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Some aspects of current State of Knowledge on Triassic series on both sides of the Central Atlantic Margin / *Quelques aspects de l'état des connaissances des séries triasiques de part et d'autre de la Marge Atlantique*

State of the art of Triassic palynostratigraphical knowledge of the Cantabrian Mountains (N Spain)

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Abstract. The present-day Cantabrian Mountains (North Spain) represent the western continuation of the Pyrenean-Cantabrian Orogen, which arose from a Cenozoic collision between the Iberian and Eurasian plates. The early Alpine sedimentary record of the Cantabrian basin is represented by the latest Carboniferous-Permian and Triassic rocks, mostly of continental origin. A lack of palaeontological data has led, until recently, to erroneous interpretations of the stratigraphic position of this sedimentary record. Within the framework of the Triassic sedimentary record in northern Spain, the precise age of six samples was determined and they were grouped into four palynological assemblages according to their taxonomic composition. The study of these assemblages includes a review of all the Triassic assemblages published to date as regards the Cantabrian Mountains, thereby optimising our Triassic palynostratigraphical knowledge of this area enabling comparisons with other Triassic assemblages of Central and SW Europe.

Keywords. Palynology, Ladinian, Carnian, Norian, Rhaetian.

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1. Introduction

Today's Cantabrian Mountains (North Spain) run parallel to the Bay of Biscay and it is considered the western range of the Pyrenean-Cantabrian Orogen that arose when the Iberian and Eurasian plates collided during the Cenozoic [Barnolas and Pujalte, 2004, Gallastegui et al., 2002, Martín-González and Heredia, 011a,b, Pulgar et al., 1999]. The early Alpine sedimentary record of the Cantabrian basin mostly consists of Carboniferous, Permian and Triassic rocks. These rocks have been traditionally analysed in separate zones broadly related to the three main geographical provinces of this area: Asturias, Cantabria and Palencia (Figure 1).

Until recently, the Permian and Triassic sedimentary record of the Cantabrian Mountains was mainly based on works from the second half of the last century (e.g., De Jong 1971, García-Mondejar et al. 1986, Martínez-García 1981, Suárez-Rodríguez 1988). Recent syntheses have tried to describe the complex stratigraphic nomenclature that existed in this region [López-Gómez et al., 2002, Martínez-García, 1990, 991a,b, Robles, 2004, Robles and Pujalte, 2004], but the lack of precise palaeontological data and the complex tectonics in the Cantabrian Mountains ruled out any definition of a detailed stratigraphic succession. As a result, numerous lithostratigraphic nomenclatures have been used for the same units, and these units have even been wrongly laterally correlated because they were only valid locally (e.g., Suárez-Rodríguez [1988], for the Asturias province; Gand et al. [1997], Martínez-García [991a,b]; for the Cantabria and Palencia provinces). In spite of these confusing correlations, studies based on tectono-sedimentary analysis made it possible to define the main fault lineaments and their post-Variscan activity [Alonso et al., 1996, Cadenas et al., 2018, Cámara, 2017, García-Espina, 1997, Julivert, 1971, Martín-González and Heredia, 011a,b, Merino-Tomé et al., 2009, Pulgar et al., 1999, Rodríguez-Fernández et al., 2002].

A recent multidisciplinary study by López-Gómez et al. [2019] has provided a new stratigraphic chart for the Permian and Triassic record of the Cantabrian Mountains, using new age attributions assigned to new lithostratigraphic units based on palaeontological data. The newly defined stratigraphic succession of these units was established for the different geographical provinces of the Cantabrian Mountains, and clearly shows lateral continuity between them. The 30 Mry long period since the early-middle Permian transition until the Middle Triassic is particularly striking because it lacks any sedimentary record. There are also other notable internal disruptions and unconformities between the lithostratigraphic units. Based on these characteristics, López-Gómez et al. [2019] have described six lithostratigraphic units (formations) from the latest Carboniferous to the Late Triassic (Figures 2, 3): the San Tirso, Acebal, Sotres, Cicera, Rueda and Transición formations. Figure 3 shows the location of samples collected along the four stratigraphic sections studied in this work.

Palynological data for the Triassic of the Cantabrian Mountains are scarce. Most of the palynological samples described prior to this work were located without stratigraphic precision and assigned to broad attributions, including general terms for facies such as "Buntsandstein" or "Keuper".

In the Triassic record, only three palynological samples have been described in previous works in the "Buntsandstein facies" (later named Cicera Formation (Fm), Figure 2). These samples were obtained near Verbios village (Palencia Province, sample 1349) and Tres Mares peak (Cantabrian Province, samples 1379 and 1410) [Sánchez-Moya et al., 2005, Sopeña et al., 2009] (Figure 4). The samples indicated a Ladinian age (Middle Triassic) and Carnian age (Late Triassic), respectively. In the "Keuper facies", Salvany [990a,b] identified a Norian assemblage near Aguilar de Campoo (Palencia province). In similar facies, two palynological samples were described near Reinosa (Cantabria province, Figure 4) and attributed an early-middle Norian age by Calvet et al. [1993]. Finally, in the same facies, two samples recovered in laminated gypsum near Poza de la Sal (southern Cantabria Province) were assigned to the late Carnian-early Norian by Barrón et al. [2001]. In the Transición Unit, defined by Suárez-Vega [1974] for the lithofacies of the transition between the Upper Triassic and Lower Jurassic, Martínez-García et al. [1998] established a late Rhaetian age near Huerces (Asturian Province). Later, in the same unit, Barrón et al. [2002, 2005, 2006] assigned different analysed samples to a Rhaetian age (Figure 4). Unfortunately, the biostratigraphic value of these assemblages is relative as they were not figured (or are only partially figured), thus preventing the verification of these taxo-

