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RESEARCH ARTICLE

A Famennian allochthonous pelagic facies in a shallow marine domain: the equivalent of the Vidrieros Formation (Cantabrian Mountains, Spain)

Facies pelágicas alóctonas en un dominio marino somero de edad Fameniense: el equivalente de la Formación Vidrieros (Cordillera Cantábrica, España)

Gerard van Loevezijn[1]

[1] Jan Sluijtersstraat 7, 3443 HP Woerden, The Netherlands

Corresponding author: stratpal.ger@gmail.com (Gerard van Loevezijn)

Key points

Description and distribution of Famennian transitional facies between shallow marine Asturo–Leonese Domain and pelagic Palencian Domain

The Upper Devonian Unconformity is pinpointed in the Famennian sequence

Establishment of Famennian stratigraphic relations between Asturo–Leonese and Palencian facies domains and their transitions

ABSTRACT

The Devonian shallow-marine facies area of the Cantabrian Zone, the Asturo–Leonese Domain, generally contains a coarse-grained succession with reefal intercalations. However, in the most external part of the Asturo-Leonese Domain an allochthonous thrust unit contains a Famennian facies different from the surrounding coarse-grained deposits, which shows great similarities with the fine-grained pelagic facies of the Palencian Domain. The complex stratigraphic relations are analyzed, and the findings incorporated in a model. The deposits of the thrust unit can palaeogeographically be interpreted as the distal southwestern continuation of the shallow marine domain, representing a facies transition between the coarse-grained shallow marine Asturo–Leonese facies in the north, and the pelagic Palencian facies in the south.

Keywords: Cantabrian Mountains; Facies; Famennian; Unconformity.

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Puntos clave

Descripción y distribución de facies transicionales del Fameniense entre un dominio marino somero Astur-Leonés y uno pelágico Palentino

Se identifica una discordancia de edad Devónico Superior en la secuencia Fameniense

Se establecen correlaciones estratigráficas y transiciones de facies Famenienses entre el Dominio Astur-Leonés y el Palentino

RESUMEN

La zona de facies marinas someras de la Zona Cantábrica (Dominio Astur-Leonés) generalmente contiene una sucesión Devónica de grano grueso con intercalaciones arrecifales. No obstante, en la parte más meridional de la pendiente montañosa, una unidad alóctona transportada por un cabalgamiento contiene facies de edad Fameniense diferentes de los depósitos de grano grueso circundantes, pero muy similares a las facies pelágicas de grano fino del Dominio Palentino. Se han analizado las complejas relaciones estratigráficas e incorporado los resultados a un modelo paleogeográfico. Los depósitos de la unidad alóctona pueden ser interpretados paleogeográficamente como facies de transición entre facies marinas someras de grano grueso del Dominio Astur-Leonés ubicadas hacia el Norte y facies pelágicas del Dominio Palentino interpretadas como la continuación distal del dominio marino somero hacia el suroeste.

Palabras clave: Cordillera Cantábrica; Facies; Fameniense; Discordancia.

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1. Introduction

The Cantabrian Mountains are an Alpine range crossing northern Spain with an east-west trend. A significant part is situated in the Cantabrian Zone, the northern external thrust and fold belt of the Variscan Iberian Massif (Matte, 1991; Díez Fernández *et al.*, 2016) (Figure 1a). It preserves an almost continuous, non-metamorphic to anchimetamorphic Palaeozoic succession.

The 2000 m thick Devonian interval of the southern Cantabrian Zone is exposed in the sections of the Rio Bernesga valley and adjacent areas. It consists mainly of an alternation of siliciclastic and carbonate units with some reef episodes; the Devonian Asturo–Leonese facies type of Brouwer (1964). The Famennian rocks fit into the coarse facies type, with sandy shales, sandstones, conglomerates, and coarse grainstone intercalations, capping a fine-grained interval.

Most Famennian localities in the southern limb of the Alba syncline (Figure 2) are classical sections, studied by several authors (Higgins *et al.*, 1964; Higgins and Wagner-Gentis, 1982; Raven, 1983; Rodríguez Fernández *et al.*, 1985; Van Loevezijn, 1986, 1988a, 1988b; García López and Sanz-López, 2002). However, an allochthonous thrust unit from the southern limb of the

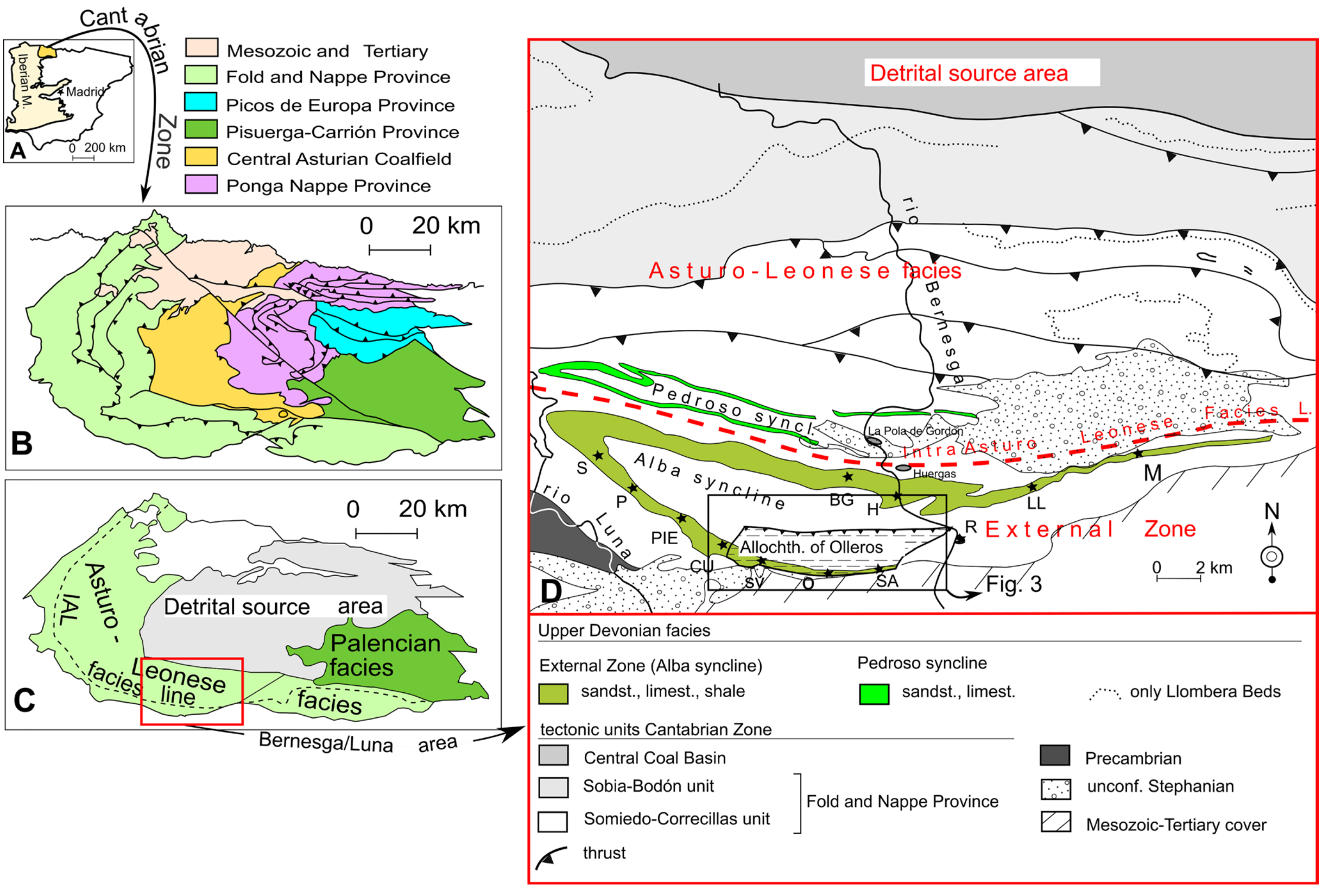

Figure 1. A) Situation map of the Iberian Peninsula with the Cantabrian Zone. B) Schematic geological map showing the main tectonostratigraphic units of the Cantabrian Zone, after Julivert (1971), and Alonso *et al.* (2009) .C) Map of the Cantabrian Zone with the major palaeogeographic units. D) Map of the southern Cantabrian Zone with the Upper Devonian distribution, location of sections, and outline of the study area. Abbreviations for the sections; Alba syncline: S = Sagüera, P = Portilla de Luna, PIE = Piedrasecha, CU = Cuevas, R = La Robla, BG = Barrios de Gordón, H = Huergas de Gordón, LL = Llombera, M = Matallana de Torío; Allochthon of Olleros: SV= Santiago de las Villas, O = Olleros de Alba, SA = Sorribos de Alba.

Figura 1. A) Mapa de localización de la Zona Cantábrica en la Península Ibérica. B) Mapa geológico esquemático mostrando las principales unidades tectonostratigráficas de la Zona Cantábrica, según Julivert (1971) y Alonso *et al.* (2009). C) Mapa de la Zona Cantábrica con las unidades paleogeográficas mayores. D) Mapa del sector meridional de la Zona Cantábrica con la distribución del Devónico Superior, localización de secciones, y contorno de la zona de estudio. Abreviaturas para las secciones: Sinclinal de Alba: S = Sagüera, P = Portilla de Luna, PIE = Piedrasecha, CU = Cuevas, R = La Robla, BG = Barrios de Gordón, H = Huergas de Gordón, LL = Llombera, M = Matallana de Torío; Alóctono de Olleros: SV= Santiago de las Villas, O = Olleros de Alba, SA = Sorribos de Alba.

syncline (Allochthon of Olleros hereafter, Figure 1) contains, near the locality of Olleros de Alba, a different, up to 43 m thick, uppermost Famennian, dark-grey, shale succession interbedded with pyritic, muddy carbonate intercalations (Figure 2). Probably because of its rare appearance in the Asturo–Leonese facies area, the fine-grained interval near Olleros de Alba was attributed to different stratigraphical units: the Fueyo Formation (van Loevezijn, 1986, 1988a), the Baleas Formation (Leyva *et al.* 1984), the Vegamián Formation (Rodríguez Fernández *et al.* 1985). A similar lithofacies type also occurs in the Famennian Vidrieros Formation of the Palencian facies area in the Pisuerga-Carrión unit (Figure 1c), an allochthonous tectonostratigraphic unit in the eastern part of the Cantabrian Zone (Sanz-López *et al.*, 1999). The lithofacies, so far, has not been found elsewhere in the Upper Devonian Asturo–Leonese facies area. Taking everything into account, Van Loevezijn and Van Loevezijn Peña (2017) introduced a new, informal name for the Famennian fine-grained succession of the Allochthon of Olleros ("equivalent of the Vidrieros Formation"; Figures 3 and 4) because (1) its unusual development in the coarse-grained Upper Devonian succession of the Alba Syncline, and (2) its similarity with the dark shales with interbedded nodular limestones of the Vidrieros Formation in the Palencian facies area of the Pisuerga-Carrión Province (Sanz López *et al.*, 1999; Van Loevezijn, 1988b).

