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The structure and timing of lateral escape during the Scandian Orogeny: A combined strain and geochronological investigation in Finnmark, Arctic Norwegian Caledonides

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Abstract

Determining the timing, duration and mechanism of tectonic events within an orogenic cycle, such as ocean subduction, continent–continent collision or gravitational collapse, is challenging, especially in ancient orogenic belts. Variations in the tectonic transport direction, however, can be used as a guide to these stages of orogeny. While thrust sheets within the Caledonian allochthon in north Norway were emplaced broadly eastwards perpendicular to the trend of the orogen, many features indicate material transport in other orientations. One dominant feature of the Magerøy Nappe, sitting above and infolded with the Kalak Nappe Complex, is the development of a strong N–S lineation orthogonal to the main transport direction. Strain measurements, in part determined by a new method, are used, in the context of the regional structural data to identify the critical stage in orogeny when compressional forces are balanced by orogen-parallel lateral escape. Quantitative 3-D strain estimation in the Magerøy Nappe indicates prolate deformation with c. 50% horizontal shortening parallel to the thrusting direction (E–W) and c. 200% extension along the orogenic strike (N–S) with c. 30% vertical shortening. Temporal constraint on this fabric is provided by Ar–Ar isotopic analysis of undeformed white mica in cross-cutting granitic pegmatites. These data show that prolate deformation occurred before the white mica cooling age of 416±4 Ma, while the previously determined depositional age of the Hellefjord Schist indicates that it occurred after 438±4 Ma. A granitic pegmatite that intruded the Hellefjord Schist after an initial deformation phase but during or prior to a later deformation, has been dated at 431±2 Ma by U–Pb zircon. A previous lower age constraint on this deformation of 428±5 Ma is given by metamorphic zircon overgrowths on fractured grains. These results constrain the continental collision between Baltica and Laurentia in Finnmark to the interval c. 431–428 Ma. Placed in a regional context, these results indicate that lateral escape was orthogonal to the thrusting direction and occurred during the continent–continent collision stage in the Scandian Orogeny before gravitationally driven collapse.

Keywords: Strain analysis; Geochronology; Scandian Orogeny; Caledonides; Lineation; Lateral escape

1. Introduction

Collisional orogens are a dramatic expression of the dynamic nature of our planet and influence numerous other earth processes including chemical, atmospheric

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and biological cycles. Orogenic belts reflect the interplay of complex tectonic forces associated with oceanic closure, subduction and collision of plates. Investigating the development of the resulting structural fabrics, quantifying the strains involved and determining the timing of critical stages in orogeny are important elements in charting the evolution of ancient mountain belts.

At its climax, the early to middle Palaeozoic Caledonian mountain belt was probably comparable in length to the present-day Himalayas (Andresen et al., 1998). Hence along strike variations in strain, orientation and timing of contractional versus extensional deformation are to be expected (Chauvet and Seranne, 1994; Krabbendam and Dewey, 1998; Braathen et al., 2000). The Scandian Orogeny is defined as the continental–continental collision between Baltica and Laurentia, involving subduction of the Baltoscandian margin beneath Laurentia (Gee, 1975; Roberts, 2003). The collision between Baltica and Laurentia is considered to have been strongly diachronous, resulting in varying durations of the Scandian event (Hacker and Gans, 2005). In this paper the term "Scandian" is used to refer to the continental collision stage of the closure of Iapetus. At any point within an orogenic system, determining the timing of collision is challenging because the resulting structures are formed progressively by convergent motion as oceanic closure culminates in full-scale continent–continent collision, the likely climax of mountain building. Later structural modifications reflect the influence of gravity-driven forces (Seguret et al., 1989; Alsop et al., 2001). Many structural fabrics within the Scandinavian Caledonides have been interpreted as the result of large-scale lateral convergence resulting in motion predominantly across the regional strike of the belt. However, there are numerous features that preserve evidence of transport directions that are not directed towards the foreland (Braathen et al., 2000). Sequential changes in kinematics as documented by variations in fabric style can sometimes be used to recognise the continental collisional phase of orogeny.

In this paper, strain measurements, in part determined by a new method, are used in the context of the regional structural data to identify the critical stage in orogeny when compressional forces are balanced by the accumulating orogenic mass resulting in orogen-parallel lateral escape. These observations are linked with a series of isotopic age determinations of minerals with clear fabric relationships to delimit the timing of continental collision. The data refine evolutionary models of the region during Caledonian deformation and yield insight into the mechanism and timing of the Scandian Orogeny in northernmost Norway.

1.1. Regional setting

The Scandinavian Caledonides consist of numerous thrust sheets of disparate origins that are classically regarded as being assembled during the early to mid-Palaeozoic. The rocks are grouped into an orogen wide tectonostratigraphic framework of Autochthon, Parautochthon, and Lower, Middle, Upper and Uppermost Allochthons (Roberts and Gee, 1985). The Parautochthon through to the lower part of the Upper Allochthon, are classically considered to have a bipartite subdivision of Baltoscandian basement, and cover sequences of Upper Precambrian and Lower Palaeozoic sedimentary rocks (Roberts, 2003). The contact above the Seve (and correlative Kalak) nappes of the lower part of the Upper allochthons (Zachrisson, 1986) is traditionally regarded as a significant break separating outboard oceanic elements from continental margin sequences deposited on Baltica basement rocks (Andréasson, 1994). However, Kirkland et al. (2006a) have demonstrated Grenville-related deformation and magmatism within correlative rocks in Finnmark, Arctic Norway and Daly et al. (1991), Kirkland et al. (2006a) and Corfu et al. (2005) have dated intrusions of broadly Cryogenian age at higher levels in the same region. This tectonomagmatic history invites a more exotic origin for rocks traditionally regarded as representing the Baltica margin of Iapetus.

Subduction of Baltica beneath Laurentia in the Silurian to Early Devonian (Gee, 1975) led to the successive shortening of diverse units including the Baltoscandian passive margin miogeocline and shelf successions and also more exotic oceanic and arc terranes derived from the Iapetus Ocean including units with Laurentian affinities from the opposite margin (Melezhik et al., 2002; Roberts et al., 2002; Yoshinobu et al., 2002).

Various phases in the destruction of the Iapetus Ocean are charted by several pluses of magmatic activity associated with characteristic plate tectonic settings (Stel-tenpohl et al., 2003). The earliest of these at about 500–480 Ma is linked with the development of ophiolites and island arcs (Dunning and Pedersen, 1988; Pedersen and Furnes, 1991). Between 480 and 450 Ma, magmatic activity is typically envisaged as occurring in continental arcs on the Laurentian margin and is now preserved in the Upper and Uppermost Allochthons (Nordgulen et al., 1993; Yoshinobu et al., 2002). During the waning stages of the Iapetus Ocean between 445 and 435 Ma, when it was a narrow seaway, just before continental collision, an extensive pulse of mantle-influenced magmatism took place. Granitic and gabbroic bodies of this age are prevalent in the Magerøy Nappe, in Finnmark (Vaasjoki and Sipila, 2001; Andréasson et al., 2003; Kirkland et al.,