2635 Ma amphibolite facies gold mineralisation near a terrane boundary (suture?) on Storø, Nuuk region, southern West Greenland

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Abstract

Gold on Storø (in the Nuuk region of southern West Greenland) occurs in a slice of strongly deformed, amphibolite facies, Neoarchaeal quartzo-feldspathic metasedimentary rocks and amphibolites in tectonic contact with the Eoarchaeal Færingehavn terrane and the Meso- to Neoarchaeal Akia terrane. The gold is associated with either löllingite (FeAs) + arsenopyrite or pyrrhotite, which belong with the amphibolite facies silicate mineral assemblages. Zircons were U/Pb dated by SHRIMP to constrain the timing of mineralisation. The 2700–2830 Ma oscillatory-zoned, high Th/U volcano-sedimentary zircon as whole grains and cores are interpreted to give the maximum depositional age of the rocks hosting the gold. A granite sheet barren of gold that cuts gold mineralised rocks gives an age of ca. 2550 Ma, which is the absolute minimum age of mineralisation. Metamorphic zircons associated with auriferous arsenopyrite (particularly close to secondary löllingite), pyrrhotite and in the coexisting amphibolite facies silicate minerals were dated *in situ*, in polished thin sections. These have lower average Th/U and yielded dates of ca. 2635 Ma, which is interpreted as the age of the gold-bearing mineral assemblages and hence probably the mineralisation.

Supracrustal packages containing abundant quartzo-feldspathic sedimentary rocks with depositional ages of ca. 2800 Ma and metamorphosed at 2650–2600 Ma also occur as folded tectonic intercalations along the western edge of the Færingehavn terrane south of Storø. Moreover, in the 3080–2960 Ma Kapisilik terrane to the north and east of Storø, high-grade metamorphic events also occurred between 2650 and 2600 Ma. However, the Eoarchaeal Færingehavn terrane to the south and east of Storø shows widespread zircon growth and recrystallisation during 2720–2700 Ma regional metamorphism, but *not* at 2650–2600 Ma. The Storø gold prospect is thus located near an important tectonic terrane boundary (cryptic suture?) between domains with different Neoarchaeal metamorphic history. Storø mineralisation at ca. 2635 Ma probably occurred during deformation of this boundary shortly after it was created, and at Storø maybe was focussed in an area of low strain in a major antiform. The general tectonic frameworks for ca. 2635 Ma gold mineralisation on Storø and in the Yilgarn Craton are similar. These gold provinces are compared and contrasted, and the likely reason why so much less gold occurs in the Nuuk region is discussed.

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The Archaean gneiss complex of the Nuuk region (Fig. 1) contains several occurrences of amphibolite facies gold mineralisation (summaries by Appel et al., 2000, 2003; Møller Stensgaard et al., 2006). The largest gold mineralisation (locally up to 36 g/t) occurs on the island of Storø in a tectonic slice of amphibolites and quartzo-feldspathic metasedimentary rocks

(Figs. 1 and 2). The Nuuk region had a protracted Neoproterozoic tectonothermal history marked by polycyclic amphibolite–granulite facies metamorphism and repeated folding and tectonic intercalation of unrelated rocks (Nutman et al., 2004; Friend and Nutman, 2005a; Nutman and Friend, 2007 and references therein). Thus, there is a choice of several Neoproterozoic tectonothermal events during which the Storø gold mineralisation could have formed.

Fig. 2. Geological sketch map of the Storø prospect based on mapping by V.R. McGregor, modified using observations of Friend et al. (1988) and Hollis et al. (2004).

In this paper, 10–20 μm metamorphic zircons occurring within gold-bearing sulphides and the associated amphibolite facies silicate assemblage were dated using sensitive high resolution ion microprobe (SHRIMP). The obtained U/Pb dates of ca. 2635 Ma are interpreted as giving the time that gold was lodged in the Storø rocks. From regional tectonic and metamorphic studies, we propose that the gold mineralisation occurred close to a terrane boundary (originally a suture?) between a domain showing pervasive high-grade 2650–2600 Ma metamorphism and a domain with only a weak 2650–2600 Ma metamorphic overprint (but pervasive 2720–2700 Ma metamorphism instead; Nutman and Friend, 2007). In the discussion, the tectonothermal setting of the Storø mineralisation is compared with that of essentially coeval Neoarchaean gold mineralisation in the Yilgarn Craton of Australia (e.g. Barnicoat et al., 1991; Kent et al., 1996; Goldfarb et al., 2001; Henson and Blewett, 2005).