The Upper Devonian succession is characterized by significant facies and thickness changes over short distances (Van Loevezijn and Van Loevezijn Peña, 2017). Although the classical sec-

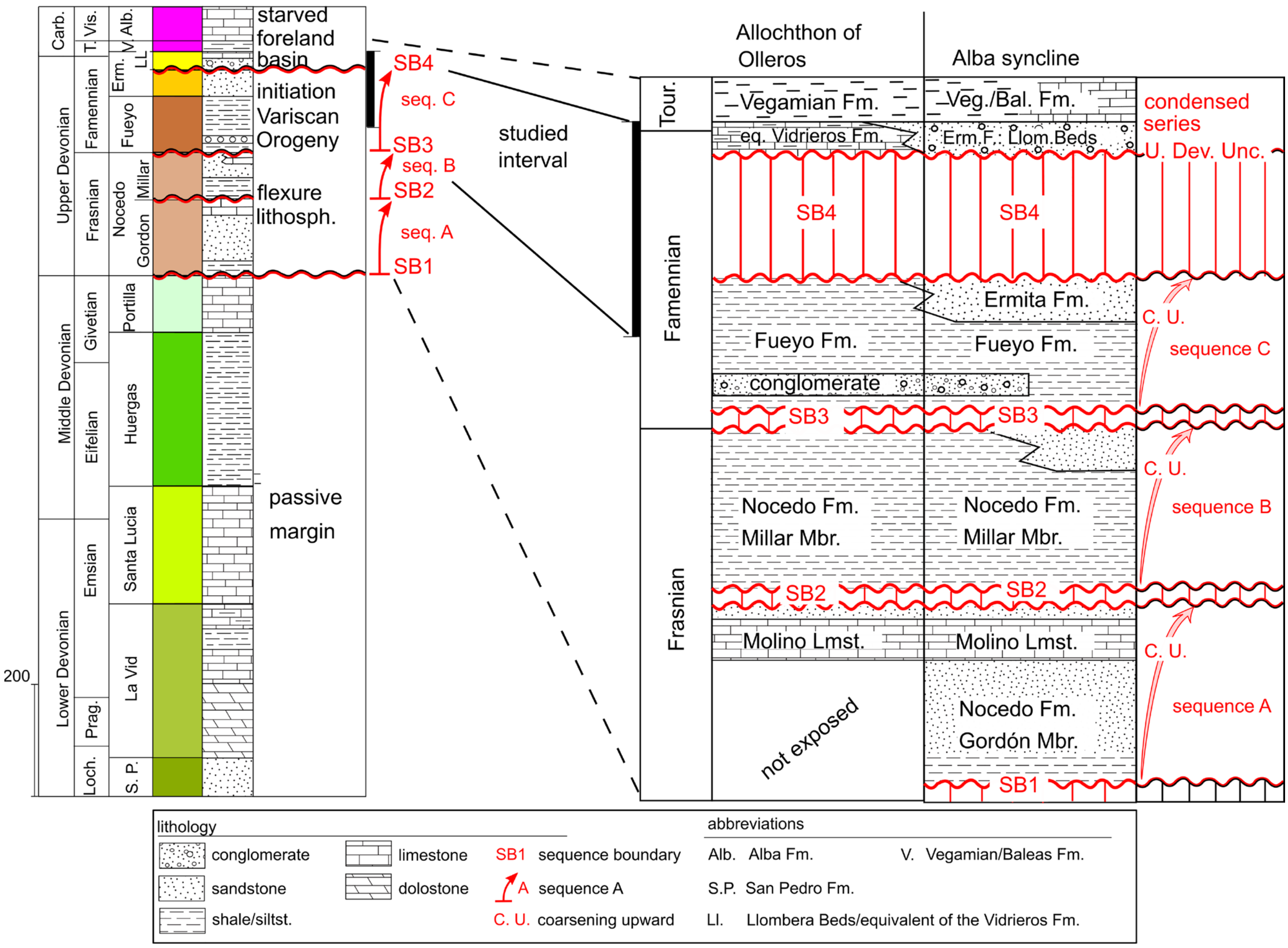

Figure 2. General Devonian stratigraphy of the southern Cantabrian Zone, with a detailed stratigraphic architecture of the Allochthon of Olleros and Alba syncline, according to Van Loevezijn and Van Loevezijn Peña, 2017. SB=sequence boundary. For legend see Figure 3.

Figura 2. Estratigrafía general para el Devónico del sur de la Zona Cantábrica, con la arquitectura estratigráfica detallada del alóctono de Olleros y el Sinclinal de Alba, según Van Loevezijn *and* Van Loevezijn Peña (2017). SB = límite de secuencia. Para la leyenda, *véase Figura 3.*

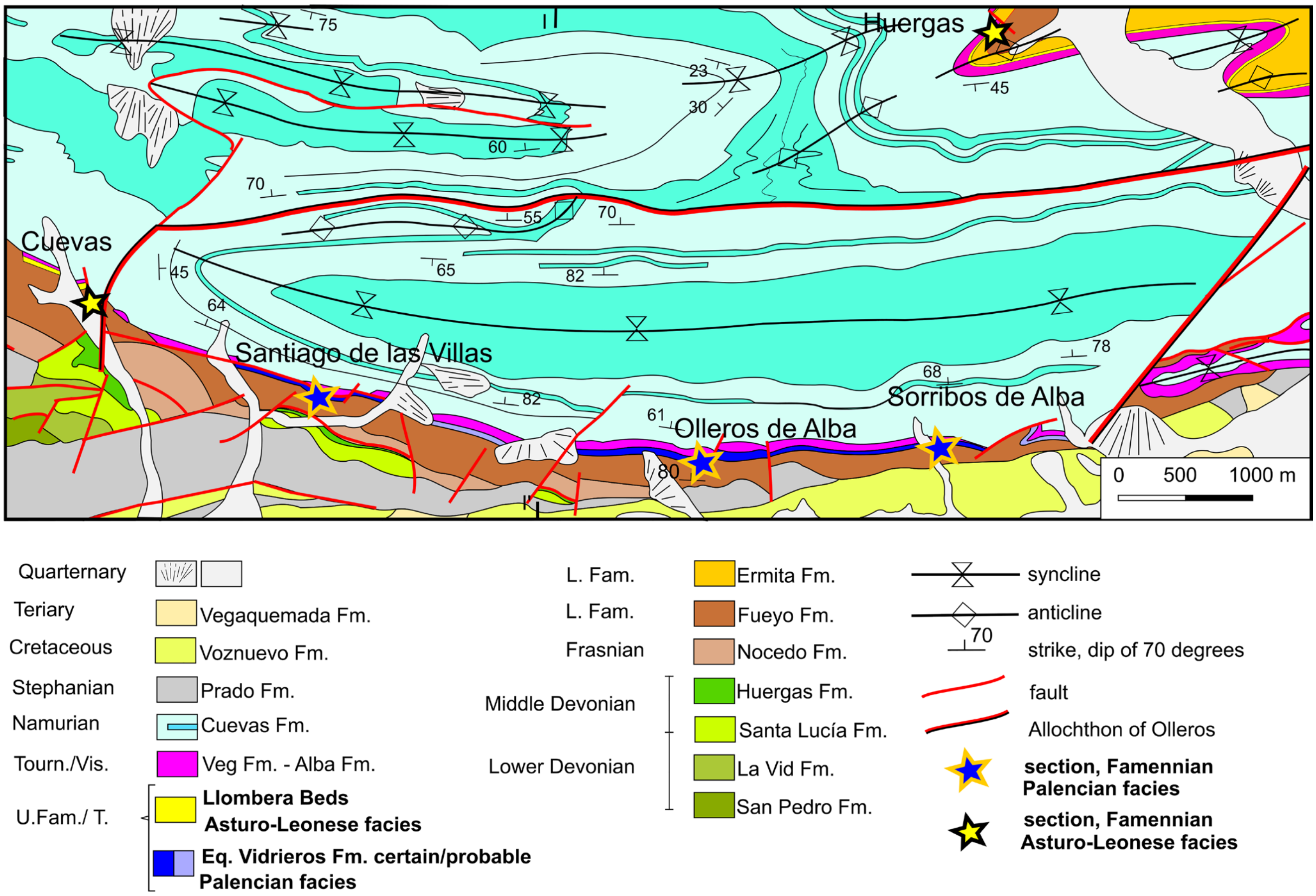

Figure 3. Geological map of the Allochthon of Olleros, with the location of the sections, and the distribution of the equivalent of the Vidrieros Formation; changed after Leyva *et al.* (1984). I – I' = Transect of Figure 4.

Figura 3. Mapa geológico del Alóctono de Olleros, con la ubicación de las secciones, la distribución del equivalente de la Formación Vidrieros; modificado de Leyva *et al.* (1984). I – I' = Trazado del corte de la Figura 4.

tions of the southern Cantabrian Zone have been studied by many authors during the last 50 years, the (complex) stratigraphic relations between the individual sections are not clear. The intercalated fine-grained facies of the Allochthon of Olleros even complicates the complex stratigraphic scheme. The aim of this study is to explore the occurrences of the equivalent of the Vidrieros Formation in the Alba syncline, and to analyse the stratigraphic relation of the Famennian fine-grained rocks with the coarse-grained Asturo-Leonese lithofacies of the Alba syncline, and with the Vidrieros Formation of the Pisuerga-Carrión Province, and finally, to construct an integrated Upper Devonian stratigraphical model. Fieldwork was carried out during the summers of 1983–1984 and 2021–2022. The new observations were compared with previous references using conodonts, and an update is given of the Famennian stratigraphic architecture of the southern limb of the Alba syncline.

2. Geological setting

2.1. Subdivisions of the Cantabrian Zone

The Cantabrian Zone is an arc-shaped Variscan foreland fold-and-thrust belt (Julivert, 1971), characterised by thin-skinned tectonics, also known as the Cantabrian Orocline (Pastor-Galán *et al.*, 2012; Weil *et al.*, 2013). It is situated in the northwestern area of the Iberian Peninsula, and is part of the Palaeozoic Iberian Massif of Lotze (1945). Structurally, the thrust belt is characterized by tectonic transport towards the core of the orocline. Illite crystallinity and conodont alteration indexes are consistent with diagenetic conditions of very low-grade metamorphism (Raven and Van Der Pluijm, 1986; Brime *et al.*, 2001). Based on stratigraphic and tectonic features, the Cantabrian Zone is subdivided into five tectonostratigraphic regions or units (Julivert, 1971), which were later slightly modified (Peréz Estaún *et al.,*1988; Alonso *et al.*, 2009). Of these, the Fold and Nappe

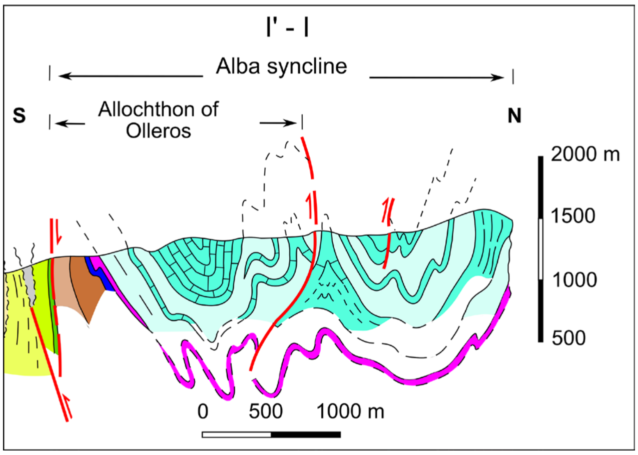

Figure 4. Cross section of the Alba syncline, with the Allochthon of Olleros indicated; after Leyva *et al.* (1984). For legend see Figure 3.

Figura 4. Corte del sinclinal de Alba, con el Alóctono de Olleros indicado; según Leyva *et al.* (1984). Para la leyenda, véase Figura 3.

Province hosts the Alba syncline (Rodríguez Fernández *et al.,* 1985). The study area is located near Olleros de Alba in an allochthonous structure of the Alba syncline (Figure 1d). It constitutes the southernmost unit of the Cantabrian Zone.

Palaeogeographically the Silurian–Devonian succession of the Cantabrian Zone is subdivided into two facies areas (Brouwer (1964), namely the Asturo-Leonese facies area and the Palencian facies area: The Asturo-Leonese facies area, located in the Fold and Nappe Province, is characterised by a shallow-marine shelf succession, with a systematic change towards more distal depositional environments and more continuous successions from the core of the Cantabrian Zone towards the outer parts of the facies area (Figure 1c). The outermost part, the External Zone, contains a thick and fairly complete Upper Devonian succession (Van Loevezijn, 1986). It is separated from the inner part with a thin and incomplete Upper Devonian by the Intra-Asturo-Leonese facies line (IAL facies line) of Raven (1983). The core of the Cantabrian Zone was an area of uplift and erosion, characterised by the near-complete absence of Silurian–Devonian strata, and the source of sediments for the surrounding Devonian Asturo–Leonese Basin (Sjerp, 1967; Van Adrichem Bogaert, 1967). The Palencian facies area is located in the Pisuerga-Carrión Province in the east, and is considered allochthonous (Frankenfeld, 1984; Weil *et al.,* 2012). This succession is characterised by pelagic faunas and scarce coarse-detrital material, and represents the deeper south (western) continuation of the Asturo–Leonese Basin.

