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RESEARCH ARTICLE

Lithostratigraphic variability and boundaries of a Givetian reef unit (Cantabrian Zone, Spain)

Variabilidad litoestratigráfica y límites de una unidad arrecifal Givetiense (Zona Cantábrica, España)

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Key point:

Analysis of the Portilla Formation sedimentation model of the Cantabrian Zone.

Analysis of the existing stratigraphic Portilla-Nocedo boundary definitions.

Proposal of a Portila-Nocedo boundary definition for the Cantabrian Zone according to the International Commission on Stratigraphy guidelines.

ABSTRACT

The Portilla Formation represents one of the major Devonian reef developments of the Cantabrian Zone and is overlain by the (mainly) siliciclastic succession of the Nocedo Formation. There is no agreement concerning the definition of the Portilla-Nocedo boundary, and several subdivisions occur in the literature. In this paper, we investigate the lithostratigraphic variability of the reefal succession and the stratigraphical consequences of the various subdivisions. The review supports the merger of the reefal limestone succession as one stratigraphic unit, the Portilla Formation, and rejects the separation of the Valdoré Limestone as a basal reefal development of the overlying Nocedo Formation.

Keywords: Givetian; Frasnian; Reef; Cantabrian.

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Análisis del modelo de sedimentación de la Formación Portilla en la Zona Cantábrica.

Análisis de las definiciones estratigráficas existentes del límite Portilla-Nocedo.

Propuesta de una definición del límite Portilla-Nocedo para la Zona Cantábrica según las directrices de la Comisión Internacional de Estratigrafía.

RESUMEN

La Formación Portilla representa uno de los principales desarrollos arrecifales devónicos de la Zona Cantábrica y está cubierta por la sucesión (principalmente) siliciclástica de la Formación Nocedo. No existe consenso sobre la definición del límite Portilla-Nocedo, y en la bibliografía se encuentran diversas subdivisiones. En este trabajo, investigamos la variabilidad litoestratigráfica de la sucesión arrecifal y las implicaciones estratigráficas de las distintas subdivisiones. La revisión respalda la integración de la sucesión de calizas arrecifales en una sola unidad estratigráfica, la Formación Portilla, y rechaza la separación de la Caliza de Valdoré como un desarrollo arrecifal basal de la Formación Nocedo.

Palabras clave: Givetiense; Frasniense; Arrecife; Zona Cantábrica.

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1. Introduction

The Devonian in the Asturian and Leonese part of the Cantabrian Mountains represents a shallow marine succession of about 2000 m, consisting of shales, sandstones, conglomerates and limestones, with up to 300 m thick reef accumulations (Brouwer, 1964) (Fig. 1). Barrois (1882) introduced the stratotype of the “Calcaire de Candás” near Candás Village (Coastal Ranges, Asturias). For the southern slope of the Cantabrian Mountains, Comte (1959) described the “Calcaire de Portilla” with its

stratotype on the east side of the "Arroyo de la Portilla" in the valley of the river Torío, north of Matallana Estación (Fig. 1), province of Leon. The Candás and Portilla Formations are equivalents (used respectively in Asturias and León) for which one name would be sufficient, but both are now widely accepted. The Portilla Formation is Givetian in age (Truyols *et al*., 1990) and represents one of the major Devonian reef developments of the Cantabrian Zone. The formation has a thickness that varies from about 75 to about 150 m over short distances (Reijers, 1972; Ten Have, 1979; Raven, 1983). The Portilla Formation is overlain by the (mainly) siliciclastic succession of the Nocedo Formation, Frasnian in age (Van Loevezijn, 1986). The boundary between the reef limestones of the Portilla Formation and the overlying siliciclastics of the Nocedo Formation is one of the major Devonian transitions in the Cantabrian Zone. However, there is no agreement concerning the definition of the Portilla-Nocedo boundary, which is the subject of an ongoing discussion. The boundary was based on the first occurrence of the brachiopod *Apousiella bouchardi* (Comte, 1959). Although fossils as rock-forming particles are part of the physical rock characteristics, their taxonomy is *not* a valid lithological basis for defining a lithostratigraphic unit, and the International Commission on Stratigraphy (https://stratigraphy.org/guide/litho) recommends defining the boundaries of lithostratigraphic units based on lithological criteria. Therefore, Raven (1983) proposed to draw the boundary between the Portilla and Nocedo Formations above the uppermost limestone bed with a thickness of at least 10 cm and the shale-siltstone-marl unit overlying the limestones of the Portilla Formation in the outer part of the Cantabrian Zone must be part of the Nocedo Formation, and cannot be part of the Portilla Formation (Figure 3 of García Alcalde, 2010). At some locations, Comte (1959) interpreted the upper part of the reef deposits as a local reef development of the overlying sandy Nocedo Formation, named it Calcaires de Valdoré, and included the unit in the base of the Nocedo Formation. Following stratigraphic/lithological criteria, this paper proposes not to use the Valdoré Limestone unit, and to incorporate the entire reefal limestone succession in the Portilla Formation.

