Scandian Ultra-High Pressure Metamorphism in the Western Gneiss Region of Norway

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An updated review is presented of the distribution and characterisation of UHP rocks within the Western Gneiss Region (WGR). Recent studies (Carswell et al., 1999; Cuthbert et al., 2000; Wain, 1997) have documented an increasing number of scattered localities where evidence is preserved indicating a late Palaeozoic UHP event. In particular, we consider the nature of the HP/UHP transition in relation to tectonic versus kinetic factors.

The Western Gneiss Region (WGR) is a large (350 x 150 km) tectonic window through the nappe pile within the internal part of the Caledonide orogen of Scandinavia. The present-day structure of the orogen results from the middle-Palaeozoic (Scandian) collision of Baltica with Laurentia during which a large assemblage of nappes was thrust eastwards (present frame of reference) over the Baltican margin. The nappe assemblage and its Baltic basement were subsequently substantially modified by west-vergent extensional "collapse" tectonics.

The rocks within the WGR are dominated by mid-Proterozoic orthogneisses of the Baltic basement, but with an autochthonous cover of late Palaeozoic metasediments and deep infolds of the nappe assemblage. Both the Baltic basement and the infolded nappes show an increasing intensity of Scandian tectonometamorphic overprint from southeast to northwest. While much of this overprint is a result of late Scandian, retrogressive, amphibolite facies metamorphism and exhumation-related deformation, common HP and UHP relics survive in the western and northwestern, coastal parts of the WGR in the form of pods and layers of eclogite and garnetiferous peridotite, and associated, restricted areas of phengite-garnet schists. However, even within the area of strongest Scandian reworking there are significant volumes of pre-Scandian lithologies showing little evidence for Scandian metamorphic transformations. Importantly, plagioclase appears to have commonly survived Scandian HP and perhaps even UHP conditions. Survival of such pre-Scandian lithologies indicates that disequilibrium was common during Scandian metamorphism, and that the efficiency of metamorphic transformations was controlled by limiting factors such as the availability of catalysing fluids, strain partitioning and temperature (Austrheim 1998). The restricted efficiency of crustal processing during collision is likely to have had an important effect on the strength and buoyancy of the subducted Baltic margin.

Petrographic features in the eclogite facies relics show a systematic pattern of variation across the WGR in concert with the intensity of Scandian re-working (Cuthbert et al., 2000). To the south of Nordfjord relatively low pressure solid inclusion assemblages and prograde compositional zoning in garnet are common and no evidence for the presence of coesite has been found (HP or quartz-stable eclogite zone). Coesite (or its polycrystalline quartz pseudomorph) appears to the north of Nordfjord and is found in a coastal strip of ~5000km^2 between Maløy and Nordøyane; garnets in eclogites and enclosing gneisses tend to lack prograde compositional zoning and lower pressure solid inclusions in this region (UHP or coesite-stable zone). At Fjørtoft, Nordøyane, microdiamonds are known from pelitic garnet-kyanite-biotite gneisses (Dobrzhinetskaya. et al., 1995).

The distribution of silica polymorphs across the WGR is consistent with thermobarometric evaluations, which indicate a regional gradient in both P and T from 500^{o}C and 1.6 GPa at Sunnfjord to >800^{o}C and 3.2 GPa in the Nordøyane area. Determined P-T conditions define a field gradient corresponding to an increase of ca. 5^{o}C/km structural depth towards the NW (Cuthbert et al., 2000), in line with the currently favoured model of increased depths of NW subduction of the Baltic Plate rocks of the WGR beneath the overriding Laurentian Plate during the Scandian orogeny.

Mantle-derived garnetiferous peridotites form metre to kilometre-scale bodies within the northern half of the WGR. These often lie along major tectonostratigraphic boundaries, at least some of which appear to be deep-level shear zones. Early parageneses are derived from Proterozoic subcontinental lithospheric mantle (Medaris, 1999), possibly emplaced from an asthenospheric plume as indicated by textural evidence for majoritic garnets and associated high-alumina orthopyroxene megacrysts (van Roermund & Drury, 1999). Neoblastic parageneses give P-T conditions broadly consistent with those of nearby eclogites within the gneisses and are thought to have developed during entrainment into, and transport with**,** subducted Baltic continental crust (Cuthbert et al., 2000).

The transition from HP to UHP eclogite facies in the outer Nordfjord area is manifested by a change from quartz to coesite as the silica polymorph stable at peak pressures, elimination/homogenisation of prograde compositional zoning in garnet, and the northward**s** disappearance of amphibolite facies solid inclusion suites in garnet cores and replacement by eclogite facies inclusion suites. This transition takes place within a 5-10km wide "mixed zone" where HP eclogites and UHP eclogites (and associated relics of HP/UHP gneisses) are closely spatially associated. Recorded pressure differences between adjacent HP and UHP eclogites are thought to be real in spite of large uncertainties. On the face of it**,** this appears to indicate strong non-lithostatic pressure gradients within this zone attributable to tectonic mixing and loss of crustal section (Wain, 1997; Cuthbert et al., 2000). However, there is some evidence to suggest that the mixed zoned may be a result of metamorphic, rather than solely tectonic processes. There is no preferential increase in strain in the country rock gneisses within this zone, nor any obvious change in lithology which might indicate a major shear zone.

