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The Ordovician–Silurian boundary beds in the El Pintado section (Sierra Morena de Sevilla Global UNESCO Geopark, SW Spain)

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Abstract. The El Pintado 1 section of the Ossa-Morena Zone (Valle syncline, SW Spain) includes a rather continuous stratigraphic succession ranging from the Upper Ordovician to the Devonian, including remarkably fossiliferous black graptolitic shales that begin their sedimentation in the basal Silurian *Akidograptus ascensus* graptolite Biozone. The investigation for the location of the Ordovician–Silurian boundary in previous beds has produced negative results, due to the existence of a probable basal gap equivalent to the lower part of the aforementioned biozone, and the absence of stratigraphically relevant fossils, such as graptolites or conodonts, that could provide a high-resolution biostratigraphy to the Hirnantian succession. Nonetheless, some interesting records of rare shelly fossils in the Valle Shale (Hirnantian) are presented, and the Rhuddanian graptolite biozonation in the lower 38 m of the Lower Graptolite Shale (Rhuddanian to Ludfordian) is discussed.

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INTRODUCTION

The Ordovician to Devonian sedimentary rocks and fossils of the Valle syncline, located in the Ossa-Morena Zone of the southwest of the Iberian Massif (Fig. 1), have been the subject of various studies since their discovery in the mid-20th century (Hernández Sampelayo, 1932; Carbajal y Acuña, 1944; Simon, 1951). These studies gained prominence following the investigations of Robardet (1976), who highlighted its sedimentary and faunal uniqueness compared to the remaining areas of the Variscan massif, establishing it as a distinct palaeogeographic area (Robardet and Gutiérrez-Marco, 1990, 2004). The environmental and biogeographic differences are particularly notable in the Silurian and Lower Devonian, represented by an outstanding, almost complete and continuous succession over 150 m thick. Practically all the graptolite biozones of this interval were recorded, making it an

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informal international reference for graptolite biostratigraphy (Gutiérrez-Marco *et al*., 2021), and one of the valued elements of Spanish geological heritage (Gutiérrez-Marco *et al.*, 2008). This is also located within the Sierra Morena de Sevilla Global UNESCO Geopark (Gutiérrez-Marco, 2022). Recently, the International Subcommission on Silurian Stratigraphy approved the replacement GSSP for the base of the Telychian Stage in this renowned Silurian section (Gutiérrez-Marco *et al.*, in press, and references therein).

Although the Silurian–Devonian graptolites have been the subject of several detailed studies (Gutiérrez-Marco *et al*., 1996; Lenz *et al*., 1996; Piçarra *et al*., 1998; Loydell *et al*., 2015), the Rhuddanian assemblages near the Ordovician–Silurian boundary have only been mentioned in general articles by Jaeger and Robardet (1979, with three species illustrated) and Robardet *et al.* (1998). Different aspects of this boundary and the earliest Silurian graptolites of the Valle syncline have also been mentioned by Štorch (1996) and Piçarra *et al.* (1997).

Aside from these works, the present note is the first to focus on the study of the Ordovician–Silurian transition with reference to the scarce Hirnantian fossils and the Rhuddanian graptolite record in the El Pintado 1 section, the most complete of all the outcrops known in the core of the Valle syncline.

GEOLOGICAL SETTING

The Valle syncline is situated in the eastern part of the Zafra–Alanís Domain of the Ossa-Morena Zone (Fig. 1). The most complete sections around the Ordovician–Silurian boundary are located on both flanks of the fold, on the northern and southern shores of the El Pintado reservoir, approximately 14 km west of Cazalla de la Sierra (province of Seville, north-central Andalusia).

The terminal Ordovician succession is represented by the Valle Shale Formation (Hirnantian, probably Hi2), whose base seals a discontinuity related to the sea-level fall caused by the Late Ordovician Gondwanan glaciation. This facilitated the emersion and karstification of the top of the Pelmatozoan Limestone, previously deposited during the global Boda warming event (Katian 3–4), and whose palaeontological record consists of diverse shelly faunas and conodonts of the *A. ordovicicus* Biozone (Sarmiento *et al*., 2008).

