Magnetic anomalies and metamorphic boundaries in the southern Nagssugtoqidian orogen, West Greenland

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Within the southern Nagssugtoqidian orogen in West Greenland metamorphic terrains of both Archaean and Palaeoproterozoic ages occur with metamorphic grade varying from low amphibolite facies to granulite facies. The determination of the relative ages of the different metamorphic terrains is greatly aided by the intrusion of the 2 Ga Kangâmiut dyke swarm along a NNE trend. In Archaean areas dykes cross-cut gneiss structures, and the host gneisses are in amphibolite to granulite facies. Along Itilleq strong shearing in an E–W-oriented zone caused retrogression of surrounding gneisses to low amphibolite facies. Within this Itivdleq shear zone Kangâmiut dykes follow the E–W shear fabrics giving the impression that dykes were reoriented by the shearing. However, the dykes remain largely undeformed and unmetamorphosed, indicating that the shear zone was established prior to dyke emplacement and that the orientation of the dykes here was governed by the shear fabric. Metamorphism and deformation north of Itilleq involve both dykes and host gneisses, and the metamorphic grade is amphibolite facies increasing to granulite facies at the northern boundary of the southern Nagssugtoqidian orogen. Here a zone of strong deformation, the Ikertôq thrust zone, coincides roughly with the amphibolite–granulite facies transition. Total magnetic field intensity anomalies from aeromagnetic data coincide spectacularly with metamorphic boundaries and reflect changes in content of the magnetic minerals at facies transitions. Even the nature of facies transitions is apparent. Static metamorphic boundaries are gradual whereas dynamic boundaries along deformation zones are abrupt.

Keywords: aeromagnetic data, magnetic anomalies, metamorphic facies, Nagssugtoqidian orogen, West Greenland

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The establishment of the Palaeoproterozoic Nagssugtoqidian orogen in West Greenland (Ramberg 1949) is based on the deformation and metamorphism of the Kangâmiut dykes, dated at 2.04 Ga by Nutman *et al.* (1999). South of the southern Nagssugtoqidian front (SNF in Fig. 1), in the southern Nagssugtoqidian foreland, Kangâmiut dykes are undeformed and cross-cut gneiss structures. North of the front, gneisses and dykes have been metamorphosed and deformed together during the Nagssugtoqidian orogeny. Here, gneiss structures and dyke margins are concordant and dykes transformed into amphibolites. This is the simple story upon which Ramberg (1949) based his definition of the 'Nagssugtoqides'. Ramberg also divided the Nagssugtoqidian orogen into three metamorphic complexes based on the metamorphic grade of the rocks. Thus the Egedesminde complex was the northernmost amphibolite facies complex, the Isortoq complex the central granulite facies complex, and the Ikertôq complex the southernmost amphibolite facies complex. The current division of the orogen (Fig. 1) is based on structural criteria, and division boundaries now follow major structural features (Marker *et al.* 1995). The current division therefore deviates considerably from Ramberg's original division for the northern and central Nagssugtoqidian orogen, whereas the

