New zircon ages from the Tasiusarsuaq terrane, southern West Greenland

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In the last three field seasons the Geological Survey of Denmark and Greenland (GEUS) has undertaken mapping in the south-eastern part of the Nuuk region in southern West Greenland, and here we present new zircon ages that help constrain the northern boundary of the Tasiusarsuaq terrane. The Archaean geology of the Nuuk region is commonly interpreted as a tectonic collage assembled through lateral accretion and collision of oceanic and continental slivers and blocks (e.g. Friend & Nutman 2005). Popular jargon describes these as terranes, bounded by faults or mylonite zones and characterised by rocks of contrasting origin on either side of their tectonic boundaries (Coney *et al.* 1980). The Isukasia and Færingehavn terranes (Figs 1, 2) are the oldest terranes at ≥3.75 Ga, and extend from the outer part of Godthåbsfjord in the south-west to the margin of the Inland Ice in the north-east, but they might not have a common geological history (Friend & Nutman 2005). The Tre Brødre terrane is mainly represented by the Ikkatoq gneiss and occurs in close spatial relationship with the Færingehavn terrane, and also as a pronounced thrust unit along the Qarliit Nunaat thrust between the Færingehavn and Tasiusarsuaq terranes (Fig. 1; Nutman *et al.* 1989). The terrane boundaries in the inner fjord region near the Inland Ice margin are less well constrained; the Tre Brødre terrane extends into the region from the south-west, the Kapisilik terrane is defined from the northern and eastern part and borders the Tasiusarsuaq terrane to the south and possibly to the east.

The terrane accretion is believed to have taken place in two events. The first terrane accretion is defined from the northern part of the region, and possibly involves the Isukasia, Kapisilik and Akia terranes. The thermal event stitching these terranes is dated to *c.* 2.99–2.95 Ga (Fig. 2; Hanmer *et al.* 2002; Friend & Nutman 2005). The second accretion phase of the major continental blocks is believed to have occurred at around 2.725–2.71 Ga. This second event is well described, and includes anatexis and emplacement of continental crust-derived granites, which are associated with contemporaneous metamorphism (Friend *et al.* 1996).

Figure 2 outlines regional plutonic, metamorphic and supracrustal events. Individual terranes were formed during relatively short time periods with active geological processes of creation and recycling of continental crust, and most of the terranes follow a similar pattern of development. The first plutonic events consisted of primitive magmas and produced tonalite–trondhjemite–granodiorite (TTG) and dioritic gneisses. Younger, more evolved granitic magmas were often intruded simultaneously with high-grade metamorphism. This development may reflect a stabilisation of the individual terranes.

