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The Silurian Section of the Valle Syncline (Sierra Norte de Sevilla UNESCO Global Geopark, Spain) as an International Standard for Graptolite Biostratigraphy

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Abstract

The Paleozoic succession of the Sierra Norte de Sevilla UNESCO Global Geopark (Ossa Morena Zone of the Iberian Massif, SW Spain) includes a nearly complete Silurian succession, ca. 150 m thick, deposited in an outer shelf setting. In the core part of the Valle syncline, the El Pintado-1 section exhibits a condensed graptolite-rich Silurian black-shale facies ranging from the base of the Rhuddanian to the upper Ludfordian. Most of the standard graptolite biozones of the Silurian System have been identified in the section. The preliminary record of Llandovery graptolites in the lower part of the succession comprises more than 200 species, 19 of them new. The El Pintado-1 geosite is of enormous value for the world's palaeontological heritage, reinforced by the future placement here of the GSSP for the base of the Telychian Stage. The fragility of the site and its scientific importance mean that the section is not open to visitors to the Geopark, and its difficult accessibility also adds some protection, favoring its conservation beyond the regional legislative framework.

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Introduction

The Silurian succession in the northern part of Seville Province is the most continuous and most fossiliferous in the Paleozoic of the Iberian Peninsula. It is represented by several important outcrops located in the Valle and Cerrón del Hornillo synclines within the Sierra Norte de Sevilla Geopark. The succession, with a total thickness of 120 to 150 m, is moderately condensed and is the same in both synclines but is better exposed and less tectonized in the Valle syncline.

The Silurian rocks lie conformably above Hirnantian (Upper Ordovician) siltstones and shales (Valle Formation), and can be divided into three successive units (Jaeger & Robardet 1979) which are, in ascending order: a) the ‘Lower Graptolitic Shales’ (up to 125 m thick) that mostly comprise sapropelitic black shales with some black siliceous chert levels; a few metres of silty black shales occur in the lowermost part and a darkgrey limestone horizon (‘*Cardiola* Limestone’: 0.50 to 0.80 m thick) occurs in the uppermost part; b) the so-called ‘*Scyphocrinites* Limestone’, which consists of 10 to 15 m of alternating black limestones and calcareous shales; and c) the ‘Upper Graptolitic Shales’ (20 m) of Lochkovian (Early Devonian age) which are rather similar to those of the lower unit but include large limestone nodules and lenses.

The whole Silurian succession is richly fossiliferous, especially the graptolitic black shales that allowed identification of 25 distinct biozones of the international standard graptolite biozonation, as well as identification of several global biotic crises and recoveries and associated oceanographic events. Silurian graptolites from the Valle syncline were first mentioned by Hernández Sampelayo (1932), some species of which were figured by Carvajal y Acuña (1944). Subsequently, Simon (1951) recognized six successive graptolite assemblages within the Llandovery–Wenlock interval. However, modern knowledge of the entire Silurian–Lower Devonian succession and graptolite faunas of the main area around the El Pintado reservoir starts with the pa-

per of Jaeger & Robardet (1979), who identified 86 species of graptolites and 21 biozones ranging from the basal Rhuddanian to the upper Lochkovian. All subsequent studies providing further biostratigraphical and palaeontological detail refer to this seminal contribution.

Location

The Valle syncline is situated in the west-central part of the Sierra Norte de Sevilla Geopark (Fig. 1A) and its core is formed by Siluro-Devonian rocks, partly submerged in the El Pintado reservoir. This is located approximately 13 km WNW of the town of Cazalla de la Sierra. The most important Silurian sections are on the northern shore of the reservoir and along gulleys leading into it (Fig. 1B). In particular, the section named ‘SW. de la ferme du Valle’ by Jaeger & Robardet (1979) and ‘section 1’ by Loydell *et al.* (2015), was shown as continuous from the Ordovician through to the upper Silurian and for much of its thickness to be lithologically monotonous black shales with rich graptolite faunas (Fig. 1C). Besides the faunal lists indicating the high graptolite diversity provided by Jaeger & Robardet (1979) and Robardet *et al.* (1998: ‘stop 1’), the potential of this section for high resolution biostratigraphy is demonstrated by the studies of Loydell *et al.* (2015) and Štorch *et al.* (2019), which resulted in the proposal of the section as a replacement GSSP for the base of the Telychian Stage (Llandovery Series). The El Pintado-1 section is the only candidate for this replacement GSSP, to be approved in 2021 by the International Subcommittee on Silurian Stratigraphy (ICS-IUGS).

