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CONTRASTING METAMORPHIC GRADIENTS: BARROVIAN-TYPE *VS.* HIGH-PRESSURE METAMORPHISM. AN EXAMPLE ON THE NORTHERN MARGIN OF GONDWANA (NW IBERIA)

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Contrasting metamorphism in adjacent terranes is characteristic of large-scale tectonic events that include both collisional and rifting scenarios. When one of those terranes is characterized by the presence of high-pressure rocks, it is more likely to be related to collisional settings, and commonly in locations close to the suture. This contribution shows an example of the aforementioned situation in the Variscan orogenic belt of NW Iberia, where a tectonic slice with high-pressure metamorphism is above rocks that underwent Barrovian metamorphism. The two involved terranes are known as the Lower Allochthon and the so called Parauthochthon, respectively. The contact between both is a shear zone with a complex evolution during the Variscan orogeny.

The Lower Allochthon recorded the continental subduction event (blueschist- and eclogite-facies conditions) of the most external part of the north Gondwana passive margin during the late Devonian (ca. 370-365 Ma) at the beginning of the Variscan collision. Followed by a buoyancy-driven exhumation triggered by the extensional collapse of the orogenic pile. Whereas the underlying Parauthochthon underwent crustal thickening resulting in a medium-pressure Barrovian-type metamorphism and a higher temperature/lower pressure Buchan-type metamorphism.

КОНТРАСТНЫЙ ГРАДИЕНТ МЕТАМОРФИЗМА: БАРРОВЕНСКИЙ ТИП ОТНОСИТЕЛЬНО ВЫСОКОБАРИЧЕСКИХ ПРЕОБРАЗОВАНИЙ НА ПРИМЕРЕ СЕВЕРНОЙ ОКРАИНЫ ГОНДВАНЫ (СЗ ИБЕРИЯ)

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Контрастный метаморфизм в соседних террейнах характерен для крупномасштабных тектонических событий, которые включают сценарии как коллизии, так и рифтинга, когда один из этих террейнов характеризуется наличием пород высокого давления. Он, скорее всего, будет связан обычно в местах, близких к сутурным зонам. Примером этих комплексов в геодинамической истории выступает Варисканский орогенный пояс СЗ Иберии, где тектонический срез с метаморфизма повышенного давления залегает над породами, подвергшимися Барроновскому этапу метаморфизма. Два задействованных террейна, известны как нижний аллохтон и так называемый «параалохтон», соответственно. Контакт между ними представляет собой зону сдвига со сложной эволюцией во время Варисканского орогенеза.

В нижнем аллохтоне было зарегистрировано событие континентальной субдукции (условия глаукофан-сланцевой и эклогитовой фаций повышенных давлений), которые отвечали самой внешней части пассивной границы северной Гондваны во время позднего девона (около 370-365 млн лет) в начале Варисканского столкновения. Затем следует эксгумация, вызванная плавучестью и экстенсионным коллапсом при формировании орогенной системы. Лежащий в основание параавтохтон способствовал утолщению земной коры и способствовал метаморфизму Барроновского типа среднего давления и метаморфизму типа Бьюкен более высокого температурного / низкого давления.

Introduction

Investigating the metamorphic evolution of the most representative areas of an orogen at a regional scale, includes the study of the processes involved in the subduction and exhumation of the terranes that form the suture realm. This is an essential task that aids deciphering the evolution of the whole orogenic edifice.

Within this general context, the Riás Schists (Llana-Fúnez, 2001) represent a metasedimentary sequence that experienced intermediate pressure (MP) Barrovian metamorphism (cf. Llana-Fúnez, 2001; Díez-Fernández, 2011). This sequence is located structurally below a thick sheet of high-pressure rocks (HP; Rodríguez et al., 2003; López-Carmona et al., 2010; 2013; 2014; Li and Massone, 2016; Puelles et al., 2017). Both units are separated by a tectonic contact interpreted as an east directed thrust (Llana-Fúnez, 2001) or as a top-to-the-west extensional detachment (Díez-Fernández, 2011). However, the metamorphic gap between the MP and the HP metamorphic rocks has not yet been described in detail. This contribution aims to characterize the processes that led to this present-day geometry through a comprehensive thermobarometric study.

