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Re–Os and U–Pb constraints on gold mineralisation events in the Meso- to Neoarchaean Storø greenstone belt, Storø, southern West Greenland

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ABSTRACT

The Storø greenstone belt in Godthåbsfjord, southern West Greenland consists of juxtaposed rock units of different age and origin, and hosts gold mineralisation that is associated with arsenopyrite along a contact between lithological units and along the axial plane of a large fold core. The age and origin of the gold is debatable, but in this paper, we present new arsenopyrite Re–Os and zircon U–Pb data to constrain the age of the Storø gold deposit. A 2.71 ± 0.05 Ga arsenopyrite isochron and 2.707 ± 0.008 Ga highly radiogenic arsenopyrite from a mineralisation along a rock contact, together with a 2.64 ± 0.02 Ga arsenopyrite isochron along the axial plane of the fold core indicate a two-stage mineralisation process. While the 2.707 ± 0.008 Ga highly radiogenic arsenopyrite provides firm support for an early mineralisation event, a mixing origin cannot yet be excluded for the 2.71 ± 0.05 Ga isochron. The 2.64 ± 0.02 Ga isochron is in perfect agreement with recent U–Pb zircon data (Nutman et al., 2007. Precambrian Research 159, 19–32) and these data are best explained by orogenic mineralisation during amphibolite facies metamorphism along structural weak planes. The initial $^{187}Os/^{188}Os$ value of 0.56 ± 0.16 for the 2.64 ± 0.02 Ga isochron indicates a crustal source for the metals, whereas the initial $^{187}Os/^{188}Os = -0.1 \pm 0.6$ for the 2.71 ± 0.05 Ga isochron remains unconstrained. Re–Os data are best explained by relatively short crustal residence times of less than 0.1 Ga, wherein the Os, and associated metals, were extracted from the mantle at a time younger than 2.8 Ga, and in which the 2.64 ± 0.02 Ga stage formed by mobilisation of an earlier mineralisation. Detrital zircon constraints imply volcanism and sediment deposition for parts of the belt at $\leq$2.84 Ga and that these units were tectonically juxtaposed to ~3.05 Ga rocks within the belt. The units that were deposited $\leq$2.84 Ga record metamorphic zircon U–Pb ages of ~2.63 Ga, but evidence for 2.72 Ga metamorphism, which is ubiquitous in adjacent terranes, is lacking.

1. Introduction

The gold potential of southern West Greenland is currently receiving interest from industry as well as academia, and several areas with possible economical potential have been identified (Grahl-Madsen, 1994; Møller Stensgaard et al., 2006). NunaMinerals A/S is currently exploring central Storø in Godthåbsfjord, north of Nuuk in southern West Greenland, and the area has been extensively mapped and drilled (van Gool et al., 2007 and references within). The gold-bearing arsenopyrite mineralisation at Storø is complex and appears to be emplaced along primary volcanic strata, as well as along later tectonic structures. Gold-bearing arsenopyrite mineralisation might thus have taken place in several stages. However, such a multistage mineralisation process is contentious, and existing geochronological evidence does not provide firm support for either a simple or a multistage mineralisation process. Bulk Pb and PbSL-dating (step-wise leaching of Pb) of arsenopyrite has yielded a ~2.86 Ga date (Juul-Pedersen et al., 2007), which is significantly older than ca. 2.65–2.63 Ga dating constraints from zircon U–Pb methods (Nutman et al., 2007), both dates have been interpreted to represent the age of mineralisation. Noteworthy, the younger age inferred by Nutman et al. (2007) is coincident with regional metamorphism, and it is feasible that this younger event represents remobilisation or reworking of older mineralisation. In this paper, we present new arsenopyrite Re–Os and zircon U–Pb data that place additional age constraints on primary sulphide

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mineralisation events. These new data support existing U–Pb age data regarding the timing and importance of metamorphism for the reworking and upgrading of the Au in the mineralisation on Storø. Furthermore, this study highlights the potential of applying Re–Os dating techniques directly on ore bearing sulphides like arsenopyrite even in complex high-grade metamorphic rocks.

2. Geology

2.1. Regional geology

The Archaean geology of the Nuuk region is a tectonic collage that is dominated by slivers of supracrustal rocks and larger blocks of orthogneisses (Nutman et al., 1989; Friend et al., 1996; Friend and Nutman, 2005a, 2005b; Nutman and Friend, 2007). The Isukasia and Færingehavn terranes (Fig. 1) are the oldest at ~3.85–3.6 Ga, and extend from the outer part of Godthåbsfjord in the southwest to the margin of the Inland Ice in the northeast (Friend and Nutman, 2005b). These terranes are composed of mainly felsic gneisses and smaller amounts of varied enclaves and belts of supracrustal, mafic and ultramafic rocks are as a whole known as the Itsaq Gneiss Complex. The felsic orthogneisses are characterised by the intrusive Paleoarchaean Ameralik dykes, and were previously known as the Amitsoq gneisses. The Itsaq Gneiss Complex is folded and thrust together with younger gneisses (generally 3.2–2.8 Ga), previously known as the Nuuk gneisses. These gneiss complexes have been divided into several terranes on the basis of their tectonothermal histories. Felsic gneisses dominate each terrane, but supracrustal greenstone belts are important, especially as these rocks commonly approximate terrane boundaries (Hollis et al., 2004; Nutman and Friend, 2007; Polat et al., 2008). The Akia terrane (Garde, 1997) and the Tasiusarsuaq terrane (Friend et al., 1988), north-west and south-west of the Itsaq Gneiss complex, respectively, are extensive units ranging in age from ~3.2 to 2.8 Ga. The Tre Brødre terrane is mainly represented by the ~2.82 Ga Ikkattoq gneiss that occurs in close spatial relationship with the Færingehavn terrane, and as a pronounced thrust unit along the Qarliit Nunaat thrust between the Færingehavn and Tasiusarsuaq terranes (Nutman et al., 1989; Friend and Nutman, 2005b). Whole-rock Sm–Nd from the Ikkattoq gneisses indicate that these gneisses were derived from remelting of several different older crustal components (up to >3.6 Ga) and trace element patterns suggest that they might represent a continental arc environment (Friend et al., 2008). The Kapisilik terrane is defined as a roughly 3 Ga old crustal component situated in the inner fjord region and separating the Færringehavn and Isukasia terranes (Friend and Nutman, 2005b). The terrane boundaries in the inner fjord region near the margin of the Inland Ice are less well constrained, and different delineations have been suggested (Næraa and Scherstén, 2008; Windley and Garde, 2009).