2. Neoarchaean tectonothermal evolution of the Nuuk region: assembly of terranes

Only brief summaries of the Neoarchaean tectonothermal evolution and terrane assembly are given here. Friend et al. (1987) and Friend et al. (1988) demonstrated that the region contains several unrelated orthogneiss complexes, which are tectono-stratigraphic terranes bounded by folded amphibolite facies Archaean mylonites. These terranes had different early histories (ages of tonalitic gneisses and intra-terrane metamorphism) prior to tectonic juxtaposition along the mylonites and pan-terrane deformation and metamorphism later in the Archaean (Friend et al., 1987, 1988; Nutman et al., 1989). McGregor et al. (1991) used the terrane assembly model to propose that the Nuuk region contains a deeply eroded Archaean continent–continent collision zone comprising mostly pre-collisional basement rocks. In the south of the

Nuuk region, the terrane assembly interpretation has been supported by detailed structural mapping and U/Pb mineral dating over the southern end of the Qarliit Nunaat fault (Fig. 1; Crowley, 2002). Zircon geochronology has indicated several important later Archaean terrane assembly events, from likely first terrane assembly at ca. 2950 Ma, through to important 2720–2680 and 2650–2600 Ma terrane assembly and high-grade metamorphism events, and finally intrusion of the ca. 2560 Ma, late kinematic Qôrqt Granite Complex (see Schiøtte et al., 1988; Friend et al., 1988, 1996; Friend and Nutman, 2005a; Nutman et al., 1989, 2004; Crowley, 2002; Nutman and Friend, 2007 for data, discussion and interpretations).

Prior to Friend and Nutman (2005a), tectonothermal evolution of the region was accommodated using the first terranes identified in the south in the 1980s—the *Færingehavn*, *Tasiusarsuaq*, *Tre Brødre* and *Akia* terranes of Friend et al. (1987) and Friend et al. (1988). With an increasing amount of remapping and zircon dating from the east of the region, Friend and Nutman (2005a) recognised that additional terranes are present, including the *Kapisilik* terrane discussed here (Fig. 1). This does not negate the earlier terrane hypothesis, but marks recognition of greater geological complexity, as more information has become available.

The Storø gold mineralisation occurs in a tectonic slice of amphibolite facies, quartzo-feldspathic metasedimentary rocks and amphibolites, bounded on both sides by folded Neoarchaean meta-mylonites (Fig. 2). The same situation occurs southwards, so that on Simiutaa, Rypeø and Angisorsuaq islands south of Nuuk (Fig. 1), this slice of quartzo-feldspathic metasedimentary rocks and amphibolites occurs in folded tectonic intercalations along the western edge of the *Færingehavn* terrane (Chadwick and Nutman, 1979; McGregor, 1984).

3. Storø gold mineralisation

3.1. Geological setting

On Storø, the tectonic slice of mineralised quartzo-feldspathic metasedimentary rocks and amphibolites is over 1 km thick, and occupies an antiform (McGregor, 1984; Hollis et al., 2004). This slice is structurally below the Eoarchaean orthogneisses of the *Færingehavn* terrane that crop out to the south and east (Fig. 2). North of the Storø mineralised rocks, there are ca. 2720 Ma granitic gneisses (samples G88/21, G88/22, G88/23 and G91/64 in Friend et al., 1996 and G04/01 Nutman and Friend, unpublished data), in which there are enclaves of Neoarchaean anorthosite and leucogabbro.

Eoarchaean rocks north of the Storø gold mineralisation are also injected by ca. 2720 Ma granite sheets (e.g. sample VM92/03 in Friend et al., 1996). The boundary between this northern domain with abundant 2720–2700 Ma granite injection and the mineralised Storø rocks is a folded mylonite. To the west, the Storø tectonic slice of mineralised rocks is separated from the Meso- to Neoarchaean Akia terrane by the Ivinnguit fault (McGregor et al., 1991) and the Storø shear zone (Hollis et al., 2004). Away from the Akia terrane's eastern tectonic boundary, effects of Neoarchaean deformation and metamorphism are slight (Nutman et al., 1989; Garde et al., 2000). Deformation of the Storø rocks is mostly strong. The gold mineralisation occurs east of the Storø shear zone, in generally less deformed rocks in the core of the antiform (Fig. 3). There are several zones of amphibolite facies gold mineralisation, with the “Main Zone” providing the samples used in this study. Most of the gold mineralisation zones are in a domain where undeformed to weakly deformed granite sheets barren of gold cross-cut mineralisation zones. Away from this domain, later ductile deformation has deformed these granite sheets (Fig. 3). The principal ore host is amphibolite, but high gold values have been found sporadically in all rock types (Petersen et al., 1996; Pedersen and Petersen, 1998; Appel et al., 2000). On the grounds of a structural study and ore petrography, Pedersen and Petersen (1998) concluded that the Storø gold occurrence is a typical structurally controlled lode-gold deposit, which formed as amphibolite facies metamorphism waned.