The main objective of this study is to decipher the pressure–temperature evolution (P–T) of the Riás Schists and describe the relationship between the two units with distinct metamorphism, within the framework of the collision, and subsequent evolution, of the Variscan orogen in the NW Iberian Massif.

Geological background

The Riás Schists outcrop in the so-called Galicia – Trás-os-Montes Zone (Fig. 1; GTOMZ; Farias et al., 1987; Arenas, 1988), in NW Iberia, in the westernmost sector of the European Variscan Belt. The GTOMZ constitutes a large allochthonous sheet superimposed over the Central Iberian Zone (CIZ; Julivert et al., 1972; 1980) and comprises (i) the structurally lower Schistose Domain (Farias et al., 1987) and (ii) the upper, overimposed, Allochthonous Complexes (Arenas, 1988).

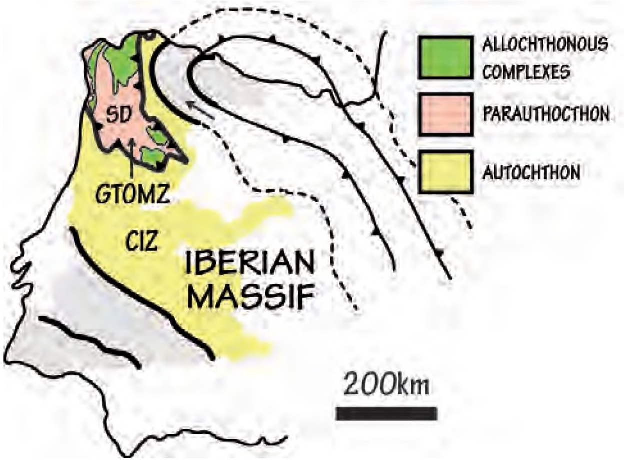

Figure 1. Distribution of the different domains of the Iberian Massif (simplified by Julivert et al., 1972, Farias et al., 1987, Martínez Catalán et al., 2002). SD-Schistose Domain; GTOMZ-Galicia – Trás-os-Montes Zone; CZI-Central Iberian Zone.

The Schistose Domain includes a thick sequence (ca. 7-8 km) of siliciclastic metasediments and felsic metavolcanic rocks Ordovician-Devonian in age, interpreted as a section of the northernmost continental margin of Gondwana during the Paleozoic, tectonically transported to the innermost areas of the continent (Martínez Catalán et al., 2009).

Although the Paleozoic sequence of the Schistose Domain and the CIZ show different characteristics, their stratigraphy and their similar variscan tectonothermal history, suggest a close paleogeographic relation (Marquínez-García, 1984; Farias et al., 1987; Díaz García, 1992; Dallmeyer et al., 1997, Murphy and Gutierrez-Alonso, 2008; Dias da Silva et al., 2012). For this reason, the Schistose Domain cannot be considered an exotic terrain and therefore, would constitute the relative autochthon, or Parauthochthon (Ribeiro et al., 1990), of the Allochthonous Complexes. In this contribution, the nomenclature proposed by Ribeiro et al. (1990) will be used.

The Allochthonous Complexes were thrusted over the Schistose Domain and consist on a succession of units with different affinities that have undergone large displacements becoming part of a huge nappe stack during the Variscan collision (Ries and Shackeleton, 1971). The succession of allochthonous units is interpreted as terranes formed in a different palaeogeographic setting, including continental margins (Lower Allochthon), consumed oceanic areas (Middle Allochthon) and magmatic arcs (Upper Allochthon). After experiencing a polyphasic Varican tectonothermal evolution, an intense thinning and a strong dismemberment of the original pile, the evolution of the Allochthonous Complexes culminated with the exhumation of their units (cf. Martínez Catalán et al., 2002; Gómez Barreiro et al., 2007; Díez-Fernández et al., 2011). Currently, they represent residual mega-klippen of the initial stacking preserved in late synforms exposed in the NW Iberian Massif of Spain (Cabo Ortegal, Órdenes and Malpica-Tui Complexes) and Portugal (Bragança and Morais Complexes), as well as in different massifs across central and western Europe.

