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Preface to the special issue "The Iberian Massif in the frame of the European Variscan Belt": a tribute to the career of Prof. José R. Martínez Catalán

Emilio González Clavijo[1], Puy Ayarza[2], Ícaro Dias da Silva[3], Juan Gómez Barreiro[2], and Francisco Gonzalez Lodeiro[4]

[1]Instituto Geológico y Minero de España, Plaza de la Constitución 1, 37001 Salamanca, Spain
[2]Departamento de Geología, Universidad de Salamanca. Plaza de la Merced, s/n, 37008 Salamanca, Spain
[3]Instituto Dom Luiz, Faculdade de Ciências, Universidade de Lisboa. Campo Grande, 1749-016 Lisbon, Portugal
[4]Departamento de Geodinámica, Universidad de Granada. Av/de la Fuente Nueva, s/n, 18071, Granada, Spain

Correspondence: Puy Ayarza (puy@usal.es)

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1 Introduction

The present *Solid Earth* Special Issue intends to be a tribute to the scientific career of Professor José R. Martínez Catalán. It has been coordinated by four people among his many former PhD students. The title represents the main focus of his research, developed at the Salamanca University, which has combined the study of the largest outcrops of the Variscan basement in the Iberian Peninsula and their correlations with the rest of the European Variscan massifs. This preface to the special issue includes two parts: the first one presents a brief summary of its content, and the second one highlights the academic and scientific achievements of Prof. José R. Martínez Catalán. The latter is written by Francisco González Lodeiro, former Rector of Granada University, ex-director of the Spanish Geological Survey and nowadays Emeritus Structural Geology Professor at Granada University, and by Puy Ayarza, Geophysics and Tectonics Professor at Salamanca University and one of the first PhD students in Martinez Catalán's career.

2 Special issue contents

The nine articles contained in the volume deal with five significant aspects of the Variscan Belt, most of them hosted by the Iberian Massif but including also data from the Pyrenees, South Armorican Domain, southern French Massif Central, and Sardinia. These main issues are (i) the characteristics and meaning of late Cambrian and Ordovician magmatism, both in the Autochthon and the Mid-Variscan Allochthon, (ii) the metamorphic evolution of the latter, which includes subduction-related high-pressure events, (iii) the syn-orogenic deposits and their relation with Variscan sutures, (iv) the geometry and origin of the late-Variscan large arcuate structures, and (v) the characteristics of the Variscan crust and their influence in the Alpine structures. A couple of papers embrace more than one of these issues.

Fungorian and Ordovician felsic magmatism from the Iberian Autochthon to Sardinia is described and analyzed by J. Javier Álvaro, Teresa Sánchez-García, Claudia Puddu, Josep Maria Casas, Alejandro Díez-Montes, Montserrat Liesa and Giacomo Oggiano in a paper that combines a wide compilation of previous data with new analyses, establishing the relationships between this important pre-Variscan magmatism and the Toledanian and Sardic unconformities. The authors propose a coherent interpretation on which the magmatism is related to the opening of the Rheic Ocean.

Another contribution by José Manuel Benítez-Pérez, Pedro Castiñeiras, Juan Gómez-Barreiro, José R. Martínez Catalán, Andrew Kylander-Clark and Robert Holdsworth, deals mainly with the origin and metamorphic evolution of the Sobrado unit, in the Allochthonous Órdenes Complex of NW Spain. But it also describes detrital zircons in paragneisses, some of them of magmatic origin and Cambrian age, interpreted as part of an active magmatic arc in the periphery of Gondwana. However, the main results of this contribution pertain to the polymetamorphic evolution of the Upper Allochthon

in NW Iberia. The paper combines U-Pb geochronology and REE geochemistry in one sample of granulite-facies paragneiss and a mylonitic amphibolite retrograde from high-pressure granulite facies. In addition to the provenance of metasediments described in the previous paragraph, the results include the establishment of a maximum depositional age for them: a Lower Ordovician age for the first granulite-facies metamorphism of intermediate pressure and for the timing of progressive exhumation from a second granulitic, high-pressure early Variscan metamorphism.

A somewhat younger high-pressure early Variscan metamorphism affects the Lower Allochthon in NW Iberia and the South Armorican Domain. It is investigated from a structural point of view by Domingo Aerden, Alejandro Ruiz-Fuentes, Mohammad Sayab and Aidan Forde in a contribution about the kinematics of subduction in the Ibero-Armorican arc based on microstructural analysis of inclusions in garnet and pseudomorphed lawsonite porphyroblasts of Île de Groix. The orientation of successive generations of inclusion trails seem to rotate counterclockwise, and the same is envisaged for the sense of subduction, which also rotates during the high-pressure event.