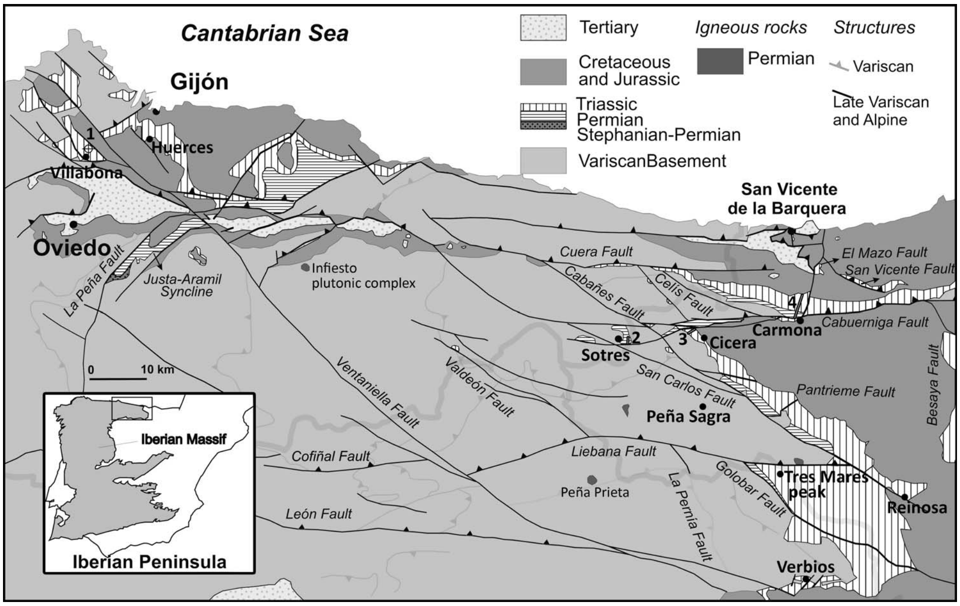

Figure 1. Simplified geological map of the central Cantabrian Mountains with the location of the studied sections and localities. Studied sections: 1 - Villabona, 2 - Sotres, 3 - Cicera, 4 - Carmona. See the sections in Figure 3. (Modified from López-Gómez et al. [2019]).

nomic classifications.

The focus of this work is the state of the art in Triassic palynological studies of the Cantabrian Mountains, along with descriptions of the four complete figured assemblages, briefly referred to previously in López-Gómez et al. [2019], using the new lithostratigraphic succession defined by these authors. These assemblages are also compared to similar ones described in different units in central and southern Europe.

2. Geological setting

The study area is located in the central part of the Cantabrian Mountains, N Spain, which includes the provinces of Cantabria, Asturias and Palencia (Figure 1). The area, located between the Astur-Galician and Basque-Cantabrian regions, flanks the middle of the Pyrenean-Cantabrian Orogen to the west and east, respectively [Martín-González and Heredia, 011a] (Figure 1). The two regions show a different evolution during the Mesozoic and Cenozoic. The western region, which presents a highly deformed Variscan basement, is almost devoid of Mesozoic sediments, and the Cenozoic synorogenic record is restricted to isolated depressions [Martín-González and Heredia, 011b]. In contrast, the eastern Basque-Cantabrian region is characterised by a thick and complete Middle Triassic to Cretaceous sedimentary record related to extensional basins [Espina, 1997, Pulgar et al., 1999].

The Uppermost Carboniferous-Lower Permian and Triassic rocks lie unconformably on the Palaeozoic basement. This basement, which represents a folded and thin-skinned belt, belongs to the foreland of the Variscan Orogen [Julivert, 1971, Rodríguez-Fernández and Heredia, 1987]. In the northern Palencia province, the latest Carboniferous sedimentary record was affected by the last emplacements of the end of the main Variscan deformation (e.g., Picos de Europa region), including foreland deposits towards the south [Merino-Tomé et al., 2009, Rodríguez-Fernández and Heredia, 1987, Rodríguez-Fernández et al., 2002]. During the early Permian, small-isolated basins developed due to collapse of the Variscan belt [Pérez-Estaún et al., 1991]. These basins were controlled by lineaments related to Variscan faults that remained active until the end of the early Permian [Rodríguez-Fernández et al., 2002], when this area was located near the equator [Ziegler, 1993].