The Riás Schists

In the vicinity of the Malpica-Tui Complex (MTC; Rodríguez, 2005) three cartographic units have been distinguished in the Parauthochthon (PA; cf. Díez-Fernández, 2011): (i) medium grade schists, whose most representative outcrop is located to the east of the MTC, from the Riás Beach to Punta de Chan de Razo; (ii) the para-derivated high-grade migmatites, which are best found in the area of the Mount Neme; and (iii) the glandular orthogneisses that outcrop to the west of the MTC, in the San Adrián Cape, and in the coastal section of the southern margin of the Ría de Arousa. The limit between the schists and the migmatites is interpreted as a metamorphic isograd, evidenced by a notable increase in the micas size due to increasing temperature in the main fabric (Díez-Fernández, 2011). Traditionally, the first two units, of sedimentary origin, have been attributed to the Paraño Group of the Schistose Domain Domain of Galicia – Trás-os-Montes (Alonso and González, 1982; Marquínez-García, 1984).

The study area includes the westernmost outcrops of the Riás Beach, located to the southeast of Malpica de Bergantiños (A Coruña, Galicia), on the popularly known Costa da Morte.

The most characteristic stratigraphic sequence of the Parauthochthon in the studied area, from the structurally lower levels to the upper ones, can be recognized from Chan de Razo Cape to Riás Beach, respectively. This sequence includes fine-grained siliciclastic rocks metamorphosed into micaschists and interbedded metasandstones, black metasiliceous rocks (lidytes) and graphite-rich schists. In the highest part the sequence (which is the aim of this study), the Riás Schists depict a stretching lineation developed on the schistosity planes. The main foliation observed is a tectonic banding defined by alternating quartz ribbons (mm to cm thick) and mica-rich domains, which include syntectonic andalusite (sample MT26; N43°17'35.88", W8°44'38.65") and occasional garnet (sample MT7; N43°17'35.61", W8°44'39.17"). Frequently, decimetric to metric quartzite levels with a little lateral continuity and quartz veins are present. Subvertical to steep west-dipping crenulations fold both, the main foliation and the stretching lineation and isoclinal folds appear when appropriate markers are present. Throughout all the metamorphic sequence, metric to decametric-scale boudins of leucogranite are frequent (cf. Llana-Fúnez, 2001; Díez-Fernández, 2011; Fig. 2).

The Riás Schists show a chemical composition of typical pelites (e.g. Atherton and Brotherton, 1982) and a medium grained porphyro-lepidoblastic texture. Quartz and planar minerals constitute more than the 50% (up to 80% in MT7) of the modal proportion of the studied samples. In addition, andalusite (≈ 40%; MT26), albite (≈ 20%), garnet (≈ 15%; MT7), staurolite (≈ 10%), ilmenite (<5%) and accessory tourmaline, carbonates and apatite (<2 %) are observed.

The studied samples represent the two most characteristic lithological types of the metasedimentary sequence (Fig. 2). Garnet-bearing micaschists (MT7) are the least abundant lithological type and outcrops a few meters from the basal shear zone that separates the Parauthochthon and the MTC. This sample is an aluminous metapelite (26.34% Al_2O_3) rich in FeO_T (8.75%). Andalusite-bearing micaschists (MT26) appear structurally below the garnet-bearing micaschists and are calcium-poor metapelites (CaO = 0.06%).