Supracrustal belts within the Nuuk region are important keys to the tectonic development as these might demarcate suture zones between different crustal blocks (c.f. McGregor, 1973; Bridgwater et al., 1974). At the inner part of the Godthåbsfjord, the Ivisaartoq greenstone belt (e.g. Polat et al., 2008) separates Eoarchaean gneisses of the Isukasia terrane to the north from Mesoarchaean gneisses of the Kapisilik terrane to the south (Fig. 1; Friend and Nutman, 2005b). In the central and southern part of the fjord, supracrustal rocks on the 'Qussuk peninsula' (Garde, 2007), Storø, Bjørneø and a number of islands to the south of Nuuk were originally thought to be dismembered thrusts of a single supracrustal unit (Malene supracrustal rocks), but are now known to consist at least two independent units of different age and origin (Schiøtte et al., 1988; Hollis et al., 2005b; Garde, 2007).

Terrane accretion has been described through various studies to have occurred in three separate events, which are associated with regional metamorphism. The first event involved the Isukasia, Kapisilik and Akia terranes, and the thermal event stitching these terranes is dated to ca. 2.99–2.95 Ga, which is also the age of the Kapisilik terrane (Fig. 1; Hanmer et al., 2002; Friend and Nutman, 2005b). The second major phase of accretion was associated with anatexis and emplacement of continental crust-derived granites, and is recorded in the Færringehavn, Tasiusarsuaq and Tre brødre terranes. The event has been dated at around 2.72–2.71 Ga (Friend et al., 1996; Næraa and Scherstén, 2008). A minor accretion event at 2.60–2.65 Ga has also been described from the Storø area (Nutman and Friend, 2007), and is discussed in some detail in this paper.

2.2. Field relationships

Gold mineralisation at Storø occurs in a km-thick sequence of Archaean melanocratic amphibolites and mesocratic to leucocratic intermediate supracrustal rocks, here referred to as the Storø greenstone belt, which is sandwiched between Archaean orthogneisses that are delineated by shear or fault zones (Fig. 2). The Storø greenstone belt is folded, together with the overlying orthogneisses, in a km-scale anti- and synform fold pattern (van Gool et al., 2007). It is overlain by a grey biotite-bearing orthogneiss, which belongs to the Eoarchaean Itsaq Gneiss Complex (McGregor, 1993), and which contains inclusions of amphibolite and ultramafic rocks, especially close to the contact with the underlying Storø greenstone belt. To the northwest, the Storø greenstone belt is truncated by the Storø shear zone, which emplaced rocks of the Storø greenstone belt on top of ca. 3.05 Ga grey biotite orthogneisses of the Akia terrane (Hollis, 2005). Nutman et al. (2007), however, indicate that there is a sliver of Eoarchaean gneiss between the Storø shear zone and the Ivinnguit fault. Amphibolite facies metamorphism is constrained to have occurred at 2.63 Ga, whereas local evidence for the regionally abundant thermal event between 2.72 and 2.68 Ga appears to be lacking (Friend et al., 1996; Hollis et al., 2006; Nutman and Friend, 2007; Nutman et al., 2007).

2.3. Tectonostratigraphy in the Storø greenstone belt

Based on existing field data, there is little doubt that the Storø greenstone belt represents a volcano-sedimentary sequence of composite origin (van Gool et al., 2007; Knudsen et al., 2007). Assuming that there are no overlooked tectonic thrusts, the supracrustal package should more or less represent a depositional sequence. There are, however, no depositional or other way-up structures, and the stratigraphy can only be deciphered through geochronological methods. A minimum age for base unit 1 is given by the ~3.05 Ga age of intrusive sheets. Subsequent units should be younger if the stratigraphy is conformable with the tectonostratigraphy. It remains unclear however, to what extent the rocks within the Storø greenstone belt represent two or more supracrustal sequences of different age and origin (cf. Ordóñez-Calderón et al., 2011). van Gool et al. (2007) describe four different units as summarised below.

The tectonostratigraphy of the Storø greenstone belt is fairly consistent throughout north central Storø. Anorthosite and gabbro in antiformal fold cores on Qingaaq and Aappalaartoq form the lowest lithological units; common to the whole map area. The anorthosite grades upward into leucogabbro and the unit is intruded by 3.05 Ga grey gneisses (Hollis, 2005). Sheets of anorthosite intrude the lowest part of the supracrustal rocks, and establish a 3.05 Ga minimum age for the supracrustal rocks near the base, the unit 1 banded amphibolite. Banded mela- to leucoamphibolite occurs at the base of the supracrustal rocks (unit 1), and distinct concordant felsic layers (predominantly quartz and plagioclase, with minor biotite) are 10 cm to 3 m wide. It is not clear whether these are an original part of a layered protolith