2.2. Regional stratigraphy

Lower to Middle Famennian deposits of the Asturo-Leonese facies are only present in the southern and westernmost parts of the Cantabrian Zone (the External Zone) (van Loevezijn, 1983, 1986). They contain the transition from the Upper Devonian clastic wedge sedimentation (Upper Devonian of sequence C) to the overlying widespread condensed series of a starved foreland basin (Figure 2) (Keller *et al.*, 2008; Van Loevezijn, 2020). The clastic wedge consists of an up to 300 m thick Fueyo Formation, and an overlying, maximum 96 m thick, Ermita Formation. The Fueyo Formation contains a lower laminated shale succession (offshore facies association), and an upper storm-bedded coarsening-upward succession (storm-bedded transition association). In the lower part of the formation a conglomerate is intercalated. The formation grades upward into the silty sandstones of the Ermita Formation and together they constitute sequence C of the sequence stratigraphical model of Van Loevezijn and Van Loevezijn Peña (2017). The sequence is separated by sequence boundary 4, the Upper Devonian Unconformity, from the overlying Uppermost Famennian–Visean condensed sequence. The maximum 10 m thick, widespread, very coarse–grained succession of the Llombera Beds rests unconformably on a varied substrate. This lithostratigraphic unit, defined by Keller *et al.* (2008), is equivalent to the unconformable, uppermost part of the Upper Devonian sandstones, classically known as the Ermita Formation. These deposits consist of discontinuous ferruginous sandy conglomeratic channel-fill sediments (fluvio-marine facies association), followed by the cross-bedded quartz arenites (upper shoreface facies association), and locally capped by sandy and bioclastic grainstone intercalations (Van Loevezijn and Raven, 2021). The unit is locally covered by a maximum of 12 m of bioclastic limestones of the Baleas Formation of Late Devonian–Early Carboniferous age, or by the Carboniferous black shales of the Vegamián Formation (Wagner *et al.*, 1971). The Devonian–Carboniferous boundary is located in the Llombera Beds or the Baleas Formation. Visean nodular limestones of the Alba Formation complete the condensed sequence. However, in the Allochthon of Olleros the Famennian succession is somewhat different; it is entirely fine grained, and lacks in the upper part the characteristic Asturo–Leonese coarse-grained sediments of the surrounding Alba syncline.

3. Stratigraphy and Facies

Out of the of twenty Upper Devonian (litho) facies types previously described in the southern Cantabrian Mountains, (Van Loevezijn and Van Loevezijn Peña, 2017; Van Loevezijn and Raven, 2020; Van Loevezijn and Raven, 2021), a total of nine occur in the investigated Famennian succession. They are grouped into seven facies associations representing distal offshore to proximal fluvial-tidal environments. The descriptions and interpretations of the facies types are summarised in Figure 5, and they will be briefly referred to in the description of the sections below. For a more detailed description and in-depth sedimentological discussion, the reader is referred to the above publications.

The Alba syncline is part of the External Zone, and contains the most complete Upper Devonian succession of the Cantabrian Zone, 300 thick in the eastern regions of the Alba syncline with a gradually increase to 600 m for the southwestern part. Next Upper Devonian outcrops to the north, in the Pedroso syncline are thin and incomplete, and belong to another unit. In this study four out of the twelve sections of the Alba syncline, previously described by Van Loevezijn (1986), located in the southern limb of the syncline between the villages Cuevas and Sorribos de Alba, were inves-

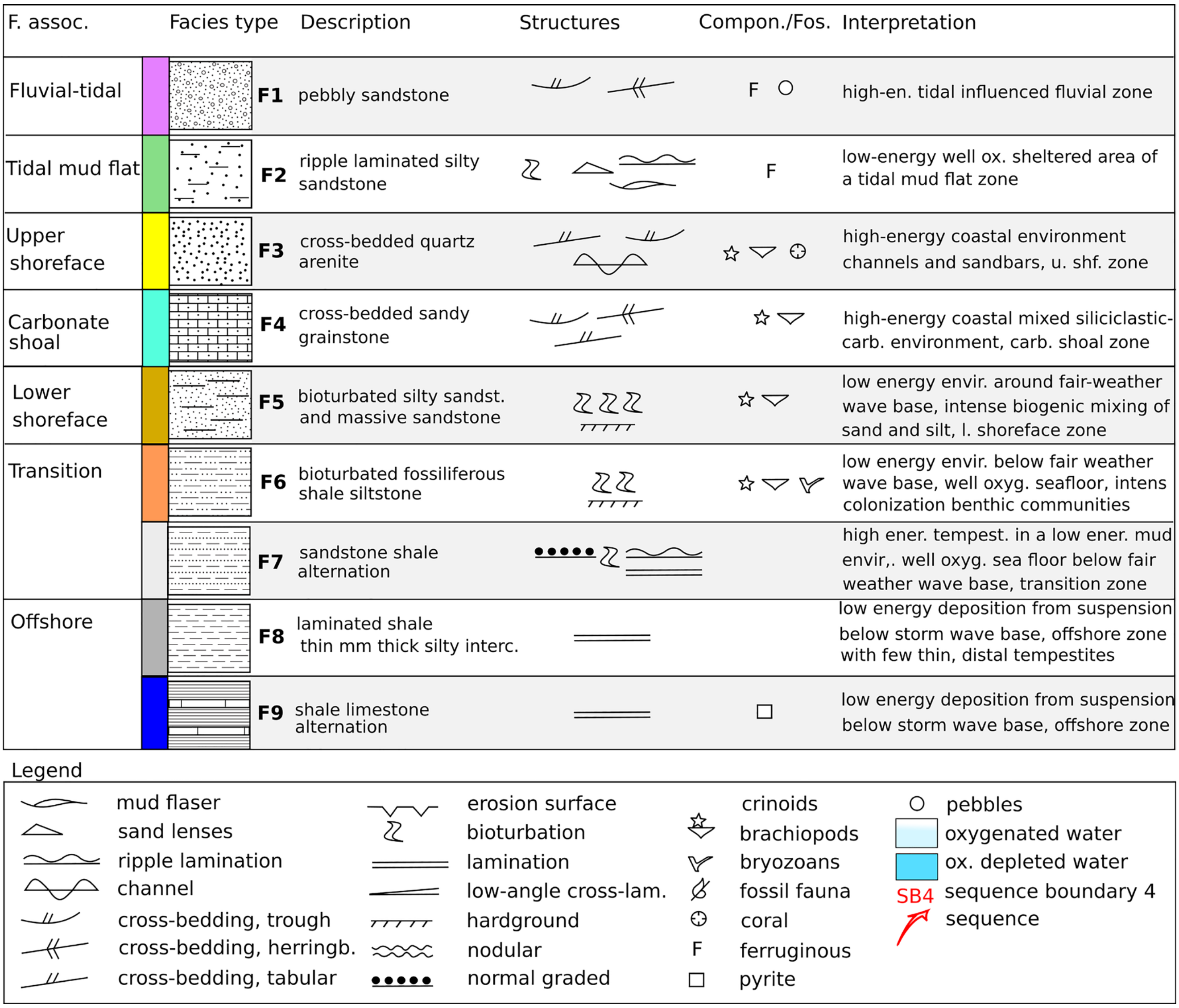

Figure 5. Lithofacies types of the investigated succession.

Figura 5. Tipos de litofacies en la sucesión estudiada.

tigated in detail. They are all but one located in the Allochthon of Olleros (Figure 3).

3.1. Section Cuevas (CU)

This section (Figure 6) is mentioned in Van Loevezijn (1986) and is located just west of the thrust unit of the Allochthon of Olleros. It is exposed on the east side of the small road to Cuevas, south of the village. At the Cuevas section the upper part of the Fueyo Formation, parts of the overlying Llombera Beds of the Ermita Formation, and the Alba Formation can be observed. The area is complicated by faults, but the section seems unaffected.

Unit 1: Fueyo Formation. Thickness: 88.1 m. Only the uppermost 13 m of this unit is shown in Figure 6. It consists of grey and brown silty shales,

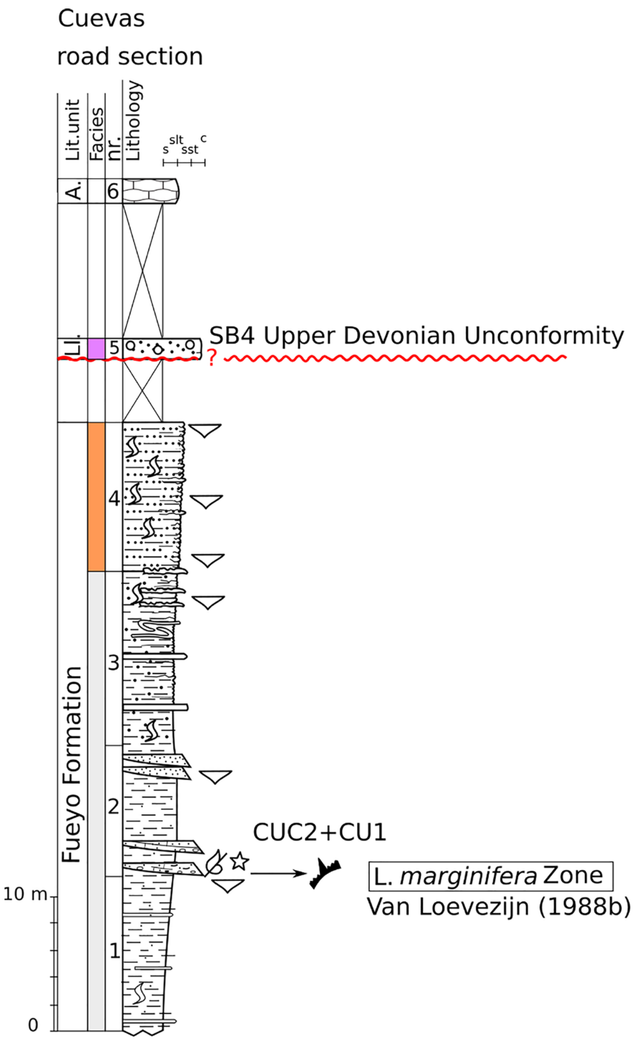

Figure 6. Section Cuevas. For legend see Figure 5. For location of section see Figure 1.

Figura 6. Sección Cuevas. Para la leyenda, véase Figura 5. Para la localización, véase Figura 1.

alternating with very fine grained, up to 10 cm thick, sandstone beds. The sandstone ratio varies between 35 and 80 %. Locally the intercalated mud layers are very thin or absent, and the sandstone beds are amalgamated. Most of the sandstone beds have sharp, gently wavy, locally clearly erosive bases and sharp tops. Unit 1 is assigned to facies type F7, the sandstone-shale alternation.

Unit 2: Fueyo Formation. Thickness: 15 m. The unit consists of grey-brown silty shales with up to 20 cm thick sandstone bed intercalations and erosive beds with pebbly lags. The beds are even laminated and low-angle cross-laminated. The downcutting layers contain a fill of pebbles up to 3 cm in diameter, bioclasts of brachiopods, crinoids, goniatites, and intraclasts of ferruginous mudstones. Unit 2 is assigned to facies type F7, the sandstone-shale alternation Two conodont samples were taken from the same channel-fill bed in the base of the unit 2: CUC2, and CU1 (Van Loevezijn, 1986, 1988b). They yield an abundant fauna of 650 conodonts/kg with *Palmatolepis sp.*, *Pa. glabra glabra, Pa. glabra pectinata, Pa. minuta minuta, Pa. schindewolfi, Polygnathus sp., P. fallax*, *P. brevilaminus, P. semicostatus, P. communis communis, P. nodocostatus, Pelekysgnathus sp., Icriodus cornutus,* and can be correlated with the Lower *marginifera* Zone.

