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# Advances in the Lower Ordovician of the western Iberian Chain, NE Spain

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### ABSTRACT

The western Iberian Chain of NE Spain represents a lateral prolongation of the West Asturian-Leonese Zone. As other proximal sectors fringing NW Gondwana, the chain comprises a conformable and continuous Furongian–Tremadocian transition, comprising a thick (3600–4500 m) Lower Ordovician sedimentary succession, exclusively composed of siliciclastic strata and deposited in mid-latitude (temperate) waters. Although the shelly fossil record is not abundant, some key trilobites and brachiopods allow the identification of distinct biogeographic links with the Argentinian margin of West Gondwana, Oaxaca (Mexico), and the neighbouring Montagne Noire (France), with which a common biostratigraphic biozonation can be envisaged. Two phosphoritic interbeds rich in linguliformean brachiopods punctuate the Valconchán and Borrachón formations, and represent event beds related to condensation processes and sedimentation of explosive ignimbritic tuffs, respectively.

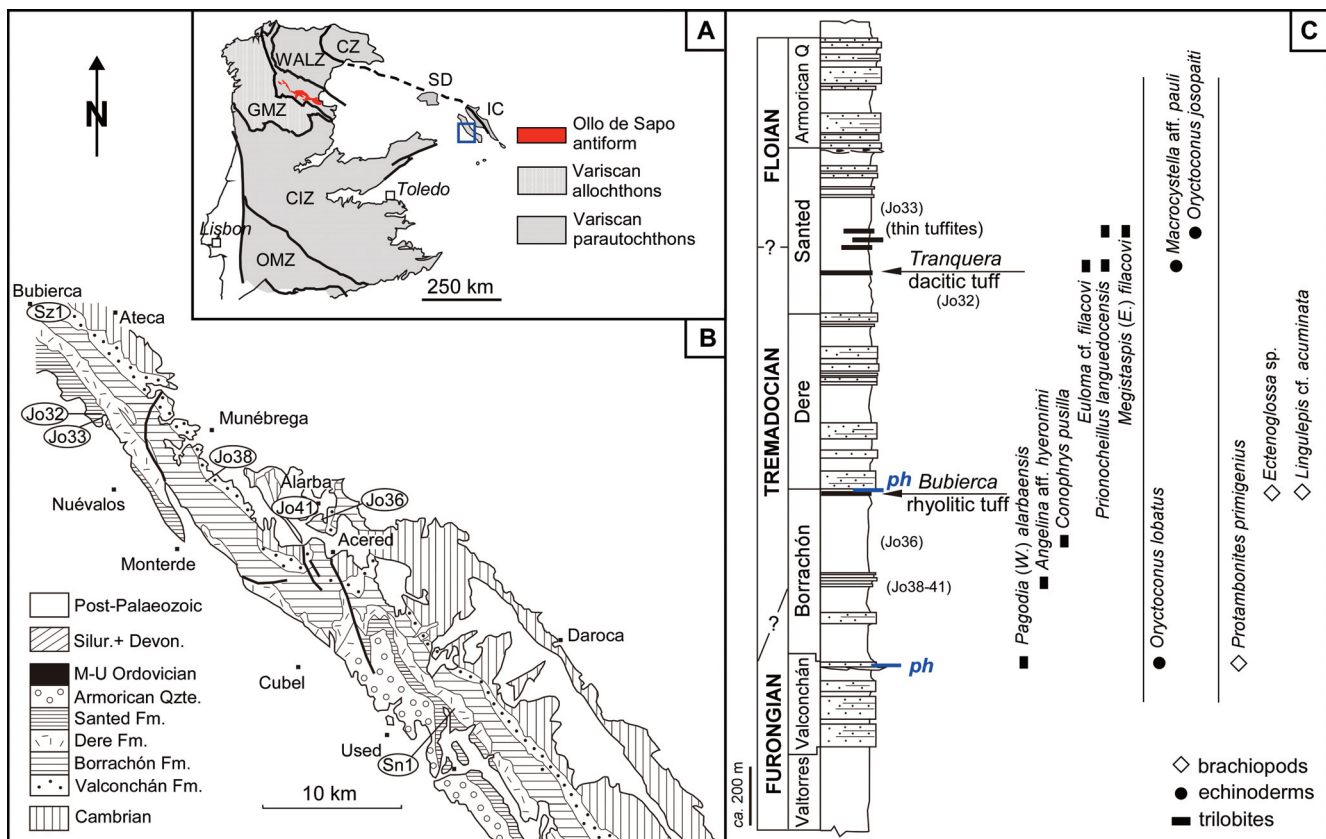
### Introduction

In the Iberian Massif, the Ollo de Sapo (‘toad eye’) magmatism has long been recognized as an enigmatic Furongian–Early Ordovician (495–470 Ma) assemblage of felsic (sub-)volcanic and plutonic rocks. The main exposures of this event crop out along the core of a 600 km long antiform fringing the northeastern edge of the Central Iberian Zone (Fig. 1A). Penecontemporaneous felsic byproducts locally occur in the neighbouring Ossa-Morena Zone and the Armorican and Occitan domains, reflecting the onset of a large igneous province (LIP) of ca 200 000 km<sup>3</sup> (García-Arias et al. 2018). The Ollo de Sapo magmatic event is also contemporaneous with the development of the so-called Toledanian