3.2. Petrography of dated mineralised samples

The two mineralised samples investigated here are from the “main zone” (G03/06 and STO84558,

Fig. 3. Vertical aerial photograph covering the “main zone” from which samples related to gold mineralisation have been dated. Note mineralisation is concentrated in a domain of low late strain where late granite sheets are cross-cutting. Outside of this domain (to left = west and to bottom = south) late strain is higher.

Fig. 4. Cathodoluminescence images of dated zircons from mineral separation of G03/06.

Figs. 2–6) and consist of almandine garnet + plagioclase + hornblende ± diopside + quartz ± titanite + pyrrhotite (with subordinate chalcopyrite) ± arsenopyrite ± löllingite (iron arsenide). Hornblende is commonly sieved with quartz, which suggests that clinopyroxene may once have been more abundant. It is possible that these rocks might have once carried higher-pressure assemblages (i.e. clinopyroxene + garnet + plagioclase + quartz ± hornblende of the high pressure granulite facies), but have subsequently been recrystallised at lower pressures, in keeping with sillimanite now being the aluminosilicate in the metasedimentary rocks on Storø.

Arsenopyrite with löllingite inclusions is rimmed by pyrrhotite (Pedersen and Petersen, 1998) and mineralised samples can contain stockworks of löllingite

veins (Fig. 6A). Gold occurs in arsenopyrite, as small free gold particles associated with the early löllingite (Pedersen and Petersen, 1998) and also within the later löllingite-bearing veins (Nutman, unpublished laser ablation ICP-MS analyses). The textures show that the mineralisation is part of an amphibolite facies assemblage coincident with:

arsenopyrite ± löllingite $\Leftrightarrow$ pyrrhotite + löllingite.

Phase relationships determined by Kretchmar and Scott (1976) show that the maximum temperature for the stability of arsenopyrite + löllingite is ca. 700 °C at $\log a_{S_2} = 1 \times 10^{-4}$ (a = activity). This is in accord with the association on Storø of these sulphides with amphibolite facies silicate mineral assemblages.

Fig. 5. $^{238}\text{U}/^{206}\text{Pb}$ vs. $^{207}\text{Pb}/^{206}\text{Pb}$ plots for zircon from the Storø gold mineralisation. (A) G03/06 mineralised rock zircons analysed as a mineral separate and *in situ* in polished section. (B) STO84558 mineralised rock zircons analysed *in situ*. (C) G03/05 non-mineralised granite dyke cutting mineralised sample G03/06. Analytical errors are portrayed at the 2σ level and in the right hand side of each frame the cumulative probability distribution for $^{207}\text{Pb}/^{206}\text{Pb}$ is shown.

3.3. SHRIMP U/Pb zircon dating of mineralised samples

Dates reported here are by the SHRIMP U/Pb zircon method on the SHRIMP I, II and RG instruments at the Research School of Earth Sciences, the Australian National University. Stern (1998) and Williams (1998) describe general analytical techniques, data calibration and analytical error assessment. Choice of analytical sites was based on cathodoluminescence (CL) and backscattered electron (BSE) imaging, and weighted mean $^{207}\text{Pb}/^{206}\text{Pb}$ dates (inverse variance weighted, 95% confidence, rounded to the nearest million years) and plotting of data in Tera-Wasserburg $^{238}\text{U}/^{206}\text{Pb}$ versus $^{207}\text{Pb}/^{206}\text{Pb}$ diagrams were undertaken using ISOPLOT (Ludwig, 1999).

Heavy mineral separation of gold mineralised sample G03/06 gave a small zircon yield. Oscillatory-zoned cores gave ≥ 2700 Ma ages with high Th/U ratios and are interpreted as volcano-sedimentary in origin (Table 1, Figs. 4 and 5). It is uncertain whether the few ca. 2700 Ma ages might be of sites that had lost some radiogenic Pb in ancient times, and thus might underestimate the age of deposition. However, several oscillatory-zoned zircons gave ages of 2800–2850 Ma, that matches the commonest age of detrital and/or volcano-sedimentary zircons found in metasedimentary rocks to the south and in the Kapisilik terrane to the northeast (Nutman and Friend, 2007). Thus 2700–2800 Ma (probably close to 2800 Ma) is considered the likely time interval for the deposition of the rocks hosting the gold mineralisation on Storø. Structureless in CL image zircon occurs as rims on oscillatory-zoned zircon and as equant grains, and is mostly lower in Th/U than the oscillatory cores. This gave a weighted mean $^{207}\text{Pb}/^{206}\text{Pb}$ date for metamorphism of 2634 ± 8 Ma ($n = 8$, MSWD = 0.73).