The Hirnantian rocks (see Fig. 2) consist of a thick sequence (around 150 m) of massive dark mudstones and siltstones with very rare sandy intercalations (some contorted), whose base fills the voids created by the partial erosion and palaeokarstification of the underlying limestones. Additionally, the unit includes two beds of particular interest: the first is located about 30 m above the base and consists of thin layers of diamictites formed by angular clasts of weathered volcanic rocks and some rounded sandstone pebbles up to 3.5 cm in diameter (Fig. 2*i*–*o*). The second level represents a 1-m thick interval, ending 0.8 m below the top of the formation, which includes thin lenses (2–19 cm thick) of ochre-coloured Mn-rich carbonates. The first of these levels closely resembles some glaciomarine diamictites widely distributed around the high-Gondwanan palaeolatitudes (*e.g.*, Chatalov, 2017), while the second could be related to similar manganiferous beds occasionally formed by starved sedimentation during relatively high sea-levels just after the Ordovician glaciation (*e.g*., Ghienne *et al.*, 2000).

With an apparently continuous and conformable contact, above the Valle Shale lies the formation known as the Lower Graptolite Shale (early Rhuddanian to late Ludfordian in age). This is a highly fossiliferous succession dominated by finely-laminated black shales, which include some levels of hard siliceous slates in its lower half and even a few thin sandstone intercalations near its base. In its upper half, there are often quite laterally continuous

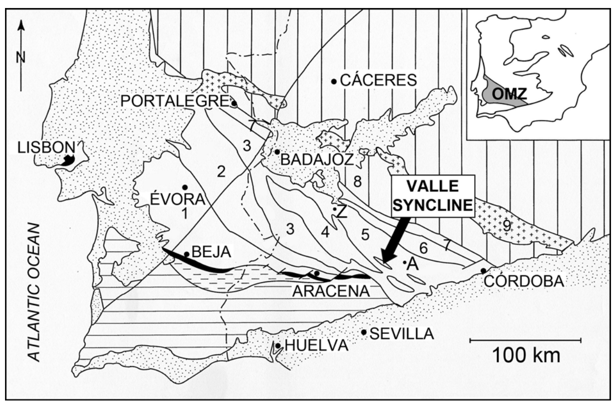

Fig. 1. Location map of the Valle syncline and El Pintado section in the southern part of the Iberian Peninsula, showing the Ossa-Morena Zone, the southern Central Iberian Zone (vertical hatching), the South Portuguese Zone (horizontal hatching), the Beja-Acebuches ophiolites (in black), the Pulo-do-Lobo oceanic Unit (dashes) and the post-Palaeozoic deposits (dotted). Numbers correspond to different structural domains detailed in fig. 1 of Robardet and Gutiérrez-Marco (1984): the Valle syncline is located in the Zafra (Z)–Alanís (A) Domain (5) of the Ossa-Morena Zone (OMZ and enhanced in grey in the inset map, referring to the outline of the Iberian Massif).

