasion technique. Geochimica et Cosmochimica Acta 46, 637–649.

Ludwig, K.R. 1993: PBDAT: A computer program for processing Pb-U-Th isotope data. Version 1.24. Revision of US Geol. Surv. open-file report, 88–542.

Ludwig, K.R. 1994: ISOPLOT: A plotting and regression program for radiogenic-isotope data, Version 2.71. Revision of US Geol. Surv. open-file report, 91–445.

Parsons, I. & Butterfield, A. 1981: Sedimentary features of the Nunarssuit and Klokken syenites, south Greenland. Journal of the Geological Society of London 138, 289–306.

Paslick C.R., Halliday A.N., Davies, G.R., Mezger, K. & Upton, B.G.J. 1993: Timing of Proterozoic magmatism in the Gardar Province, southern Greenland. Geological Society of America Bulletin, 105, 272–278.

Patchett P.J. 1977. Rb-Sr geochronology and geochemistry of Proterozoic Basic Intrusions in Sweden and South Greenland. Unpublished PhD thesis, University of Edinburgh, UK.

Salje, E.K.H., Chrosch, E. & Ewing R.C. 1999: Is 'metamictisation' of zircon a phase transition? American Mineralogist 84, 1107–1116.

Stacey, J.S. & Kramers, J.D. 1975: Approximation of terrestrial lead isotope evolution by a two-stage model. Earth and Planetary Science Letters 26, 207–221.

Steiger, R.H. & Jäger, E. 1977: Convention on the use of decay constants in geo- and cosmochronology. Earth and Planetary Science Letters 36, 359–362.

Upton, B.G.J. & Emeleus, C.H. 1987: Mid-Proterozoic alkaline magmatism in Southern Greenland: the Gardar Province. In: Fitton, J.G. & Upton, B.G.J. (eds) Alkaline Igneous Rocks, Special Publication, Geological Society of London 30, 449–471.

van Breemen, O., Aftalion M & Allaart, J.H. 1974: Isotopic and geochronologic studies on granites from the Ketilidian mobile belt of South Greenland. Geological Society of America Bulletin 85, 403–412.