Phase and gap, which place upper Tremadocian–Floian rocks overlapping with the inherited palaeorelief of tilted Ediacaran–Cambrian blocks. Their unconformable contact, ranging from paraconformities to angular discordances, involves a stratigraphic gap of ca 22 m.y. This unconformity can be correlated with the ‘Furongian gap’ of the Ossa-Morena Zone and the Anti-Atlas of Morocco, and the Norman gap of the Central and North Armorican domains (Álvaro et al. 2021). The Toledanian Phase, however, is absent in the most proximal sector of the Iberian margin, i.e. the West Asturian-Leonese and Cantabrian zones, and their lateral prolongations into the Sierra de la Demanda and Iberian Chains (Fig. 1A, B). In the latter, a continuous and conformable Furongian–Lower Ordovician transition has traditionally been documented, unaffected by the Toledanian uplift and erosion. The Furongian–Tremadocian trilobite, echinoderm and brachiopod assemblages of the western Iberian Chain are updated and summarized in this short communication.

### Results and discussion

The Iberian Chains, located in the NE of the Iberian Peninsula (Fig. 1A, B), represent a lateral prolongation of the West Asturian-Leonese and Cantabrian zones. There, the Furongian–Lower Ordovician strata consist of successive alternations of shale- and sandstone-dominated sedimentary units, and comprise, from bottom to top, the Valtorres Formation (Acón Group), the Valconchán, Borrachón, Dere and Santed formations (Ateca Group, broadly coinciding with the ‘Iberian Series’ of Schmitz 1971 and Josopait 1972), and the Armorican Quartzite Formation (Fig. 1C).

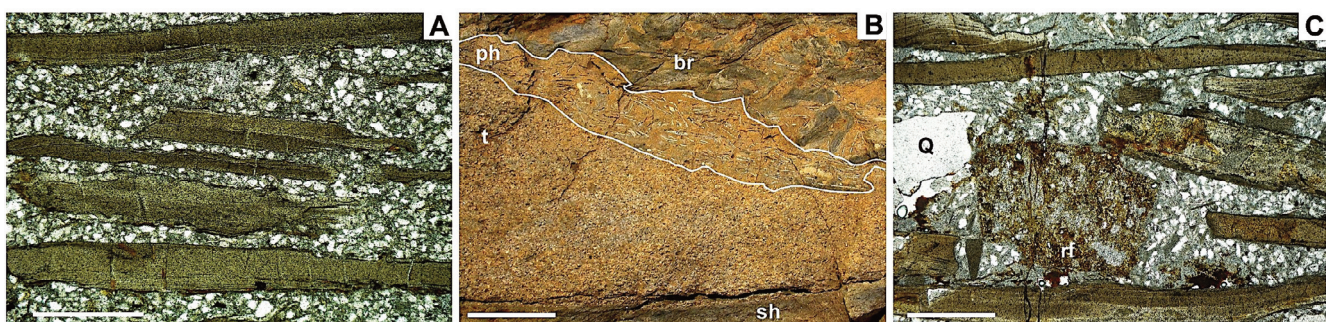
The Valtorres Formation, 200–350 m thick, consists of monotonous green shales, locally punctuated by sandstone interbeds and silica concretions. Towards its top, there is a gradual increase in the thickness and abundance of sandstone interbeds.