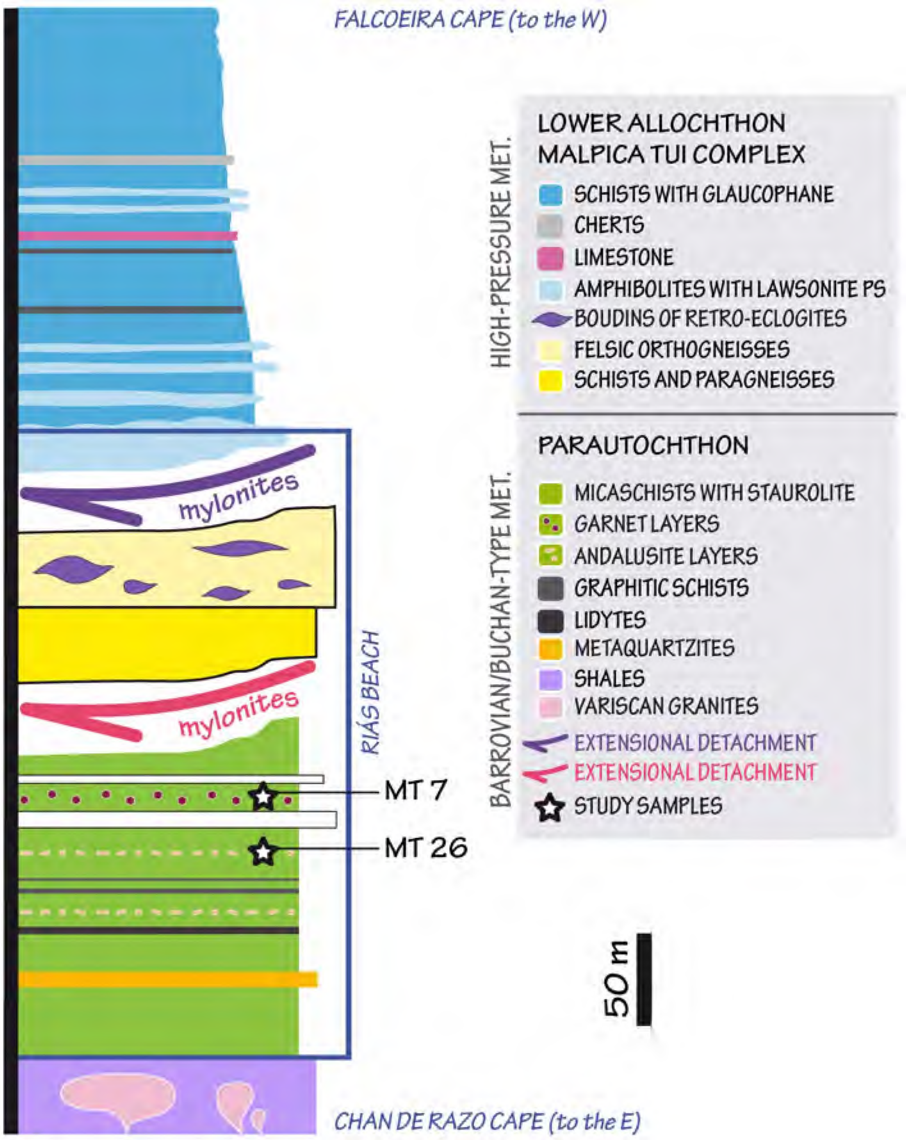

Figure 2. Idealized lithostratigraphic column of the coastal section in the vicinity of the Malpica-Tui Complex from Chan de Razo Cape to Falcoeira Cape. Modified from Llana-Fúnez, 2001 and López-Carmona et al., 2014.

This chemical/mineralogical variation may be due to compositional differences in their respective protoliths or because each lithology underwent a different metamorphic evolution due to their distinct location in the original pile. Nonetheless, currently both samples appear side by side and interbedded without apparent lithological change at the outcrop scale. Moreover, levels with garnet or andalusite are scarce and are concentrated near the shear zone in parallel layers that are centimeters apart from each other. In this contribution, both hypotheses will be analyzed.

Both samples show a subparallel mineralogical banding formed by alternating phyllosilicates (muscovite, biotite and chlorite) and quartz, which gives the rock a planar-planolinear aspect and define the main foliation, which is a schistosity S_2.

The fabric of the first deformation event registered in this lithology is a S_1 foliation, defined by inclusions of relict minerals within the core of garnet (quartz and rutile needle out of the microprobe beam resolution) and andalusite porphyroblasts (staurolite, muscovite, biotite and rutile partially replaced into ilmenite).