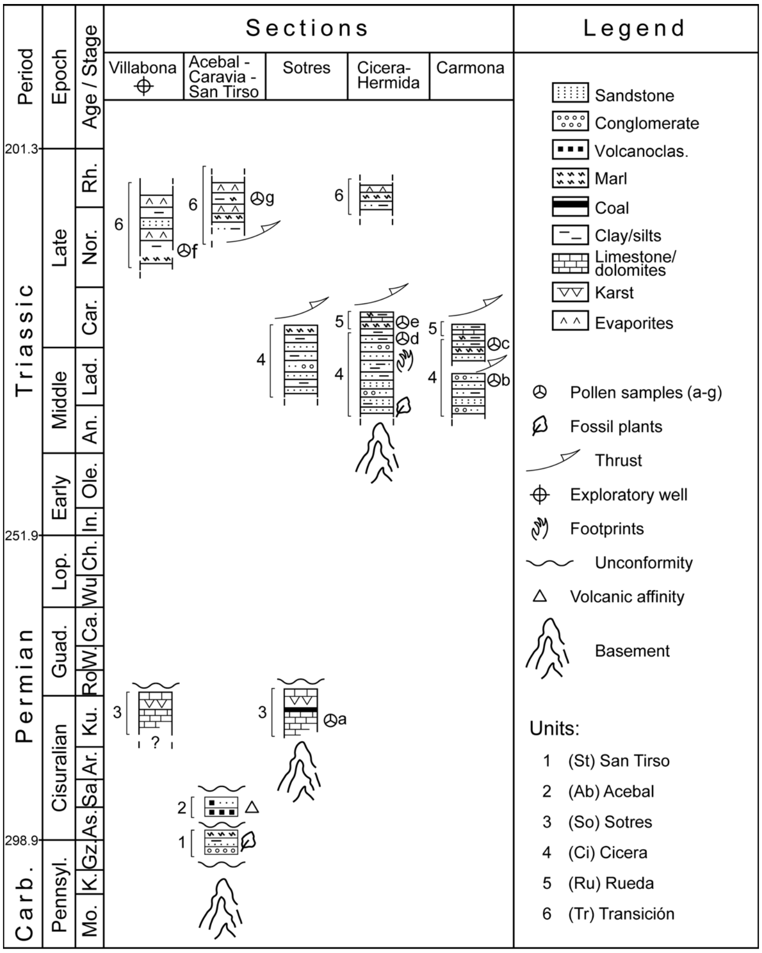

Figure 2. Stratigraphic location of the differentiated Permian and Triassic lithostratigraphic units (1 to 6) based on new palaeontological data in the Cantabrian Mountains. Palynological samples: (a) So1, (b) Ca1, (c) SP5, (d) Cic11, (e) Cic12, (f) VBO17, (g) Cueli (modified from López-Gómez et al. [2019]).

Substantial plate reorganisation started during the beginning of the Mesozoic with an extensional event related to the break-up of Pangea and opening of the Bay of Biscay [Ziegler, 1993, Ziegler and Stampfli, 2001]. This extensional phase expanded until the Late Triassic-Early Jurassic but was reactivated in the Late Jurassic-Early Cretaceous [Cadenas et al., 2018, Espina, 1997, Tugend et al., 2014]. The present-day relief of the Cantabrian Mountains is the consequence of an Eocene-early Oligocene crustal uplift episode [Fillon et al., 2016, Martín-González et al., 2012, 2014] that continued locally until the latest Miocene [Martín-González and Heredia, 011b].

2.1. *Triassic lithological units*

This work is based on the Triassic stratigraphical scheme recently proposed in the Cantabrian Mountains by López-Gómez et al. [2019]. In order to locate accurately the palynological assemblages studied here, a summary of the three Triassic formations defined in that scheme is outlined below (Figures 2, 3):

Cicera Fm. This unit near Cicera village was first described in López-Gómez et al. [2019] (Figure 1). It is mostly comprised of fine-medium grained red sandstones alternating in the middle-upper half with red dark lutites. The Cicera Fm rests unconformably

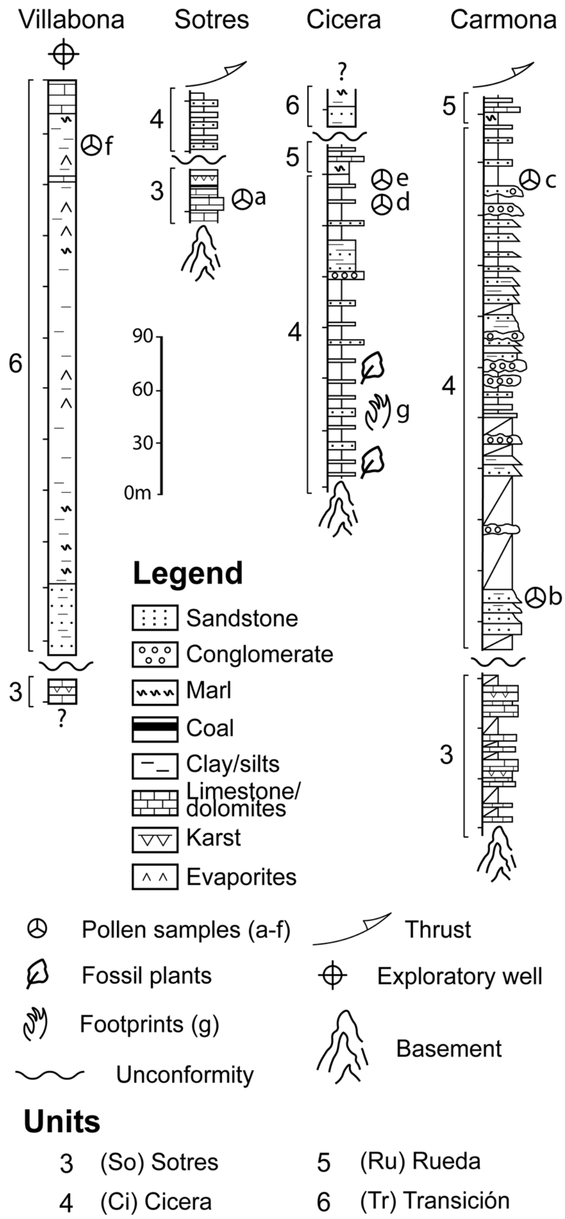

Figure 3. Field sections and borehole Villabona where the samples were obtained. For a more detailed lithological and sedimentological description see López-Gómez et al. [2019]. Samples: a. SO-1 [Juncal et al., 2016], b. Carmona 1, c. S. Pedro-5, d. Cic11, e. Cic12, f. VBO-17, g. Cic-x. Location of the samples (in m from the base of the sections): a - 23 m, b - 35 m, c - 411 m, d - 92.5 m, e - 93 m, f - 394 m, g - 18 m. Sample Cu-1, described in the text, was obtained from De la Horra et al. [2012] at Cueli village, near Villabona borehole, and in similar stratigraphical position to VBO-17 sample. Geographical location of the sections: Villabona: 43° 27′ 50″, 5° 50′ 18″; Sotres: 43° 14′ 09″, 4° 44′ 18″; Cicera: 43° 14′ 10″, 4° 34′ 12″; Carmona: 43° 16′ 50″, 4° 20′ 18″.

on various previous units, or directly on the basement. It represents the classic Triassic “Buntsandstein facies”, as described by García-Mondejar et al. [1986] and Robles and Pujalte [2004] for La Cohilla