**Fig. 1.** **A** – pre-Variscan exposures of the Iberian Massif. Abbreviations: CIZ – Central Iberian Zone, CZ – Cantabrian Zone, GMZ – Galicia Trás-os-Montes Zone, IC – Iberian Chains, OMZ – Ossa-Morena Zone, SD – Sierra de la Demanda, and WALZ – West Asturian-Leonese Zone; **B** – fossiliferous outcrops of the western Iberian Chain (boxed in Fig. 1A): Jo – Josopait (1972), Sn – Scheuplein (1970), and Sz – Schmitz (1971); **C** – Furongian–Lower Ordovician stratigraphic framework of the Iberian Chains with stratigraphic ranges of reported shelly fossils; *ph* – shelly phosphorites.

The overlying Valconchán Formation, 30–300 m thick, consists of thin- to thick-bedded sandstones and quartzites with shale and conglomerate interbeds. Trilobites of the Valtorres Formation and the lowermost part of the Valconchán Formation (Josopait 1972; Wolf 1980; Shergold and Sdzuy 1991) form a Furongian association, which includes agnostids (*Pseudagnostus* sp.) and trilobites, such as *Aphelaspis* aff. *Aphelaspis* *rara*, *Elegantaspis* cf. *beta*, *Parachangshania*? sp., *Punctaspis*? *schmitzi*, and *Valtorresia* *volkeri* (Shergold and Sdzuy 1991), associated with the brachiopods *Billingsella* *jalonensis* and *B. perarea* (Havlíček and Josopait 1972). According to Shergold and Sdzuy (1991), this fauna may be considered to be approximately equivalent to the *Parabolina*

*spinulosa* Zone of Baltica. In contrast, the upper part of the Valconchán Formation has yielded the trilobite *Pagodia* (*Wittekindia*) *alarbaensis* (Shergold and Sdzuy 1991), the pelmatozoan holdfast *Oryctoconus* *lobatus* (Álvarez and Colchen 2002; Zamora et al. 2009), and the brachiopod *Protambonites* *primigenius* (Havlíček and Josopait 1972). Based on the occurrence of their respective genera and subgenera in Afghanistan, Turkey and the Cantabrian Zone, this endemic assemblage has traditionally marked the Furongian–Tremadocian transition in the Iberian Chains. Near Valconchán village, the topmost part of the Valconchán Formation contains a condensation phosphorite level, up to 10 cm thick, composed of disarticulated and broken linguliformean brachiopods (Fig. 2A),



**Fig. 2.** Lower Ordovician phosphorites from the western Iberian Chain. **A** – thin-section photomicrograph of linguliformean brachiopods forming the condensation phosphoritic level of the Valconchán Formation, near Valconchán; **B** – rhyolitic tuff (t) embedded in the shales (sh) of the Borrachón Formation, overlain by a phosphoritic shelly (ph) level and breccia (br) rich in clasts derived from three underlying facies, near Bubierca; **C** – thin-section photomicrograph with linguliformean brachiopods associated with rhyolitic fragments (rf) and engulfed quartz (Q) clasts. Scales = 1 mm (A, C) and 4 cm (B).