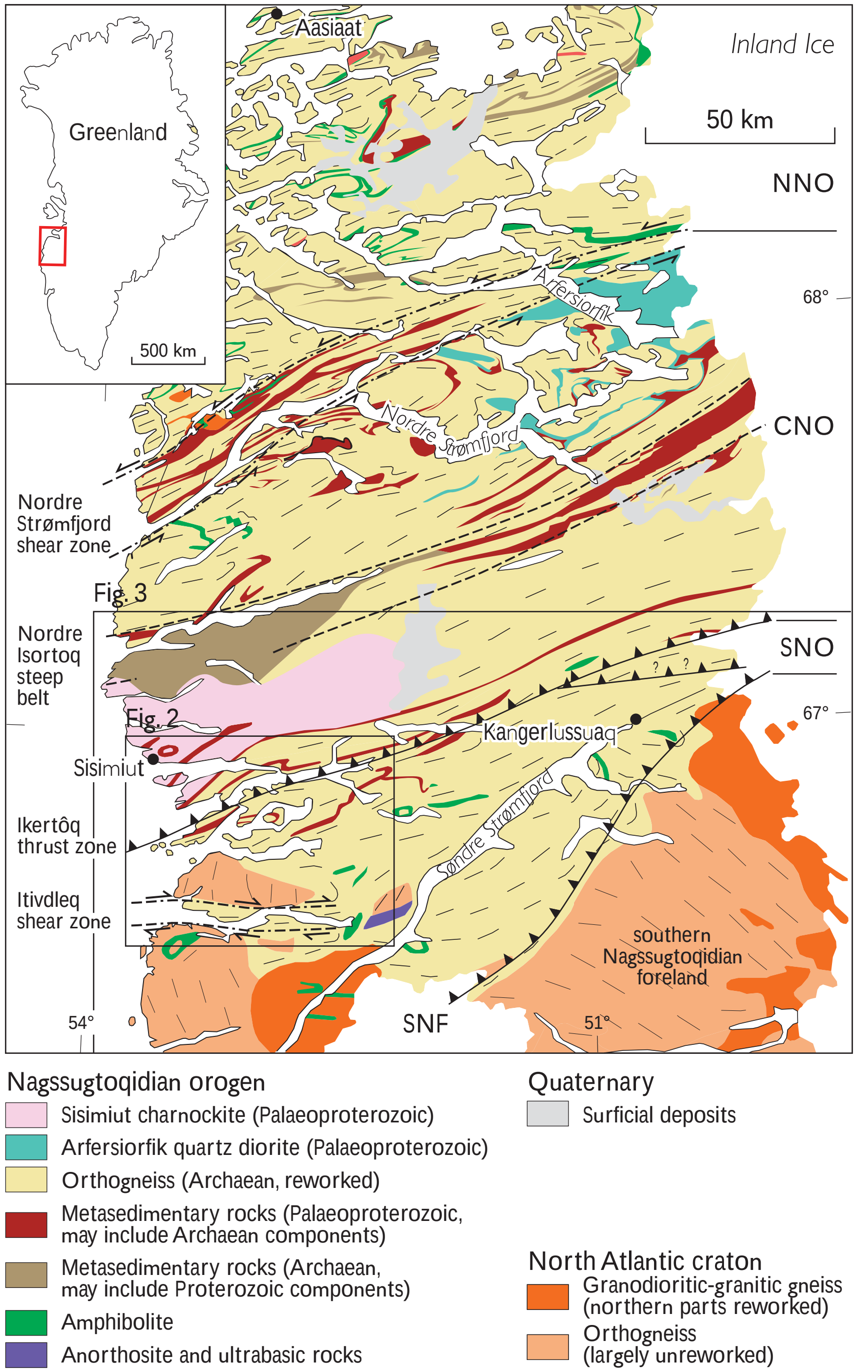


Fig. 1. Schematic geology of the southern part of the Nagssugtoqidian orogen and adjacent forelands (modified from Escher & Pulvertaft 1995 and Marker *et al.* 1995). SNO, southern Nagssugtoqidian orogen; CNO, central Nagssugtoqidian orogen; NNO, northern Nagssugtoqidian orogen; SNF, southern Nagssugtoqidian front. The locations of thrust and shear zones are defined from trends observed in the aeromagnetic data; note that the E–W-trending thrust zone with question marks north of Kangerlussuaq is uncertain, as this structure has not been confirmed by geological mapping. Black frames show the locations of Figs 2, 3.