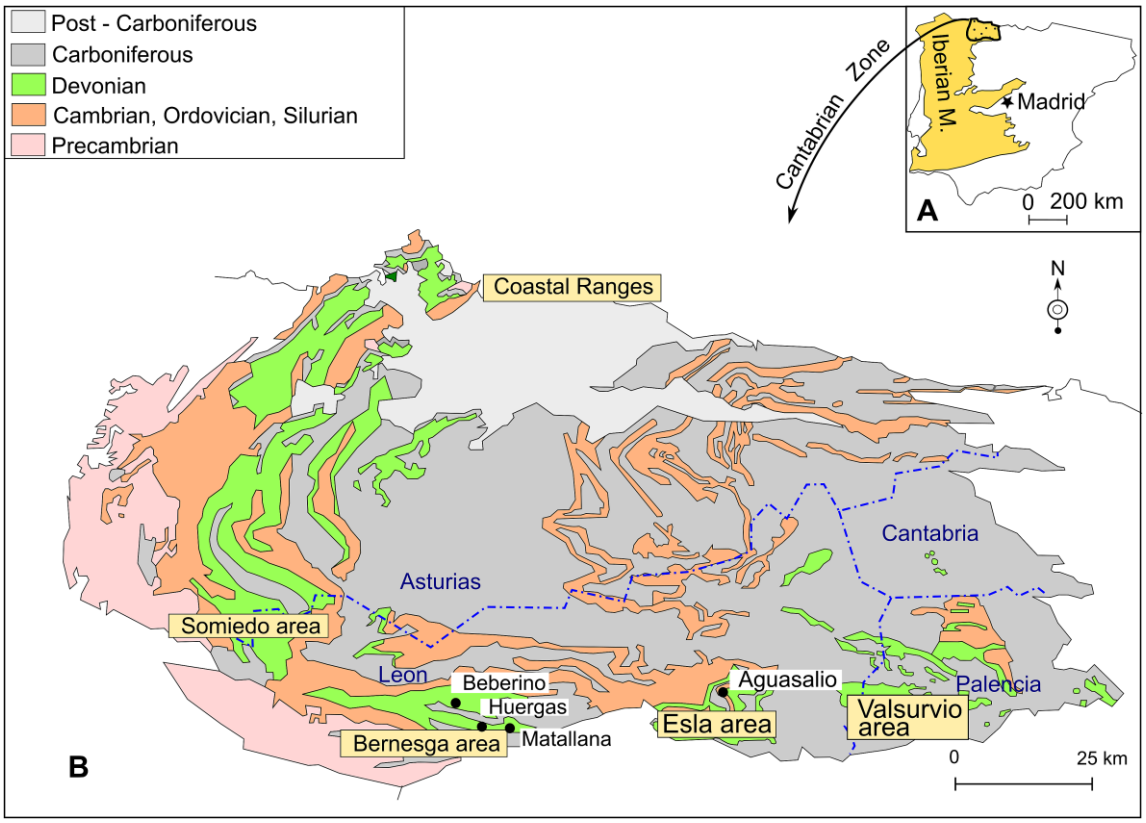

Figure 1. A) Situation map of the Iberian Peninsula with the Iberian Massif and the Cantabrian Zone. B) Map of the Cantabrian Zone with the Devonian distribution, location of sections and areas mentioned in the text.

Figura 1. A) Mapa de situación del Macizo Ibérico y la Zona Cantábrica en la Península Ibérica. B) Mapa de la Zona Cantábrica con la distribución devónica, localización de secciones y áreas mencionadas en el texto.

2. Portilla - Candás subdivisions

Many authors described the limestones of the Portilla and Candás Formations in detail (e.g., Reijers, 1972, 1973, 1974, 1980; Mohanti, 1972; Van der Baan, 1970; Ten Have, 1979; Bereskin in Sánchez de la Torre, 1977; Bereskin, 1978; Raven, 1983; Fernandez Martínez *et al*., 1994), each with their own local facies model and subdivision. The general sedimentological model (Reijers, 1972; Raven, 1983), a standard facies division for the whole Cantabrian region, involves backreef facies with mud-supported limestones and marls, a reef tract with biostromal and biohermal limestones, and forereef facies of bioclastic and (sandy) oolitic limestone grading to deeper water marls and shales (Fig. 2). Note that, although the Candás and Portilla Formations are reefal limestones, a considerable amount of silt and sand can be admixed or intercalated between the ooidal-grainstone layers of the fore-reef deposits, and silty shale intercalations in the backreef deposits (Reyers, 1972; Ten Have, 1979). Generally, no significant amounts of siliciclastic sediment are present in the massive boundstones of the reef facies.

Generally, the Portilla and Candás Formations are composed of a lower interval of bioclastic, ooidal limestones of the fore reef facies, transitionally overlain by an episode of reef development. Detrital limestones, shales and sandstones unconformably overlie the reef-bearing unit. Above, a unit with a second reef development occurs. Based on these general lithological distribution patterns, several different subdivisions have been proposed for both formations (Fig. 3). Guided by these local subdivisions, Raven (1983) proposed a subdivision for the whole Cantabrian region to compare and correlate both formations all over the Cantabrian Zone; a lower and an upper biostromal reef limestone (members A and C), and a more siliciclastic middle member (Member B). This subdivision can be recognised immediately in the field (Fig. 4). The general facies distribution patterns of Reijers (1973) and Raven (1983) were used by Fernandez *et al.* (1997) to develop a sequential analytic platform evolution model for the Candás and Portilla Formations.