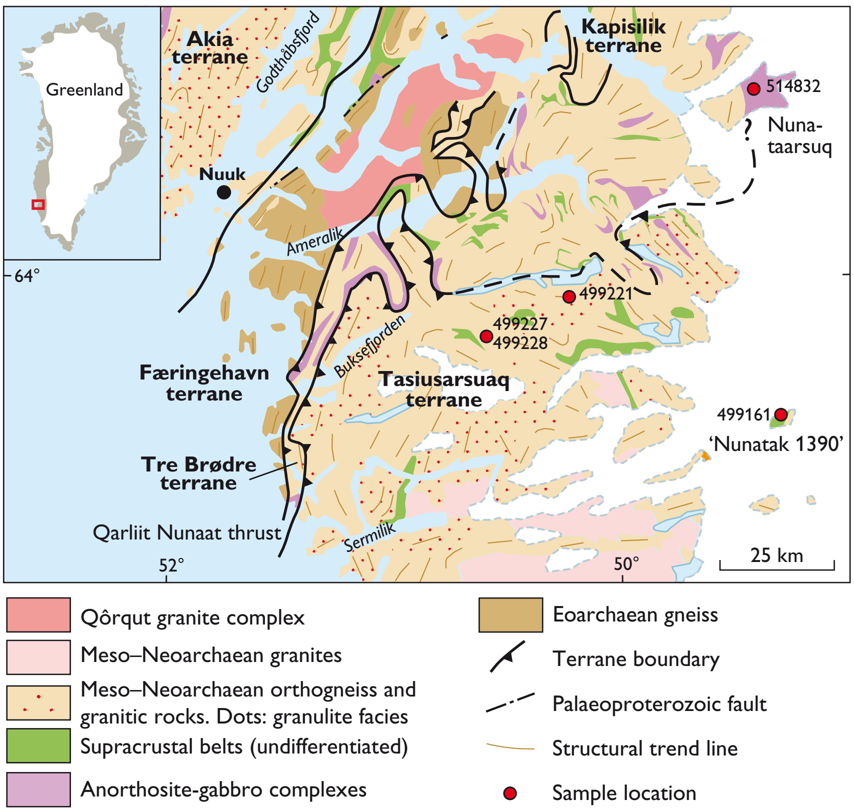

Fig. 1. Geological map of the southern Nuuk region (modified from Escher & Pulvertaft 1995), with locations and numbers of samples discussed in this paper.

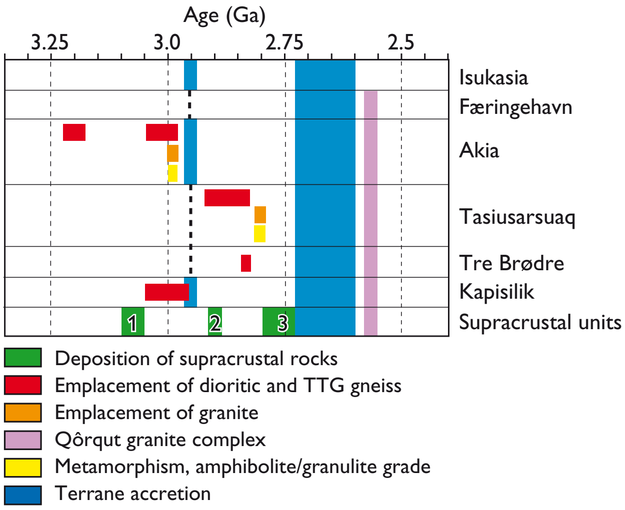

Fig. 2. Time lines for igneous and metamorphic events in the Nuuk region. Numbers for the supracrustal units refer to (1) Ivisaartoq and Qussuk, (2) 'Nunatak 1390' and (3) Storø. Data from Pidgeon & Kalsbeek (1978), Friend & Nutman (2001), Crowley (2002), Hanmer *et al.* (2002), Friend & Nutman (2005), Polat *et al.* (2008), Nutman & Friend (2007), Garde (2007) and Knudsen *et al.* (2007).

The Tasiusarsuaq terrane

The Tasiusarsuaq terrane is dominated by 2.92–2.84 Ga tonalite and granodiorite gneisses (Friend & Nutman 2001; Crowley 2002). The main regional metamorphism is of amphibolite facies grade, however, granuite facies or retrogressed granulite facies rocks are present in large areas (Fig. 1). Peak granulite facies conditions have been dated at 2.81–2.79 Ga (Pidgeon & Kalsbeek 1978; Crowley 2002). Greenschist facies rocks have been observed on 'Nunatak 1390', which we in the present article suggest is part of the Tasiusarsuaq terrane.

Northern boundary of the Tasiusarsuaq terrane

The north-western boundary of the Tasiusarsuaq terrane in the Buksefjorden area (Fig. 1) has been described in some detail. Narrow mylonite zones define a boundary between granulite facies gneisses of the Tasiusarsuaq terrane and prograde amphibolite facies gneisses of the Tre Brødre terrane. Prograde amphiolite facies metamorphism dated at around 2.74–2.70 Ga is presumably related to the terrane accretion and has not been recorded within the Tasiusarsuaq terrane itself (Crowley 2002), which was thrust upon the Tre Brødre terrane during orogenesis (Nutman *et al.* 1989). The eastern extension of the northern Tasiusarsuaq terrane boundary remains speculative. Here we present zircon U-Pb age data from six selected rock samples collected in the vicinity of the proposed eastern extension of the northern Tasiusarsuaq terrane boundary.