The matrix foliation (S_2) includes the rim of the garnet porphyroblasts, staurolite, muscovite, biotite, ilmenite, andalusite, chlorite and quartz.

Finally, post-S_2 foliation is associated with the aforementioned crenulations and is characterized by C' shear bands affecting S_2. Secondary muscovite, biotite and chlorite grow in the post-S_2 foliation planes. Other structures related to this foliation are symmetrical pressure tails and shadows, quartz ribbons and mica fish.

If both lithologies experienced the same metamorphic evolution, and therefore, the growth or absence of certain phases is determined by the bulk rock chemistry, based on the textural observations, three foliations can been identified in the Riás Schists : S_1, preserved in the core of garnet and andalusite porphyroblasts and composed of g_{CORE} + st + mu + bi + q ± ru/ilm; the matrix foliation S_2, that includes the mineral assemblage g_{RIM} + st + mu + bi + ilm + and + chl + q ± pl; and post-S_2 that comprises mu + bi + chl + ab + q ± tourmaline, zircon, Fe/Ti oxides and carbonate.

If each of the lithologies described reflects a different structural position in the original pile, and therefore recorded different metamorphic conditions, garnet and andalusite never coexisted in equilibrium in the same paragenesis. Thus, in the structurally upper sequence (to the W; sample MT7) garnet- and staurolite-Barrovian zones can be distinguished.