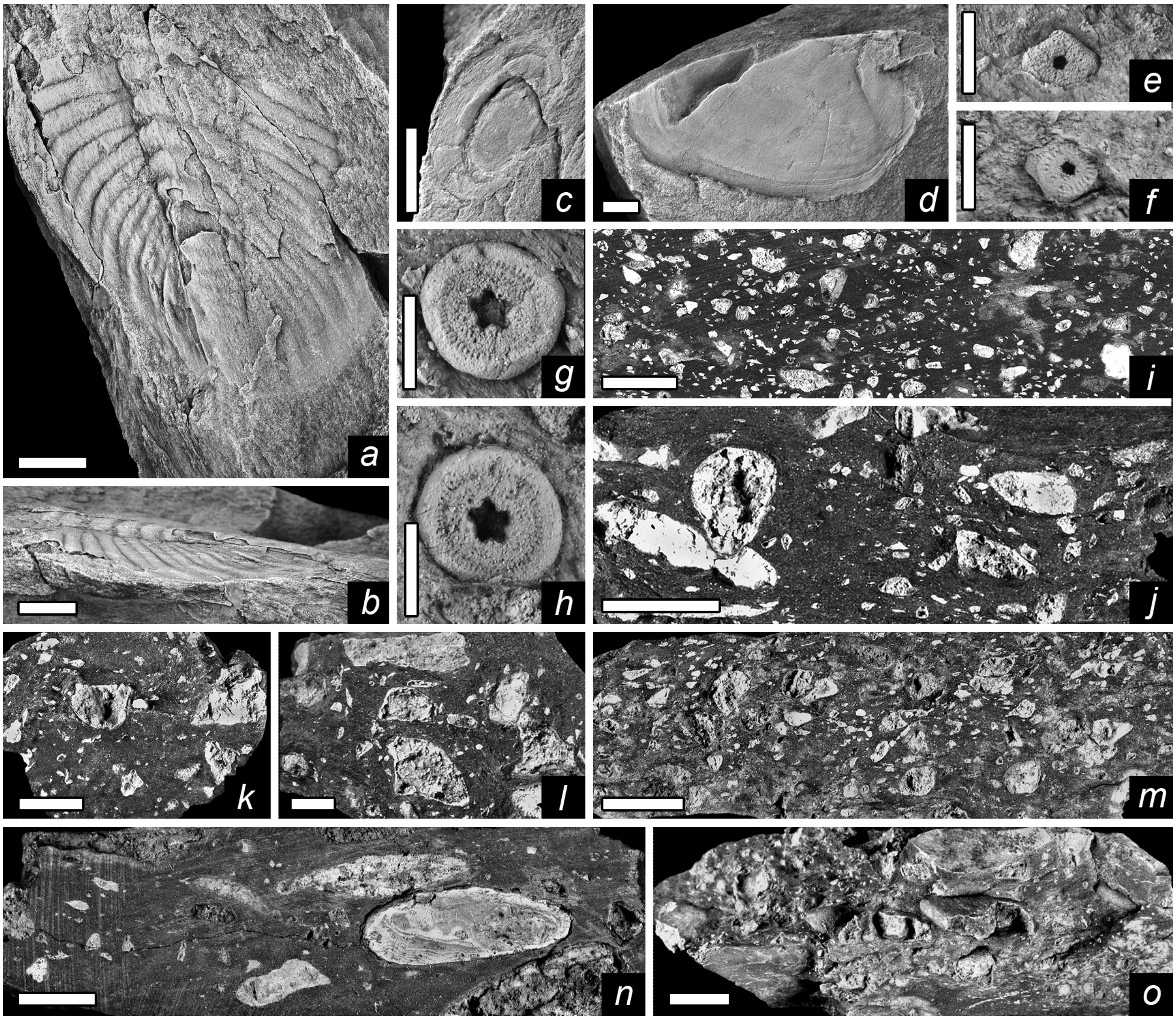

Fig. 2. Hirnantian fossils and rocks from the Valle Shale. *a, b*) *Mucronaspis* cf. *mucronata* (Brongniart), pygidium in dorsal (*a*) and left-lateral (*b*) views, MGM-8590O; *c*) indeterminable ?plectonotine gastropod, right side of a flattened shell, MGM-8591O; *d*) right valve of an indeterminable ?modiolopsid bivalve, MGM-8592O; *e*–*h*) latex casts of some pelmatozoan columnals, including *Pentagonopentagonalis* (col.) sp. (*e*) and *Pentagonocyclicus* (col.) sp. (*g, h*), MGM-8593O-1, MGM-8594O-1; MGM-8593O-2 and MGM-8594O-2, respectively; *i*–*o*) cross-sections of the diamictic horizons showing angular clasts of volcanic rocks (mostly weathered) and small rounded impure sandstone pebbles, MGM-8595O to MGM-8601O. Specimens *a* to *h* whitened with MgO. Scale bars = 5 mm (*a, b, i*–*k, m*–*o*) and 2 mm (*c*–*h, l*).

alternating beds formed by black shales and thin horizons of black cherts.

Figure 3 shows the palaeontological content of the described units around the Ordovician–Silurian boundary, as described below.

METHODOLOGY

The sections on both shores of the El Pintado reservoir were re-sampled repeatedly, the latest campaign led to the discovery of new Rhuddanian graptolite horizons in the Lower Graptolite Shale not mentioned in previous works (Fig. 3). The palaeontological material from the Valle Shale was partly studied using latex replicas (Fig. 2*e*–*h*) and whitened with magnesium oxide vapours before photography.

All figured specimens are housed in the palaeontological collection of the Museo Geominero (IGME-CSIC), Madrid (registration prefix MGM).