Tasiusarsuaq tonalite

A migmatised tonalite representative of the basement gneisses in the northern part of the terrane was collected for zircon U-Pb age determination (Fig. 1; sample 499221 in the Survey numbering system). The rock contains lenses of amphibolite and has abundant migmatite veins. Palaeosome was separated from neosome by sawing slabs of each, and both sub-samples were dated. The internal zircon textures are very similar in both palaeosome and neosome. Zircon grains have complex internal textures often with dark shells separating the core from the rim (Fig. 3a, b). The cores display igneous oscillatory zonation to homogeneous textures. The age data for the palaeosome are concordant within 10% for 63 spots (n = 65), and regress to an essentially zero age lower intercept. We therefore use the $^{207}Pb/^{206}Pb$ ratios, which yield an age of 2.868 ± 0.004 Ga (Fig. 4a; n = 62/65, ± 2σ, MSWD = 1.5). The outliers are slightly younger, presumably due to ancient Pb loss. The neosome data are concordant within 10% for 55 spots (n = 57; Fig. 4b); close inspection of the $^{207}Pb/^{206}Pb$ age data indicates that two ages at *c.* 2.87 and *c.* 2.80 Ga can be differentiated (Fig. 4b). However, this is speculative as the data suffer from insufficient precision in conjunction with an apparent 'age smear' as noted in the palaeosome, presumably due to ancient Pb-loss. Nevertheless, the two suggested ages at *c.* 2.87 and *c.* 2.80 Ga are in excellent agreement with the palaeosome date and known ages for granulite facies metamorphism in the region (Pidgeon & Kalsbeek 1978; Crowley 2002). Discordant granite sheets 2.72 Ga old cut the gneisses in this part of the Tasiusarsuaq terrane (Friend *et al.* 1996), but no such age component was found in this rock.

'Nunatak 1390' and Nunataarsuk

'Nunatak 1390' comprises rocks with some of the best preserved primary textures and structures found in the Tasiusarsuaq terrane. In brief, 'Nunatak 1390' contains a volcanic series with variably preserved pillow lava sequences that are succeeded by melanocratic-ultramafic ash and rocks with flow structures (Stendal & Scherstén 2007). Rhyolitic rocks

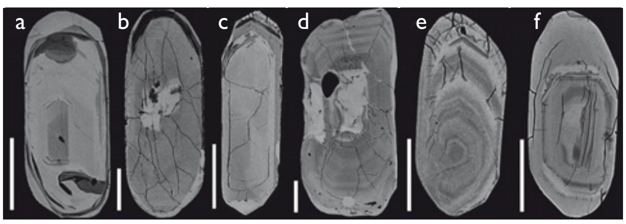

Fig. 3. Backscattered electron images of representative zircon grains for each dated sample. Zircons were separated, picked, mounted in epoxy and polished to expose the central part of the grains. Scale bars = 50 µm. (a) 499221 palaeosome; (b) 499221 neosome; (c) 499161; (d) 514832; (e) 499227; (f) 499228.