Unit 3: Fueyo Formation. Thickness: 15 m. The unit consists of grey brown silty shales with 5–20 cm thick sandstone bed intercalations, and an upwards increase of bioturbation. In the upper half of the unit soft sediment deformation structures occur. Unit 3 is assigned to facies type F7, the sandstone-shale alternation.

Unit 4: Fueyo Formation. Thickness: 11 m. The unit consists of sandy shales and siltstones with a nodular appearance, and an abundant brachiopod fauna. The nodular appearance is here interpreted as due to heavily bioturbation. Unit 4 is assigned to facies type F6, the bioturbated silty shale.

Unit 5: Llombera Beds. Thickness: 1.7 m. Above 5 m of not-exposed section, a massive medium to coarse-grained sandstone unit occurs, with pebbles up to 1 cm. Unit 5 is assigned to facies type F1, pebbly sandstone.

Unit 6: Above 10 m of not-exposed section, the nodular limestones of the Alba Formation occur.

3.2. Section Santiago de las Villas (SV)

This section (Figure 7) is located in the westernmost part of the Allochthon of Olleros along a

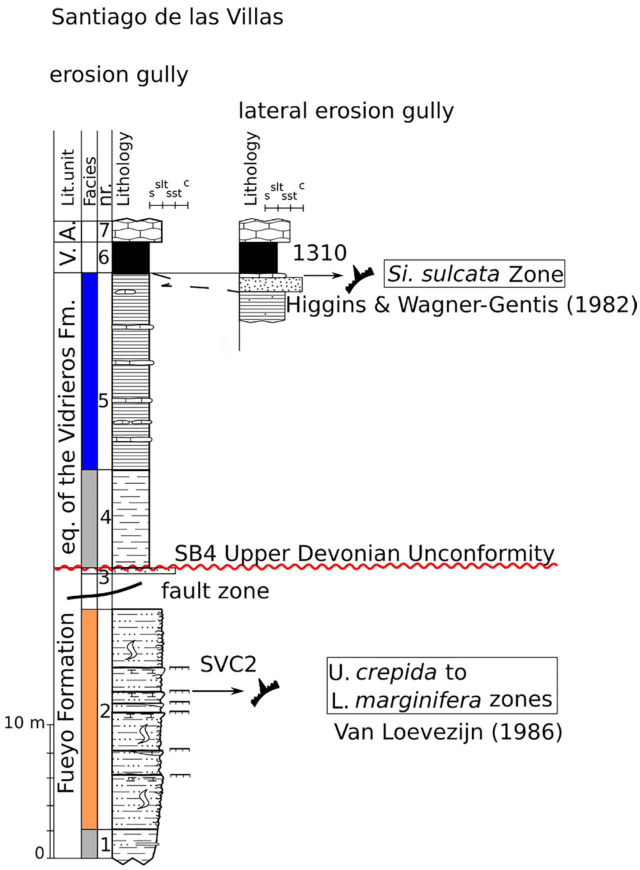

Figure 7. Section Santiago de las Villas. For legend see Figure 5. For location of section see Figure 1.

Figura 7. Sección Santiago de las Villas. Para la leyenda, véase Figura 5. Para la localización, véase Figura 1.

hillslope in an erosion gully about 600 north of the village Santiago de las Villas, and was described by Rodríguez Fernández *et al.* (1985) and Van Loevezijn (1986, 1988a). The shales of the Fueyo Formation, the shale-limestone succession of the equivalent of the Vidrieros Formation, and the overlying black shales and nodular limestones of the Vegamián and the Alba formations respectively can be observed. In the same locality of Santiago de las Villas Higgins and Wagner-Gentis (1982) described a slightly different succession with a sandstone bed above the shale-limestone lithofacies. Therefore, we assume that the section is located laterally of that section described by Rodríguez Fernández *et al.* (1985) and Van Loevezijn (1986) (1988a).

Unit 1: Fueyo Formation. Thickness: 91m. The unit is underlain by the conglomerate interval from the base of the Fueyo Formation (Rodríguez Fernández *et al.,* 1985; Van Loevezijn, 1986), a deposit that is beyond the scope of this study. In Figure 7 only the uppermost 2 m of the unit is shown. It consists of grey-brown shales, with occasional thin intercalations of laminated siltstones. Sandstone represents less than 10% of the lithology. The unit is poor in fossils. The uppermost metres are moderately bioturbated. Unit 1 is assigned to facies type F8, laminated shale.

Unit 2: Fueyo Formation. Thickness: 16.4 m. The unit consists of calcareous argillaceous siltstones, intensively bioturbated, which causes a nodular mottled appearance (facies type: F6, bioturbated shaly siltstone). The unit contains several calcareous bored horizons, interpreted as hardgrounds (Van Loevezijn 1986). A conodont sample from one of these horizons has provided *Polygnathus semicostatus*, *Pandorinellina insita*, and *Palmatolepis pectinata.* (Van Loevezijn, 1986: sample SVC2), indicating the *crepida* to *marginifera* zones.

Unit 3: Fueyo Formation (?). Thickness: 0.2 m. Above 3 m of unexposed section, 0.2 m of poorly exposed sandstone occurs (facies type: F5, sandstone). According to Rodríguez Fernández (1985) this part of the section corresponds with a fault zone. The offset of the fault is uncertain.

Unit 4: Equivalent of the Vidrieros Formation. Thickness: 7.5 m. This unit consists of grey laminated shales without silty or sandy admixtures (Facies type: F8, laminated shale), and constitutes the lower part of the equivalent of the Vidrieros Formation (Van Loevezijn & Van Loevezijn-Peña, 2017).

Unit 5: Equivalent of the Vidrieros Formation. Thickness: 22.2 m. The unit consist of laminated dark-grey pyritic shales with thin carbonate-mudstone bed intercalations up to 8 cm thick (facies type: F9, shale-limestone alternation). From a grey limestone bed just below the black shales of the Vegamián Formation Higgins and Wagner-Gentis (1982) mentioned a conodont fauna with many *Polygnathus communis communis*, and few *Protognathodus meischneri*, *Pr. kockeli, Pseudopolygnathus primus, Polygnathus inornatus,* and *Bispathodus stabilis* referred to as *Protognathodus* fauna, which probably can be correlated with the *Si. sulcata* Zone of Ziegler and Sandberg (1990) (García López and Sanz López, 2002), or with the *Protognathodus kockeli* Zone of the revised global conodont scheme of Spalletta *et al.* (2017).

Unit 6: Vegamián Formation. Thickness: 4.7 m. Black splintery shales.

Unit 7: This unit includes part of the overlying nodular limestones of the Alba Formation.

3.3. Section Olleros de Alba (O)

This section (Figure 8), eastward from the section north of Santiago de las Villas, is also located in the Allochthon of Olleros. It is exposed in a hillslope gully, 500 m east of the village Olleros de Alba (Raven, 1983; Van Loevezijn, 1986, 1988a), where from base to top the upper part of the Fueyo Formation, the equivalent of the Vidrieros Formation, the Llombera Beds of the Ermita Formation, and parts of the Vegamián and Alba formations crop out. Immediately north of Olleros de Alba on the road from La Robla to La Magdalena, the upper units (Llombera Beds, Vegamián Formation, Alba Formation) are exposed in a section that has been described in detail by many authors, *e.g.*, Higgins and Wagner-Gentis (1982), Raven, (1983), Rodríguez Fernández *et al.* (1985), García López and Sanz López (2002). The section studied at the gully contains the intervals described below.

Unit 1: Fueyo Formation. Thickness: 60.1 m. This unit represents the upper part of the Fueyo Formation. It consists of a fine-grained succession of laminated shale with few thin, mm to cm thick, silt intercalations (facies type: F8, laminated shale). Near the top of the unit bioturbation increases. Only the uppermost meters of the unit are shown in Figure 8.

Unit 2: Equivalent of the Vidrieros Formation. Thickness: 12.75 m. This unit consists of calcareous shaly siltstone with very fine-grained sand admixed and with intercalations of limestone (wackestone) lenses and beds up to 15 cm thick. Previous sampling for conodonts (Raven, 1983; Van Loevezijn, 1988a) yielded the following results: Raven (1983) reported from a sample from this unit *Spatognathodus bohlenanus*, *Sp. strigosus*, *Polygnathus* sp., and *Bispathodus stabilis*. Sample OC1 (Van Loevezijn, 1988a) contains *Pandorinellina plumulus*, *Polygnathus communis*, *Palmatolepis gracilis gracilis*, *P. gracilis sigmoidalis*, *Spatonagthodus* cf. *bohlenasus*, *Icriodus* cf. *Icriodus cornutus*, *Polygnathus* sp., and *P. inornatus*. Sample OA1 (Van Loevezijn, 1988a) yields *Bispathodus costatus* and *Polygnathus communis.* These faunas indicate latest Famennian. Similar conodont associations were correlated with the *costatus* Zone in Higgins and Wagner-Gentis (1982) and Raven (1983), a zone very common in the Cantabrian Mountains. These faunas probably represent the *Pa. expansa* Zone or the Lower *Si. praesulcata* Zone of Ziegler and Sandberg (1990) (García López and Sanz López, 2002), or the *Bispathodus costatus* to *Bi.*

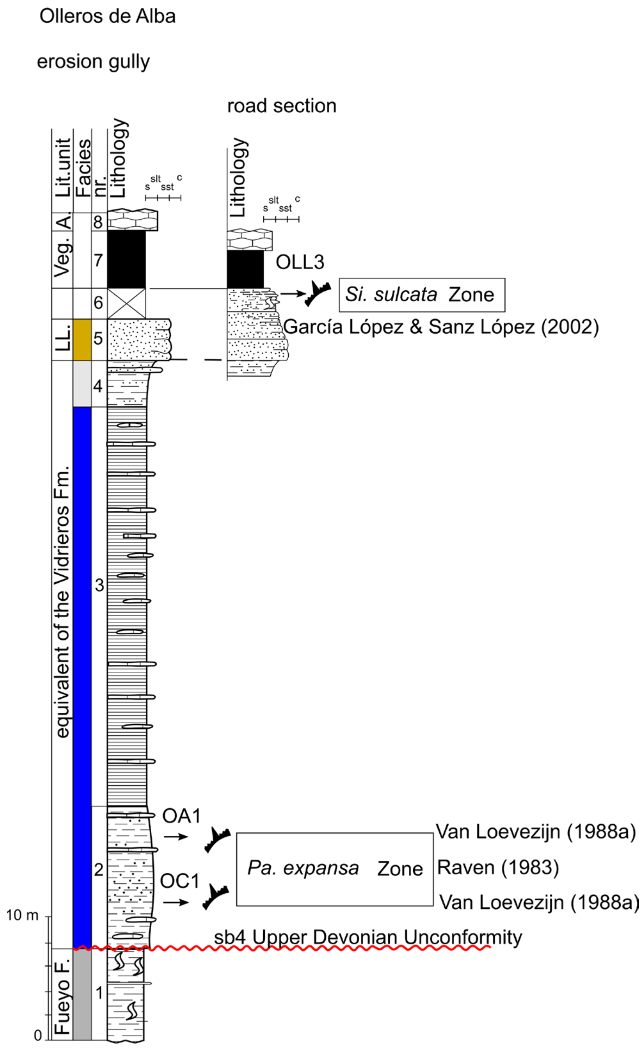

Figure 8. Section Olleros de Alba. For legend see Figure 5. For location of section see Figure 1.

Figura 8. Sección Olleros de Alba. Para la leyenda, véase Figura 5. Para la localización, véase Figura 1.

ultimus zones of the revised global conodont scheme of Spalletta *et al.* (2017).