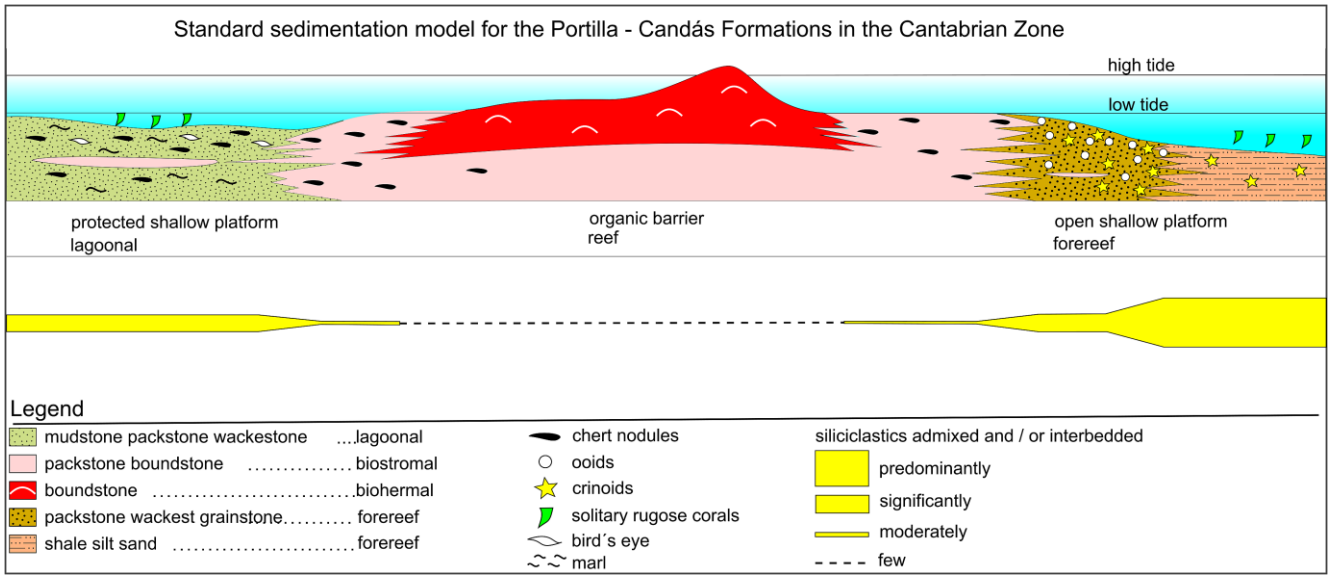

Figure 2. General sedimentation model of the Portilla – Candás Formations with a backreef, reeftract and forereef (modified after Reijers, 1972; Bereskin in Sanchez de la Torre, 1977 and Raven, 1983).

Figura 2. Modelo general de sedimentación de las Formaciones Portilla – Candás con arrecife posterior, arrecife transversal y arrecife anterior (modificado según Reijers, 1972; Bereskin en Sanchez de la Torre, 1977 y Raven, 1983).

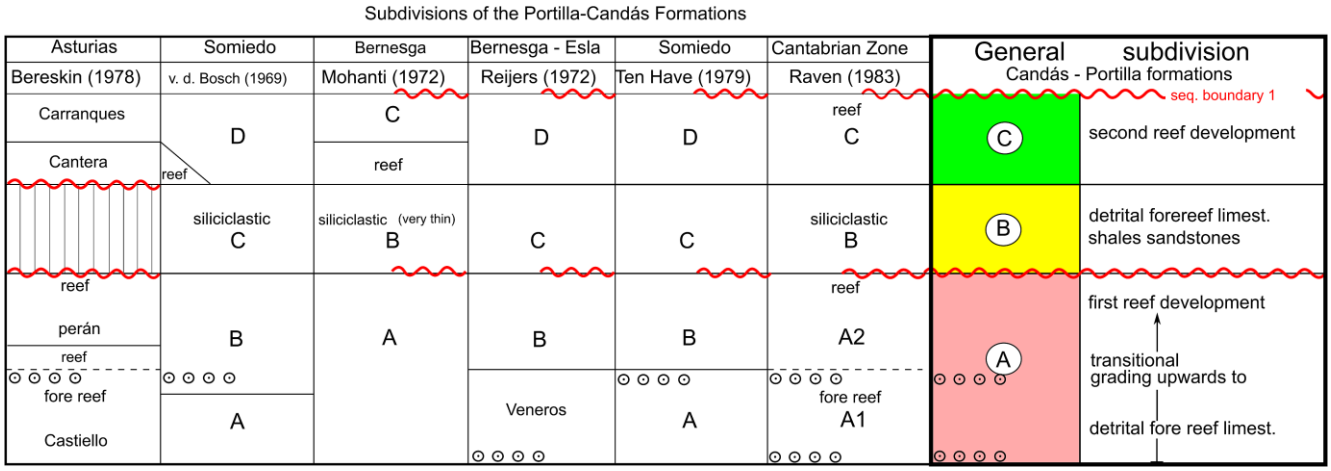

Figure 3. Different subdivisions in members of the Portilla and Candás Formations. The proposed general subdivision (changed after Raven, 1983) is to the right.

Figura 3. Diferentes subdivisiones en miembros de las Formaciones Portilla y Candás. La subdivisión general propuesta (modificada según Raven, 1983) se encuentra a la derecha.