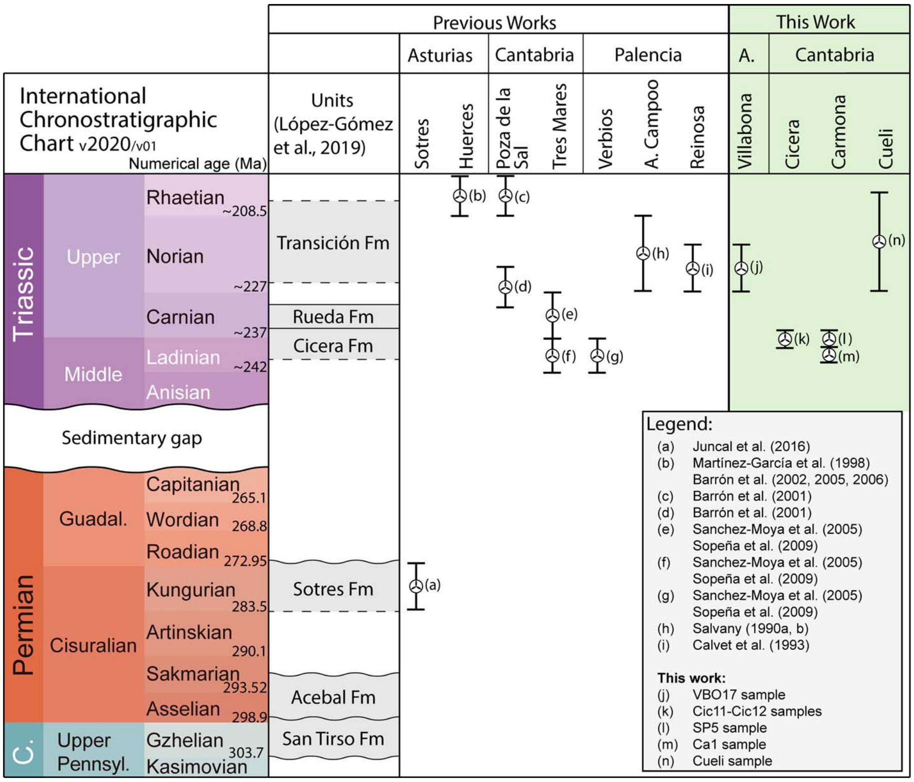

Figure 4. Age attributions of lithostratigraphic units based on palynological assemblages in the Cantabrian Mountains. Comparison with previous works.

section, north of the Peña Sagra peak, in southern Cantabria (Figure 1). It is interpreted as the development of mixed sandy and gravelly braided fluvial systems in the lower part of the unit, evolving into increased floodplain deposits in the middle part. This unit, however, has been erroneously described as the Caravia Fm in different areas, and considered Lower or upper Permian, depending on the study (e.g., Martínez-García 991a,b, Martínez-García et al. 2001, Wagner and Martínez-García 1982). Prior to the work of López-Gómez et al. [2019], this misinterpretation generated erroneous stratigraphic correlations.

Rueda Fm. This unit was first described in López-Gómez et al. [2019]. It lies conformably on the Cicera Fm and consists of yellowish-grey dolomites and green marls to form a total thickness of 3.5 m. The unit was interpreted by these authors as shallow-carbonate, marine inter-supratidal deposits.

Transición Fm. This unit was first described by Suárez-Vega [1974] and later also studied by Suárez-Rodríguez [1988] and Manjón et al. [1992] and related to the Upper Triassic–Lower Jurassic sedimentary record. It consists of red-green marls with intercalated red sandstones, and shows gypsum beds and limestones at the top. The unit was interpreted by these authors as deposited under shallow marine and supratidal conditions.

3. Material and method

The studied palynological samples are stratigraphically located in in three different sections (Sotres, Cicera and Carmona) and one borehole (near Villabona village) described in López-Gómez et al. [2019]. Detailed sedimentary data are shown in this latter work, but a sketch of these units is shown in Figures 2 and 3.

Table 1. List of species recorded from study area

Assemblages / Taxa List	*Alisporites grauvogeli* Klaus 1964	*Alisporites opii* Daugherty 1941	*Aratrisporites granulatus* Klaus 1960	*Calamospora tener* (Leschik) Mädler 1964	*Camerosporites secatus* Leschik 1956	*Chordasporites singulichorda* Klaus 1960	*Classopollis torosus* (Reissinger) Balme 1957	*Classopollis zwolinskae* (Lund) Traverse 2004	*Duplicisporites granulatus* (Leschik) Scheuring 1970	*Enzonalasporites vigens* Leschik 1955	*Illinites chitonoides* Klaus 1964	*Lunatisporites noviaulensis* (Leschik) de Jersey 1979	*Microcachryidites doubingeri* Klaus 1964	*Microcachryidites fastidioides* (Jansonius) Klaus 1964	*Ovalipollis cultus* Scheuring 1970	*Ovalipollis ovalis* (Krutzsch) Scheuring 1970	*Ovalipollis pseudoalatus* (Thiergart) Schuurman 1976	*Paracirculina quadruplicis* Scheuring 1970	*Patinasporites densus* Leschik 1955	*Plaesiodictyon mosellanum* Wille 1970	*Praecirculina granifer* (Leschik) Klaus 1960	*Quadraeculina anellaeformis* Malyavkina 1949	*Rhaetipollis germanicus* Schulz 1967	*Triadispora crassa* Klaus 1964	*Triadispora epigona* Klaus 1964	*Triadispora falcata* Klaus 1964	*Triadispora plicata* Klaus 1964	*Triadispora staplinii* (Jansonius) Klaus 1964	*Triadispora suspecta* Klaus 1964	*Triadispora verrucata* (Schulz) Scheuring 1970	*Vallasporites ignacii* Leschik 1956	*Vitreisporites pallidus* (Reissinger) Nilsson 1958	*Alisporites* sp.	*Calamospora* sp.	*Chasmatosporites* sp.	*Chordasporites* sp.	*Cycadopites* sp.	*Platysaccus* sp.	*Trachysporites* sp.	*Verrucosisporites* sp.
Carmona	■		■		■	■			■				■				■					■				■		■	■						■		■	■		
San Pedro	■			■	■				■		■	■	■	■		■	■				■			■		■	■	■		■		■	■	■		■				■
Cicera	■	■	■		■	■			■	■					■		■			■				■	■	■	■	■			■									■
Villabona					■		■	■	■								■	■	■				■										■						■	

