



The Friningen Garnet Peridotite (central Swedish Caledonides). A good example of the characteristic PTt path of a cold mantle wedge garnet peridotite



Mattia Gilio ^{a,b,*}, Frediano Clos ^{a,c}, Herman L.M. van Roermund ^a

^a Structural Geology and Tectonics Department of Earth Sciences, Utrecht University, Budapestlaan 4, Utrecht, 3508 TA, The Netherlands

^b Dipartimento di Scienze della Terra, Ambiente e Vita, University of Genova, Corso Europa 26, 16132 Genova, Italy

^c School of Geosciences, Monash University, Clayton, VIC 3800, Australia

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ABSTRACT

We present pseudosections of Cr-bearing garnet peridotite that together with new mineral–chemical data allow quantification of the early PT conditions of the original lithospheric mantle assemblage (M1) of the Friningen Garnet Peridotite (FGP) located in the central/middle belt of the Seve Nappe Complex in central Sweden. Results indicate that the early, coarse grained, olivine + orthopyroxene + clinopyroxene + “high Cr” garnet assemblage (M1a) was formed at 1100 ± 100 °C and 5.0 ± 0.5 GPa. These metamorphic conditions were followed by an inferred late Proterozoic exhumation event down to 850–900 °C and 1.5 GPa (M1b). The latter PT estimate is based on the breakdown of high-Cr M1a garnet ($\text{Cr\#} = 0.065$) + olivine into an orthopyroxene + clinopyroxene + spinel ($\text{Cr\#} = 0.15\text{--}0.25$) ± pargasite kelyphite (M1b) and the exsolution of garnet from Al-rich orthopyroxene and clinopyroxene. The M1b kelyphite is overprinted by an early-Caledonian UHP mineral assemblage (M2; $T = 800$ °C and $P = 3.0$ GPa), equivalent to the earlier discovered UHP assemblage within an eclogitic dyke that cross-cuts FGP. In the garnet peridotite M2 is displayed by low-Cr garnet ($\text{Cr\#} = 0.030$) growing together with spinel ($\text{Cr\#} = 0.35\text{--}0.45$), both these minerals form part of the olivine + orthopyroxene + clinopyroxene + garnet + spinel + pargasite M2 assemblage. The formation of plagioclase + diopside symplectites after omphacite and breakdown of kyanite to sapphirine + albite in internal eclogite and the breakdown of M2 olivine + garnet to amphibole + orthopyroxene + spinel assemblages (M3) in garnet peridotite indicate post-UHP isothermal decompression down to 750–800 °C and 0.8–1.0 GPa (=M3). Multiphase solid-and fluid inclusion assemblages composed of Sr-bearing magnesite, dolomite or carbon decorate linear defect structures within M1a–b minerals and/or form subordinate local assemblages together with M2 minerals. The latter are interpreted as evidence for infiltration of early-Caledonian COH-bearing subduction zone fluids. The well-defined PTt-deformation path of the FGP resembles that of a mantle wedge garnet peridotite. The M1 assemblage originates from the base of a cold, old and thick subcontinental lithospheric mantle that is inferred to extend asymmetrically leading to extreme exhumation of FGP down to lithospheric conditions around 1.5 GPa and 850–900 °C. After that the FGP became incorporated into the subducting continental crust of the SNC during “early-Caledonian” subduction (M2) down to UHP conditions (800 °C/3.0 GPa), subsequently followed by exhumation back to sub-crustal levels. As such, FGP is the first locality in the Swedish Caledonides from which two UHP metamorphic events are described, the first event can be related to the formation of an ancient (>1.0 Ga) lithosphere underneath a craton (Rodinia) and the second is of early-Caledonian age.

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1. Introduction

Mantle fragments, tectonically introduced into the continental crust during plate collisional processes, are a common feature of major orogenic belts throughout the world (Coleman, 1971; Den Tex, 1969).

In the Scandinavian Caledonides, most orogenic peridotites consist of spinel dunite, harzburgite or serpentinite. However, occurrences exclusively restricted to (U-)HP metamorphic terranes also contain an (ultra-) high pressure garnet–olivine-bearing assemblage (Brueckner, 1977; Brueckner et al., 2010; Carswell et al., 1983; Eskola, 1921; Krogh

Abbreviations: Cr#, $(\text{Cr})/(\text{Cr} + \text{Al})$; FGP, Friningen garnet peridotite; KSP, Kittelfjäll spinel peridotite; Mg#, $(\text{Mg})/(\text{Mg} + \text{Fe})$; SCLM, sub-continental lithospheric mantle; MW-GP, mantle wedge garnet peridotite; SZ-GP, subduction zone garnet peridotite; WBA, wide beam analyses; SNC, Seve Nappe Complex; UHP, ultra-high pressure; WGC, Western Gneiss Complex.