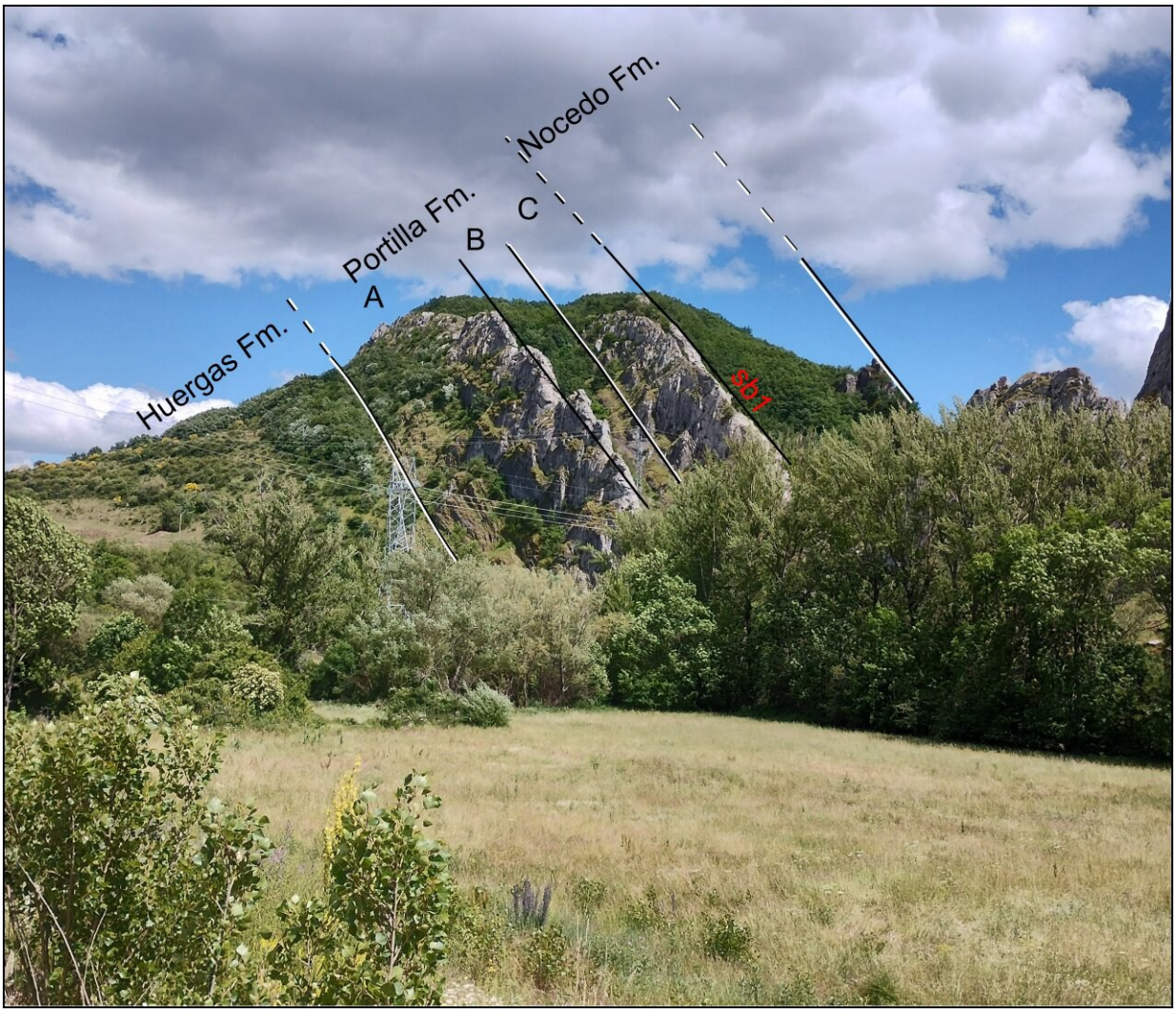

Figure 4. Subdivision of the Portilla Formation north of Beberino.

Figura 4. Subdivisión de la Formación Portilla al norte de Beberino.

3. Biostratigraphy

There is no agreement concerning the age of the Caldas - Portilla Formations. Many authors drew the Givetian-Frasnian boundary within the formations (e.g., Comte, 1959; Brouwer, 1964; Mohanti, 1972; Reijers, 1972; Raven, 1983; García Lopez, 1987). In more recent work the formations are considered to be Givetian in age, though they can reach locally into the Frasnian (Truyols *et al.,* 1990; García Alcalde *et al*., 2002: Fig. 6.4). García Alcalde (1996) defined 29 faunal intervals in the Devonian of the Cantabrian Zone, of which the numbers 20-22 correlate (partly) with the Portilla Formation and number 23 with the overlying Valdoré Limestone. The uppermost limestones of the Portilla Formation underlying the Nocedo Formation contain conodonts of the Givetian *hermanni-cristatus* Zone (Van Loevezijn, 1988: sample BGC1; García López & Sanz- López, 2002a). The trilobites *Phacops rana* aff. *rana, Baradocryphaeus matallanensis,* the tentaculitoid *Striatostiliolina striata*, and the bivalve *Buchiola* all occur a few metres above the Portilla-Nocedo boundary (Van Loevezijn, 2020). The conodonts *Polygnathus decorosus* and *Icriodus asymmetricus* were found in burrowed calcareous concretions 3 m above the base of the Nocedo Formation near Barrios de Gordón (Van Loevezijn, 1988: sample BGC2 1988). These faunal elements indicate a probable Frasnian age. Conodonts from the basal part of a calcareous development in the siliciclastic Nocedo Formation, 144 m above the Portilla-Nocedo boundary (Huergas section in the Bernesga valley), indicate the Upper *falsiovalis* Zone (García López & Sanz-López, 2002a). This places the Portilla – Nocedo bounding surface in the southern slope of the Cantabrian Zone close to the Givetian– Frasnian boundary. Conodont faunas from the uppermost part of the Candás Formation at the Cantabrian coast, the northern mountain slope, represent the early Frasnian (García-López & Sanz-López, 2002b). Therefore, in the coastal ranges, the upper boundary of the Candás limestone is slightly younger than that of León. Boundaries of lithostratigraphic units commonly cut across time surfaces (https://stratigraphy.org/guide/litho), and the Portilla-Nocedo boundary is no exception: it cuts across the Givetian-Frasnian time surface.