Samples Ca1 and SSP5 were collected at 35 m and 411 m respectively from the base of the Carmona Section (Figures 2 and 3). Cic11 and Cic12 were obtained at 92.5 m and 93 m in the upper part of Cicera section near Cicera village (Figures 2, 3). Sample VBO17 was obtained at 394 m from the Villabona borehole exploratory well (cuN-69B) in the Transición Fm via the MINERSA mining company (Villabona village, Asturias, Spain) and Sample Cu-1, described in the text, was obtained from De la Horra et al. [2012] at Cueli village, near the Villabona borehole, in a similar stratigraphic position to VBO17 sample.

Palynological samples were processed in the Palynology Laboratories of the Department of Geodinámica, Estratigrafía y Paleontología (Complutense University of Madrid) and the Geosciences Department (University of Vigo). In the former, laboratory-standard palynological procedures were used. To remove carbonate and silicate minerals, hydrochloric acid (HCl, 10%) and hydrofluoric acid (HF 40%) were first added and the samples then were stirred with 10% hydrochloric acid for 45 min to remove secondary compounds produced during the hydrofluoric acid attack. At the University of Vigo, a dispersing agent was added to facilitate filtering and sieving at 10 μm. The prepared slides were examined at this University's facilities using a Leica DM 2000 LED microscope and a Leica ICC50 W camera to take photos at ×1000 magnification.

4. Results

Six new palynological samples were obtained from the Triassic record of the Cantabrian Mountains (Figure 3), four in the Cicera Fm (Samples Ca1, SP5, Cic11 and Cic12) and two in the Transición Fm (samples VBO17 and Cu-1) (Figure 4). The Cueli Beach sample (Cu-1 sample), which belongs to the Transición Fm, is attributed to the Norian-middle Rhaetian interval due to the presence of *Classopollis* spp. and *Ovalipollis pseudoalatus* (Thiergart) Schuurman 1976. This latter sample is poorly preserved with no robust palynological assemblage, but we consider it is worthwhile to indicate its existence. The other five positive samples have been grouped into four assemblages due to their similar composition (Table 1, Figure 5). The palynological assemblages are figured separately in the supplementary data (Supplementary Figures S1, S2, S3 and S4).

5. Discussion

The scarcity of the Triassic palaeontological data in the Cantabrian Mountains and the misguided lithostratigraphy used in some previous works are among the main reasons for the revision offered in our study.

The present work shows the complete data partially presented in López-Gómez et al. [2019], which are essential to infer the age of the lithological units