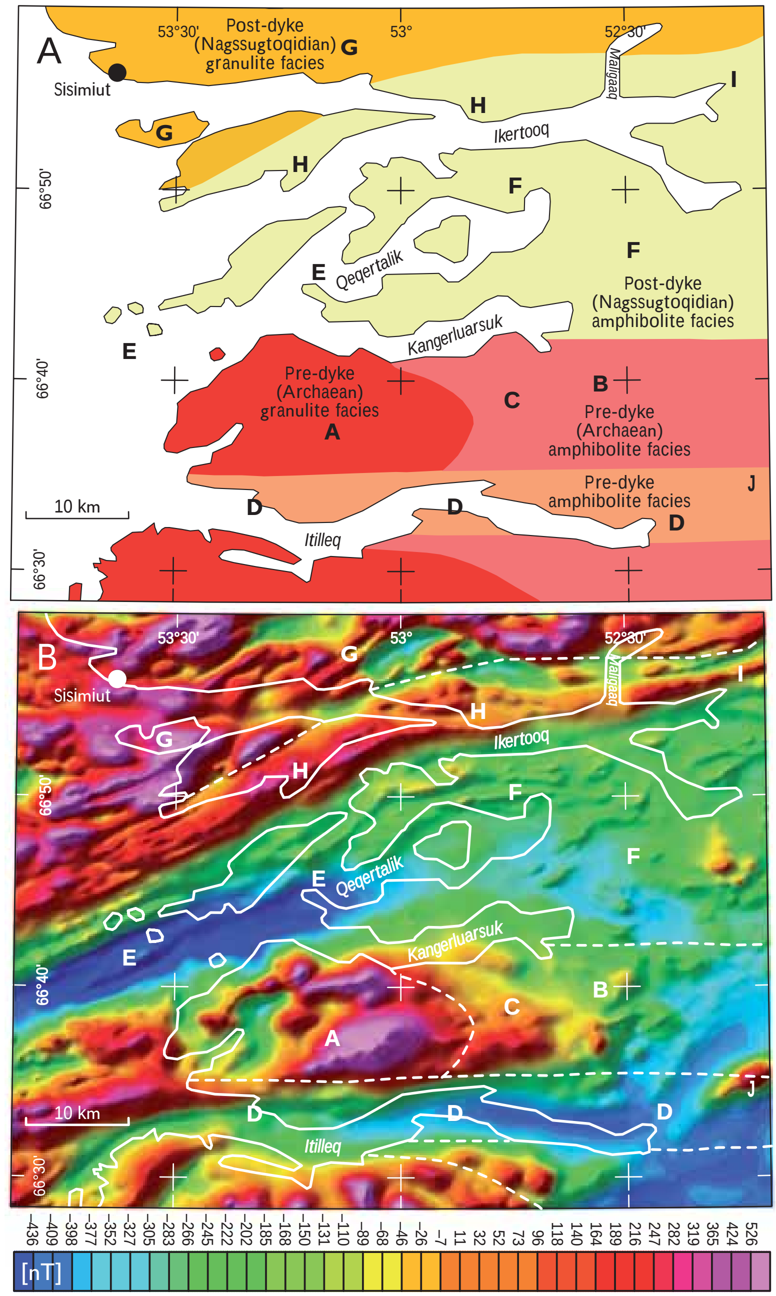
southern Nagssugtoqidian orogen corresponds almost exactly to Ramberg's original Ikertôq complex.

The southern Nagssugtoqidian orogen (SNO in Fig. 1) in the coastal region between Sisimiut and Itilleq consists mainly of quartzofeldspathic gneisses of granodioritic to tonalitic composition. Several supracrustal layers occur, particularly in the northern part of the SNO. The supracrustal rocks are mainly garnet-biotite schists, rusty weathering biotite gneisses and amphibolites. The metamorphic grade is low amphibolite facies to granulite facies, and due to the fortunate timing of the intrusion of the Kangâmiut dykes it is possible to assign relative ages to the different metamorphic terrains in the region.

Pre-dyke metamorphism and deformation

South of and immediately north of Itilleq, the Kangâmiut dykes are largely undeformed, unmetamorphosed and

Fig. 2. Correlation between metamorphic facies and aeromagnetic anomaly patterns in the Itilleq–Ikertooq region. White lines indicate approximate metamorphic facies boundaries based on geological field work; labels A–J are explained in the text. A: Distribution and relative ages of metamorphic facies. B: Total intensity magnetic field anomaly map. Shadow of magnetic field pattern modelled from a light source with inclination 45° and declination 315°.



cross-cut gneiss structures. The main dyke direction is NNE–SSW, and a subordinate direction is E–W to ESE–WNW (Fig. 1). Upon entering the Itilleq area, the dyke trends are E–W, parallel to the fjord. This change in trend also corresponds to a change in foliation trend in the host gneisses. However, the dykes are still largely undeformed and unmetamorphosed within this E–W trend. The metamorphic grade of host gneisses north and south of Itilleq is granulite facies in western parts and amphibolite facies in eastern parts (Fig. 2A). However, all along the E–W trend in Itilleq, gneisses are in low amphibolite facies.

The dyke behaviour in the Itilleq region led to the interpretation that prior to intrusion of the Kangâmiut dykes the area was stabilised in amphibolite-granulite facies with a variable northerly trend of the foliation (Grocott 1979; Korstgård 1979). At some point prior to dyke intrusion an E–W zone of strong deformation was established along Itilleq, downgrading gneisses to low amphibolite facies (epidote-muscovite). Within this Itivdleq shear zone, dykes intruded along the shear fabrics and show a variety of primary pinch-and-swell structures (Nash 1979). Outside the shear zone, dyke margins are straight-sided indicating that dykes intruded along brittle fractures.

Post-dyke metamorphism and deformation

Farther north of Itilleq, from Kangerluarssuk and northwards (Fig. 2A), dykes are thoroughly deformed and parallel to country rock structures. Both dykes and country rock structures are in amphibolite facies. Foliation trends are variable ENE–WSW around west-plunging fold axes.