However, the bounding surface between Portilla and Nocedo Formations is also a sequence boundary (sb1) (Van Loevezijn & Van Loevezijn Peña, 2017), which updip is an unconformity with subaerial exposure and erosion, and downdip is a correlative conformity (Van Loevezijn, 2020). Therefore, locally, the upper part of the Portilla Formation is missing, as was demonstrated by Reijers (1972), Van Staalduinen (1973) and Raven (1983).

4. Valdoré limestone

Comte (1938, 1959) interpreted the upper part of the Givetian reef succession in the Esla area as a local reefal development of the overlying siliciclastic Nocedo Formation, named it Calcaires de Valdoré, and included the reef unit in the basal part of the Nocedo Formation. Comte (1959) explicitly mentioned the difficulty separating the unit from its underlying Portilla reef succession, with similar reefal lithofacies. Thus, he based the Calcaires de Valdoré on its supposed geologic connection with the Nocedo Formation. Still, from a lithological point of view, it should be part of the limestones of the Portilla Formation. Later, the unit was named Valdoré Limestone as a reefal development of the Nocedo Formation by subsequent authors (e.g., Truyols *et al.*, 1990; García Alcalde *et al.*, 2002, among others) (Fig. 5), without a formal description with type section. The difficulty of the lower Valdoré Limestone boundary was also noticed by Truyols *et al*. (1990). Due to the definition of the Valdoré Limestone, it interfingers with the Portilla and Nocedo Formations. There is a strong opposition against such subdivisions (e.g., Wheeler & Mallory, 1959). The approximately 100 m thick unit (García Alcalde, 1995) consists of calcareous sandstones and shales with biostromal reef deposits. Although the lower boundary is unclear, subsequent authors correlated the unit with the members B and C of the Portilla Formation (Fernandez *et a*l.,1997; García Alcalde, 2012: Fig. 13).

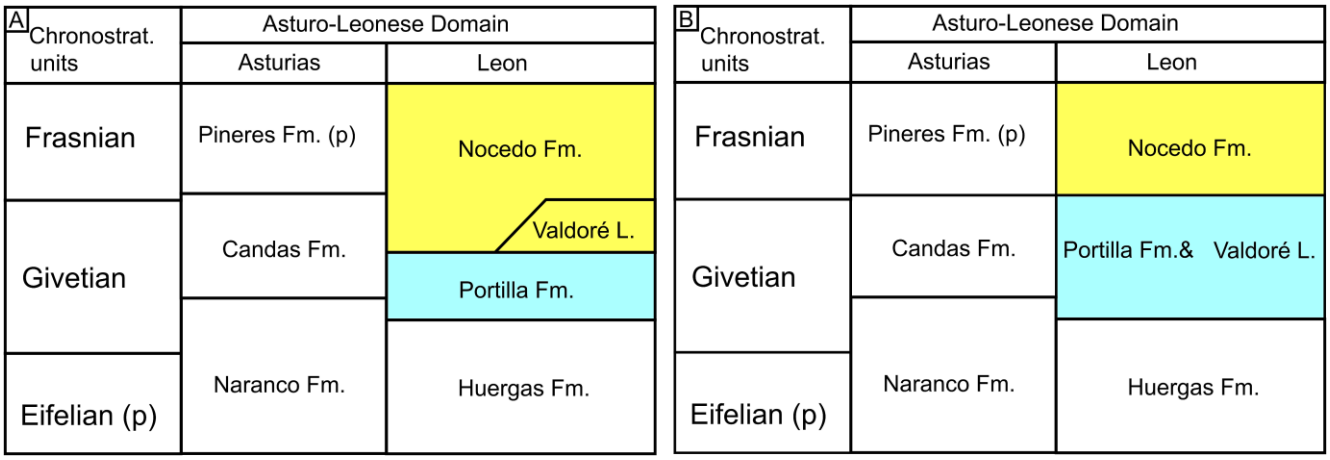

Figure 5. A) Middle-Upper Devonian lithostratigraphic scheme of the Cantabrian Zone with the Valdoré Limestone as a local reefal succession included in the basal part of the Nocedo Formation, which correlates with the Late Givetian. Slightly modified after Méndez-Bedía *et al.* (1994): Figure 3; García Alcalde (1996): Figure 4; García Alcalde *et al.* (2002): Figure 6.6. B) Middle-Upper Devonian lithostratigraphic scheme of the Cantabrian Zone with the local reefal succession of the Valdoré Limestone as part of the Portilla Formation. Interpretation after García Alcalde *et al.* (2002): Figure 6.4. Yellow=Nocedo Formation, blue=Portilla Formation.