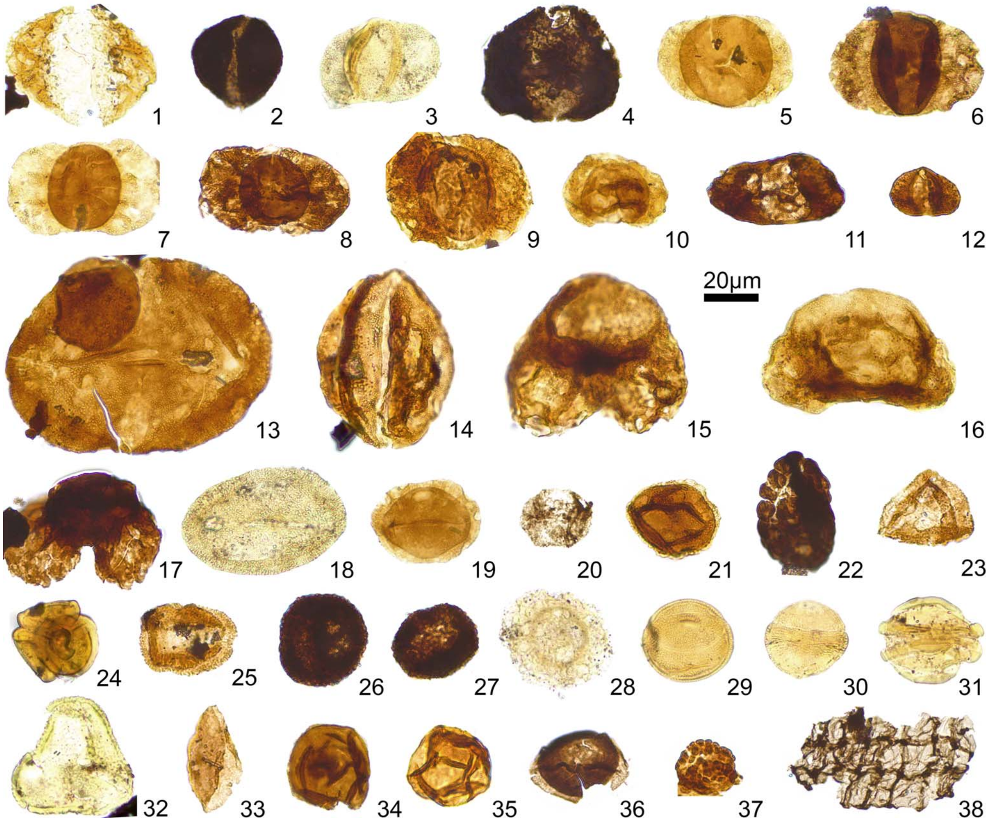

Figure 5. Representative palynomorphs of the different associations. Palynological assemblages are figured completely in supplementary data. (1) *Alisporites grauvogeli* Klaus 1964. (2) *Alisporites opii* Daugherty 1941. (3) *Alisporites* sp. (4) *Triadispora epigona* Klaus 1964. (5) *Triadispora plicata* Klaus 1964. (6) *Triadispora staplinii* (Jansonius) Klaus 1964. (7) *Triadispora crassa* Klaus 1964. (8) *Triadispora suspecta* Klaus 1964. (9) *Triadispora verrucata* (Schulz) Scheuring 1970. (10) *Lunatisporites noviaulensis* (Leschik) de Jersey 1979. (11) *Chordasporites singulichorda* Klaus 1960. (12) *Vitreisporites pallidus* (Reissinger) Nilsson 1958. (13) *Illinites chitonoides* Klaus 1964. (14) *Chasmatosporites* sp. (15) *Microcachryidites doubingeri* Klaus 1964. (16) *Microcachryidites fastidioides* (Jansonius) Klaus 1964. (17) *Platysaccus* sp. (18) *Ovalipollis pseudoalatus* (Thiergart) Schuurman 1976. (19) *Ovalipollis ovalis* (Krutzsch) Scheuring 1970. (20) *Ovalipollis cultus* Scheuring 1970. (21) *Praecirculina granifer* (Leschik) Klaus 1960. (22) *Camerosporites secatus* Leschik 1956. (23) *Duplicisporites granulatus* (Leschik) Scheuring 1970. (24) *Paracirculina quadruplicis* Scheuring 1970. (25) *Quadraeculina anellaeformis* Malyavkina 1949. (26) *Vallasporites ignacii* Leschik 1956. (27) *Enzonalasporites vigens* Leschik 1955. (28) *Patinasporites densus* Leschik 1955. (29) *Classopollis torosus* (Reissinger) Balme 1957. (30) *Classopollis zwolinskae* (Lund) Traverse 2004. (31) *Rhaetipollis germanicus* Schulz 1967. (32) *Trachysporites* sp. (33) *Cycadopites* sp. (34) *Calamospora tener* (Leschik) Mädler 1964. (35) *Calamospora* sp. 36. *Aratrisporites granulatus* Klaus 1960. (37) *Verrucosisporites* sp. (38) *Plaesiodictyon mosellanum* Wille 1970.

in this area. A complete list of figured elements is provided to correlate our new data with previous palynological records in nearby areas.

5.1. *Late Ladinian-early Carnian assemblages*

The palynological data of the Triassic rocks starts with the study of the Cicera Fm characterised by the presence of voltzian conifer types (including the genera *Triadispora* and *Ovalipollis*) and the Circumpolles group (*Duplicisporites*, *Camerosporites*, *Paracirculina*). Cicera Fm could be separated into lower part with a Longobardian age (Carmona assemblage), and an upper part with a Longobardian-Cordevolian transition in age (San Pedro and Cicera assemblages).

The Carmona assemblage (Figure S1, Supplementary data) from the lower part of the Cicera Fm is Longobardian in age (late Ladinian), due to the presence of *Camerosporites secatus*, *Chordasporites singulichorda*, *Duplicisporites granulatus*, *Illinites chitonoides*, *Lunatisporites noviaulensis*, *Microcachryidites doubingeri*, *Ovalipollis pseudoalatus*, *Triadispora falcata*, *Triadispora staplinii*, and *Triadispora suspecta*. This composition is equivalent to the "second assemblage" in Adloff et al. [1987], the SC-1 assemblage from Sancerre-Couy core, Paris Basin [Juncal et al., 2018] and the palynological associations described from the Mâconnais Region in France [Adloff and Doubinger, 1979], in Jura, France [Adloff et al., 1984], the Largentière area, Ardèche, France [Doubinger and Adloff, 1977], the Monte San Giorgio, Southern Alps, Switzerland [Scheuring, 1978]. These assemblages correspond to the *Camerosporites secatus–Enzonalasporites vigens* phase [Van Der Eem, 1983], the *Heliosaccus dimorphus* Zone of Orłowska-Zwolińska [1983, 1985, 1988] emended by Herngreen [2005], the *Heliosaccus dimorphus* Zone [Kürschner and Herngreen, 2010] (Figure S5, Supplementary data). The bisaccate pollen grain *Lunatisporites noviaulensis* started to occur first in the Guadalupian (middle Permian) of WestEurope (e.g., Bercovici et al. 2009) and in the late Permian (Lopingian) in the southern Alps of Italy (Bulla section, western Dolomites, Italy; Spina et al. [2015]). The presence of this taxa in assemblage with other taxa such as *Illinites chitonoides*, *Microcachryidites doubingeri* and *Microcachryidites fastidioides* is characteristic of the Early-Middle Triassic and rarely appear in early Carnian assemblages (e.g., Doubinger and Adloff 1983, Doubinger and Bühmann 1981, Eshet 1990, Foster 1979, Galasso et al. 019a,b, Kürschner and Herngreen 2010, Orłowska-Zwolińska 1984, 1985). These taxa co-occur with the circumpolles species *Camerosporites secatus, Duplicisporites granulatus* and *Praecirculina granifer* which show significant diversification on the Ladinian – Carnian boundary (e.g., Brugman et al. 1994, Cirilli 2010, Kürschner and Herngreen 2010, Mietto et al. 2012, Roghi 2004, Roghi et al. 2010, Van Der Eem 1983, Visscher and Brugman 1981, Visscher and Krystyn 1978).