Unit.3: Equivalent of the Vidrieros Formation. Thickness: 28.7 m. This unit consists of dark-grey clean shales, with evenly spaced interbedded dark-grey, pyrite-bearing, laminated limestone (facies type: F9, shale-limestone alternation). Bed thickness is approximately 8 to 15 cm. In the upper half of the succession limestone lenses occur. No macro fossils were observed, and bioturbation structures are absent.

Unit 4: Equivalent of the Vidrieros Formation. Thickness: 5.8 m. This unit consists of silty shale with an upward increase of interbedded sandstone beds up to 20 cm thick (facies type: F7, sandstone-shale).

Unit 5: Llombera Beds. Thickness: 3.4 m. This unit is poorly exposed and consists of a succession of up to 50 cm thick, yellow, very fine to fine-grained sandstone beds (facies type: F5, massive sandstone).

Unit 6: unexposed interval of 2.5 m. Laterally, in the classical road section north of Olleros de Alba approximately the same interval consists of silty limestones from where García López and Sanz López (2002) reported the presence of *Siphonodella sulcata*, indicating at least the *Si. sulcata* Zone of Ziegler and Sandberg (1990) (sample OLL3), or the *Pr. kockeli* Zone of the revised conodont scheme of Spalletta *et al.* (2017).

Unit 7: This unit consists of 5.1 m of black splintery shales of the Vegamián Formation.

Unit 8: This unit contains the basal part of the nodular limestone succession of the Alba Formation.

3.4. Section Sorribos de Alba (SA)

This section (Figure 9) is described by Van Loevezijn (1986) and Van Loevezijn 1988a). It is exposed in a hillslope gully, 500 m northwest of the village Sorribos de Alba. The upper part of the Fueyo Formation, the overlying equivalent of the Vidrieros Formation, and parts of the Vegamián and Alba formations are exposed. The base of the Famennian succession is unconformably covered by Cretaceous deposits.

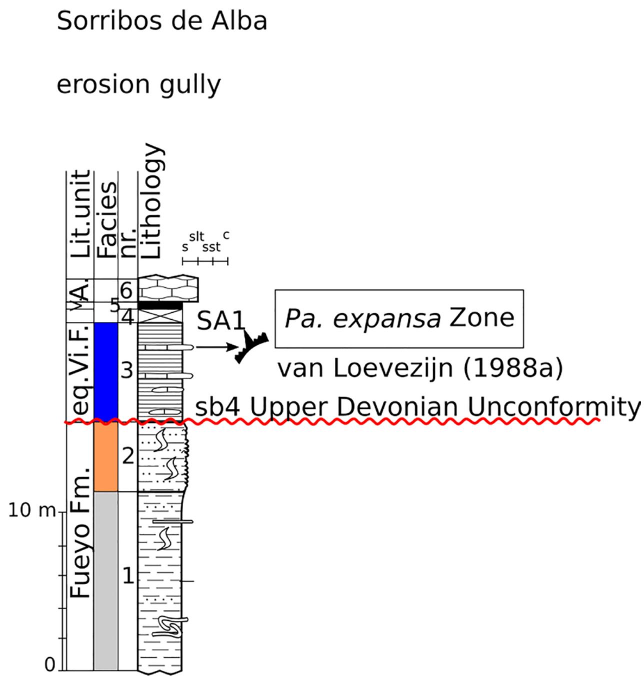

Figure 9. Section Sorribos de Alba. For legend see Figure 5. For location of section see Figure 1.

Figura 9. Sección Sorribos de Alba. Para la leyenda, véase Figura 5. Para la localización, véase Figura 1.

Unit 1: Fueyo Formation. Thickness: 130.1 m. This unit consists of a succession of grey brown shales with thin siltstone intercalations, up to 10 cm thick, and represents the upper part of the Fueyo Formation (facies type: F8, laminated shale). In the upper 20 m bioturbation, and carbonate content gradually increases upward. Slump-folded sandstone beds occur 9.5 m below the top of the unit. Only the uppermost part of the unit is shown in Figure 8.

Unit 2: Fueyo Formation. Thickness: 5.7 m. The unit consists of calcareous, argillaceous siltstones. The sediment is intensively bioturbated with a nodular mottled appearance (facies type: F6, bioturbated shaly siltstone).

Unit 3: Equivalent of the Vidrieros Formation. Thickness: 6.1 m. The unit consists of dark-grey shales, with limestone (mudstone) lenses in the lower half of the unit and limestone (mudstone) bed intercalations in the upper half. Bed thickness is max. 10 cm. Occasionally calcareous sandy silt beds are intercalated. Van Loevezijn (1988a) reported the conodont fauna *Polygnathus communis*, *Bispathodus stabilis*, *Bi. costatus*, and *Palmatolepis gracilis* from the upper half of the unit. The fauna contains similar elements as the conodont samples from the base of the equivalent of the Vidrieros Formation at Olleros de Alba, and indicates the latest Famennian.

Unit 4: Unexposed interval of 1.1 m.

Unit 5: This unit consists of 0.2 m of black splintery shales of the Vegamián Formation.

Unit 6: Red nodular limestone of the Alba Formation.

3.5. Discussion of sections

The Cuevas section, located just west of the Allochthon of Olleros, mainly consists of the silty shales of the Fueyo Formation with sharply-bounded sandstone bed intercalations, channels and soft sediment deformed sandstone layers. The internal structures of the sandstone beds resemble the storm wave generated succession with hummocky cross stratification of Dott and Burgeois (1982) and Jelby *et al.* (2020) (see Van Loevezijn, 2022). Storm bedded successions in the upper part of the Fueyo Formation can be observed in the western and northern sections of the Alba syncline (Van Loevezijn, 1986; Van Loevezijn, 2022); sections PIE, P, S, BG, H, LL, M) (Figure 1D). The pebbly sandstone bed of the top of the section can be correlated with the few-metre thick, very coarse-grained interval west of Cuevas. The break in grainsize to microconglomerates is also observed in the uppermost part of the Upper Devonian succession of the Sil area (Van Loevezijn and Raven, 2021) and can be correlated with SB4, the Upper Devonian Unconformity, which in the Cuevas section lies either at the base of the microconglomerate bed, or in the underlying covered interval between units 4 and 5. The Fueyo succession at Santiago de las Villas is finer grained, and probably represents a more distal environment. The usual Famennian succession in the western and northern parts of the Alba syncline, with a shale-sandstone alternation in the upper half of the Fueyo Formation, finally overlain by a sandstone of the Ermita Formation, is absent. Instead, the finer grained Fueyo succession is overlain by a bioturbated siltstone unit containing six calcareous hardgrounds (Van Loevezijn and Van Loevezijn Peña, 2017). Overlying a covered interval, dark-grey shales interbedded with lime mudstone of the equivalent of the Vidrieros Formation follow. In Cuevas and sections further to the west of the Alba syncline this lithofacies is absent. The unit is overlain by the Carboniferous black shales of the Vegamián Formation. The Famennian successions at Olleros de Alba and Sorribos de Alba are very similar to that at Santiago de las Villas. The Fueyo Formation mainly consists of shales with thin siltstone intercalations, and lacks the sandier upper half with the channels and tempestite deposits, found in the sections elsewhere in the Alba syncline outside the Allochthon of Olleros (Van Loevezijn, 1986). The uppermost Fueyo strata, immediately below the equivalent of the Vidrieros Formation sediments are nodular, with intensely bioturbated horizons. Above, the silty grey shales with limestone lenses of the equivalent of the Vidrieros Formation follow, with conodont faunas, which probably can be correlated with the *Pa. expansa* Zone. At Olleros de Alba the silty shale succession fines upward to dark grey to black shales with laminated limestone (mudstone) beds and lenses, indicating a gradual shift to distal offshore areas where a condensed carbonate-mud succession was deposited. The uppermost metres of the equivalent of the Vidrieros Formation contain a gradual shift from dark-grey calcareous shales to grey silty shales with sandstone bed intercalations, and has a gradual contact with the overlying very fine to fine-grained sandstones of the Llombera Beds, with an Early Carboniferous conodont fauna. Elsewhere in the Alba syncline, outside the Allochthon of Olleros, the Llombera Beds consists of coarse-grained, microconglomeratic sandstones with coarse sandy and bioclastic limestone intercalations (Van Loevezijn and Van Loevezijn Peña, 2017; Van Loevezijn and Raven, 2021), but in this location they are finer grained with shaly intercalations and silty carbonate beds (García López and Sanz López, 2002). The gradational contact between the equivalent of the Vidrieros Formation and the overlying Llombera Beds indicates that these deposits are genetically related. Consequently, the Upper Devonian Unconformity cannot be located between these units. In this study we tentatively correlate the unconformity with the Middle to Late Famennian hiatus between the top of the Fueyo Formation of Middle Famennian age, and the succession of the equivalent of the Vidrieros Formation of latest Famennian age. Eastward, at Sorribos de Alba, the equivalent of the Vidrieros Formation is thinly developed.

4. Famennian–Tournaisian of the Allochthon of Olleros

The boundaries of the Allochthon of Olleros are not everywhere obvious: The western and northern limits are clearly defined by the fault pattern (Figure 3); its eastern boundary however, is not straightforward from the geological map. In this study, it is tentatively taken at the southwest-northeast running fault: The Upper Famennian succession east of the fault consists of coarse sandstones and limestones of the Asturo-Leonese facies (Figure 1, section R, north of La Robla) (see Van Loevezijn, 1986). The investigated Famennian sections in the Allochthon of Olleros, show a somewhat different Famennian stratigraphy.

Fueyo Formation: Most of the lower part of the formation in the Allochthon of Olleros is unconformably covered by Stephanian or Cretaceous deposits. The exposed upper part of the formation is very fine-grained and lacks the sandier interval in the top with the channels and tempestite deposits found elsewhere in the Alba syncline. Instead, the uppermost metres are made of bioturbated silty shales. A conodont fauna from the top of the formation can be correlated with the Middle Famennian *marginifera* Zone.

Ermita Formation: The Ermita sandstones on top of the Fueyo Formation below the Upper Devonian Unconformity, do not occur in the Allochthon of Olleros.

Equivalent of the Vidrieros Formation: This dark-grey, pyrite-bearing, shale-carbonate unit only occurs in the Allochthon of Olleros, overlying the Upper Devonian Unconformity. It is 6 m to 43 m thick, and represents a pelagic succession, deposited away from the reach of the coarse-grained coastal sediment supply. It contains conodont faunas of the uppermost Famennian, which probably represent the *Pa. expansa* Zone or the Lower *Si. praesulcata* Zone (Loevezijn, 1986, 1988a; García López and Sanz López, 2002). These deposits are coeval/laterally equivalent with the uppermost Famennian coarse-grained sandy and bioclastic intercalations of the Llombera Beds outside the Allochthon of Olleros, with similar conodont faunas (Raven, 1983; García López and Sanz López, 2002).

Llombera Beds: In most parts of the Allochthon of Olleros, the unit is absent, and only locally can be observed. It is very thin, and consists of fine-grained sandstones with calcareous silty intercalations. Elsewhere in the Alba syncline, the Llombera Beds consists of up to 10 m thick, coarse-grained deposits with ferruginous ooids and coarse-grained limestone intercalations (Van Loevezijn and Raven, 2021). The uppermost beds of the unit contain a conodont fauna of the *Si. sulcata* Zone (Higgins and Wagner-Gentis, 1982; García López and Sanz López, 2002).

Baleas Formation: The limestones of the Baleas Formation do not occur in the Allochthon of Olleros. The formation is observed northwards of the Alba syncline, and east of the thrust unit (Figure 1D), in the classical section immediately north of La Robla, along the old road to Puente de Alba (Rodríguez Fernández *et al.*, 1985; Van Loevezijn, 1986 and many more). There the presence of *Si. sulcata* is recognized in the uppermost part of the Llombera Beds of the Ermita Formation (Rodríguez Fernández *et al.*, 1985), which can be correlated with the *Protognathodus kockeli* Zone of the revised conodont scheme of Spalletta *et al.* (2017).

Vegamián Formation: The Carboniferous black splintery shales occur in the entire southern limb of the Alba syncline, including the Allochthon of Olleros, with a thickness between 1.5 and 5 m, and are overlain by the limestones of the Alba Formation.