Figura 5. (A) Esquema litoestratigráfico del Devónico Medio-Superior de la Zona Cantábrica con la Caliza de Valdoré como sucesión arrecifal local incluida en la parte basal de la Formación Nocedo, que se correlaciona con el Givetiense Superior. Ligeramente modificado de Méndez-Bedía *et al.* (1994): Figura 3; García Alcalde (1996): Figura 4; García Alcalde *et al.* (2002): Figura 6.6. B) Esquema litoestratigráfico del Devónico Medio-Superior de la Zona Cantábrica con la sucesión arrecifal local de la Caliza de Valdoré como parte de la Formación Portilla. Interpretación según García Alcalde *et al.* (2002): Figura 6.4. Amarillo=Formación Nocedo, azul=Formación Portilla.

Siliciclastic intercalations are common in the Portilla fore reef and backreef successions and are part of the sedimentation model of the Portilla Formation (Reijers, 1972; Ten Have, 1979; Raven, 1983), as local sand, silt and shale intercalations at different stratigraphic levels within the reefal limestone succession. Consequently, it is very difficult, or even impossible, to consistently mark the base of the Valdoré Limestone. Moreover, the reefal limestone facies of both the Portilla Formation and the Valdoré Limestone are very similar; there is hardly any lithological distinction between them; both are reef-bearing limestone units (Mendez Bedía *et al*., 1994), and separation depends entirely on the recognition of the underlying siliciclastic layer, locally challenging to recognise. Therefore, most authors ignore the Valdoré Limestone and gather the entire reefal limestone succession as one lithostratigraphic unit: the Portilla Formation (Reyers, 1972; Ten Have, 1979; Mohanti, 1972; Raven, 1983; Van Loevezijn, 1986, among others) (Fig. 6). On neither the IGME geological maps of the 70's, 80's, and 90's of the past century, neither the 1:50000 maps of the 50's, 60's, and 70's of the southern Cantabrian Mountains from the Geological Institute Leiden, a Valdoré Limestone unit is indicated; the entire reef limestone unit is mapped as Portilla Formation. The Valdoré Limestone is not a mappable lithological unit: it contains a questionable lower boundary and has similar lithofacies to the underlying Portilla reef limestones.

The upper bounding surface of the Portilla Formation straddles the Givetian-Frasnian boundary, and the basal part of the overlying Nocedo is probably Frasnian, generally not Givetian (Van Loevezijn, 1988, 2020; García Alcalde *et al.,* 2002: figure 6.4). Its basal part consists of sandstones close to the palaeohighs of the core area of the Cantabrian Zone and becomes shalier towards the outer part of the Cantabrian Zone. We have to bear in mind that the Nocedo Formation consists of a mixed siliciclastic–carbonate succession, and the siliciclastic sediment, therefore, often contains considerable amounts of carbonate admixed and/or intercalated (Van Loevezijn & Raven, 2017). However, the calcareous sandstones, shales, and (locally) sandy-shaly limestones in the basal part differ from the bio-constructed reef limestones of the underlying Portilla Formation, and field observations (Reijers, 1972; Mohanti, 1972; Raven, 1983; Van Loevezijn, 1986) do not support a lateral transition between the upper Portilla reefs and basal Nocedo sandstones, as proposed by Comte (1938, 1959).