Syn-orogenic deposits are important for understanding tectonic processes, and their study must include facies, provenance, ages and structures to which they are linked as well as those affecting them. Three papers are devoted to this subject in northern and southern Iberia. Their results are important for understanding the closure of oceanic realms and plate collisions. The contribution by Irene Pérez-Cáceres, David Jesús Martínez Poyatos, Olivier Vidal, Olivier Beyssac, Fernando Nieto, José Fernando Simancas, Antonio Azor and Franck Bourdelle deals with the Pulo do Lobo domain, one of the units forming part of the suture between the Ossa-Morena and South Portuguese zones. The authors use X-ray diffraction, EPMA-derived X-ray compositional mapping and Raman spectrometry of carbonaceous material to establish the conditions of deformation during Upper Devonian (epizonal) and Carboniferous (epizone-anchizone) metamorphic events. No evidences of high-pressure metamorphism were found, and authors conclude that the unit was not involved in the subduction process during the formation of the suture.

Manuel Francisco Pereira, Cristina Gama, Ícaro Dias da Silva, José Brandão Silva, Mandy Hofmann, Ulf Linnemann and Andreas Gärtner analyze the chronostratigraphy and provenance of syn-orogenic Carboniferous basins in the Ossa-Morena Zone in southern Portugal, close to the South Portuguese Zone. They define age limits for the different local formations and establish a correlation with magmatic events. Moreover, using K-S test and multidimensional scaling (MDS) analysis, the authors find a variability of sources. These include a Devonian magmatic arc probably linked with Laurussia, and recycled materials from the Ossa-Morena and South Portuguese zones, which represent the western continuation of the Saxothuringian and Rhenohercynian zones of Central Europe respectively.

Syn-orogenic deposits linked to the emplacement of the NW Iberian Allochthon are described and interpreted by Emilio González Clavijo, Ícaro Dias da Silva, José R. Martínez Catalán, Juan Gómez Barreiro, Gabriel Gutiérrez-Alonso, Alejandro Díez Montes, Mandy Hofmann, Andreas Gärtner and Ulf Linnemann in a work based on mapping, detrital zircon dating and identification of sedimentary and volcanic olistoliths. Most of the Variscan flysch and related deposits occur in the Lower Parautochthon, an imbricated thrust sheet bounded at its base by Silurian carbonaceous slates. Detrital zircons include a scarce but significant Variscan population (400–320 Ma). MDS analysis shows recycling and mixing of sources, with a cluster derived from the Upper Parautochthon preorogenic Paleozoic volcanics and another fed by multiple Gondwanan sources, including the three recognized allochthonous groups and the Autochthon.

Orogenic-scale, plan view arcuate structures are a characteristic of most mountain chains, and the Variscan Belt is not an exception. The most important in terms of size and tightness is the Ibero-Armorican Arc or Cantabrian Orocline, whose core and southern branch occur entirely in the Iberian Massif while the northern branch can be followed in the Armorican Massif and the British Isles. But other arcuate structures have been described in central Iberia, the French Massif Central and the Bohemian Massif. The contribution by Daniel Pastor-Galán, Gabriel Gutiérrez-Alonso and Arlo B. Weil offers a complete compilation of the structural and paleomagnetic characteristics of the two largest arcuate structures present in the Iberian Massif, the Cantabrian and Central Iberian ones, arguing that they are not a coupled double orocline, but their age and deformation mechanisms are different. In addition, the above mentioned contribution by Domingo Aerden, Alejandro Ruiz-Fuentes, Mohammad Sayab and Aidan Forde, includes a comparison between the sets of inclusion trails in porphyroblasts of the South Armorican Domain and the Lower Allochthon of Galicia and northern Portugal in NW Iberia. The alignment of inclusions in both domains is assumed as having been the same during subduction, which suggests that the Ibero-Armorican arc existed at the time. The misfit of inclusion trails orientations between both sides of the Gulf of Biscay are then used to estimate the rotation of Iberia during its opening.