Significance of the El Pintado Silurian Geosite

Among the various Silurian sections documented around the El Pintado reservoir, the El Pintado-1 section is the most complete. It is a largely undeformed, graptolitic section ranging from the basal Rhuddanian to close to the Ludlow/Přídolí boundary, with a stratigraphical thickness exceeding 120 m. Previous records of graptolites (Jaeger & Robardet 1979) comprised 85 species (49 from

the Llandovery, 24 from the Wenlock and 12 from Ludlow strata). But subsequent studies on Llandovery graptolites (Robardet *et al.* 1998; Loydell *et al.* 2015; Štorch *et al.* 2019) have significantly increased the number from 49 to more than 200 species, in only the lower 64 m of the Silurian succession.

The four standard graptolite biozones of the Rhuddanian are recognized; the Aeronian is represented by five graptolite biozones, showing a gap in sedimentation which spans the upper *triangulatus* – lower *leptotheca* biozones and probably another, shorter gap in sedimentation in the *sedgwickii* Biozone. From the Telychian only the graptolites of its basal part have been studied (*guerichi* and lower *turriculatus* biozones). The remaining Telychian strata, as well as the Wenlock, Ludlow and Přídolí parts of the section have not yet been studied in detail. Modern revisions of the graptolites from these latest series have been investigated elsewhere in the Valle syncline (Gutiérrez-Marco *et al.* 1996; Piçarra *et al.* 1998), and the El Pintado-1 section also has great potential to provide new data in this regard.

Graptolite biozones recognized in the Silurian succession are well-correlatable with coeval strata elsewhere in peri-Gondwanan Europe, Avalonia and Baltica. The taxonomic composition of the assemblages is typical of an outer shelf setting. Graptolite diversity declines considerably in specific parts of the succession in coincidence with global events; research on this is at an early stage but it has been possible to characterize the ‘*utilis* Event’ in the upper part of the *guerichi* Biozone and the ‘*lundgreni* Event’ in the upper part of the homonymous Biozone. The $\delta^{13}\text{C}_{\text{org}}$ record through the upper Aeronian and lower Telychian at El Pintado reveals no major excursions, and the records through the *guerichi* Biozone of El Pintado and Arctic Canada are remarkably similar (Loydell *et al.* 2015).

Despite the fact that the El Pintado-1 section has not been studied in its entirety, its outstand-

ing graptolite record indicates the existence of a complete and continuous sedimentary succession through the upper Aeronian and lower Telychian. The First Appearance Datum (FAD) of the distinctive and easily recognizable species *Spirograptus guerichi* (Fig. 1D) has been selected by the International Subcommittee on Silurian Stratigraphy as the delimiting criterion for the base of the Telychian Stage (Llandovery Series). Having received approval from the Subcommittee that the El Pintado-1 section is the best documented section in the world to define this boundary, the IUGS will formally approve the unanimous candidacy of the Andalusian section to host the corresponding GSSP (*Global Stratotype Section and Point*), which would represent, together with another Cretaceous site in progress, the sixth/seventh Spanish GSSP (three of them located in geoparks), the eighth/ninth of the Iberian Peninsula, and the oldest of them all.

Geotourism and Geotrail Potential

The Ordovician to Devonian sedimentary rocks and fossils of the Valle syncline are one of the aspects designated as of geological interest in the geopark, which is not open to visitors because its interest is exclusively scientific and there is a risk of palaeontological plunder. The outstanding Silurian section cited above is within the territory of the El Pintado reservoir, which belongs to the Guadalquivir River Hydrographic Confederation of the Spanish Ministry of Environment. The accessibility to the northern shore of the reservoir is via a dirt road that runs through a large private property with highly restricted entry, but with some facilities for scientific research.

Conserving the Geosite

The Andalusian Regional Government gives the area additional protection designation, including Natural Park Sierra Norte de Sevilla (declared in 1989), Special Conservation Zone (ZEC, 2012), Special Protection Area for Birds (ZEPA – EU, 1989) and the territory is part of the UNESCO Biosphere Reserve ‘Dehesas

de Sierra Morena' (2002), European and Global Geopark (2011) and UNESCO Global Geopark (2015).

It is necessary to highlight that the Paleozoic succession of the Valle syncline was catalogued in 2008 as a Spanish geological place of international significance (Geosite PZ-006: Gutiérrez-Marco *et al.* 2008), in the frame of the project 'Global geosites' coordinated by the European Association for the Conservation of the Geological Heritage (ProGEO – IUGS) and made official by the Spanish Geological Survey (IGME). As a direct consequence of this, the outstanding Silurian outcrops of the syncline were later included in the Andalusian Inventory of Georesources (code 660: 'Silurian deposits of El Pintado Reservoir') by the Andalusian Regional Government. In addition to the

obvious international interest of the El Pintado-1 section from chronostratigraphical and biostratigraphical perspectives, another important heritage aspect must be considered. This is that, palaeontologically, it is the type locality for 19 new species of graptolites (so far), one of them named after the UNESCO Geopark designation: *Parapetalolithus sierranortensis* Loydell, Frýda & Gutiérrez-Marco, 2015 (Fig. 1E).