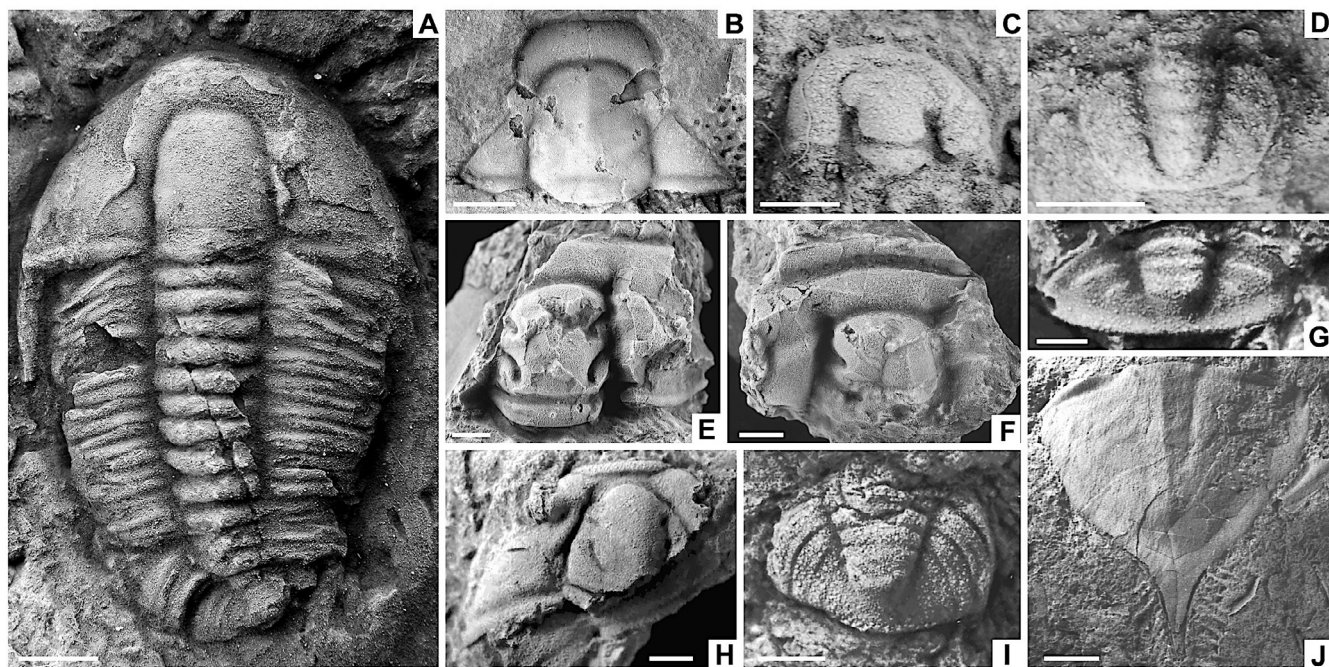
and separating two shallowing-upward shoaling cycles, up to 2.4 m thick.

The overlying Borrachón Formation, 320–900 m thick, comprises mainly green shales with subsidiary sandstone interbeds, which have yielded trilobites (e.g., *Angelina* aff. *hyeronimi*, *Asaphellus* sp., *Conophrys pusilla*, and *Dikelocephalina* sp.), acritarchs and ichnofossils (*Cruziana simplicata*, *C. furcifera* and *C. rugosa*) (Schmitz 1971; Josopait 1972; Kolb and Wolf 1979; Wolf 1980). The occurrence of age-diagnostic acritarchs allows its assignment to the Tremadocian. The presence of the olenid *Angelina* aff. *hyeronimi* (reported by Hammann et al. 1982, 24; and illustrated in Fig. 3A, B) allows taxonomic and biogeographic links with *A. hyeronimi*, a key species crossing the Furongian–Tremadocian boundary interval in Argentina (where the stratigraphic range comprises the *Cordylodus intermedius*, *C. lindstromi* and *C. angulatus* conodont-based zones; Tortello 2003) and the basal Tremadocian of Mexico (Robison and Pantoja-Alor 1968), which would suggest that the Furongian–Tremadocian boundary should be tentatively located within the lowermost part of the Borrachón Formation. *C. pusilla* (Fig. 3C, D) allows correlation with the homonymous Tremadocian biozone from the southern Montagne Noire (Vizcaíno and Álvaro 2003). A rhyolitic tuff located in the vicinity of Bubierca (Figs 1B, 2B, C) has yielded broken linguliformean brachiopods, such as *Ectenoglossa* sp. and *Lingulepis* cf. *acuminata* (Wolf 1980).

The overlying sandstones and quartzites of the Dere Formation are 420–850 m thick and contain ichnofossils (*Cruziana simplicata* and *C. rugosa*), poorly preserved linguliformean brachiopods, trilobites (e.g., *Asaphellus* sp.)

and molluscs, and acritarchs (Scheuplein 1970; Schmitz 1971; Havlíček and Josopait 1972; Wolf 1980).