The characteristics of the Variscan crust in the Iberian Central System (ICS) and its two foreland basins, namely the Duero and Tajo basins, are investigated by Juvenal Andrés, Puy Ayarza, Martin Schimmel, Imma Palomeras, Mario Ruiz and Ramón Carbonell by using autocorrelation of seismic noise. This contribution identifies a ICS Variscan crust especially rich in granitoids. The latter are well exposed in the surface but the data show their continuation into the lower crust and its prolongation to the north and south, as yet unknown due to the cover of the Duero and Tajo basins. More-

over, the work allows the authors to explain the role of late Variscan crustal-scale faults in the Alpine architecture resulting from the Africa-Europe convergence during the Cenozoic.

Another contribution, by Puy Ayarza, José Ramón Martínez Catalán, Ana Martínez García, Juan Alcalde, Juvenal Andrés, José Fernando Simancas, Immaculada Palomeras, David Martí, Irene DeFelipe, Chris Juhlin and Ramón Carbonell, describes the structure of the Variscan crust in the Iberian Massif and its evolution based mainly on normal incidence seismic data but including some wide angle and natural source seismic acquisitions. The paper shows the migrated and reprocessed (post-stack) sections of all vertical incidence reflection profiles acquired to date across the Iberian Massif. Thus, their image has been homogenized, and their interpretation has been accompanied by coinciding geological cross sections. A common feature characterizes the Variscan basement: a very reflective lower crust whose well-defined upper limit is a discontinuity which has often acted as a decoupling level. This is interpreted as the Conrad discontinuity, and its depth and relationships with significant reflections is quite variable, allowing a correlation among the thickness of the lower crust (i.e., the position of the Conrad discontinuity), the evolution of the different Variscan domains and its effect on Aline overprinting.

We want to thank all contributors for providing new data to further help to understand the evolution of the Varsican Orogen.

3 José Ramón Martínez Catalán: an excellent regional geologist

José Ramón Martínez Catalán (Figs. 1 and 2) got his Science Degree (mention in Geology) at the University of Madrid by the end of 1970, after defending a BSc on the stratigraphic study of Oligocene copper-bearing beds in the Ebro Valley. Soon after, in 1972, he started his career at the Spanish Geological Survey, where he mapped four, 1 : 50 000 sheets for the Spanish Geological Map (plan MAGNA). The area he worked on was located in central Galicia, one region of complicated and poorly known geology, with scarce previous cartographic data. That was Jose Ramón's first contact with the geology of the Iberian Massif, and more precisely with the NW Iberian Peninsula, the region he has devoted to most of his career.

As part of his first overseas experiences, on March 1973, José Ramón started his teaching activity as Assistant professor in Geology at the University of Concepción (Chile), but the military coup headed by General Pinochet suddenly interrupted the academic activity. After some difficulties related to the political situation, he left Chile on October 1973 and moved to Ecuador. From November 1973 to October 1974, José Ramón was hired by the University of Guayaquil as an Associated Professor in Economic Geology. On November 1974, he got back to Spain where he got a position as Assistant Professor at the University of Salamanca. Simultaneously, he started his PhD funded by a grant of the Spanish Ministry of Science and Education. His thesis' goal was the stratigraphy and structure of the Lugo Dome (West Asturian-Leonese Zone, Iberian Massif). It was supervised by Professor Florencio Aldaya, and was presented at the University of Salamanca on May 1981, receiving the maximum grade.

On September 1981, already with a doctor degree, he was promoted to "Profesor Encargado de Cátedra". On December 1984, he got a permanent position as Lecturer at the University of Salamanca, promoting to Full Professor on October 1998. On September 2018, he became Professor Emeritus. Since then, he has maintained his academic and research activity at the Geology Department of the University of Salamanca.

Along these years, José Ramón has been often in charge of every Structural Geology and Tectonics courses in the Geology Degree at the University of Salamanca. He has also been involved in several post-graduate courses related to Geophysics, Tectonics, Structural Restoration, and Collisional Tectonics. Furthermore, José Ramón has supervised fifteen PhD thesis, most of them focused on the tectonic evolution of the NW and central regions of the Iberian Massif. Nowadays, he is still advising several BSc, MSc and PhD thesis.

Regional geology has always been the main focus of Professor Martínez Catalán's career. After his incorporation to the University of Salamanca in 1974, he resumed his participation in the Spanish plan MAGNA, being directly involved in the mapping of numerous sheets in Galicia (1 : 50 000 and 1 : 200 000 scales), and as an external consultor in a few 1 : 50 000 sheets located in the Cáceres and Salamanca provinces. These cartography tasks were combined with its PhD thesis fieldwork at NW Spain. Both were paramount for the specialization of José Ramón as a regional geologist, and for his interest in the evolution of large-scale structures in the frame of the Variscan orogeny.