Polished slabs of gold mineralised rocks G03/06 and STO84558 were searched for zircons *in situ* (BSE imaging and phase identification by energy dispersion analysis—Fig. 6 shows setting of all dated zircons). In G03/06, 20–10 μm zircons occur within and along the boundaries of auriferous arsenopyrite. Where they are within auriferous arsenopyrite, they are often associated with löllingite veins (Fig. 6A). These zircons are equant, moderate to low Th/U grains and yielded a $^{207}\text{Pb}/^{206}\text{Pb}$ date of 2628 ± 28 Ma ($n = 5$, MSWD = 0.63). Combining the mineral separation and the polished slab metamorphic zircon data yields a weighted mean $^{207}\text{Pb}/^{206}\text{Pb}$ age of 2633 ± 8 Ma (MSWD = 0.65). The large uncertainty is a combination of the small analytical spot of 10 μm and the only moderate to low U abundance (100–30 ppm), which together give only a small flux

(A) G03/06 dated zircons

(B) STO84558 dated zircons

Fig. 6. Secondary electron backscatter images of zircons analysed *in situ* in Storø mineralised rocks. (A) Sample G03/06, (B) sample STO84558.

Pb⁺ ions to measure. A larger (20 μm) zircon in hornblende near arsenopyrite has higher Th/U (~0.4), and two analyses gave identical dates of 2830 Ma (Table 1). This grain is interpreted to be volcano-sedimentary in origin. In STO84558, one 10 μm zircon (disturbed and

suffered radiogenic Pb-loss) was found within pyrrhotite and has the youngest apparent age (Table 1), and 10–15 μm zircons occur at a pyrrhotite–diopside grain boundary and hosted by diopside, hornblende and titanite near pyrrhotite (Fig. 6B). These are mostly low

Th/U (<0.1), and because they have low U abundance (mostly <100 ppm), their analytical errors are large, as for G03/06. Excluding the disturbed grain within pyrrhotite, the remaining six analyses cluster close to concordia and have a pooled date of 2636 ± 27 Ma (MSWD=0.70; Fig. 6B). Pooling all the data for the metamorphic zircons (G03/06 and STO84558) yields a $^{207}\text{Pb}/^{206}\text{Pb}$ weighted mean date of 2633 ± 8 Ma (MSWD=0.63).

A non-mineralised, weakly deformed granite dyke (G03/05, Table 1; Fig. 5C) cuts mineralised sample G03/06. The zircons in this dyke are very high U + Th and largely metamict. Two rare sites showing relict oscillatory zoning and generally lower U abundance with dates of ca. 2550 Ma are considered to give an imprecise determination on the intrusion of the granite dyke. This provides the youngest age limit of mineralisation.

4. Regional context of the Storø gold mineralisation

The gold-mineralised rocks on Storø experienced amphibolite facies metamorphism between 2650 and 2600 Ma (Hollis et al., 2006), with 2633 ± 8 Ma proposed here as the timing of gold mineralisation. The zircon geochronology shows no clear evidence for 2720–2700 Ma metamorphism in the mineralised rocks. This is despite that to the north there is a major expanse of 2720 Ma granite and that the Færingehavn terrane to the south was metamorphosed at 2715–2680 Ma (Friend et al., 1996; Nutman and Friend, 2007).

Neoarchaean high-grade metamorphic assemblages in the Nuuk region vary in age and character between the different tectono-stratigraphic terranes (Friend and Nutman, 2005a; Nutman and Friend, 2007). These metamorphic events are summarised here and in Fig. 7, to provide regional context to the timing of amphibolite facies metamorphism and mineralisation on Storø.

4.1. Kapisilik terrane and the package of quartzo-feldspathic metasedimentary rocks with amphibolites intercalated with the western Færingehavn terrane

The Kapisilik terrane (Friend and Nutman, 2005a) crops out to the north and east of Storø (Fig. 1). It was first recognised at the eastern end of Kapisillit fjord around Kapisillit village, and to the north on Ivisaartoq, where it contains the ca. 3080 Ma Ivisaartoq supracrustal belt (Fig. 1). Mapping in 2005 under the auspices of the Geological Survey of Denmark and Greenland (Friend and Nutman, 2005b) combined with further reconnaissance

Fig. 7. Zircon dating of Neoarchaean tectonothermal events in the Nuuk region and timing of Storø gold mineralisation. Only published data and that in this paper are shown. Metamorphic zircon growth is shown as cumulative frequency probability diagrams combined with histograms.