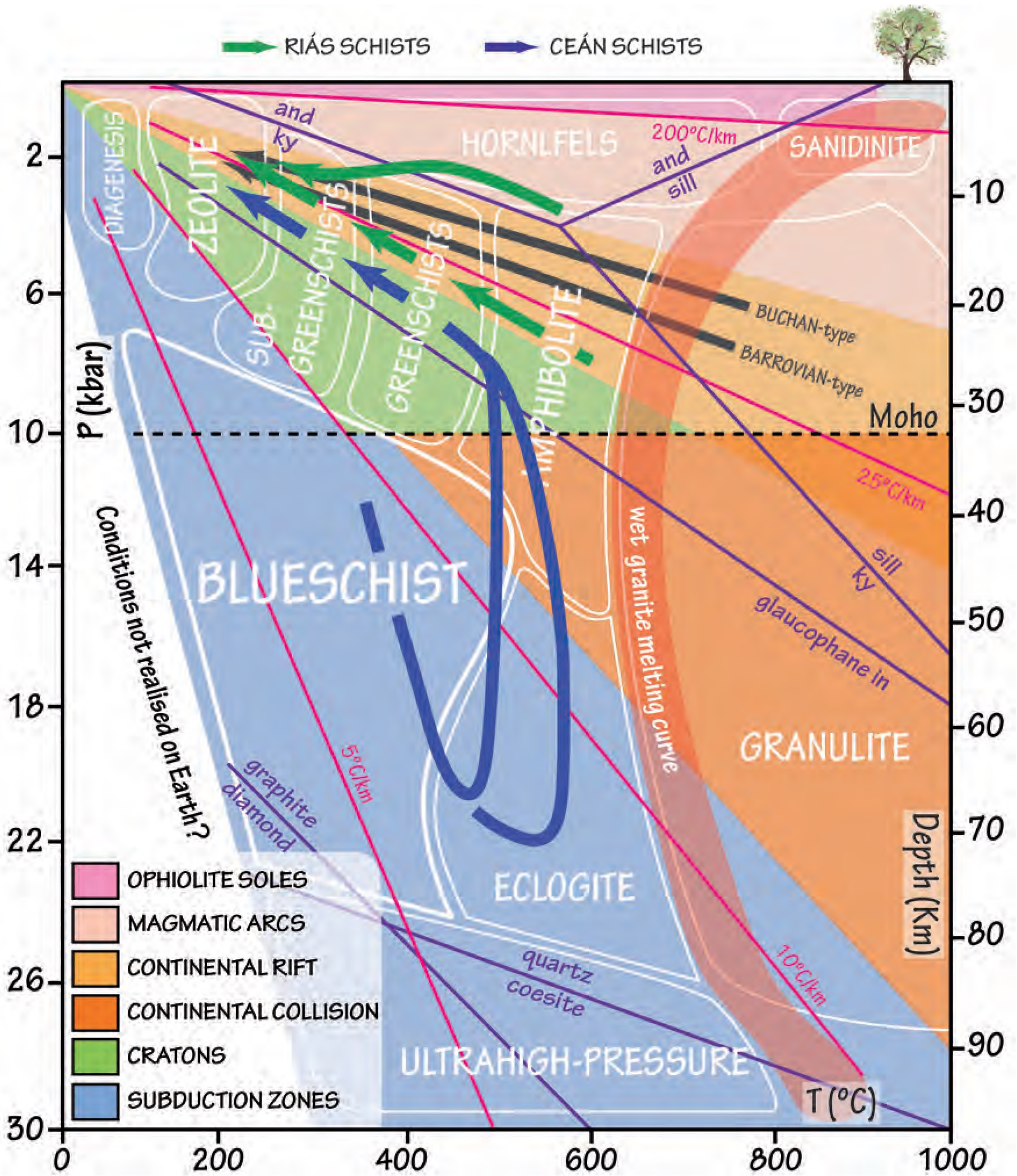

Figure 3. Summary of the peak P–T conditions and P–T paths of the Ceán Schists (López-Carmona et al., 2013; 2014) and the Riás Schists (Solís-Alulima, in press). Metamorphic facies and tectonic settings are shown in terms of pressure and temperature conditions inside the Earth. Modified after Hacker (2001) and Bentley (2010) using data from Yardley (1989), Spear (1993), Oberhänsli et al. (2004) and Bousquet et al. (2008). Diagnostic reactions are also shown for reference: aluminosilicate stability fields after Holdaway (1971); diamond=graphite after Kennedy & Kennedy (1976); coesite=quartz after Hemingway et al. (1998) and glaucophane-in line after Corona et al. (2013). The shallowest Moho after Blackwell (1971) is also included.

Whereas the structurally lower sequence (to the E; sample MT26) is characterized by a high-temperature/low-pressure Buchan-type metamorphism in the andalusite zone. The garnet-staurolite schists contain g + st + mu + bi + chl+ pl + q + ru/ilm and accessory phases and the andalusite-bearing schists comprise st + and + mu + bi + chl+ pl + q + ru/ilm and accessory phases.

Thermobarometry

Based on natural observations, regardless of the interpretation of a shared or separate metamorphic evolution of both lithologies, multiequilibrium termobarometry using P–T pseudosections suggest that M2 represents the metamorphic peak, the deepest burial depth, and it has been estimated at maximum pressures of *ca*. 8 kb and 600 ºC in garnet-staurolite micaschists (Sample MT7), which would be equivalent to ca. 25-35 km burial depth . The retrograde stage records decompression from the kyanite stability zone in the amphibolite facies, to the andalusite stability zone in the greenschist facies (Fig. 3). Peak metamorphic conditions for M2 in andalusite-bearing micaschists suggest maximum pressures of *ca*. 4 kb and 600 ºC and decompression with slight heating (entering in the sillimanite zone; ca. 640 ºC).

Calculated models also predict that the stability fields of garnet and andalusite for the effective compositions used do not coexist, as observed at outcrop and thin section scales.

Conclusions: Rias Schists *vs.* Cean Schists

The Cean Schists outcrop in the Malpica-Tui Allochthonous Complex, to the west of the study area. These schists represent the westernmost margin of Gondwana subducted during the Variscan orogeny (in Devonian times). They experienced a metamorphic evolution in the blueschist-facies conditions, reaching ca. 70 km deep (P_{max} ~ 22 kbar).

Estimations made in the Rias Schists, and the spatial relationship between both lithologies (see Fig. 3) suggest that they formed part of the same continental margin at the beginning of the Variscа orogeny but experienced very different tectonothermal evolution due to their putative position in the passive margin and hence, in the orogenic wedge, despite their proximity in their nowadays current geographic location.

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