Continuing northwards the metamorphic grade increases and reaches granulite facies north of Ikertooq fjord (Fig. 2A). In addition, gneiss structures and metamorphosed dykes take on a pervasive E–W orientation (Ikertôq thrust zone, Fig. 1) with a steeply N-dipping foliation and N-plunging stretching lineations.

The interpretation of field observations in the northern SNO is that the metamorphism and deformation are post-dyke, the metamorphic transition is prograde, and the Ikertôq thrust zone represents a zone of southward ductile thrusting whereby deeper-seated rocks are brought up from the north.

Facies transitions

Within the Itilleq–Ikertooq region four types of facies transitions or boundaries are recognised. Two of these are prograde and two are associated with strong deformation in ductile shear zones.

The amphibolite–granulite facies transition in the Archaean areas around Itilleq is prograde and static in the sense that the boundary was not established as a result of a deformational event, but reflects static equilibration of the mineral assemblages to the conditions that prevailed when the rocks were at their deepest crustal level. During later uplift the rocks escaped any significant metamorphic changes due to the absence of deformation, and the metamorphism reflects their initial Archaean state.

The granulite to low amphibolite facies and amphibolite to low amphibolite facies transitions along Itilleq are retrograde and dynamic in the sense that they were established as a direct consequence of the deformation along the Itivdleq shear zone. Mineral assemblages in the shear zone were equilibrated to the metamorphic conditions of a higher crustal level than reflected in the surrounding gneisses, and the shearing triggered this re-equilibration.

The amphibolite–granulite facies transition north of Ikertooq is both prograde and dynamic. It can be considered as a displaced prograde and static transition brought up into a sub-vertical position by the overthrust movement along the Ikertôq thrust zone (Fig. 1).

Magnetisation

Comparing the magnetic anomaly map for the area (Fig. 2B) with the metamorphic map (Fig. 2A) a striking coincidence of magnetisation and metamorphic boundaries is evident. More information on the magnetic field data and the geological interpretations can be found in Rasmussen & van Gool (2000), Nielsen (2004) and Nielsen & Rasmussen (2004).

Strong magnetisation in pre-dyke Archaean granulite facies areas just north of Itilleq (A in Fig. 2B) is attributed to a higher content of magnetite or other magnetic minerals. A likely explanation for this is production of magnetite by the breakdown of hydrous (Fe, Mg)-Al-silicates (e.g. biotite, amphibole) during the transition from amphibolites to granulite facies according to the general reaction: hydrous (Fe, Mg)-Al-silicates ± SiO_2 ± O_2 = K-feldspar + (Fe, Mg)-silicates ± magnetite + H_2O. The lower magnetisation in pre-dyke Archaean amphibolite facies areas (B in Fig. 2B) relative to pre-dyke Archaean granulite facies areas indicates no additional production of magnetite. The gradual increase in magnetic intensity (C in Fig. 2B) marks the gradual prograde facies transition.

The elongate low magnetic anomaly coincident with the Itivdleq shear zone (D in Fig. 2B) is caused by extensive breakdown of magnetic minerals. This may be due to chemical breakdown during metamorphic retrogression to pre-dyke amphibolite facies aided by circulating fluids in the shear zone, and mechanical destruction of the magnetic mineral grains. The abrupt changes in anomaly patterns from D to A (Fig. 2B) across the metamorphic facies transition and deformation boundary are a response to the dynamic nature of this boundary.

Previously suggested possible shearing south of Ikertooq (E in Fig. 2B; Grocott 1979; Korstgård 1979) contemporaneous with the shearing at Itilleq (D in Fig. 2B) is supported by similarities in the character of the anomaly patterns. The post-dyke amphibolite facies areas at, and south of, Ikertooq (F in Fig. 2B) indicate the Palaeoproterozoic retrogression to amphibolite facies and deformational reworking. The boundary between the pre-dyke Archaean amphibolite facies and the post-dyke amphibolite facies areas does not have a well-defined magnetic signature (between B and F in Fig. 2B).