The San Pedro and Cicera assemblages (Figures S2 and S3, Supplementary data) are attributed to the Longobardian-Cordevolian transition (late Ladinian-early Carnian) due to the presence of Middle Triassic sporomorphs such as *Chordasporites singulichorda*, *Lunatisporites noviaulensis*, *Triadispora crassa*, *Triadispora epigona*, *Triadispora falcata*, *Triadispora plicata*, *Triadispora staplinii* and the late Ladinian-Carnian taxa such as *Camerosporites secatus*, *Duplicisporites granulatus*, *Ovalipollis pseudoalatus,* as well as the occurrence of the typical Carnian taxa *Triadispora verrucata* and *Vallasporites ignacii*. The taxonomic composition of the San Pedro and Cicera assemblages is equivalent to that of the SC-2 assemblage, described by Juncal et al. [2018], of the Sancerre-Couy core (Paris Basin), obtained from levels associated with anhydrite sabkha deposits with black silty clays. These levels correspond to the Ladinian-lower Carnian cycle, which is the lateral equivalent of the Lettenkhole Fm in the eastern part of the Paris Basin [Bourquin et al., 2002]. The occurrence of typical Carnian taxa such as *Vallasporites ignacii* in association with late Ladinian-Carnian sporomorphs is also reported in the lower part of the Koudiat El Halfa borehole in Central Tunisia [Mehdi et al., 2009] and in the early Carnian microflora from the Djerba Melita 1 Borehole in southeasstern Tunisia [Buratti et al., 2012].

The San Pedro and Cicera assemblages correspond to the *Triadispora verrucata* subzone of the *Camerosporites secatus* Zone Herngreen [2005], which is defined by the first appearance datum (FAD) of *Triadispora verrucata* and correlates with the *Conbaculatisporites longdonensis*, later *Porcellispora longdonensis*, Zone of Orłowska-Zwolińska [1983, 1985, 1988] and zones GTr 12–13 of Heunisch [1999] (Figure S5, Supplementary data). The *Camerosporites secatus* Zone Herngreen [2005] is defined by the FAD of *Camerosporites secatus*, which coincides with the early Carnian *Enzonalasporites vigens–Patinasporites densus* phase of Van Der Eem [1983] (Figure S5, Supplementary data), and it is associated with the first appearance of *Patinasporites densus, Triadispora verrucata*, and *Vallasporites ignacii* [Blendinger, 1988, Buratti and Cirilli, 2007, Cirilli, 2010, Fisher and

Dunay, 1984, Hochuli and Frank, 2000, Hochuli et al., 1989, Kürschner and Herngreen, 2010, Roghi, 2004, Roghi et al., 2010, Van Der Eem, 1983, Visscher and Brugman, 1981].

The composition of the Carmona assemblage, occurring in the lower levels of the Cicera Fm, almost exclusively comprises conifer pollen (e.g., *Chordasporites*, *Lunatisporites*, *Microcachryidites*), including numerous *Triadispora* specimens. In contrast, in the San Pedro and Cicera assemblages, the presence of water-transported spores, such as those of lycophytes (*Aratrisporites*), horsetails (*Calamospora*) and ferns (as *Verrucosisporites* and *Vitreisporites*), can be seen. Moreover, the appearance of the fresh-brackish water alga *Plaesiodictyon mosellanum* suggests proximity to a fluvio-deltaic source or coastal system as it tolerates hypersaline environments [Brugman et al., 1994, Hochuli et al., 1989, Kustatscher et al., 2012, Lindström et al., 017a, Paterson et al., 2017, Vigran et al., 2014]. This hypothesis is coherent with the sedimentological interpretations of the Cicera Fm, since the uppermost part of this unit shows a transition with the underlying Rueda Fm, interpreted as inter-supratidal, shallow-marine mixed sediment [López-Gómez et al., 2019]. Furthermore, in the Cicera section, two footprint samples were obtained 74.5 m below Cic11 sample [López-Gómez et al., 2019] (Figure 3). In the latter work, the authors suggest that these footprints could correspond to *Lagerpetidae*, and they have been linked to biped animals, in accordance with their functional tridactyl II–IV pes, which is similar to numerous tridactyl footprints of dinosauroïd forms found in Anisian–Ladinian beds in SE France [Gand and Demathieu, 2005].

The Ladinian-early Carnian assemblage of the Cicera Fm is equivalent to the upper part of the "Buntsandstein facies" described by Sánchez-Moya et al. [2005] and Sopeña et al. [2009], who collected three palynological samples near the Verbios village (Palencia Province, sample 1349) and the Tres Mares peak (Cantabrian Province, samples 1379 and 1410). These authors attributed Samples 1349 and 1410 to the Ladinian (Middle Triassic), based on the presence of the genera *Duplicisporites* and *Triadispora*, the taxa *Ovalipollis pseudoalatus* and "the absence of *Echinitosporites iliacoides, Heliosaccus dimorphicus, Partitisporites quadruplices*", and the predominance of bisaccate pollen. Moreover, the presence of *Eucommiidites microgranulatus* is reported in sample 1410. According to Schulz and Heunisch [2005], the presence of this species indicates a Ladinian-early Carnian age [Sopeña et al., 2009]. These two samples were compared with the Ladinian assemblages from the Pyrenees [Fréchengues et al., 1993], the Catalan Coastal Range [Solé de Porta et al., 1987] and the Iberian Ranges [Doubinger et al., 1990, Sopeña et al., 1995]. The last sample obtained in the Tres Mares peak (Cantabrian Province, Sample 1379) was assigned to the Carnian (Late Triassic) due to the presence of *Vallasporites ignacii* and *Enzonalasporites* sp., and "the absence of *Kuglerina meieri, Craterisporites rotundos, Partitisporites* sp. and *Spiritisporites spirabilis*" [Sánchez-Moya et al., 2005]. Sopeña et al. [2009] removed *Vallasporites ignacii* and *Enzonalasporites* sp. from the list and attributed it to the late Ladinian-Carnian due to increased circumpolles and similarity with the upper Ladinian of the Castilian Branch of the Iberian Ranges [Sopeña et al., 1995] and the Carnian of the Miravet Fm, Prades area of the Catalan Coastal Range [Solé de Porta et al., 1987].