5. Famennian–Tournaisian of the Palencian Domain

The Famennian succession of the Palencian Domain occurs in allochthonous units found in a Carboniferous flysch basin in the south-eastern part of the Cantabrian Zone. This area lies presently 100 km east of the Alba syncline without any palinspastic restoration. It represents the fine-grained pelagic facies, originally formed as the distal southwestern continuation of the shallow-marine Asturo–Leonese facies domain (Frankenfeld, 1984). It consists of the nodular limestones of the upper part of the Cardaño Formation (15 m), the quartzites of the Murcia Formation (100 m) and the overlying brown-grey and black shales, with interbedded nodular limestone beds and limestone lenses of the Vidrieros Formation (100 m). The upper Cardaño and Murcia formations contain early Famennian faunas (Lobato-Astorga, 1977; Sanz-López *et al.*, 1997). The Vidrieros Formation contains middle and late Famennian faunas (Raven, 1983; Sanz-López *et al.*, 1999). The succession is overlain by the Tournaisian black shales of the Vegamián Formation.

The Vidrieros section at Peña Quebrada (Sanz-López *et al.*, 1999) yields conodont faunas from the Lower *marginifera* to the *sulcata* zones of the conodont scheme of Ziegler and Sandberg (1990), or with the *marginifera* to *kockeli* zones of the revised scheme of Spalletta *et al.* (2017) (Van (Adrichem Bogaert, 1967; Sanz-Lopez *et al.*, 1999), and correlates partly with the equivalent of the Vidrieros Formation in the Allochthon of Olleros, which contains a similar lithofacies succession.

6. Stratigraphic architecture

In Figure 10, the Famennian stratigraphic model of the southern Cantabrian Zone is presented. The Fueyo Formation in the Alba syncline consists of a lower laminated shale succession of the fine-grained offshore facies association and an upper storm-bedded coarsening-upward succession of the transition facies association, passing upward to the coastal sandstones of the Ermita Formation. In the Allochthon of Olleros the sandy upper unit of the Fueyo Formation and the sandstones of the Ermita Formation below the unconformity are replaced by a fine-grained succession, which is considered part of the Fueyo Formation. The location of the Upper Devonian Unconformity in the Alba syncline is located at the base of the coarse-grained Llombera Beds of the Ermita Formation (Van Loevezijn and Van Loevezijn Peña, 2017; Van Loevezijn and Raven, 2021). However, in the Allochthon of Olleros the Llombera Beds are formed of a thin, fine-grained succession, which

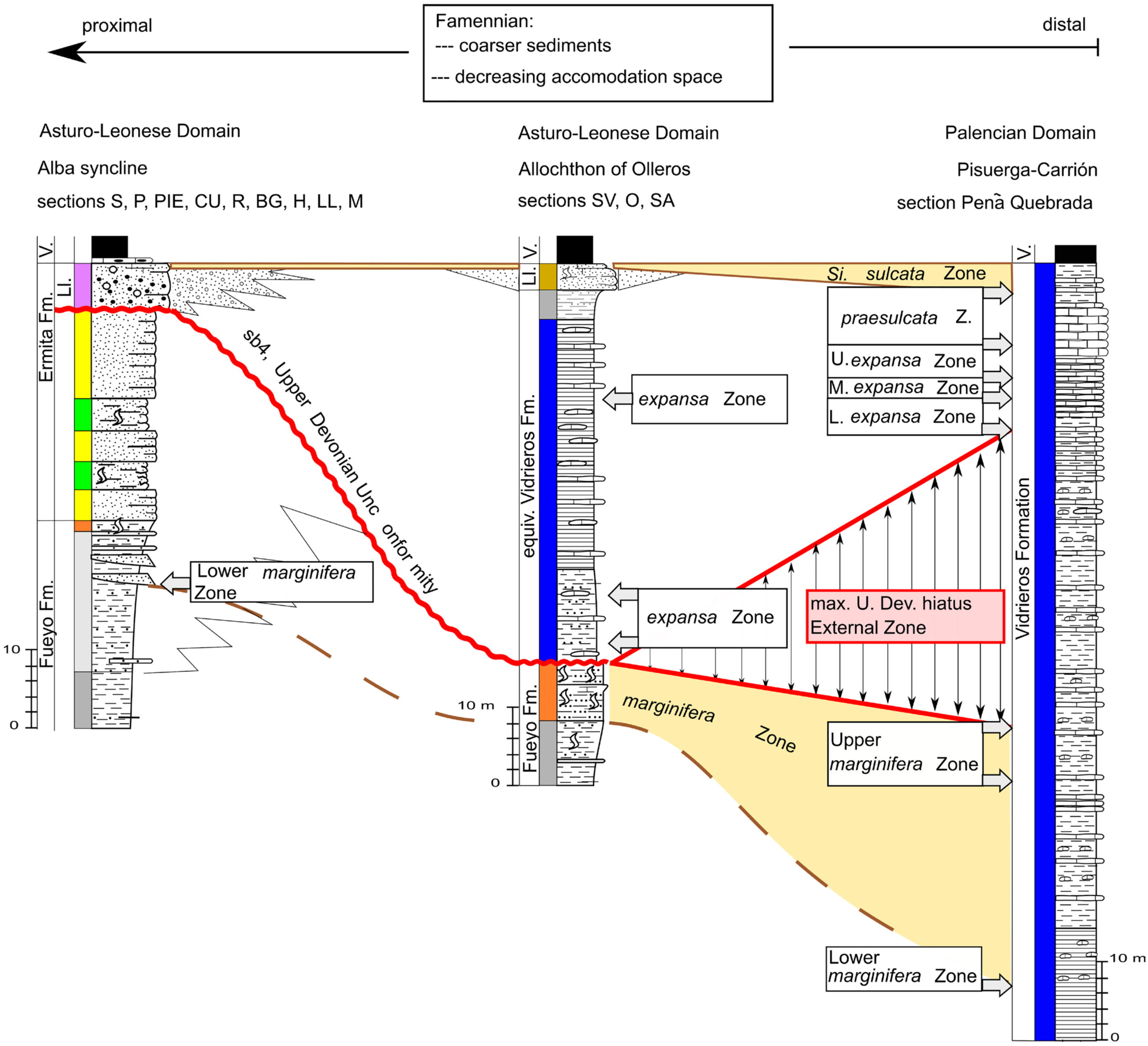

Figure 10. Famennian stratigraphic architecture, with the proposed correlation between the Alba syncline, the Allochthon of Olleros, and the Vidrieros Formation in the Palencian Domain. Conodont biozones after Ziegler and Sandberg (1990). Pena Quebrada section after Sanz-López et al. (1999). For legend see Figure 5. For location of sections see Figure 1.

Figura 10. Arquitectura estratigráfica Fameniense, con propuesta de correlación entre el sinclinal de Alba, el Alóctono de Olleros, y la Formación Vidrieros del Dominio Palentino. Biozonas de conodontos según Ziegler *and* Sandberg (1990). Pena Quebrada section según Sanz-López et al. (1999). Para la leyenda, véase Figura 5. Para la localización, véase Figura 1.

in the Olleros de Alba section gradually overlies the equivalent of the Vidrieros Formation. The unconformity is interpreted to lie between the Fueyo Formation of Middle Famennian age and the deposits of the equivalent of the Vidrieros Formation of Latest Famennian age, and consequently the unconformity represents a large part of the Upper Famennian. The equivalent of the Vidrieros Formation can be correlated with the coarse-grained succession of the Asturo-Leonese facies in the Alba syncline (Llombera Beds of the Ermita Formation), and with the fine-grained Vidrieros Formation of the Palencian facies area. Although the outermost part of the Asturo–Leonese facies domain contains the most complete Upper Devonian succession of the Cantabrian Zone (García-Ramos and Colmenero, 1981; Raven, 1983; Van Loevezijn, 1986), conodont faunas indicate that sequence boundary 4 of Van Loevezijn and Van Loevezijn Peña (2017), the Upper Devonian Unconformity, located above sequence C (Figure 2), represents a large part of the

Famennian. In the distal Palencian facies domain sequence boundary 4 is probably a correlative conformity.

Thus, the Allochthon of Olleros constitutes the southernmost part of the Asturo-Leonese facies area, with an original location assumed between the Asturo- Leonese facies deposits in the north, and the pelagic Palencian deposits in the south-west, and can palaeogeographically be interpreted as a transition between both facies domains. From the correlation panel a lateral fining of the Famennian succession and a change to more distal deposits can be inferred, from the proximal coarse-grained succession of the Alba syncline, via the Allochthon of Olleros, towards the fine-grained distal succession of the Palencian Domain. Also, an increase of the accommodation space can be inferred towards the Palencian succession.

7. Middle Famennian palaeogeography

The Upper Devonian coarsening-upward sequence C contains the Lower–Middle Famennian succession. It only occurs in the outermost part of the Cantabrian Zone; the External Zone of the Asturo–Leonese facies area. In the Alba syncline close to the uplifted northern area, a thick interval of sand bars and channel-fill deposits with mud-flat intercalations of the Ermita Formation was deposited (Van Loevezijn and Raven, 2021; Van Loevezijn, 2022) (Figure 11). Distally, the storm bedded succession of the Fueyo Formation occurs (Van Loevezijn, 2020; 2022). Unidirectional downwelling storm flows in response to coastal setup, facilitated by the steep shelf profile, transported large amounts of sediment and eroded the seafloor (see Midtgaard, 1996; Grundvag *et al.*, 2020; Jelby *et al.*, 2020). The bottom-current erosion resulted in shore-normal scours, indicating a consistent sediment transport towards the SSW (Van Loevezijn, 2020, 2022), approximately perpendicular to the E-W running palaeoshoreline (Sanchez de la Torre 1977, Raven 1983). Transport and erosion were followed by rapid deposition and reworking by oscillatory currents operating in the zone between fair-weather wave base and storm-wave base (see Grundvag *et al.*, 2020, Jelby, *et al.*, 2020). The basin-ward gradual decrease of the gravity-flow power resulted in a distal thinning of the tempestites, and a gradual decrease