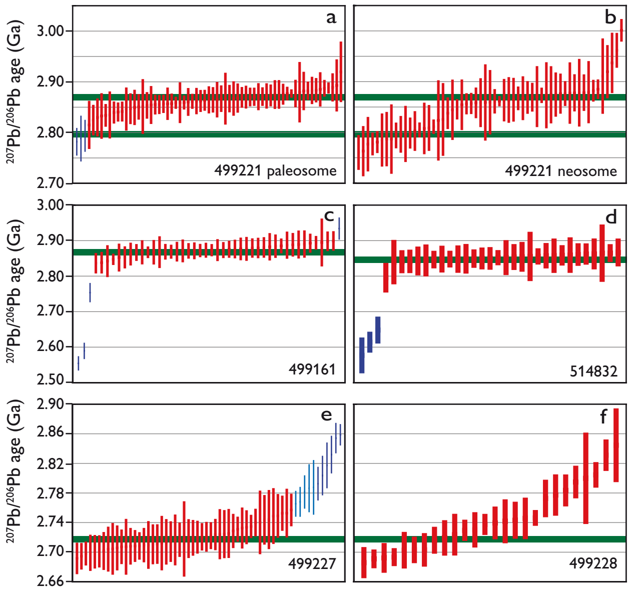

Fig. 4. Zircon 207Pb/206Pb ages. All errors presented at 2 sigma levels. (a) Sample 499221 palaeosome. The red bars represent data used to calculate crystallisation age (green horizontal bar). Five blue bars are rejected due to assumed ancient lead loss. (b) Sample 499221 neosome. The upper green horizontal bar represents the crystallisation age for the paleosome and the lower green horizontal bar represents the known granulite facies event for the Tasiusarsuaq terrane. (c, d) Samples 499161 and 514832. The red bars represent data used to calculate crystallisation ages (green horizontal bar) and the blue bars were rejected due to assumed ancient lead loss. (e) Sample 499227: Red bars represent data used to calculate crystallisation or metamorphic age (green horizontal bar), and the blue bars are assumed to be inherited from an older source. (f) Sample 499228. The red bars define an ancient lead loss trend with age components as in sample 499227. Age determinations were carried out on the Element 2 Laser ICPMS at GEUS. Detailed analytical procedures are described in Frei et al. (2006).

are intercalated with the pillow lava sequences, and were interpreted as ignimbrites by Stendal & Scherstén (2007). In 2007, however, intrusive discordant dykes that appear to feed into the rhyolites were discovered, and it may be that some or all of these rocks are significantly younger sills. Zircons were extracted from a rhyolite sample (499161) for dating, and in spite of the alternative interpretations either date the pillow lava sequence or provide a minimum age for it. The zircon grains have bright homogeneous cores and darker rims and/or zones within the cores (Fig. 3c). The dark areas may extend into the bright areas and contain minor amounts of Ca and Al, which could indicate destabilisation and partial zircon breakdown. Of 48 age determinations 43 define a recent Pb loss line and a $^{207}Pb/^{206}Pb$ age of 2.873 ± 0.005 Ga (n = 43/48, ± 2σ, MSWD = 1.7). One grain (two analyses) is concordant at *c.* 3.2 Ga. We interpret the 2.873 ±0.005 Ga age to represent the time of crystallisation of the rhyolite. The origin of the 3.2 Ga old grain is unclear, but we speculate that it is inherited from rocks of this age. Gneisses with palaeosomes of this age have been found farther to the west in the Tasiusarsuaq terrane (Næraa & Scherstén, unpublished data).

Eastern Nunataarsuk is characterised by an anorthosite-amphibolite-granite succession. Granite sample 514832 for geochronology is from an area where granite and slices of amphibolite with local pillow structures in low-strain areas form the major successions; the granite-amphibolite contact is either an irregular and intrusive or a boudinaged contact parallel to the foliation, and the granite is interpreted as late to posttectonic relative to a locally defined S1 foliation (Kolb & Stendal 2007). Zircon grains from the granite have oscillatory-zoned cores surrounded by thin homogeneous rims (Fig. 3d). Oscillatory-zoned grains plot along a recent Pb-loss line and yielded a $^{207}Pb/^{206}Pb$ age of 2.852 ± 0.005 Ga (n = 30/33, ± 2σ, MSWD = 0.30, concordant within 10%), which we interpret as the intrusive age of the granite. The rims were generally too narrow to be analysed with our standard 20 µm laser spot; however, three analyses gave a poorly defined upper intercept age of 2.58 ± 0.04 Ga.