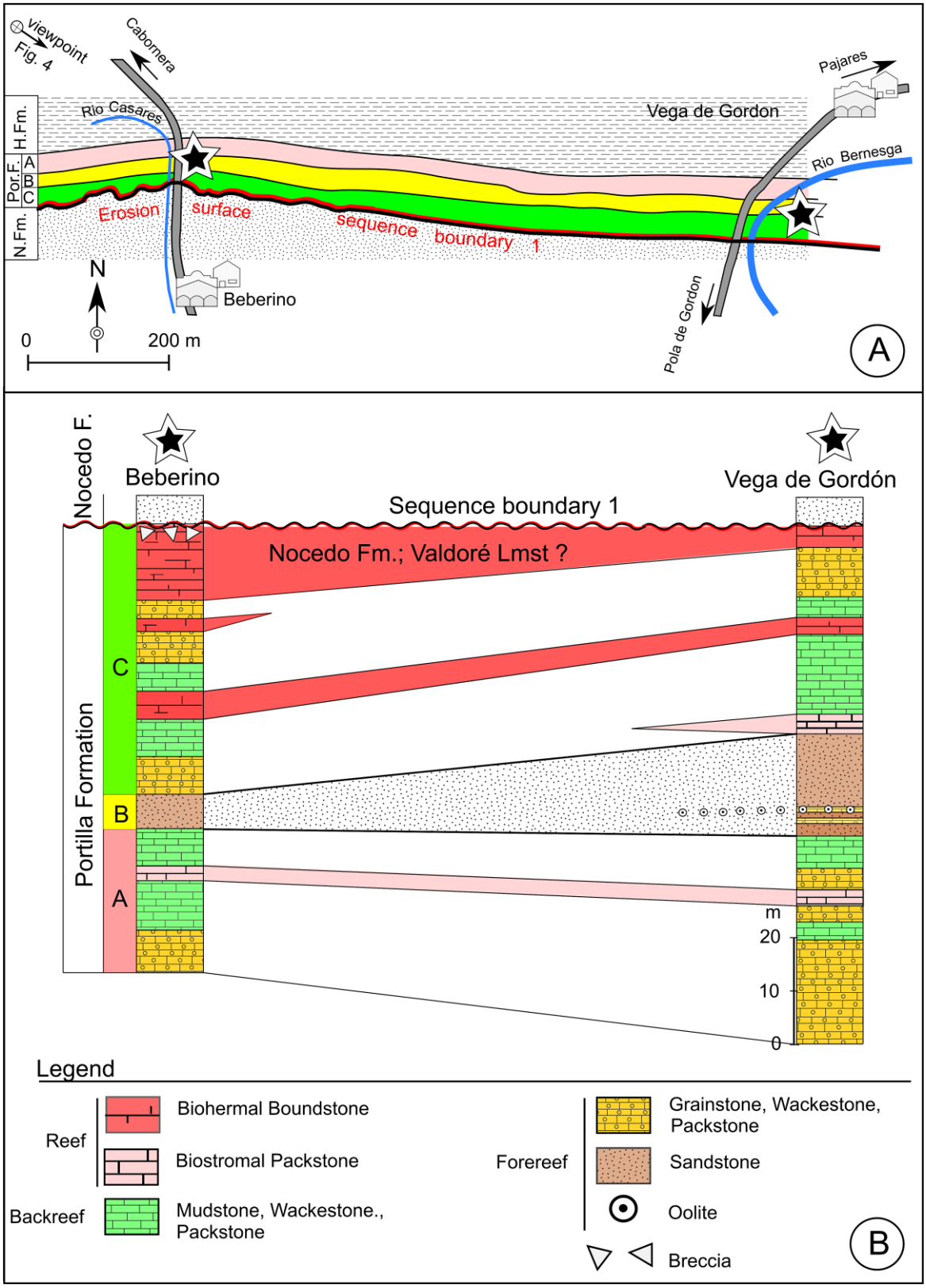

Figure 6. A) Map of the Portilla Formation between the villages Beberino and Vega de Gordón, with the members and the erosional surface of sequence boundary 1 indicated. B) Cross-section through the Portilla Formation in the Bernesga area; sections were measured by Reijers (1972) with some observations of the author.

Figura 6. A) Mapa de la Formación Portilla entre los pueblos de Beberino y Vega de Gordón, con los miembros y la superficie erosiva del límite de secuencia 1 indicados. B) Sección transversal a través de la Formación Portilla en el área de Bernesga; las secciones fueron medidas por Reijers (1972) con algunas observaciones del autor.

5. *Sensu stricto* and *sensu lato*

García Alcalde *et al.* (e.g., 1985, 2002) introduced a Portilla Formation *sensu stricto* (Portilla Formation without the Valdoré Limestone) and a Portilla Formation *sensu lato* (Portilla Formation *s.s.* and Valdoré Limestone). A similar stratigraphic situation occurs when calcareous parts of the overlying Nocedo Formation are included in the Portilla Formation as a sandy development of the reefal limestone formation (see the Aquasalio section in Frankenfeld, 1979: Fig. 18). Although the latter stratigraphic interpretation is not widely accepted, it is very confusing and now in literature various Portilla upper boundaries are used: Portila *s.s*, Portilla *s.l.*, Portilla Formation *sensu* Frankenfeld (1979) (Fig. 7). With the same arguments, one can of course also define a *sensu stricto* and a *sensu lato* Nocedo Formation… Depending on the Portilla definition, the age of the formation top varies considerably, from Middle-Late Givetian to Frasnian (Truyols *et al*., 1990; García Alcalde, 1995, 1996; García Lopez & Sanchez Lopez, 2002a). It is not always indicated, and often one has to guess the Portilla definition used (e.g., see Menendez Bedía *et al.,*1994, with the Valdoré unit indicated in the stratigraphic scheme, but in the sections the entire reefal succession is included in the Portilla Formation). This also affects the interpretation of the fossil content of the Portilla-Nocedo boundary successions.