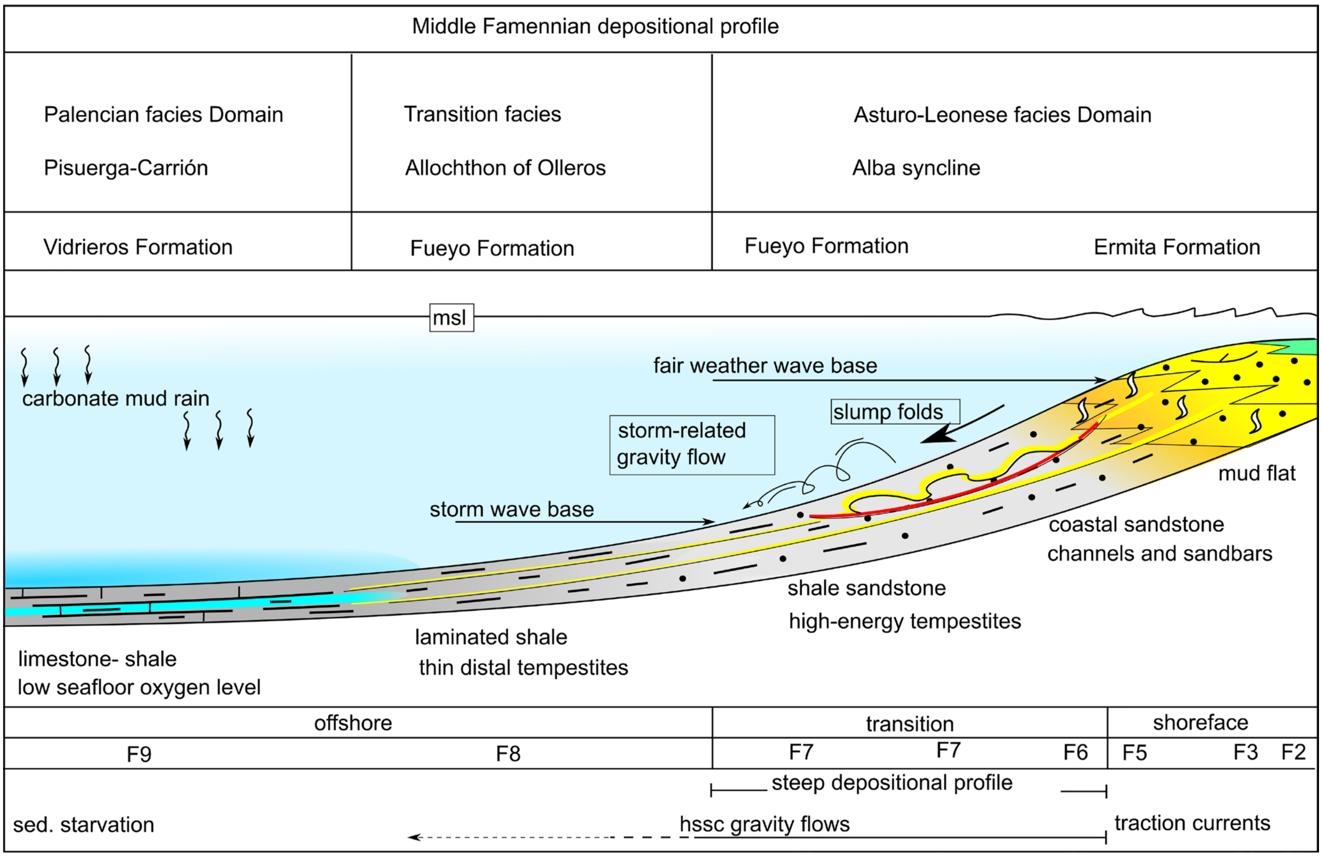

Figure 11. Early–Middle Famennian depositional profile. For legend see Figure 5.

Figura 11. Perfil deposicional durante el Fameniense Inferior-Medio. Para la leyenda, véase Figura 5.

of siliciclastic deposition in an offshore direction (Einsele, 2000). These fine-grained successions can be observed in the Allochthon of Olleros, where the northern sandy deposits are replaced by a shelf mudstone interval containing thin siltstone laminae. It is interpreted that the relative subsidence of the External Zone, creating the accommodation space for the tempestite succession, and the uplift of the nearby core area of the Cantabrian Zone in the north, see below, resulted in a steepening of the depositional profile. Fast tempestite sedimentation on these unstable slopes resulted in the collapse of the shallow-water sandy deposits and the downslope transport of unlithified or partly lithified sediments. Slump horizons can be observed in the shales and sandy shales of the Fueyo sections in the Alba syncline near Piedrasecha, Cuevas, Sorribos de Alba, Llombera and Matallana (Van Loevezijn, 2022).

In the distal offshore area outside the reach of the siliciclastic coastal supply sedimentation rate was very low. Siliciclastic sediment starvation facilitated the development of a condensed black calcareous mud succession, grading upward in grey brown muds (basal units 1 and 2 of the Vidrieros Formation, Peña Quebrada section of Sanz López *et al.*, 1999), indicating a deepening episode with oxygen-depleted sedimentation. The Lower–Middle Famennian dark calcareous shale facies occurs only in the Palencian pelagic facies area, and can be observed in the lower half of the Vidrieros Formation.

8. Late-Latest Famennian palaeogeography

The Upper Devonian Unconformity is the result of the Late Devonian uplift and erosion of the core of the Cantabrian Zone (Keller *et al.*, 2008; Van Loevezijn, 2017). This is a time when the most external margin of the Gondwana continent was incorporated into a subduction zone (Abati *et al.*, 2010, 2018; Díez Fernández *et al.*, 2016). So, deformation inboard this main continent can be framed within this major tectonic change in the evolution of Gondwana. The subsequent Late Famennian deepening episode is characterized in the distal parts of the basin by dark fine-grained calcareous shales and marlstones (Figure 12). In the proximal part a thin veneer of fluvial-tidal pebbly sandstones, conglomerate channels, and carbonate shoals extended over the former emerged inner part of the Asturo-Leonese Basin and the central parts of the Cantabrian Zone, where a thin, condensed succession was deposited with internal erosion surfaces, and hardground and mineralisation surfaces.

In the Alba syncline above the Upper Devonian unconformity, the few-metre-thick, coarse-grained Llombera Beds contain herringbone cross-bedding, fining-upward conglomerate channel fills, and sandy limestone intercalations, indicating a fluvial-tidally influenced shallow marine area, with carbonate shoals and channels in between. The Llombera Beds close to the Allochthon of Olleros, are finer grained (sections Piedrasecha and La

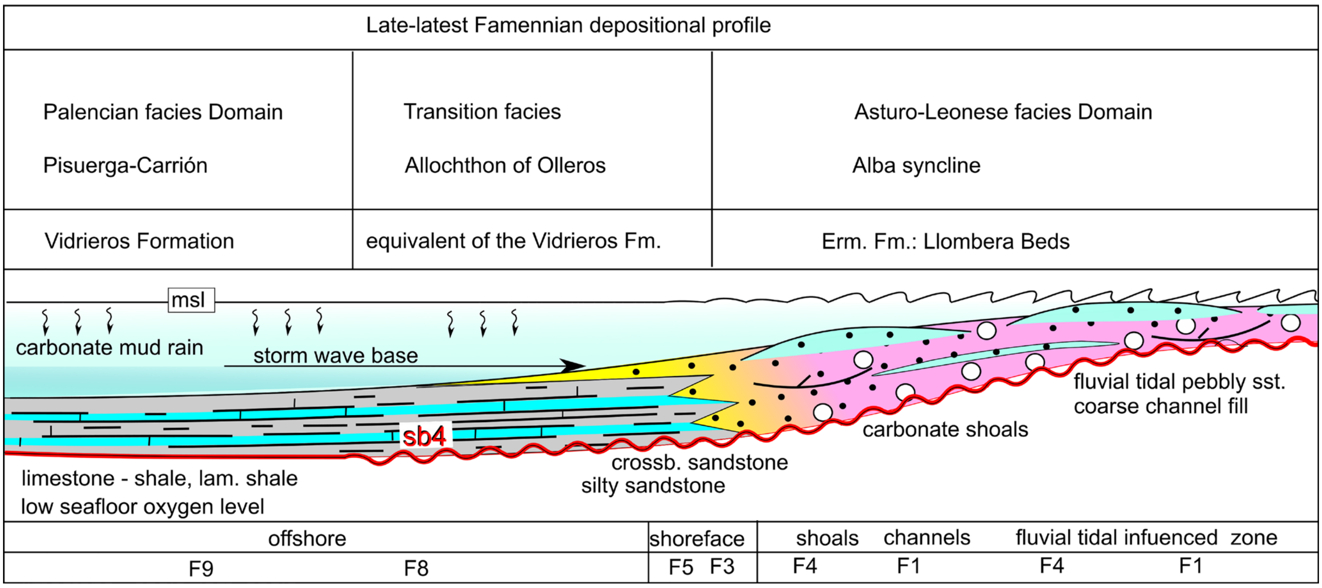

Figure 12. Late–latest Famennian depositional profile. For legend see Figure 5.

Figura 12. Perfil deposicional durante el Fameniense Superior y tardío. Para la leyenda, véase Figura 5.

Robla; Van Loevezijn, 2017). In the Allochthon of Olleros, the Llombera Beds consist of silty sandstones, and are only locally present. There, a succession of dark pyritic shales with interbedded carbonate mudstones of the equivalent of the Vidrieros Formation rests on the Upper Devonian Unconformity, and correspond to the limestones with levels of shales and marls in the upper part of the Vidrieros Formation of the Palencian facies domain (approximately unit 5 of the Peña Quebrada section, in Sanz López *et al.*, 1999).

9. Conclusions

In this study the stratigraphical relations of the southernmost Upper Devonian units of the Cantabrian Zone are investigated, and a stratigraphical model is proposed. The most important findings of the model are:

– The Allochthon of Olleros contains a unique fine-grained Famennian succession (equivalent of the Vidrieros Formation), which differs from the surrounding coarse-grained successions in the Alba syncline.
– The equivalent of the Vidrieros Formation consists of dark-grey shales and interbedded mudstone beds and lenses, and is very similar to the typical Devonian, fine-grained pelagic facies of the Palencian Domain.
– The equivalent of the Vidrieros Formation contains conodont faunas that can be correlated with the *costatus* Zone of the adapted conodont scheme for the Cantabrian Mountains of Higgins and Wagner-Gentis (1982) and Raven (1983), probably with the *expansa* Zone of the zonation scheme of Ziegler and Sandberg (1990), or with the *Bispathodus costatus* to *Bi. ultimus* zones of the revised global zonation of Spalletta *et al.* (2017).
– The Famennian succession of the Allochthon of Olleros can palaeogeographically be interpreted as transitional facies between the coarse-grained shallow marine Asturo–Leonese facies in the north, and the pelagic Palencian facies, interpreted as the distal southwestern continuation of the shallow marine domain.
– The Upper Devonian Unconformity in the Allochthon of Olleros is located between shales of the Fueyo Formation and the overlying shale–limestone alternation of the equivalent of the Vidrieros Formation. The hiatus represents a large part of the Famennian. Downdip in the distal Palencian facies domain, its correlative conformity displays no obvious facies contrast, and its stratigraphic position can only be approximated.

Acknowledgements

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References

Abati, J., Gerdes, A., Fernández-Suárez, J., Arenas, R., Whitehouse, M. J., and Díez Fernández, R. (2010). Magmatism and early-Variscan continental subduction in the northern Gondwana margin recorded in zircons from the basal units of Galicia, NW Spain. Geological Society of America Bulletin, 122, 219-235.

Abati, J., Arenas, R., Díez Fernández, R., Albert, R., and Gerdes, A. (2018). Combined zircon U-Pb and Lu-Hf isotopes study of magmatism and high-P metamorphism of the basal allochthonous units in the SW Iberian Massif (Ossa-Morena complex). Lithos, 322, 20-37.

Alonso, J. L. L., Marcos, A., and Suárez, A. (2009). Paleogeographic inversion resulting from large out of sequence breaching thrusts: the León Fault (Cantabrian Zone, NW Spain. A new picture of the external Variscan Thrust Belt in the Ibero-Armorican Arc. Geologica Acta, 7(4), 451-473.

Berelson, W. M., Balch, W. M., Najjar, R., Feely, R. A., Sabine, C., and Lee, K. (2007). Relating estimates of $CACO_3$ production, export, and dissolution in the water column to measurements of $CACO_3$ rain into sediment traps and dissolution on the seafloor: a revised global carbonate budget. Global Biochemical Cycles, 21, 1-15.

Brime, C., García Lopez, S., Bastida, F., Valin, M. L., Sanz Lopez, J., and Aller, J. (2001). Transition from diagenesis to metamorphism (Cantabrian Zone, northwestern Spain). Journal of Geology, 109, 363-379.

Brouwer, A. (1964). Deux facies dans le Dévonien des Montagnes Cantabriques Méridionales. Brevoria Geologica Asturica, 4, 3-10.

Díez Fernández, R., Arenas, R., Pereira, M. F., Sánchez Martínez, S., Albert, R., Martín Parra, L. M., Rubio Pascual, F. J., and Matas, J. (2016). Tectonic evolution of Variscan Iberia: Gondwana - Laurussia collision revisited. Earth-Science Reviews, 162, 269-292.

Dott, R. H., and Burgeois, J. (1982). Hummocky stratification: significance of its variable bedding sequences. Geol. Soc. Am., 93, 663-680.

Einsele, G. (2000). Sedimentary Basins, Evolution, Facies and Sediment Budget. - 2nd edition, Berlin (Springer), 792 pp.

Frankenfeld, H. (1984). Deckenbewegungen im Namur der östlichen Kantabrischen Gebirges und die damit verbundenen Vorstellungen über die Paläogeographie der Namur- und prä- Namur-Schichen. Zeitschrift der Deutschen Gesellschaft für Geowissenschaften, 135, 223-241.