Table 1
SHRIMP U/Pb zircon analyses

Labels	Grain type	U (ppm)	Th (ppm)	Th/U	Comm. $^{206}\text{Pb}\%$	$^{238}\text{U}/^{206}\text{Pb}$ ratio	$^{207}\text{Pb}/^{206}\text{Pb}$ ratio	207/206 date (Ma)	Concordance (%)
G03/06 gold mineralised rock, Storø—mineral separation UTM 495887, 7143007									
1.1	r,h,p,fr	160	18	0.11	0.10	1.946 ± 0.065	0.1794 ± 0.0009	2647 ± 8	101
1.2	c,osc,p,fr	344	217	0.63	0.19	2.827 ± 0.098	0.1930 ± 0.0008	2768 ± 7	71
2.1	e,h,p	183	9	0.05	0.04	1.856 ± 0.060	0.1771 ± 0.0011	2626 ± 10	106
3.1	r,h,p	90	4	0.04	0.15	1.886 ± 0.061	0.1771 ± 0.0019	2626 ± 18	105
3.2	c,osc,p	382	52	0.14	0.51	1.760 ± 0.060	0.2035 ± 0.0019	2854 ± 15	102
3.3	c,osc,p	592	100	0.17	0.40	1.831 ± 0.067	0.2018 ± 0.0018	2841 ± 15	99
4.1	c,osc,p	166	55	0.33	0.16	1.837 ± 0.063	0.2134 ± 0.0013	2931 ± 10	96
4.2	r,h,p	90	3	0.04	0.32	2.071 ± 0.077	0.1775 ± 0.0016	2630 ± 15	97
5.1	r,h,ov	40	15	0.37	0.09	1.994 ± 0.070	0.1784 ± 0.0020	2638 ± 19	99
6.1	e,h,ov	104	12	0.11	0.11	1.849 ± 0.058	0.1783 ± 0.0016	2637 ± 15	106
7.1	c,osc,p,fr	153	23	0.15	0.38	2.140 ± 0.131	0.1895 ± 0.0028	2738 ± 24	90
7.2	r,h,p,fr	109	13	0.12	0.32	2.075 ± 0.070	0.1763 ± 0.0016	2619 ± 15	97
8.1	c,osc,p,fr	459	151	0.33	0.07	1.810 ± 0.064	0.1867 ± 0.0008	2713 ± 7	105
9.1	h,p	166	12	0.07	0.07	2.075 ± 0.067	0.1773 ± 0.0010	2628 ± 9	97
G03/06 gold mineralised rock, Storø—in situ analyses									
1.1	in arsenop	104	2	0.02	0.50	1.996 ± 0.096	0.1764 ± 0.0024	2619 ± 22	100
2.1	arsenop-hbl contact	55	6	0.12	5.41	2.276 ± 0.173	0.1753 ± 0.0089	2608 ± 87	90
3.1	arsenop-hbl contact	37	6	0.15	1.01	2.034 ± 0.143	0.1757 ± 0.0036	2613 ± 35	99
4.1	arsenop-hbl contact	42	7	0.17	0.84	1.951 ± 0.073	0.1746 ± 0.0040	2602 ± 38	103
5.1	arsenop-hbl contact	89	24	0.27	0.41	1.917 ± 0.091	0.1812 ± 0.0029	2664 ± 27	102
6.1	in hbl	444	193	0.43	0.14	1.798 ± 0.105	0.2007 ± 0.0016	2832 ± 13	101
6.2	in hbl	393	160	0.41	0.69	1.877 ± 0.099	0.2005 ± 0.0027	2831 ± 22	97
G03/05 granitic dyke cutting gold mineralized rock G03/06, Storø UTM 495887, 7143007									
1.1	meta,p	8251	602	0.07	0.08	2.197 ± 0.114	0.1606 ± 0.0011	2462 ± 11	98
2.1	meta,p	2107	78	0.04	0.45	1.731 ± 0.056	0.1687 ± 0.0006	2544 ± 6	116
3.1	meta,p	4491	1300	0.29	11.80	0.861 ± 0.158	0.1227 ± 0.0428	1996 ± 800	249
4.1	meta,p	3211	128	0.04	0.06	1.327 ± 0.045	0.1567 ± 0.0007	2420 ± 7	150
5.1	meta,p	2511	278	0.11	2.27	1.969 ± 0.081	0.1691 ± 0.0031	2548 ± 31	104
STO84558 gold mineralised rock, Storø—in situ analyses $64^{\circ}24.571'\text{N}$ $51^{\circ}05.643'\text{W}$									
1.1	in pyrrhotite	22	2	0.11	7.10	1.990 ± 0.098	0.1581 ± 0.0137	2436 ± 155	108
2.1	in titanite	34	1	0.02	0.44	1.920 ± 0.080	0.1776 ± 0.0024	2630 ± 23	103
3.1	Edge of cpx	114	7	0.07	0.54	2.182 ± 0.053	0.1786 ± 0.0021	2640 ± 19	92
4.1	in cpx	160	9	0.06	2.81	1.882 ± 0.084	0.1781 ± 0.0042	2635 ± 40	104
5.1	in hbl	13	4	0.33	11.16	1.969 ± 0.212	0.1377 ± 0.0141	2198 ± 189	121
6.1	in hbl	32	2	0.07	5.93	1.947 ± 0.099	0.1771 ± 0.0078	2626 ± 75	102
7.1	hbl–titanite bound	48	4	0.09	9.03	1.916 ± 0.145	0.1945 ± 0.0127	2781 ± 111	97

p = prismatic, eq = equant and ovoid, e = end, m = middle, r = overgrowth, c = core rex = recrystallised, osc = oscillatory finescale zoning, s = sector zoning, h = homogeneous, hd = homogeneous dark, f = fragment, anh = anhedral, meta = metamict domains corrected with model Pb of Cumming and Richards (1975) for likely age of rock.