Previous studies (Wain, 1997) have emphasised the metamorphic homogeneity of individual eclogite bodies (i.e. their wholly HP or UHP character). However, detailed examination of two localities reveals "hybrid" HP/UHP lithologies. At Vetrhuset, Nordpollen near the northern edge of the mixed zone as defined by Wain (1997) and Cuthbert et al. (2000), inclusions of polycrystalline quartz after coesite are found within garnet and omphacite in eclogites and within garnets in garnet-kyanite-quartz-zoisite-phengite schists. However, some garnets also exhibit clear prograde compositional zoning and (in eclogites) concentrations of blue-green amphibole in their cores. At Årsheimneset, Statlandet, well within the UHP zone as previously defined, opx-free eclogite layers within a large body of opx eclogite have well-developed prograde zoned garnets with blue-green amphibole inclusions in garnet cores (Carswell et al., 1985; Smith, 1988). The enclosing opx eclogite contains polycrystalline quartz after coesite. Both of these localities are clear examples of the survival of HP eclogite characteristics in localised domains within UHP eclogites, indicating restricted prograde development of UHP eclogite from a HP (and previously amphibolite facies) precursor.

Hence an alternative interpretation of the HP/UHP transition zone is that the first appearance of coesite to the north of Nordfjord is an isograd, marking the final locus of conditions for the quartz-coesite inversion. The association of the coesite isograd with the change in garnet characteristics may be explained by the approximate coincidence of the amphibole-out reaction with the quartz-coesite inversion and the coeval attainment of temperatures high enough to enhance intragranular diffusion and chemical homogenisation of garnet. The apparent intermingling of eclogite bodies with either HP or UHP characteristics in a 5-10km wide mixed zone is inferred to result from inefficiency in recrystallisation and reaction progress due to variations in strain and fluid input. Bulk compositional effects on mineral stability may also have been important; for example the magnesian composition of the Årsheimneset eclogite may explain the survival of amphibole inclusions in its constituent garnets well beyond the coesite isograd. The efficiency of the HP-UHP transformation is likely to have been affected by the rate at which the crust was fed down through this critical zone of pressure-dependant reaction surfaces in relation to the rates of reaction.

Overall, whilst we accept that exhumation-related deformation may have caused some redistribution of eclogite types, our recent observations suggest that the HP/UHP transition in the outer Nordfjord area of the WGR represents a complex isograd within a crustal slab which was quasi-coherent during subduction. In this interpretation the garnet peridotites could either have been emplaced (obducted?) prior to deep level subduction and underwent HP/UHP metamorphism along with the subducted crust, or they were entrained directly from the mantle as the crustal slab became dismembered during exhumation.

Explanation of the HP-UHP transition zone and other enigmatic features of the WGR thus requires consideration not only of tectonics, but also of kinetic controls on the highly variable mineral reactivity displayed by these rocks during a rapid cycle of subduction and exhumation associated with the Scandian plate collision.

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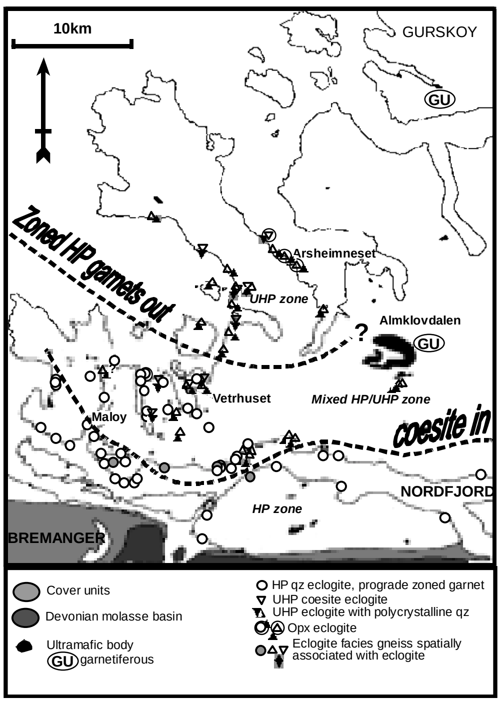

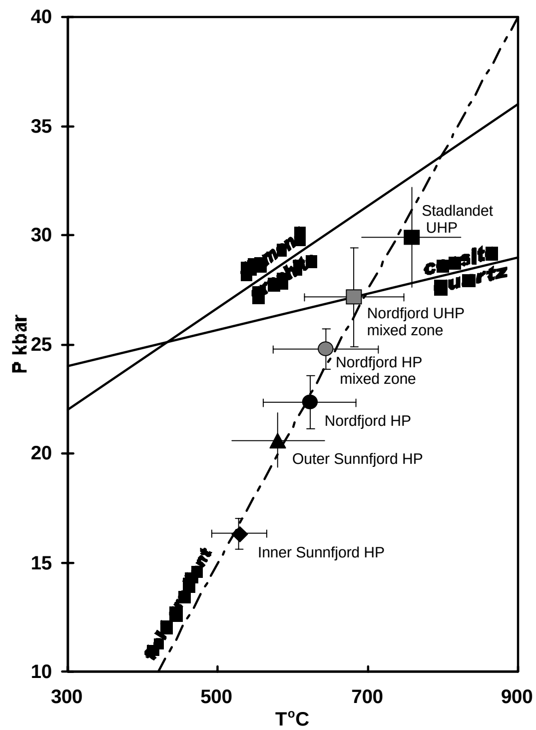

Figure 1
Simplified geological map of the outer Nordfjord area in the WGR showing the distribution of HP and UHP lithologies and the limits of the HP, mixed and UHP zones as defined by Cuthbert et al. (2000).

Figure 2
Average P&T for geographic and petrographic groups of eclogites in the WGR estimated from grt-cpx-pheng thermobarometry, after Cuthbert et al. (2000).