García-López, S., and Sanz-López, J. (2002). Devonian to Lower Carboniferous conodont biostratigraphy of the Bernesga Valley section (Cantabrian Zone, NW Spain). In: S. García- López, and F. Bastida (Eds.), Paleozoic conodonts from northern Spain. Cuadernos del Museo Geominero, 1, Madrid, 163-205.

García-Ramos, J. C., and Colmenero, J. R. (1981). Evolución sedimentaria y paleogeogáfica durante el Devónico en la Cordillera Cantábrica. Program. Int. Corr. Geol. (2a parte). Real Academia de Ciencias Exactas, Físicas y Naturales, Segunda Parte, 61-71.

Grundvag, S. A, Jelby, M. E., Olaussen, S., and Sliwinska, K. K. (2020). The role of shelf morphology on stormbed variability and stratigraphic architecture, Lower Cretacious, Svalbard. Sedimentology, 68(1), 196-237.

Gutiérrez-Alonso, G., Fernández-Suárez, J., Pastor-Galán, D., Johnston, S. T., Linnemann, U., Hofmann, M., Shaw, J., Colmenero, J. R., and Hernández, P. (2015). Significance of detrital zircons in Siluro-Devonian rocks from Iberia. Journal of the Geological Society, 172, 309-322.

Higgins, A. C., Wagner-Gentis, H. T., and Wagner, R. H. (1964). Basal Carboniferous strata in part of Northern León, Spain. Bulletin de la Belge de Géologie Paléontology et Hydrology, 72(2), 205-248.

Higgins, A. C., and Wagner-Gentis, H. T. (1982). Conodonts, goniatites and the biostratigraphy of the earlier Carboniferous from the Cantabrian Mountains, Spain. Palaeontology, 25(2), 313-350.

Jelby, M. E. Grundvag, S. A, Hansen, W. A., Olaussen, S., and Stemmerik, L. (2020).

Tempestite facies variability and storm-depositional processes across a wide ramp: Towards a polygenetic model for hummocky cross-stratification. Sedimentology, 67, 742-781.

Julivert, M. (1971). Décollement tectonics in the Hercynian Cordillera of NW Spain. American Journal Science, 270, 1-29.

Keller, M., Bahlburg, H., Reuther, C. D., and Weh. A. (2007). Flexural to broken foreland basin evolution as a result of Variscan collisional events in northwestern Spain. In: R. D. Hatcher, M. P. Carlson, J. H. McBride, and J. R. Martínez Catalan (Eds.), 4-D Framework of the Continental Crust. Geological Society of America, Memoir, 200, 1-22.

Keller, M., Bahlburg, H., and Reuther, C. D. (2008). The transition from passive to active margin sedimentation in the Cantabrian Mountains, Northern Spain: Devonian or Carboniferous? Tectonophysics, 461, 414-427.

Kullmann, J., and Schönenberg, R. (1975). Geodynamische und palökologische Entwicklung im Kantabrischen Variszikum (Nordspanien). Ein interdiziplinäres Arbeitskonzept. Neues Jahrbuch für Geologie und Paläontologie Monatshefte, 3, 151-166.

Leyva, F., Matas, J., and Rodríguez Fernández., L. R. (1984). Mapa y memoria de la Hoja n° 129 (La Robla). Mapa geológico de España E. 1:50000. Segunda serie (MAGNA), Primera edición. IGME, 98 pp.

Lobato-Astorga, L. (1977). Geología de los valles altos de los ríos Esla, Yuso, Carrión y Cea (NE de León, NO. de Palencia, SO de Santander). Institución Fray Bernardino de Sahagún, León, 192 pp.

Lotze, F. (1945). Zur Gliederung der Varisziden in der Iberischen Meseta. Geotektonische Forschungen, 6, 78-92.

Lüning, S., Wendt, J., Belka, Z., and Kaufmann, B. (2004). Temporal–spatial reconstruction of the early Frasnian (Late Devonian) anoxia in NW Africa: new field data from the Ahnet Basin (Algeria). Sedimentary Geology, 163, 237-264.

Marcos, A., and Pulgar, F. J. (1982). An approach to the tectonostratigraphic evolution of Cantabrian thrusts and fold belt, Variscan Cordillera of NW Spain. Neues Jahrbuch für Geologie und Paleontologie Abhandlungen, 163, 256-260.

Martín-Merino, G., Fernández, L. P., Colmenero, J. R., and Bahamonde, J. R. (2014). Mass-transport deposits in a Variscan wedge-top foreland basin (Pisuerga area, Cantabrian Zone, NW Spain). Marine Geology, 356, 71-87.

Matte, P. (1991). Accretionary history and crustal evolution of the Variscan belt in Western Europe. Tectonophysics, 196, 309-337.

Midtgaard, H. H. (1996). Inner-shelf to lower-shoreface hummocky sandstone bodies with evidence of geostrophic influenced combined flow, Lower Cretaceous, west Greenland. Journal of Sedimentology, 66, 343-353.

Peréz-Estaún, A., Bastida, F., Alonso, J. L., Marquínez, J., Aller, J., Álvarez-Marrón, J., Marcos, J., and Pulgar, J. A. (1988). A thin-skinned tectonics model for an arcuate fold and thrust belt: the Cantabrian Zone (Variscan Ibero-Armorican Arc). Tectonics, 7, 517-537.

Pastor-Galán, D., Guttiérrez-Alonso, G., Weil, A. B., Fernández-Suárez, J., Johnston, S. T., and Murphy, J. B. (2012). A virtual tour of the Ibero-Armorican orocline. In: S. Johnson, and G. Rosenbaum (Eds.). Journal of the virtual explorer, 43(2): doi: 10.3809/virtex.2011.00292.

Pastor-Galán, D., Merino, M., and Corrochano, D. (2014). Timing and structural evolution in the limb of an orocline; The Pisuerga Carrión unit (southern limb of the Cantabrian Orocline, NW Spain). Tectonophysics, 622, 110-121.

Raven, J. G. M. (1983). Conodont biostratigraphy and depositional history of the Middle Devonian to Lower Carboniferous in the Cantabrian Zone (Cantabrian Mountains, Spain). Leidse Geologische Mededelingen, 52, 265-339.

Raven, J. G. M., and Van Der Pluijm, B. A. (1986). Metamorphic fluids and transtension in the Cantabrian Mountains of northern Spain: an application of the conodont colour alteration index. Geological Magazine, 123(6), 673-681.

Reuther, C. D. (1977). Das Namur im südlichen Kantabrischen Gebirge (Nordspanien), Krustenbewegungen und Faziesdifferenzierungen im Übergang Geosynklinale–Orogen. Clausthaler Geologische Abhandlungen, 28, 1-122.

Rodríguez Fernández, L. R., García Alcalde, J. L., and Menéndez-Álvarez, J. R. (1985). La sucesión del Devónico Superior y Carbonífero Inferior en el sinclinal de Alba (León, NO de España). Compte Rendu X Congreso International de Estratigrafía y Geología del Carbonífero, 1, 133-146.

Sanz-López, J., García López, S., and Montesinos, J. R. (1997). Conodontos de la Formación Cardaño en el límite Frasniense-Fameniense (unidad del Gildar Montó, Dominio Palentino, Zona Cantábrica). XIII Jornadas de Paleontología, Reunión Internacional Proyecto 351 PICG, La Coruña; Libro de resúmenes y excursiones, 234-237.

Sanz-López, J., García López, S., and Arbizu, M. A. (1999). Biostratigraphy and sedimentation of the Vidrieros Formation (Middle Famennian – Lower Tournaisian) in the Gildar-Montó unit (northwest Spain). In: Serpagl, E. (ed), Studies on Conodonts. Proceedings of the seventh European Conodont Symposium. Bolletin della Societá Paleontologica Italiana, 393-406.

Savdra, C. E., and Bottjer, D. J. (1986). Trace fossil model for reconstruction of paleo-oxygenation in bottom waters. Geology, 14(1), 3-6.

Sjerp, N. (1967). The geology of the San Isidro-Porma area (Cantabrian Mountains, Spain). Leidse Geologische Mededelingen, 38, 55-128.

Spalletta, C., Perri, M. C., Over, D. J., and Corradini, C. (2017). Famennian (Upper Devonian) conodont zonation: revised global standard. Bulletin of Geosciences, 92(1), 31-57.

Van Adrichem Bogaert, H. A. (1967). Devonian and Lower Carboniferous conodonts of the Cantabrian Mountains (Spain) and their stratigraphic application. Leidse Geologische Mededelingen, 39, 1-129.

Van Loevezijn, G. B. S. (1983). Upper Devonian block movements and sedimentation in the Asturo-Leonese Basin (Cantabrian Mountains, Spain). Leidse Geologische Mededelingen, 52(2), 185-192.

Van Loevezijn, G. B. S. (1986). Stratigraphy and facies of the Nocedo, Fueyo and Ermita formations (Upper Devonian to lowermost Carboniferous) in León, N Spain. Scripta Geologica, 81, 1-116.

Van Loevezijn, G. B. S. (1988a). Upper Devonian to Lowermost Carboniferous concretion types and their stratigraphic significance (Cantabrian Mountains, N Spain). Trabajos de Geología, 17, 57-66.

Van Loevezijn, G. B. S. (1988b). The Famennian of the Cantabrian Mountains, northwestern Spain. Neues Jahrbuch für Geologie und Paläontologie, Monatshefte, 5, 278-292.

Van Loevezijn, G. B. S., and Van Loevezijn Peña, A. L. M. (2017). Facies cycles and sequences in the Upper Devonian of the Bernesga area. Zeitschrift der Deutschen Gesellschaft für Geowissenschaften, 168(3), 313-339.

Van Loevezijn, G. B. S. (2020). Forebulge dynamics and sedimentary response of an initial Variscan foreland basin; the Upper Devonian of the southern Cantabrian Mountains, N Spain. Zeitschrift der Deutschen Gesellschaft für Geowissenschaften, 171(3), 249-276.

Van Loevezijn, G. B. S., and Raven, J. G. M. (2020). Facies patterns and depositional processes of two Frasnian mixed siliciclastic-carbonate systems in the Cantabrian Mountains, NW Spain. Geologos, 26, 1-23.

Van Loevezijn, G. B. S., and Raven, J. G. M. (2021). The Upper Devonian of the river Sil area: a stratigraphic correlation between León and Asturias, northern Spain. Boletín Geológico y Minero de España, 132(5), 325-354.

Van Loevezijn, G. B. S. (2022). Upper Devonian soft sediment deformation structures in Frasnian and Famennian tempestites and related sediments, Cantabrian Mountains, Spain. Zeitschrift der Deutschen Gesellschaft für Geowissenschaften, (in press). https://doi.org/10.1127/zdgg2022/0324.

Van Veen, J. (1965). The tectonic and stratigraphic history of the Cardaño area, Cantabrian Mountains, Northwest Spain. Leidsche Geologische Mededelingen, 35, 45-104.

Wagner, R. H., Winkler Prins, C. F., and Riding, R. E. (1971). Lithostratigraphic units of the lower part of the Carboniferous in northern León, Spain. Trabajos de Geología, 4, 603-663.

Weil, A. B, Gutiérrez-Alonso, G., and Wicks, D. (2013). Investigating the kinematics of local thrust sheet rotation in the limb of an orocline: a paleomagnetic and structural analysis of the Esla tectonic unit, Cantabrian-Asturian Arc. NW Iberia. International Journal of Earth Sciences, 102, 43-60.

Ziegler, W. (1962). Phylogenetische Entwicklung stratigraphisch wichtige Conodont-Gattungen in der Manticoceras-Stufe (Oberdevon Deutschland). Neues Jahrbuch für Geologie und Paleontologie Abhandlungen, 114, 142-168.

Ziegler, W., and Sandberg, C. A. (1990). The Late Devonian Standard Conodont Zonation. Courier Forschungsinstitut Senckenberg, 121, 1-115.