Tectonophysics 480 (2010) 149–171

Contents lists available at ScienceDirect

Tectonophysics

journal homepage: www.elsevier.com/locate/tecto

High-temperature deformation during continental-margin subduction & exhumation: The ultrahigh-pressure Western Gneiss Region of Norway

Bradley R. Hacker [a], Torgeir B. Andersen [b], Scott Johnston [a,1], Andrew R.C. Kylander-Clark [a], Emily M. Peterman [a,2], Emily O. Walsh [a,3], David Young [a,*,4]

[a] Department of Earth Science, University of California, Santa Barbara, CA 93106, USA
[b] Universitetet i Oslo, Department of Geosciences, P.O. Box 1047 Blindern, 0316 Oslo, Norway

ARTICLE INFO

Article history:
Received 27 January 2009
Received in revised form 30 July 2009
Accepted 10 August 2009
Available online 20 August 2009

Keywords:
Norway
Eclogite
Exhumation
Ultrahigh-pressure metamorphism
Symplectite

ABSTRACT

A new dataset for the high-pressure to ultrahigh-pressure Western Gneiss Region allows the definition of distinct structural and petrological domains. Much of the study area is an E-dipping homocline with E-plunging lineations that exposes progressively deeper, more strongly deformed, more eclogite-rich structural levels westward. Although eclogites crop out across the WGR, Scandian deformation is weak and earlier structures are well preserved in the southeastern half of the study area. The Scandian reworking increases westward, culminating in strong Scandian fabrics with only isolated pockets of older structures; the dominant Scandian deformation was coaxial E–W stretching. The sinistrally sheared Møre–Trøndelag Fault Complex and Nordfjord Mylonitic Shear Zone bound these rocks to the north and south. There was moderate top-E, amphibolite-facies deformation associated with translation of the allochthons over the basement along its eastern edge, and the Nordfjord–Sogn Detachment Zone underwent strong lower amphibolite-facies to greenschist-facies top-W shearing. A northwestward increase in exhumation-related melting is indicated by leucosomes with hornblende, plagioclase, and Scandian sphene. In the western 2/3 of the study area, exhumation-related, amphibolite-facies symplectite formation in quartzofeldspathic gneiss postdated most Scandian deformation; further deformation was restricted to slip along biotite-rich foliation planes and minor local folding. That the Western Gneiss Region quartzofeldspathic gneiss exhibits a strong gradient in degree of deformation, implies that continental crust in general need not undergo pervasive deformation during subduction.

1. Introduction

How continental crust is exhumed from ultrahigh-pressure depths remains one of the most intriguing tectonic problems. An excellent place to study ultrahigh-pressure (UHP) rocks and their exhumation is the Western Gneiss Region (WGR) of Norway, where the ~5000 km^2 Caledonian UHP terrane is surrounded to the north, east and south by associated high-pressure rocks covering 30,000 km^2 (Fig. 1). This paper integrates structural geology and structural petrology from a geologic transect across the WGR to address four large-scale questions: i) What was the volume of rock that was exhumed from (U)HP conditions? Assessing the scale of (U)HP metamorphism assists in defining the tectonic setting in which (U)HP tectonism occurs and the magnitude of its impact on Earth evolution. ii) How was deformation partitioned throughout the (U)HP terrane during subduction and exhumation—i.e., were the (U)HP rocks subducted and exhumed as a coherent and intact sheet or did they disaggregate/delaminate during subduction and/or exhumation? iii) How did deformation vary temporally, from the beginning of subduction to the end of exhumation—e.g., did intense deformation mark the entire subduction and exhumation cycle? iv) What was the relationship between deformation and metamorphism during subduction and exhumation—e.g., did deformation and metamorphism occur in stages or were they continuous and coeval during exhumation?

To address these questions, this paper presents outcrop to thin-section observations of structures and metamorphic minerals. It begins with an overview of the study area; explains how various deformation and metamorphic events can be distinguished; characterizes the eclogite-, granulite-, and amphibolite-facies structures; describes various structural domains; and ends with a discussion of the implications for the questions posed above.

