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Palaeoproterozoic metamorphism and cooling of the northern Nagssugtoqidian orogen, West Greenland

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ABSTRACT

Lu–Hf and Sm–Nd garnet geochronology combined with geothermobarometric calculations allowed us to gain new insight into the metamorphic evolution of the Northern Nagssugtoqidian orogen (NNO), in West Greenland. Three samples were collected from the southern (SM 310 and SM 316) and northern (SM 339) parts of the NNO. They revealed amphibolite-grade Palaeoproterozoic metamorphism under peak temperature conditions decreasing from c. 810 to 840 °C at 7.5 kbar (SM 310, 316) to c. 690 °C at 10 kbar (SM 339) in the southern and northern part of the NNO, respectively. Our garnet dating defines two episodes: (1) at c. 1780 Ma, determined by Lu–Hf in sample SM 316 and Sm–Nd in sample SM 339, most likely approximating the time of garnet growth, and (2) at c. 1750 Ma defined by the remaining Sm–Nd dates, reflecting time of cooling below isotopic closure. Original garnet growth patterns preserved by HREE (SM 316) and clearly seen zonation of Sm and Nd (SM 339) suggest that the garnets may not have been completely reset and thus, the obtained age of 1780 Ma could be fairly close to the time of garnet crystallisation.

The growth of peak metamorphic mineral assemblages in the southern NNO took place after the end of deformation, as demonstrated by sample SM 316 that was collected from an undeformed mafic dyke cutting across the regional fabric. In contrast, sample SM 339 revealed synkinematic growth of peak metamorphic paragenesis that crystallised in a low angle top-to-SW shear zone overprinted on the pre-existing fabric. Our results are consistent with the interpretation of the NNO as an Archaean crustal block, the Aasiaat domain, that was affected by Palaeoproterozoic metamorphism and localised deformation at 1780 Ma, i.e., 70 Ma after the Nagssugtoqidian collision. This event can be compared to the formation of steep belts (major left-lateral strike-slip shear zones) in the central part of the Nagssugtoqidian orogen. The Aasiaat domain is considered to be an independent microplate separating the Nagssugtoqidian and Rinkian orogens which define respectively its southern and northern margins. The interpretation presented implies the existence of two discrete tectonic sutures to the north and south of the Aasiaat domain.

1. Introduction

The Nagssugtoqidian orogen of West Greenland represents a deeply eroded belt of Palaeoproterozoic deformation and metamorphism largely composed of reworked Archean gneisses. It is characterised by a prominent ENE-trending structural grain that truncates pre-existing Archean trends and deflects a Palaeoproterozoic dyke swarm (e.g., Escher et al., 1976; Ramberg, 1949). The metamorphic and cooling history of the central and southern Nagssugtoqidian orogen is fairly well established by numerous geochronological studies (e.g., Connelly et al., 2000; Connelly and Mengel, 2000; Kalsbeek and Nutman, 1996; Willigers et al., 1999, 2002). They document a high-grade metamorphic event at c. 1850 Ma (Connelly et al., 2000; Taylor and Kalsbeek, 1990) followed by very slow cooling (Willigers et al., 1999, 2001, 2002). The evolution of the northern part of the Nagssugtoqidian orogen is less constrained due to the lower amount and precision of geochronological data (e.g., Connelly and Mengel, 2000; Willigers et al., 2002) and uncertain northward extent of Palaeoproterozoic overprint. An important issue is whether the Nagssugtoqidian deformation and metamorphism decline in this area, earlier considered transitional to a stable Archean craton (e.g., Hoffman, 1990; van Kranendonk

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et al., 1993), or continue towards the more northerly located Rinkian orogen (Connelly et al., 2006).

We apply Sm–Nd and Lu–Hf geochronology combined with trace element distribution study to better constrain the timing of garnet growth relative to the main metamorphic episode in the northern Nagssugtoqidian orogen. This approach allows more accurate interpretation of metamorphic ages and estimation of the significance of Palaeoproterozoic overprint in the area. Moreover, our new geochronological results constrain a prolonged post-tectonic cooling history for the northern section of the Nagssugtoqidian orogen. We attempt to investigate the temporal relationship between the growth of peak metamorphic mineral assemblages that are used for geothermobarometrical calculations and the time of peak Nagssugtoqidian metamorphism as constrained by crystallisation of metamorphic zircon.

2. Geological setting

The Nagssugtoqidian orogen is conventionally subdivided into the southern, central and northern segments (SNO, CNO and NNO, respectively) with boundaries aligned with the Palaeoproterozoic structural trend (Marker et al., 1995; Ramberg, 1949; Fig. 1). A metamorphic zonation within the orogen largely mimics its tectonic subdivision. The SNO and NNO consist predominantly of amphibolite facies grade rocks whereas the CNO consists of mostly granulite facies grade rocks. Rare geothermobarometric estimates of peak metamorphic conditions in the CNO yield temperatures in excess of 800 °C and pressures of 7–9 kbar (Davidson, 1979; Hansen, 1979; Mengel, 1983). Widespread migmatization and the presence of sillimanite as the stable aluminosilicate in metapelites throughout the orogen both indicate high-temperature metamorphism. Well-equilibrated granoblastic polygonal textures of rocks suggest a long period of post-kinematic annealing. Several dating methods indicate that peak metamorphism in the CNO occurred at c. 1860–1840 Ma and that temperatures subsequently slowly decreased at rates of 1–3 °C/Ma (Connelly et al., 2000; Kalsbeek and Nutman, 1996; Taylor and Kalsbeek, 1990; Willigers et al., 2002). Rocks in the CNO were still above 650 °C at c. 1775 Ma and only reached approximately 580 °C by c. 1740 Ma (Connelly et al., 2000; Willigers et al., 2001).