zircon geochronology (Hollis et al., 2005; J. Hiess, personal communication, 2006) shows that the Kapisilik terrane extends westwards along Kapisillit fjord, towards Storø (Fig. 1). The precise nature of the western boundary of this terrane against Eoarchaeoan rocks and younger anorthosite intruded by abundant ca. 2720 Ma granite is still unknown, and has been shown as a row of question marks on Fig. 1. In the Kapisilik terrane, relicts of high-pressure assemblages in amphibolites and melts found with kyanite in metasedimentary rocks have been dated at ca. 2650 Ma (Nutman and Friend, 2007). *In situ* ca. 2600 Ma anatexis locally in orthogneisses of the Kapisilik terrane (sample G87/223 in Friend and Nutman, 2005a; Fig. 1) and ca. 2630 Ma granite intruded into the Ivisaartoq supracrustal belt (sample G03/78 in Nutman and Friend, 2007; Fig. 1) show that high temperatures persisted until 2600 Ma. Therefore the Kapisilik terrane shows widespread evidence of 2650–2600 Ma metamorphism and granite emplacement, with no evidence of older (2720–2700 Ma) metamorphism (Fig. 7).

Where metasedimentary rocks of the Storø package are exposed on the islands of Simuitaa, Rypeø and Angisorsuaq south of Nuuk (Figs. 1–7), metamorphic growth of zircon occurred in several episodes between 2650 and 2580 Ma (including 2635 Ma), with no evidence for older, 2720–2700 Ma metamorphism (Schjøtte et al., 1988; Nutman et al., 2004; Nutman and Friend, 2007).

4.2. *Færingehavn terrane, its carapace of Neoarchaeoan supracrustal rocks, the Tre Brødre terrane and Tasiarsarsuaq terrane*

South and east of the Storø gold mineralised rocks lies the Færingehavn terrane of Eoarchaeoan gneisses, overlain by a panel of Neoarchaeoan supracrustal rocks. (Friend et al., 1987, 1988; Nutman et al., 1989; Crowley, 2002; Nutman and Friend, 2007). Neoarchaeoan deformation and metamorphism of the Færingehavn terrane and its carapace of Neoarchaeoan supracrustal rocks resulted in anatexis and widespread growth of metamorphic zircon. Dating of metamorphic zircon in these rocks is summarised in Fig. 7 (from Bennett et al., 1993; Friend et al., 1996; Friend and Nutman, 2005b; Nutman et al., 1997, 2000, 2002, 2004; Nutman and Friend, 2007). Neoarchaeoan metamorphic zircon growth occurred at 2720–2680 Ma (with noted exception VM90/07—see below), in striking contrast to the 2650–2600 Ma metamorphism in the Kapisilik terrane and the Storø package of quartzo-feldspathic metasedimentary rocks and amphibolites (Fig. 7). Exception VM90/07 is a sample of pegmatite-banded orthogneiss

from a small island just northeast of Storø (Fig. 1) that shows growth of low Th/U metamorphic zircon at ca. 2610 Ma. This can be accounted for by this sample being at the important tectonic boundary with rocks showing the 2650–2600 Ma metamorphism. It developed pegmatites and metamorphic zircons at 2610 Ma during the reworking of this boundary under amphibolite facies conditions. The Tre Brødre and Tasiarsarsuaq terranes structurally overlying the Færingehavn terrane show little evidence of regional metamorphism at either 2720–2680 or 2650–2600 Ma. However, a sample of a late amphibolite facies mylonite traversing the Tasiarsarsuaq terrane (sample G01/26 in Nutman and Friend, 2007) shows 2650–2600 Ma zircon growth, indicating disruption of the Tasiarsarsuaq terrane by shear late zones at that time (Figs. 1 and 7).