* Corresponding author at: Dipartimento di Scienze della Terra, Ambiente e Vita, University of Genova, Corso Europa 26, 16132 Genova, Italy.

E-mail addresses: mattia.gilio@edu.unige.it (M. Gilio), frediano.clos@monash.edu (F. Clos), h.l.m.vanroermund@uu.nl (H.L.M. van Roermund).

et al., 2006; Medaris, 1984; Spengler, 2006; Spengler et al., 2009; Van Roermund, 1989; Van Roermund and Drury, 1998). An outstanding, though classic, question therefore is: are the garnet–olivine assemblages formed during deep subduction of low pressure peridotites (i.e. chlorite-, plagioclase- or spinel-bearing) and serpentinites, or do these garnet–olivine bearing ultramafic massifs represent fragments of deeper parts of the lithospheric (or asthenospheric) mantle, detached from the mantle-wedge and trapped into the continental crust during deep subduction or eduction processes (Brueckner, 1998)? Thus, garnet peridotites can form by prograde metamorphism after burial and subduction to pressures higher than about 1.6 GPa of Al-bearing ultramafic bodies present in the continental crust prior to subduction or the underlying (low pressure) lithospheric mantle. This type is called subduction zone garnet peridotite (SZgp). Good examples are: 1) prograde serpentinites (Cima di Gagnone, Central Alps; Scambelluri et al., 2014; Trommsdorff and Evans, 1974) and Tromsø Nappe, Scandinavian Caledonides (Krogh et al., 2006), 2) spinel peridotites (Bergen Arcs; Kühn et al., 2000) and Ulten/Nonberg, Italian Alps (Obata and Morten, 1987; Scambelluri et al., 2006), 3) basal sections of layered mafic intrusions i.e. the Fe–Ti subtype of Carswell et al. (1983) with Eiksundalen in Norway being the prototype (Jamtveit, 1987). Alternatively, during descent as well as re-ascent, in deeper parts of a continental subduction system, the friction between the subducting continental crust and the overlying lithospheric (and asthenospheric) mantle wedge may cause slices of garnet–olivine bearing mantle to get trapped into the descending and ascending plate (Brueckner et al., 2010). These mantle slices would then follow the continental crust during ongoing subduction and eduction. This type of garnet peridotite is called mantle wedge garnet peridotite (MWgp; Van Roermund, 2009). The fundamental importance of MWgp stems from the capabilities of depleted and ultra-depleted peridotite bodies to preserve foliations, textures, mineral compositions and trace element and isotope signatures that precede the (U)HP metamorphic event, while being almost immune to LP metamorphic overprints and deformation phases. Thus, MWgp's form ideal proxies to study medium to large scale lithospheric mantle processes (Zhang et al., 2011) related to structural and chemical geodynamics (Bebout, 2007; Zheng, 2012), i.e. chemical and physical processes that otherwise can only be studied at much smaller scales using mantle xenoliths in basaltic intrusions.

Isolated ultramafic bodies of different dimensions (from km- to cm-scale), composition and metamorphic grade or structure occur in every unit of the Seve Nappe Complex (SNC), central Swedish Caledonides (Bucher-Nurminen, 1991). These orogenic peridotites were traditionally interpreted as fragments of sub-oceanic, Iapetus-related, lithosphere that became incorporated into the Scandian nappe pile during the Caledonian orogeny (Coleman, 1971; Du Rietz, 1935; Qvale and Stigh, 1985; Zwart, 1974). Van Roermund (1989) first challenged this interpretation, describing the occurrence, mineralogy, petrogenesis and tectonic implications of garnet peridotites from a relatively small area in northern Jämtland, central Sweden. The type locality of these garnet peridotites is the Friningen Garnet Peridotite (FGP), exposed in the Central/Middle Belt of the SNC, close to the SE side of Lake Friningen (Fig. 1). Other garnet peridotites also occur in this area.