The tectonic evolution of the Nagssugtoqidian orogen involved collision of the North Atlantic craton in the south and a lesser known continental mass to the north (e.g., Kalsbeek et al., 1987; van Gool et al., 1999). The latter is commonly termed the Disco craton (e.g., Grocott and Davies, 1999; van Gool et al., 2002; van Kranendonk et al., 1993; Wardle and van Kranendonk, 1996) or the Aasiaat domain (Garde and Hollis, 2010) although it may also represent the southern margin of the Rae Craton (Connelly et al., 2006). The pre-collisional convergence is documented by the occurrence of Palaeoproterozoic calc-alkaline intrusive rocks with supra-subduction geochemical signatures (Kalsbeek et al., 1987), emplaced between 1920 and 1870 Ma (Connelly et al., 2000; Kalsbeek and Nutman, 1996; Whitehouse et al., 1998). These rocks were accreted onto the Nagssugtoqidian orogen at the onset of continental collision soon after the termination of magmatic activity (van Gool et al., 2002). The collisional event continued under peak metamorphic conditions established due to ensuing crustal thickening. The latter must have been associated with WNW-directed thrusting that was documented at the outcrop-scale in the CNO (van Gool et al., 1999). The high-temperature penetrative fabrics in rocks are cut throughout the orogen by straight-walled pegmatite dykes that postdate the ductile thrusting event. The oldest dated pegmatite (1821 ± 2 Ma; Connelly et al., 2000) provides a minimum age for thrust-related fabric development in the CNO. The subsequent phase of shortening was accommodated by large-scale upright folding with an E–W trend. The time of folding is constrained by the 1825 ± 1 Ma age of a granite body emplaced in the hinge of an antiform (Connelly et al., 2000). Between 1821 and 1778 Ma, temperatures remained sufficiently high to generate pegmatites, metamorphic zircon, and titanite (Connelly et al., 2000). The final increments of shortening exploited pre-existing fabrics in steep fold limbs to form the orogen-scale sinistral strike–slip high strain zones at c. 1775 Ma (Connelly et al., 2000).

Effects of Palaeoproterozoic deformation in the NNO are difficult to separate from the pre-existing potentially Archean structural grain. This is due to the lack of suitable time markers such as arc-related intrusions or Palaeoproterozoic supracrustal rocks intercalated with the Archean gneisses. Several of the thin supracrustal belts in the area are known to be Archean (Thrane and Connelly, 2006), but most are of unknown age. Only the Naternaq (Lersletten) supracrustal belt about 40 km SE of Aasiaat has yielded an ion microprobe U–Pb maximum depositional age of 1904 ± 8 Ma (Thrane and Connelly, 2006). Consequently, no definite northern Nagssugtoqidian deformation front can be defined and potential northward continuity of Palaeoproterozoic deformation remains an open question.

Time constraints of metamorphism in the NNO are provided by Thrane and Connelly (2006), who conducted laser ablation ICPMS dating of zircons from amphibolite facies Archean metasediment. Although the authors did not carry out studies of internal zircon structure, they were capable of extracting ages from metamorphic rims, which in one case gave ^{207}Pb/^{206}Pb ages of c. 1850 Ma. Notably, zircons from similar rocks did not reveal any Palaeoproterozoic metamorphic overprint (Thrane and Connelly, 2006). A late phase of ductile fabric development in the NNO is constrained by the age of a late-kinematic pegmatite dyke dated at 1837 ± 12 Ma with the same technique (Thrane and Connelly, 2006). These results suggest that, like the CNO, the penetrative fabric in the NNO was produced during the c. 1850 Ma Palaeoproterozoic event, and deformation waned soon afterwards. On the other hand, Garde and Hollis (2010) summarised results of systematic mapping in the NNO (Garde, 2004, 2006; van Gool, 2006) which suggest that a ∼50 km wide crustal block immediately to the north of the Nordre Strømfjord shear zone, which consists of Archaean orthogneiss and metavolcanic belts, has altogether escaped Nagssugtoqidian deformation. According to Garde and Hollis (2010), the NNO did record Palaeoproterozoic heating under amphibolite-facies conditions, and c. 1800–1750 Ma pegmatites were locally formed. Evidence for the absence of Nagssugtoqidian deformation and for only moderate Palaeoproterozoic heating is based on (1) the presence of metamorphosed but completely undeformed, east–west-trending mafic dykes of presumed Palaeoproterozoic age NE of the settlement Attu (Garde, 2004), and (2) an Archean U–Pb zircon age of a well-preserved, synkinematic granite vein (2748 ± 19 Ma, Thrane and Connelly, 2006) occurring on the limb of a major fold belonging to the latest established fold phase and showing that the penetrative deformation took place in the Archean.

Initial cooling of the NNO is documented by a titanite U–Pb age of 1775 ± 10 Ma that was obtained from an Archean gneiss (Connelly et al., 2000). This is consistent with the 1790 +3/−2 Ma monazite age of an undeformed pegmatite dyke (Connelly et al., 2000). Further cooling of the NNO is constrained by Ar-release spectra that yielded plateau ages for hornblende and muscovite in the range of 1740–1715 +13/−20 Ma and 1705–1673 +9/−12 Ma, respectively (Willigers et al., 2002). These imply locally faster cooling of the NNO at c. 5–7 °C/Ma for the period between c. 1740–1700 Ma (Willigers et al., 2002).

The metamorphic grade varies in the NNO from granulite facies in the south to amphibolite facies farther north. The contact