Among José Ramón's most important contributions, we would like to highlight those devoted to deciphering the geometry and kinematics of the km-scale folds and shear zones in the NW Iberian Peninsula. He also has a high interest in the correlation of the NW Iberian Allochthonous Units with their counterparts in other European Variscan outcrops (i.e., Armorican and Central Massifs in France, Bohemian Massif in the Czech Republic), something that has led him to publish some of his later works.

In Martínez Catalán's papers, the geological map is the keystone to stablish the precise geometry needed to build cross-sections that can be restored. Furthermore, José Ramón has systematically used the available geophysical data, e.g., seismic reflection profiles and potential field anomalies, which have allowed him to constraint the geometry of structures at depth. Regarding temporal and spatial evolution of deformation and kinematics, he has followed the classical approach based on the structural analysis at micro- and meso-

Figure 1. Professor Martínez Catalán during a field trip in 2007.

scale, but also the modern techniques that take into account the metamorphic and geochronological data derived from different methods.

Among his contributions as first author, many are close to 200 cites (e.g., Martinez Catalán et al., 1997, 2009, 2007, 1996). The most significant ones regarding the West Asturian-Leonese Zone deal with the characterization of the internal structure of the Lugo Dome and the description of the basal thrust of the Mondoñedo Nappe. In the Central Iberian Zone, his most valuable contributions are those related to the mapping and interpretation of the extensional syn-orogenic detachments and transcurrent shear zones in the Salamanca area and the Spanish Central System (Martínez Catalán et al., 2014). Also, his constraints on the structure and age of Central Iberian Arc have yielded works with more than ∼ 150 cites in 10 years (Martinez Catalán, 2011). Finally, he has recently published an ambitious review paper based on the correlation of the allochtonous units in the European Variscides (Martinez Catalán et al., 2021). This paper has allowed him to carry out a thorough reconstruction of the Variscan Orogen.

However interested in Geology in general (Fig. 2), José Ramón has concentrated most of his research on the study of the Galicia–Trás-os-Montes Zone. Back on the 1970s, this region had been the focus of several European schools of Geology, being the University of Leiden with the leadership of Prof. Emile Den Tex the most important one. Prof. Den Tex supervised a good number of PhD thesis mostly devoted to petrological and geochemical issues. In contrast, the structural studies were rather scarce by that time. The research group of Prof. Martínez Catalán covered this gap, having paid special attention to the structure of the Órdenes Complex and the Malpica-Tuy Unit.

Nowadays, thanks to the works of Prof. Martínez Catalán and his PhD students, the internal structure of Allochthonous Units of the NW Iberian Massif is well known. Furthermore, these contributions have served to understand the processes responsible for the convergence during the subduction and collisional stages of the Variscan orogeny in NW Iberia. The results of the research group have also been used to continue and interpret the Variscan suture of NW Iberia along the whole European Variscan belt. Prof. Martínez Catalán's research has been mostly financed by public funds obtained in competitive calls of the Spanish National Research Program, as well as via contracts with the Spanish Geological Survey directly related to geological mapping.

The scientific production of Prof. Martínez Catalán is backed up by ∼ 100 papers published in international journals, most of them with a high impact factor, as well as a good deal of contributions included in international books. Most of his works, especially those as first author, are highly quoted in papers related to the Variscan orogen. Last but no least, his map sheets at 1 : 50 000 and 1 : 200 000 scales from the NW and Central Iberian Massif published by the Spanish Geological Survey serve as starting point for a good number of studies carried out by other researchers working on

Figure 2. Jose Ramón visiting the Earth's guts at Erta Ale volcano (Afar, Ethiopia).

the geological evolution of these regions. These cartographic contributions are essential for the exploration and evaluation of different geological resources (mining, hydrogeology), as well as for civil engineering and natural hazard studies.

Martinez Catalán's career is an example of quality, focus and cooperation. His performance has been acknowledged by the recent Stanford list of the top 2 % world scientists, among whom he is included. The knowledge of the Iberian Massif geology and its integration with that of the European Variscides has greatly advanced due to his efforts and dedication. May he continue working for many more years.

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