* Corresponding author.
E-mail address: hacker@geol.ucsb.edu (B.R. Hacker).
[1] Now at the Department of Physics, California Polytechnic State University, San Luis Obispo, CA, 93407, USA.
[2] Now at the Department of Earth and Planetary Sciences, University of California, Santa Cruz, CA 95064, USA.
[3] Now at the Department of Geology, Cornell College, Mount Vernon, IA, 52314, USA.
[4] Now at the Department of Geology, University of Texas, San Antonio, TX, 78249, USA.

0040-1951/$ – see front matter
doi:10.1016/j.tecto.2009.08.012

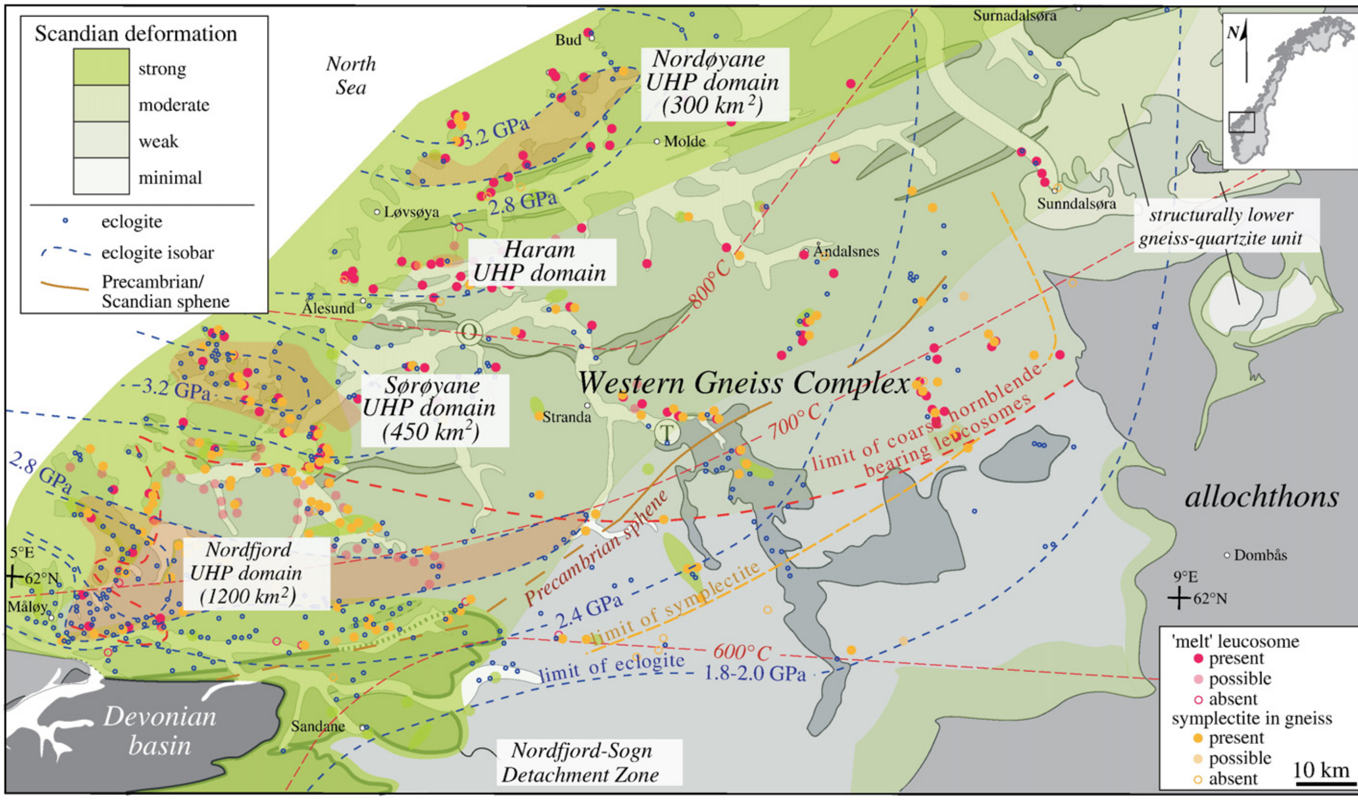

Fig. 1. The Western Gneiss Region consists of Western Gneiss complex basement overlain by allochthons (gray, after Lutro and Tveten (1998) and Tveten et al. (1998)). Multiple features show a general northwestward increase: i) the intensity of Scandian deformation (green shading) (not determined in the allochthons east of the Western Gneiss Region or in the Devonian basin); ii) eclogite pressures (locations of isobars are poorly constrained); iii) peak metamorphic temperatures (Kylander-Clark et al., 2008); iv) the abundance of hornblende-bearing leucosomes; and v) the presence of symplectite-bearing gneiss. Sphene have Scandian ages in the northwest and Precambrian ages in the southeast (Tucker et al., 1990; Kylander-Clark et al., 2008). NE boundary of Nordøyane UHP domain after Vrijmoed et al. (2006). All contacts shown are faults, except the NW edge of the Devonian basin.

1.1. The Western Gneiss Region

The Western Gneiss Region (Fig. 1) is composed of Proterozoic Fennoscandian gneisses (chiefly orthogneisses from c. 1650 Ma and 950 Ma) (cf. Austrheim et al., 2003; Skår and Pedersen, 2003), often referred to as the Western Gneiss Complex (WGC), overlain by continental and oceanic allochthons (see below). The early Paleozoic orogeny during which these units were deformed, metamorphosed, and juxtaposed is the Caledonian Orogeny (Fig. 2). The final stage of this orogeny–called the Scandian Orogeny–included the following: i) closure of the Iapetus ocean and emplacement of allochthons onto Baltica from ~430 to 410 Ma (Tucker et al., 2004; Hacker and Gans, 2005); ii) Baltica–Laurentia collision and westward subduction of the Baltica basement and portions of the allochthons to ultrahigh-pressure depths from ~425 to 400 Ma (Andersen et al., 1991; Andersen, 1998; Bingen et al., 2004; Root et al., 2004; Terry and Robinson, 2004; Root et al., 2005; Kylander-Clark et al., 2007; Kylander-Clark et al., 2008); and iii) exhumation to shallow crustal levels from ~400 to ~385 Ma (Andersen, 1998; Terry et al., 2000a; Tucker et al., 2004; Hacker, 2007; Walsh et al., 2007). The WGC is locally imbricated with Caledonian nappe units—as suggested by the presence of a structurally lower gneiss–quartzite unit (Gee, 1980; Krill, 1980) in the northeastern part of the study area (Storli thrust of Tucker et al., 2004) (Fig. 1)—but the main parts of the WGR is autochthonous as shown by the continuous exposures below the nappes across from the foreland to the hinterland region.

The most common rock type of the WGC in the study area is biotite ± hornblende ± garnet tonalitic and granodioritic gneiss with 5–80% (typically 20–40%) cm-scale granitic leucosomes (Gjelsvik, 1951; Bryhni, 1966; Dransfield, 1994). This tonalitic gneiss grades with increasing K-feldspar abundance into biotite granitic gneiss that underlies ~10% of the study area, and with increasing muscovite into a two-mica tonalitic gneiss that comprises ~5%. All these rock types are cut by pegmatitic biotite-bearing granite dikes and all contain meter- to millimeter-scale blocks and layers of mafic rock: biotite gneiss, amphibolite and/or eclogite (Eskola, 1921) (the mineralogy depends on bulk composition, block/layer size, and degree of retrogression). Subordinate rock types include quartzite, carbonate, anorthosite, gabbro, garnet–mica gneiss, and peridotite (Gjelsvik, 1951; Bryhni, 1966; Dransfield, 1994; Robinson, 1995).

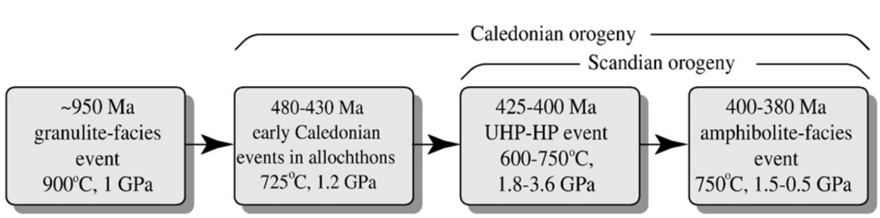

Fig. 2. Western Gneiss Region experienced a sequence of granulite-facies Precambrian, early Caledonian amphibolite-facies, Scandian UHP, and Scandian amphibolite-facies metamorphic–deformation events.