Public awareness of the geosite will be ensured by the future integration of the section in the publications and in the Environmental Education Plan of the Geopark, which promotes activities in several of its educational centres, partly sponsored by the Departments of the Environment and Education and Science of the Andalusian Regional Government.

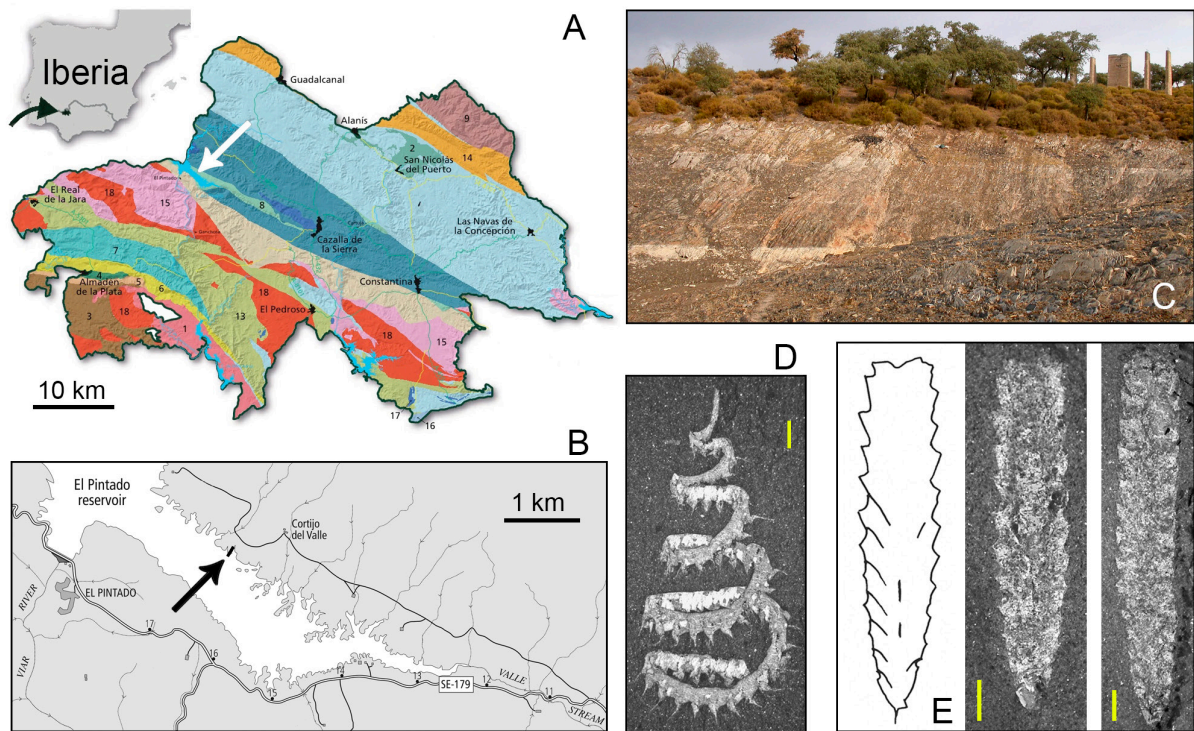


Figure 1. A) The location of the Valle syncline on a map of the Iberian Peninsula (upper left) and on a general geological map of the Sierra Norte de Sevilla Geopark (arrow). B) Map of the eastern end of the El Pintado reservoir showing the location of the El Pintado-1 Silurian section (arrow) with the new GSSP for the base of Telychian. C) Field photograph of a part of the Llandovery (right and center) to lower Wenlock (left) strata in the section. D) *Spirograptus guerichi*, the index species for the base of the Telychian Stage. E) *Parapetalolithus sierranortensis*, a lower Telychian species dedicated in 2015 to the geopark. Scale bar represents 1 mm. Source of maps: A, adapted from Pérez Muñoz *et al.* (2020); B, adapted from Loydell *et al.* (2015).

Summary

The Silurian succession of the Valle syncline in the Sierra Norte de Sevilla Geopark is richly fossiliferous, especially the sapropelitic black shales that contain numerous levels with graptolites, whose abundance and diversity has allowed identification of 25 distinct biozones of the international standard graptolite biozonation, as well as identification of global biotic crises and recoveries and associated oceanographic events. The condensed, almost entirely black shale succession of the Ossa Morena Zone was deposited in deeper shelf environments than existed in other parts of Iberia and the Gondwanan shelf. The most similar successions are those of Thuringia (Germany), the Carnic Alps (Austria and Italy), SE Sardinia (Italy), Bohemia (Czech Republic), and some north African areas, but the El Pintado-1 section represents a compilation of all of them in a single section, therefore with enormous value for the world's palaeontological heritage. The placement of the GSSP for the base of the Telychian Stage and El Pintado being the type locality of several new graptolite species also reinforces the need for future protection and conservation of this internationally important geosite.

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