5. Discussion

5.1. *Age of the Storø gold mineralisation*

The metamorphic zircons from both gold mineralised samples give a weighted mean $^{207}\text{Pb}/^{206}\text{Pb}$ date of 2633 ± 8 Ma (shortened hereafter to ca. 2635 Ma), which we propose is the likely time of mineralisation coincident with amphibolite facies metamorphism. In detail, mineralisation is likely to be complex, and not synchronous within the 16 million years 95% confidence limit of the geochronology presented here. A possible time span for mineralisation is in accord with the conclusion of Pedersen and Petersen (1998) based on their sulphide petrography, because they noted that primary mineralisation involved development first of auriferous löllingite, with evolution to a slightly lower-temperature arsenopyrite–gold assemblage. Furthermore, gold also occurs locally in late cross-cutting löllingite veins, particularly where they intersect or change direction (Nutman, unpublished laser ablation ICP-MS analyses). Nonetheless, the age of the rocks (2700–2830 Ma) and the age of 2560 Ma for cross-cutting granite sheets barren of gold, give the broadest time frame possible for the complete mineralisation history (Fig. 7).

5.2. *Tectonic setting of the Storø gold mineralisation: located near a deformed ca. 2650 Ma suture?*

The ca. 2635 Ma Storø mineralisation developed during metamorphism and deformation near a major tectonic boundary between a domain of crust that suffered 2650–2600 Ma high-grade metamorphism (Storø supracrustal package and Kapisilik terrane) and another

one (Færingehavn terrane and associated ca. 2840 Ma supracrustal rocks) that suffered 2720–2700 Ma high-grade metamorphism (Figs. 1 and 7).

Structural, metamorphic and geochronological data indicate that domains with 2720–2680 Ma versus 2650–2580 Ma metamorphic signatures are separated by meta-mylonites (mapping in Friend and Nutman, 1991; Fig. 1). This boundary was subsequently folded at least twice under amphibolite facies conditions, to give its complex outcrop pattern.

Presently, the position of the folded tectonic boundary is best known on the southern side of Kapisillit fjord (Fig. 1) and on Storø (Fig. 2). Although there is much to learn about this boundary, it must be of major importance (a suture?) for the Nuuk region, because as shown by Nutman and Friend (2007) it divides two domains with different-aged Neoproterozoic high-grade metamorphic events. The large antiform on Storø involving abundant supracrustal rocks of different competency would promote mineralisation on Storø, setting it apart from other locations along the possible suture.

There are two explanations for the lack of pandemic 2650–2600 Ma metamorphic zircon growth in the Færingehavn terrane. The first is that the Færingehavn terrane was in the upper plate in a ca. 2650 Ma collisional event that was responsible for the high-pressure metamorphic assemblages of that age developed in the Kapisilik terrane (kyanite in metasedimentary and high-pressure granulite assemblages in mafic rocks—Nutman and Friend, 2007). In which case, gold mineralisation at ca. 2635 Ma might have occurred during exhumation of the lower plate, with deformation and amphibolite facies metamorphism of the suture. This postulated exhumation would have brought the Kapisilik terrane ca. 2650 Ma high-pressure metamorphic assemblages to the same crustal level as rocks to the south that did not suffer that metamorphism. Such exhumation of the southern edge of the Kapisilik terrane and associated supracrustal rocks with 2650–2600 Ma metamorphism would place the Storø gold mineralisation in a 2650–2600 Ma extensional regime related to reworking of a slightly older suture. The second explanation is that the boundary between the two metamorphic domains is yet younger still. In this scenario, tectonic intercalation would have to be no later than intrusion of the late kinematic 2560 Ma Qôrqt Granite Complex, that intrudes the boundary between the two metamorphic domains (Fig. 1).

Other gold showings in the Nuuk region yet to be dated are in the 3080 Ma supracrustal rocks on Ivisaartoq to the northeast of Storø, in the Eoarchean Isua supracrustal belt to the north and in ca. 3080 Ma?

supracrustal rocks west of the Ivinniguit fault (Appel et al., 2003; Hollis et al., 2004). However, given the complexity of the region's Archaean tectonic evolution, it would be unwise to assume ca. 2635 Ma as a uniform age for other gold mineralisation in the region.

5.3. Comparison of Storø and ca. 2630 Ma Yilgarn (Western Australia) gold mineralisation

The Yilgarn shows a spread in gold mineralisation events, including some earlier than 2630 Ma such as Wal-laby (Salier et al., 2001). However, from mineralised rocks the plethora of ca. 2630 Ma ages is taken to mark a major mineralisation and fluid movement event spanning all crustal levels (Barnicoat et al., 1991; Groves, 1993; Goldfarb et al., 2001). Thus amphibolite to granulite facies mineralisation in the west Yilgarn such as at Griffins Find and lower grade, greenschist facies mineralisation of the Kalgoorlie terrane in the east are coeval at ca. 2630 Ma (Barnicoat et al., 1991; Kent et al., 1996). Note then, that the Yilgarn and Storø mineralisation is essentially contemporaneous.