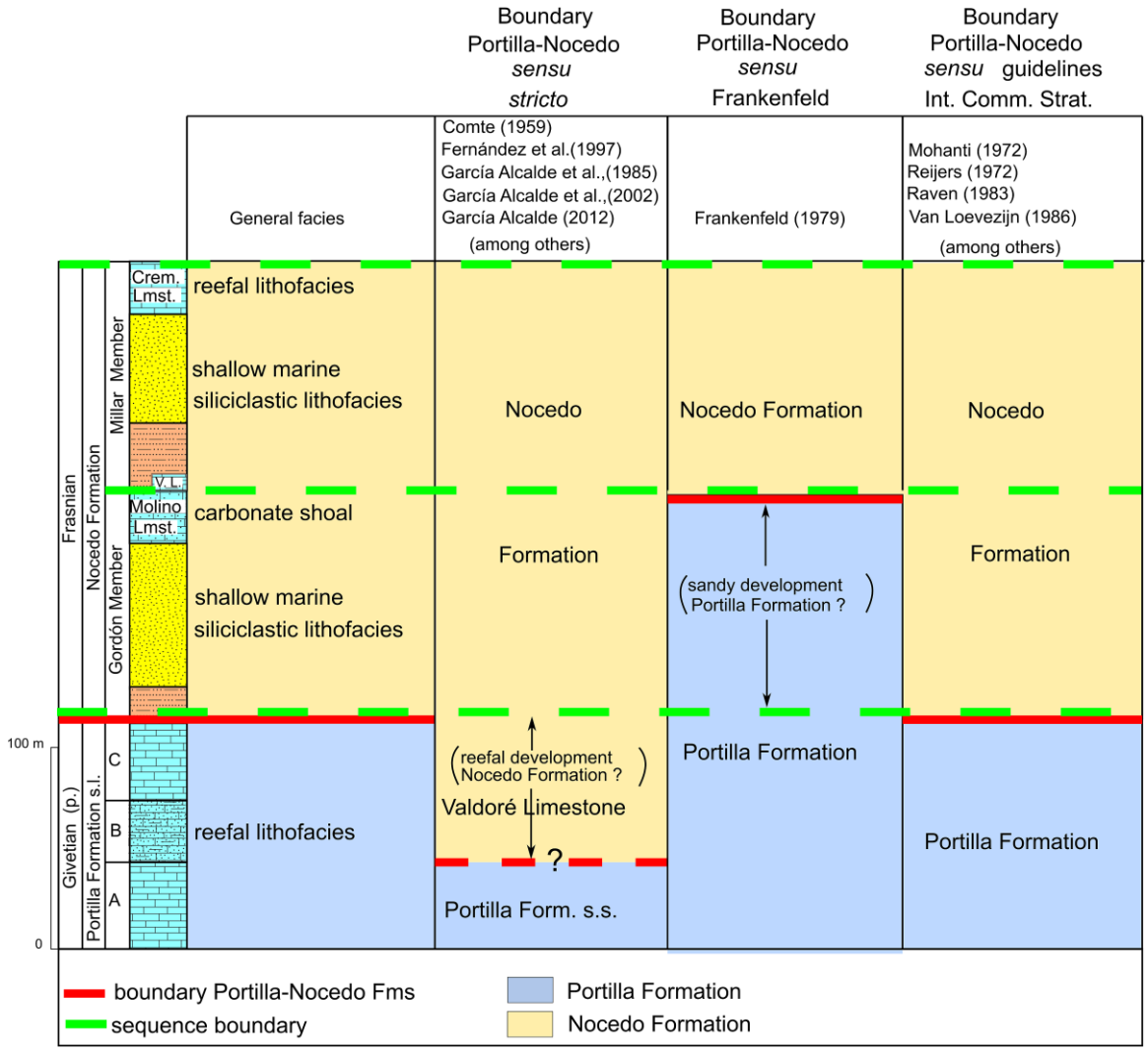

Figure 7. The different interpretations of the Portilla-Nocedo boundary. At the right is the proposed boundary location according to the guidelines of the International Commission on Stratigraphy; V. L. =Varga Limestone, Crem=Crémenes Limestone.

Figura 7. Las diferentes interpretaciones del límite Portilla-Nocedo. A la derecha se muestra la ubicación propuesta del límite según las directrices de la Comisión Internacional de Estratigrafía; V. L. =Caliza Varga, Crem =Caliza Crémenes.

6. ICS guidelines

The International Commission on Stratigraphy (https://stratigraphy.org/guide/litho) provides guidelines for lithostratigraphic units. "*A lithostratigraphic unit is a body of rocks that is defined and recognized on the basis of its lithologic properties (…) and not by their inferred age, the time span they represent, inferred geologic history, or manner of formation (…) No formation is considered justifiable and useful that cannot be delineated at the scale of geologic mapping practiced in the region (…)*". Thus, it is recommended that boundaries between lithostratigraphic units be defined based on lithological criteria. The Valdoré Limestone has the same lithofacies as the underlying reef deposits, and the lower bounding surface is such that it can be complicated to recognise in the field. Therefore, the Valdoré Limestone is not a mappable unit. In summary, according to the international stratigraphic guidelines, the Valdoré Limestone is unjustifiable.

7. Conclusions

The Valdoré Limestone contains reefal lithofacies very similar to the lithofacies of the underlying Portilla Formation. It is defined based on its inferred manner of formation as a local (questionable) reefal development of the Nocedo Formation, and its lower contact is not well defined, making a correlation difficult or doubtful. As such, it is not a justifiable lithostratigraphic unit according to the International Commission on Stratigraphy guidelines. The threefold Portilla-Candás subdivision in the Cantabrian Zone eliminates the need for the Valdoré Limestone unit. Therefore, it is preferable not to use it and to incorporate the entire reefal limestone succession in the Portilla Formation and the calcareous siliciclastic succession in the overlying Nocedo Formation, making the Devonian stratigraphic subdivision of the Cantabrian Zone without the *sensu stricto* and *senso lato* definitions, more robust and less confusing.

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Authorship contribution statement

Gerard van Loevezijn: Investigation, Methodology, Validation, Writing – original draft.

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