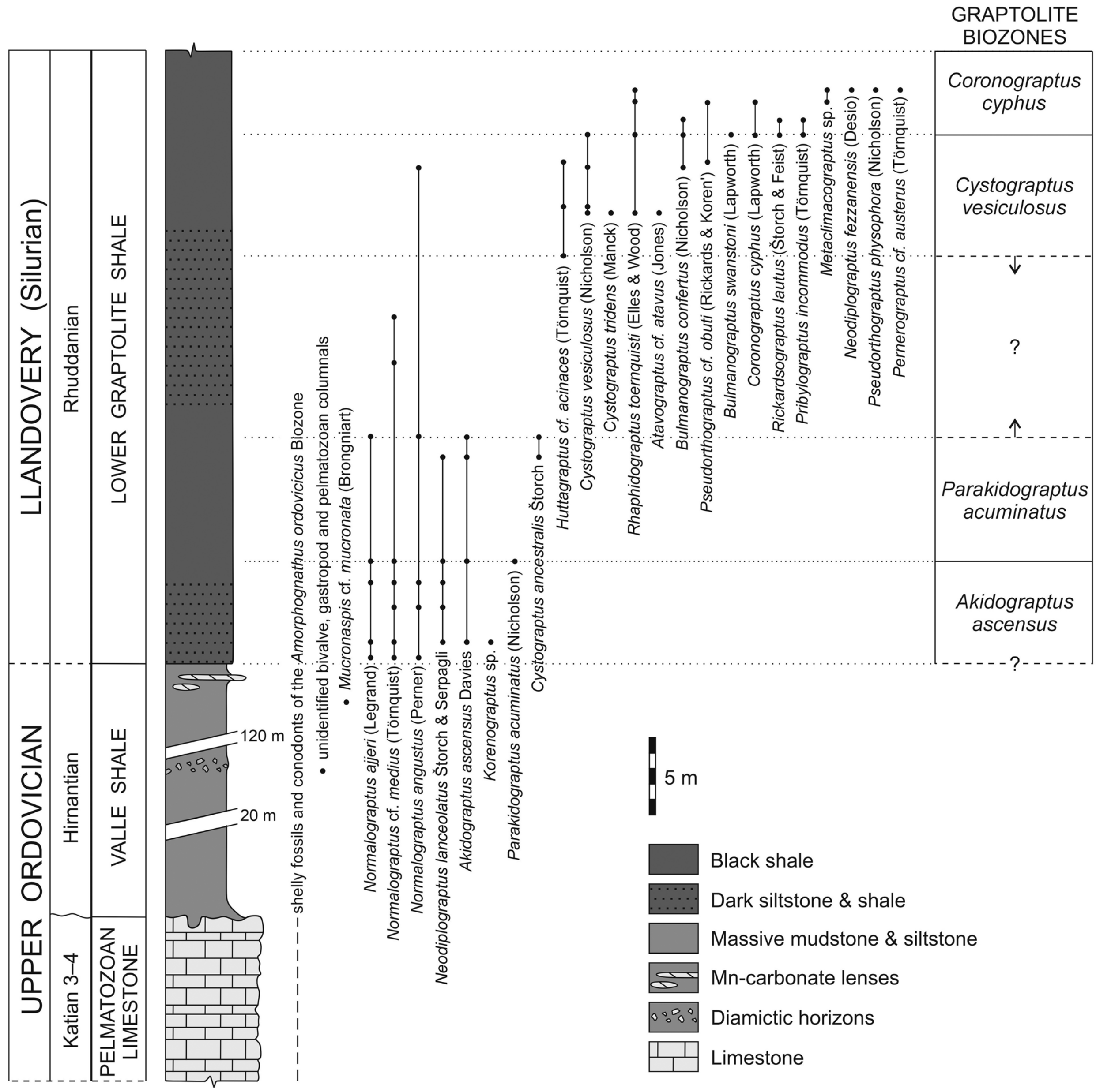

Fig. 3. The Ordovician–Silurian boundary interval of the El Pintado 1 section, showing the stratigraphic ranges of identified fossils.

RESULTS

The sparse Hirnantian palaeontological record is limited to a few shelly fossils of no biostratigraphic value (Fig. 2*c*–*h*), except for the discovery of a single specimen of the trilobite *Mucronaspis* cf. *mucronata* (Brongniart). This is represented by the internal mould of a fragmentary isolated pygidium (Fig. 2*a*–*b*), which, despite its poor preservation, agrees with this cosmopolitan dalmanitid species based on the arrangement and number of pleural and interpleural furrows, as well as the number of axial rings. However, due to the absence of the pygidial spine and cephalic characters, a more complete identification is not possible. Beside being distributed almost globally in the Hirnantian, often part of the Hirnantia Fauna, this species has also been recorded in various localities in the Iberian Peninsula (Colmenar *et al.*, 2019, and references therein). Another interesting aspect lies in the record of well-preserved columnal plates of pelmatozoans, which do not appear to be reworked from older beds, as they correspond to columnal morphotypes unknown among the rather uniform Katian assemblages of southwestern Europe and North Africa (Botquelen *et al*., 2006, and references therein). The most notable morphotype (Fig. 2*g–h*) also differs from *Pentagonocyclicus* (col.) sp. described in the Hirnantian of Portugal (Colmenar *et al*., 2019) due to the presence of a well-developed epifacet, a smooth areola, and a narrow crenularium. On the other hand, the micropalaeontological samples taken from the Mn-carbonate horizons close to the top of the unit yielded negative results.