Summaries of this ca. 2630 Ma Yilgarn event (and similar ones in other Archaean cratons) have remarked that the main mineralisation occurs just after major crustal accretion (Goldfarb et al., 2001). In the Yilgarn, gold is accumulated in diverse structural traps, related particularly to a series of structurally late (D₂) domes and breaching faults that disrupt a major earlier mid crustal structure which shows up as strong reflectors in seismic studies (e.g. Vearncombe, 1998; Groves et al., 2000; Blewett et al., 2004; Henson and Blewett, 2005). In much of the southern Yilgarn there is division between ca. 2700 Ma greenstone sequences at higher crustal levels and a gneissic basement below (with 3300–3500 Ma crustal components demonstrated in the latter by Pb–Pb isotopic studies of granitoids (Oversby, 1975), 3100–4350 Ma detrital zircons in “basal” quartzites (Wyche et al., 2004) and from 3100 to 3500 Ma zircon xenocrysts in crustally contaminated basalts (Compston et al., 1986). The emplacement of late kinematic granitoids heavily disrupted both the basement and the greenstones, to the extent that the basement rocks to the greenstones have been largely obliterated. Although it is mostly considered that the greenstones were deposited on a sialic basement, the contacts between them have been heavily modified by D₁ thrusting, also with isoclinal folding in the greenstones (e.g., Swager, 1997). The early D₁ thrusts would have caused some crustal thickening. Henceforth, the boundary between sialic “basement” and the greenstone successions was modified in a complex D₂ event wherein

crustal extension gave rise to strong shallow-dipping anisotropy that now lies at depths between 4 and 7 km, then upright folding and development of complex arrays of upright shear zones. This D₂ event has been named the Wangkathaa Orogeny by Blewett et al. (2004), who in their detailed structural and seismic study, demonstrated that D₂ was episodic and involved switching in tectonic mode (compression–extension–compression) resulting in folding, local basin formation and normal faulting. Such a regime is ideal for transporting and trapping auriferous fluids. Thus gold was transported and trapped during D₂ structural modification of a major D₁ (thrust?) trans-crustal boundary between packages of unrelated rocks.

Fundamental D₁ thrusts in orogenic complexes are not always easy to detect, follow and study, particularly in the poorly exposed areas such as the Yilgarn. This is because of their strong modification, and essentially obliteration in many places by the superimposed D₂ shearing and folding, and disruption of them by the intrusion of late kinematic crustally derived granitoids. Even in the Nuuk region, with approaching 100% exposure and 1500 m of relief, the important D_{1(2650 Ma)} tectonic boundary separating the 2650 Ma high pressure metamorphic domain from another domain without that metamorphism is only coming to light after decades of detailed geological investigation and geochronology (Nutman and Friend, 2007). Gold mineralisation on Storø occurred shortly after juxtaposition of these domains, and lies close to the suture between them, in a major antiform. Thus there are certainly some parallels between the timing and setting of gold mineralisation at both Storø and in the Yilgarn, where a fundamental D₁ structural boundary (thrust?) is affected by complex D₂ folding, later shearing events and disruption by syn- to post-kinematic granites derived by melting of the lower crustal plate.

In the case of the Nuuk region, upper and lower plates were both orthogneiss-dominated with <5% mafic supracrustal rocks, whereas in the Yilgarn the footwall was orthogneiss-granitoid dominated, but the hanging wall was a ca. 2700 Ma greenstone succession dominated by mafic volcanic rocks. This lithological difference between the Yilgarn goldfields and the Nuuk region might explain why there are orders of magnitude more gold in the Yilgarn than the Nuuk region.

6. Conclusions

- Metamorphic zircons of ca. 2635 Ma in the Storø gold mineralisation have been dated *in situ*. We propose that ca. 2635 Ma is the likely time of gold minerali-

sation coincident with a phase of amphibolite facies metamorphism.

- The gold mineralisation occurred near the boundary between a crustal domain that experienced 2650–2600 Ma amphibolite facies polymetamorphism (including high pressure metamorphism at ca. 2650 Ma—Nutman and Friend, 2007) and another domain where effects of 2650–2600 Ma events was much weaker and generally absent. This boundary might be a ca. 2650 Ma suture (event D_{1(2650 Ma)}), with 2650 Ma high-grade events focussed in the (now exhumed) lower plate.
- If correct, then Storø gold was emplaced during the D_{2(2650–2600 Ma)} reworking of the D₁ terrane boundary (suture). D₂ was a complex event that comprised exhumation of the terrane with 2650 Ma high-pressure metamorphism, then upright folding and development of shear zones. Gold might be focussed at Storø, because there is there a large body of supracrustal rocks with varying competencies, located in an antiform, close to the terrane boundary.
- In broadest terms, there are some similarities between the deposition of gold at Storø and in the southern Yilgarn. Both occurred between 2650 and 2600 Ma, during late kinematic D₂ reworking of an earlier D₁ regime, between two packages of unrelated rocks.

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