The shale-dominated Santed Formation, 200–950 m thick, has yielded ichnofossils, trilobites, brachiopods, echinoderms and acritarchs (Schmitz 1971; Josopait 1972; Wolf 1980; Zamora et al. 2009). The Tremadocian – ‘Arenig’ (Floian) boundary interval is currently placed within this formation. Josopait (1972), Wolf (1980) and Hammann et al. (1982) reported the youngest Tremadocian and oldest ‘Arenig’ trilobites in the vicinity of the Tranquera dam (Fig. 1B). The uppermost Tremadocian fossil assemblage occurs within a dacitic tuffitic bed (Josopait’s Fp 32; Álvaro et al. 2008), which has yielded, among others, the trilobites *Euloma* cf. *filacovi* and *Prionocheilus* cf. *languedocensis*, whereas the lowermost ‘Arenig’ assemblage (Josopait’s Fp 33) contains *Prionocheilus* cf. *languedocensis* and *Megistaspis* (*Ekeraspis*) cf. *filacovi* (Fig. 3E–J). Wolf (1980) correlated both levels biostratigraphically with the ‘faunizones’ E and F of the southern Montagne Noire, which were re-evaluated by Vizcaíno and Álvaro (2003) as two different fossil assemblages (not yet found in the same section of the Montagne Noire) belonging to the *Euloma filacovi* Zone, which would include the Tremadocian–Floian boundary interval. Finally, the overlying Armorican Quartzite Formation, 450–650 m thick, consists of two thick-bedded quartzite and sandstone members separated by a shale-dominated middle member. The formation has yielded rare brachiopods, conularids, bivalves and trilobites (Babin and Hammann 2001), and ichnofossils (*Cruziana rugosa* and *C. imbricata*). A recent U–Pb dating of K-bentonites embedded in the Armorican Quartzite (upper Barrios Formation) of the Cantabrian



**Fig. 3.** Representative Early Ordovician trilobites (reported by Hammann et al. 1982, but not previously illustrated) from the western Iberian Chain; all fossils are housed in the Palaeontological Museum of the University of Zaragoza. **A, B** – complete skeleton and cranium of *Angelina* aff. *hyeronimi* from Josopait’s (1972) localities Jo38 and Jo41, south of Munébrega and Alarba villages; **C, D** – cranium and pygidium of *Conophrys pusilla* from Josopait’s locality Jo36, south of Alarba village; **E–G** – two cranidia and one pygidium of *Euloma* cf. *filacovi* from Josopait’s (1972) locality Fp32 (dacitic tuff) at La Tranquera dam; **H, I** – cranium and pygidium of *Prionocheilus* cf. *languedocensis* from Josopait’s (1972) localities Fp32 and Fp33 at La Tranquera dam; **J** – pygidium of *Megistaspis* (*Ekeraspis*) cf. *filacovi* from Josopait’s (1972) locality Fp33 at La Tranquera dam. Scales = 2 mm (E, F, H, I) and 1 mm (A–D, G, J).

Zone, northern Spain, has yielded an age of  $477.47 \pm 0.93$  Ma (Gutiérrez-Alonso et al. 2016), a result extremely close to the currently accepted interpolated age for the Tremadocian–Floian boundary GSSP at  $478.6 \pm 1.7$  Ma.

## Conclusions

The western Iberian Chain of NE Spain comprises a thick (3600–4500 m) and conformable Lower Ordovician sedimentary succession, exclusively composed of siliciclastic strata and deposited in mid-latitude (temperate) waters fringing NW Gondwana. The Furongian–Tremadocian boundary interval lies within the Borrachón Formation, where the trilobite *Angelina* aff. *hyeronimi* supports a direct correlation with the Argentinian margin of Gondwana and Oaxaca. The Tremadocian–Floian boundary interval is placed within the Santed Formation, where the trilobites *Euloma* cf. *filacovi*, *Prionocheilus* cf. *languedocensis* and *Megistaspis* (*Ekeraspis*) cf. *filacovi* allow a direct correlation with the southern Montagne Noire, France. Two phosphoritic interbeds rich in linguliformean brachiopods punctuate the Valconchán and Borrachón formations, and represent event beds related to condensation processes and sedimentation of explosive ignimbritic tuffs, respectively.

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