This study is focused on a detailed description of the fundamental microstructures, mineral compositions, and mutual time relationships among the various mineral assemblages occurring within the FGP body. This is done to define a PT-t-d path, which turns out to be characteristic for a MWgp. This study also includes results of the earlier age dating work by Brueckner and Van Roermund (2004, 2007) and the recent discovery of UHPM conditions in a meta-basic dyke cross-cutting the FGP (Janák et al., 2013). However, the latter discovery requires a microstructural and mineralogical correlation between metabasic and ultrabasic rock types present within the FGP. In previous studies, Van Roermund (1989) and Brueckner et al. (2004) did not accurately determine the pre-Caledonian PT conditions of the FGP due to the pervasive resetting of the pre-Caledonian mineral compositions used to calculate their formation conditions. The aim of this work is therefore: 1) to

determine the pre-Caledonian mantle conditions of the FGP, 2) to construct a definitive PT-t-d path for the FGP and 3) to compare this PT-t-d path with that of the associated metabasic rocks (Janák et al., 2013). New results are obtained from thermodynamic modelling. Finally, we present also the fundamental olivine microstructures and fabrics (supplementary material). This is done to calculate flow stress levels operating within the sub-continental lithospheric mantle (SCLM) during Proterozoic, early-Caledonian subduction and subsequent return to sub-crustal levels.

2. Geological background

The overall internal structure of the SNC consists of a number of thrust sheets composed of heterogeneous lithological compositions and variable structural-metamorphic (including UHP) histories (Andréasson, 1994; Gee et al., 2008, 2013; Strömberg et al., 1984; Williams and Zwart, 1977; Zachrisson, 1969; Zachrisson and Stephens, 1984). In northern Jämtland, the SNC directly overlies the low-grade lower Allochthon (not visible in Fig. 1) and it underthrusts the Köli Nappes in the west (Fig. 1). Here, the SNC is divided into three main belts, from top to bottom: the Western, Central and Eastern Belts (Trouw, 1973; Van Roermund and Bakker, 1984; Williams and Zwart, 1977; Zwart, 1974).

The Upper Seve Nappe (Western Belt) consists of garnet bearing quartz–micaschists with local lenses of amphibolite and serpentinite. The Middle Seve Nappe (Central Belt) is formed by several tectonic lenses consisting of migmatitic kyanite–sillimanite gneiss, quartz–feldspar gneiss and (garnet) amphibolite. In one of these lenses, the Ertsekey Lens (also known as Avarado Gneiss; Fig. 1), Van Roermund and Bakker (1984) described eclogites formed at 1.8–2.4 GPa/780 °C and hosted by migmatitic gneisses. Several foliated, lens-shaped, dunite and harzburgite bodies occur, usually close to the contact between the various rock units (Fig. 1). Some of these ultramafic rocks contain the characteristic (U)HP garnet–olivine assemblage. The Lower Seve Nappe (Eastern Belt) consists of garnet-bearing micaschist, kyanite–staurolite schist, quartz–feldspathic gneiss, amphibolite, quartzite, calc-silicate and garnet–biotite rocks. These rocks do not show any evidence of HP metamorphism or partial melting, except for the Tjeliken Lens (Fig. 1), where eclogites and garnet peridotites occur (Van Roermund, 1985, 1989). According to previous studies by Van Roermund (1985), Tjeliken eclogites were formed around 1.3–1.5 GPa/550–620 °C (Van Roermund, 1985). However, after new methods of calculating PT conditions became available, Majka et al. (2013) determined these conditions to be around 2.7–2.8 GPa/700 °C. Scattered ultramafic bodies are found within all units of the Lower Seve Nappe, two of which, both included in the Tjeliken Lens, contain the HP garnet–olivine assemblage (Van Roermund, 1989).

From top to bottom, the SNC shows first an increase, followed by a decrease in metamorphic grade, with granulite to eclogite facies rocks in the Central/Middle Belt and lower to middle amphibolite facies rocks in the adjacent Eastern/Lower and Western/Upper Belts. The Tjeliken UHP lens forms an exception to this general rule. Another characteristic of metamorphism within the Central/Middle Seve belt is that calculated metamorphic pressure varies along the axis of the Caledonian orogen. Highest pressures occur in the Avarado Gneiss (≥ 1.8 GPa), intermediate pressures in the Marsfjället gneiss (1.25–1.8 GPa) and lowest pressures in the Lillfjället gneiss (≤ 1.25 GPa; Fig. 1).

3. Previous investigations of the Friningen Garnet Peridotite

The Friningen Garnet Peridotite (FGP) is a 200 × 30 m sized ultramafic lens occurring within the Central Belt of the SNC, close to the structural top of the eclogite-bearing migmatitic Ky–Sil–Kfs gneiss (Ertsekey lens) near Lake Friningen (Fig. 1). The FGP was first mentioned by Du Rietz (1935) while Van Roermund (1989) made the first detailed field and petrographic description, presented EMP mineral

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