The increase in magnetisation north of Ikertooq (G in Fig. 2B) corresponds to rocks metamorphosed under granulite facies conditions after dyke intrusion and brought up by overthrusting. The offset between the mapped facies boundary north of Ikertooq (Fig. 2A) and the boundary between high and low magnetisation (H in Fig. 2B) can be explained as partially due to non-exposed post-dyke

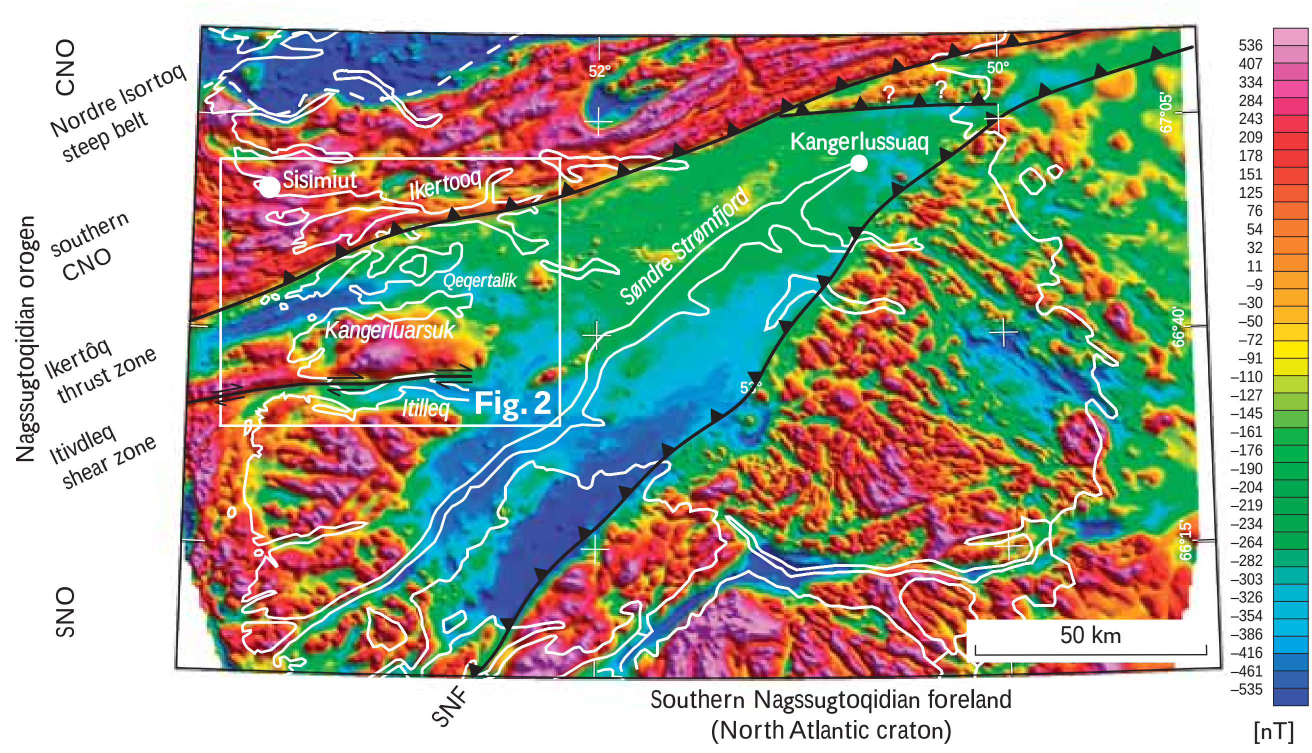


Fig. 3. Total intensity magnetic field anomaly map of the south-eastern part of the Nagssugtoqidian orogen and its foreland, with the location of the Itilleq–Ikertooq region (white frame, Fig. 2). Abbreviations as for Fig. 1; shadow on magnetic data as for Fig. 2. The E–W-trending thrust zone with question marks north of Kangerlussuaq is uncertain, as this structure has not been confirmed by geological mapping.

granulite facies rocks, and partially to the effect of stacked thrust panels of post-dyke amphibolite and granulite facies rocks with alternating low and high magnetic intensity anomalies (I in Fig. 2B). Isolated high intensity anomalies can be correlated with distinct lithologies or intrusives (e.g. an anorthosite complex at J in Fig. 2B). The presence or absence of Kangâmiut dykes is not reflected in the aeromagnetic data.

The observed correlations between metamorphic facies, deformation and magnetisation can be extended to other areas of the SNO (Fig. 3) provided that the background gneisses are lithologically fairly homogeneous, as is generally the case in the southern Nagssugtoqidian orogen. Where gneiss lithologies are more variable, such as in the Nordre Isortoq steep belt (Fig. 1) and the Nordre Strømfjord shear zone (Sørensen *et al*. 2006, this volume) correlations tend to depend on lithology rather than metamorphic grade.

Acknowledgements

The authors thank Graham Leslie and Chris Pulvertaft for their concise and constructive reviews.

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Manuscript received 10 November 2004; revision accepted 1 November 2005