Veined gneiss and cross-cutting tonalitic schist

In the southern part of the region, a slightly schistose tonalite (499227) has an intrusive cross-cutting relationship to a veined tonalitic gneiss (499228) with amphibolite enclaves. Abundant veins of granitic pegmatite appear to have formed by partial melting of the veined gneiss along amphibolite boudin necks, along the foliation and along the tonalite-gneiss contacts. The zircon grains from the tonalite (499227) have complex internal textures. Many of them have oscillatory zoned cores and homogeneous rims and/or internal zones (Fig. 3e). A total of 49 of 60 U-Pb zircon age determina- tions define a $^{207}Pb/^{206}Pb$ age of 2.719 ± 0.005 Ga (n = 49/60, ± 2σ, MSWD = 2.2, concordant from 91 to 113%). The remaining 11 age determinations form an array towards older ages and presumably represent ancient Pb-loss in grains as old as *c.* 2.859 ± 0.014 Ga (single grain $^{207}Pb/^{206}Pb$ age; Fig. 4e). The zircon grains from the veined gneiss (499228) generally have thick, homogeneous, bright rims surrounding cores that are highly cracked and commonly metamict; only a few cores show remains of oscillatory zonation (Fig. 3f). The spread in ages indicates ancient lead loss from 2.85 to 2.7 Ga with no obvious $^{207}Pb/^{206}Pb$ age plateau (Fig. 4f); one grain was dated at *c.* 3.1 Ga. The interpretation of the age data remains speculative, but given the altered appearance, the metamorphic rims and the relationship with the tonalite (499227), it seems reasonable to assume a metamorphic overprinting of the rock at *c.* 2.72 Ga, perhaps related to the accretion with the Tre Brødre terrane.

Discussion and summary

The zircon crystallisation age of 2.87–2.85 Ga for samples 499221, 499161 and 514832 and a somewhat speculative metamorphic age at 2.80 Ga for sample 499221 correlate very well with known crystallisation ages and granulite facies events within the Tasiusarsuaq terrane. These ages are significantly younger than ages of rocks from the Kapisilik terrane but older than those of the Tre Brødre terrane. It is thus tempting to ascribe these areas to the Tasiusarsuaq terrane. To include the 'Nunatak 1390' is straightforward, while including Nunataarsuk implies a major northerly extension of the terrane that requires confirmation by further work. Age data alone naturally do not justify the inclusion of these areas into the Tasiusarsuaq terrane, but it appears to be the most straightforward option based on the available information. More importantly, the ages obtained from the rhyolite and granite at 'Nunatak 1390' (2.873 Ga) and Nunataarsuk (2.853 Ga) provide minimum extrusive ages for the associated mafic greenstones and might reflect the onset of crustal growth in this block. Furthermore, the emerging terrane configuration might indicate that the Tasiusarsuaq terrane accreted with the Kapisilik terrane in the north-east and with the Tre Brødre terrane in the south-west.

The ages from the schistose tonalite (499227) and the veined gneiss (499228) are too young to readily represent known events within the Tasiusarsuaq terrane. The inferred metamorphic ages rather correlate with the thermal event associated with prograde amphibolite facies metamorphism within the Tre Brødre terrane. However, situated well within the Tasiusarsuaq terrane these rocks would not have experienced a prograde metamorphic path during terrane accretion. Furthermore, there is evidence for ≥2.85 Ga old zircons, which are too old to readily fit with known ages of the Tre Brødre terrane. We speculate that the northern part of the Tasiusarsuaq terrane may represent a nappe complex, and that the investigated rocks either represent a tectonic window exposing footwall rocks that experienced prograde metamorphism and partial melting during overthrusting, or that fluids released from footwall-induced zircon Pb-loss and/or partial melting in the overriding nappe.

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