The early Silurian fossils (see Fig. 4) are represented in the Lower Graptolite Shale by at least 23 species of graptolites, which allow the assignment of the basal 38 m of this formation in the El Pintado 1 section to the Rhuddanian (Fig. 3). All the biozones corresponding to this lowest stage of the Llandovery Series have been characterized in these levels, with the decision made not to combine the ranges of the *Akidograptus ascensus* and *Parakidograptus acuminatus* in a single biozone, following current criteria for peri-Gondwanan Europe (Štorch, 2023). From the previous data (Jaeger and Robardet, 1979; Robardet *et al*., 1998) and those obtained here, it is inferred that the lower part of the *A. ascensus* Biozone is probably missing, due on one hand to the absence of many of the graptolite species commonly recorded in that position, some of which extend their range from the latest Hirnantian, and on the other hand to the presence of *Neodiplograptus lanceolatus* (Fig. 4*e–f*) in the lowermost part of the section, which is absent in the lower part of the *A. ascensus* Biozone or combined *A. ascensus–P. acuminatus* Biozone in peri-Gondwana (Štorch *et al*., 2019b; Štorch, 2023).

The base of the *Parakidograptus acuminatus* Biozone is marked by the occurrence of this zonal index species (Fig. 4*a–c*), but the upper boundary with the *Cystograptus vesiculosus* Biozone consists of an interval of 12 m lacking any species of sufficient stratigraphic significance to be assigned to one or the other biozone. Nevertheless, the graptolite record in the *C. vesiculosus* Biozone exhibits almost entirely the species, such as *Huttagraptus* cf. *acinaces*, *Rhaphidograptus toernquisti*, *Bulmanograptus confertus*, and *Cystograptus tridens*, that begin their stratigraphical range in the upper part of the biozone, so the base of the same could eventually be located well down in the almost barren interval.

Finally, the *Coronograptus cyphus* Biozone is characterized by the record of the nominal species and a typical assemblage, although the diversity in the studied section is comparatively lower than that recorded in another section located immediately to the east of this (Loydell *et al*., 2015, no. 5 in their fig. 4), where Aeronian graptolite biostratigraphy is being investigated at high resolution (Štorch *et al*., 2019a).

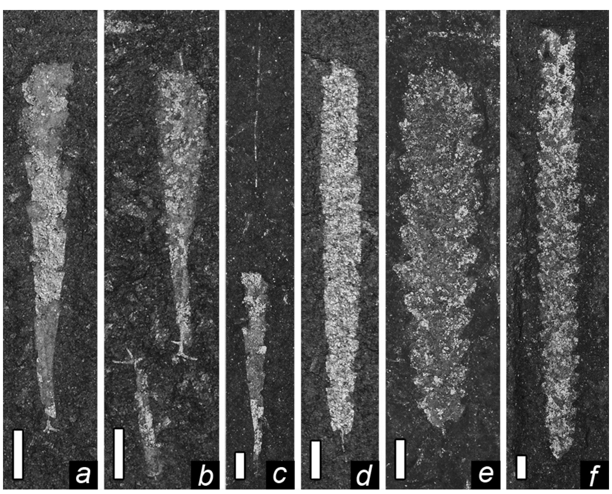

Fig. 4. Selected graptolites from the *Akidograptus ascensus* Biozone (early Rhuddanian), El Pintado 1 section. *a–c*) *Akidograptus ascensus* Davies, MGM-219S, MGM-220S and MGM-221S, respectively; *d*) *Normalograptus angustus* (Perner), MGM-222S; *f, g*) *Neodiplograptus lanceolatus* Štorch and Serpagli, MGM-223S and MGM-224S, respectively. Scale bars = 1 mm.

CONCLUSION

Although the Lower Palaeozoic succession represented in the Valle syncline (Zafra–Alanís Domain of the Ossa-Morena Zone) is considered one of the most complete in the southern Iberian Peninsula and has been listed among the Spanish global geosites, the detailed stratigraphical study of the formations around the Ordovician–Silurian boundary has not been able to demonstrate the existence of a perfect continuity of deposition between the two systems. That is because, on the one hand, the Valle Shale Formation, representative of the terminal Ordovician (Hirnantian, probably Hi2), has not yielded any graptolite or conodont data capable of providing a high-resolution biostratigraphic potential; on the other hand, because in the most famous and renowned section of El Pintado 1, the overlying Lower Graptolite Shale evidences a probable basal gap in highly condensed facies, which would correspond at least to the lower part of the *Akidograptus ascensus* graptolite Biozone, which is also lacking in any other section in the north of Seville as well as in many other Ordovician–Silurian boundary sections of the peri-Gondwanan Europe (Štorch, 1996, 2023; Štorch *et al.*, 2019b).

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