5.2. *Norian assemblages*

Between the early Carnian and Norian, an overall decline of 50% in palynofloral diversity has been described in NW Europe [Kürschner and Herngreen, 2010]. Thus, Norian flora in Europe generally show low taxonomic diversity and are dominated by conifers (accounting for 80–90% of the assemblages: Dalla-Vecchia [2000], Dalla-Vecchia and Selden [2013], Dobruskina [1993, 1994], Kustatscher et al. [2018], Pacyna [2014]). During the Norian, a significant change is recorded for the "Late Triassic palynofloras" that corresponds to the first appearance of *Classopollis* pollen [Visscher and Brugman, 1981], and this is broadly related to the diversity decline among terrestrial vertebrates and marine invertebrates [Tanner et al., 2004, Weems, 1992]. This gymnosperm pollen is produced by plants belonging to the extinct conifer family Cheirolepidiaceae [Francis, 1983, Jarzen and Nichols, 1996], which are similar to the extant family Cupressaceae and resemble modern juniper bushes [Riding et al., 2013], and it is dominant in assemblages obtained in the Transición Fm (Villabona assemblage).

The presence of the late Ladinian-Carnian genera *Duplicisporites, Enzonalasporites* and

Camerosporites is common in lower Norian successions [Cirilli, 2010], but has not been recorded in younger sediments [Kürschner and Herngreen, 2010]. The Norian successions were attributed by Herngreen [2005] to the *Granuloperculatipollis rudis* Zone (Figure S5, Supplementary data), based on the FAD of its marker species and the abundance of *Classopollis meyeriana* and *Classopollis zwolinskae*. This zone corresponds to zones 16–17 of Heunisch [1999], the middle-upper part of the *Corollina meyeriana* Zone of Orłowska-Zwolińska [1984] (Figure S5, Supplementary data). Moreover, although *Rhaetipollis germanicus* was considered a Rhaetian age taxon (e.g., Schulz and Heunisch 2005, Visscher and Brugman 1981), the FAD of *Rhaetipollis germanicus* is uncertain. Fisher [1979] described the appearance of this taxon in Norian palynological assemblages (Palynological Zone VIII, Canadian Artic Archipelago) and Smith [1982] suggested reconsidering the palynological dating involving this taxon after studying the early Norian ammonoid-dated strata in Svalbard. Kürschner and Herngreen [2010] also suggest that a late Norian appearance of this taxon cannot be excluded in central and northwestern Europe, due to the absence of continental deposits during this time that could be readily correlated with marine successions. Therefore, Norian and lower Rhaetian palynological assemblages are generally rather homogeneous [Kustatscher et al., 2018].

For all the aforementioned reasons, and due to the presence *Camerosporites secatus*, *Classopollis zwolinskae*, *Classopollis torosus*, *Duplicisporites granulatus*, and *Rhaetipollis Germanicus*, the Villabona assemblage (Figure S4, Supplementary data) of the Transición Fm is Lacian-Aulanian in age (early-middle Norian).

In "Keuper facies" such as those present in the Transición Fm, Salvany [990a,b] identified a scarce Norian assemblage in Aguilar de Campoo (Palencia province). This sample contains *Triadispora* sp., *Ovalipollis ovalis*, *Praecirculina granifer*, *Duplicisporites granulatus*, *Patinasporites densus*, *Camerosporites secatus*, *Classopollis* sp., *Granuloperculatispollis rudis* and unidentified bisaccates. These authors suggest a lower-middle Norian age, based on the abundance of *Classopollis* and the presence of *Granuloperculatispollis rudis*. The presence of *Triadispora* sp., *Classopollis* sp., *Duplicisporites granulatus* and *Camerosporites secatus* is coherent with this assignation. In similar facies, two palynological samples were described in the Reinosa area (Cantabria province) and attributed an early-middle Norian age by Calvet et al. [1993]. These samples include *Alisporites* sp., *Ovalipollis ovalis*, *Praecirculina granifer*, *Duplicisporites granulatus*, *Classopollis* sp. and *Granuloperculatispollis rudis*.

Furthermore, Barrón et al. [2001] described two assemblages in laminated gypsum deposits near Poza de la Sal (Cantabria Province). These samples would correspond to the Transición Fm. These authors suggested a late Carnian-early Norian age for one of the assemblages because of the presence of *Triadispora* spp. and *Camerosporites secatus* and the "absence of genus *Corollina*" (= *Classopollis*). They considered that the gypsum of Poza de la Sal was older than similar lithologies with Norian age proposed by Hernando et al. [1977] in Albendiego (Guadalajara, Spain) and Salvany [990a,b] for the grey gypsum of Aguilar de Campoo (Palencia, Spain) included in "Keuper facies". The second assemblage was attributed to the Rhaetian, based on the relative abundance of the genus *Corollina* (= *Classopollis*) and because "the first register (genus *Corollina*) was in Rhaetian age by Visscher and Brugman [1981], or in the upper part of Norian by Pedersen and Lund [1980]". Today, we know that the genus *Classopollis* appears in the early Norian (e.g., Kürschner and Herngreen 2010), hence the gypsum of Poza de la Sal described by Barrón et al. [2001] should be early Norian.

5.3. *Rhaetian assemblages*

In the Transición Fm, a palynological assemblage was also described near Huerces (Asturias Province) by Martínez-García et al. [1998] (Figure 4). These authors suggested a Rhaetian-late Rhaetian age owing to the presence of *Classopollis classoides*, and relative abundance of *Ovalipollis ovalis* and *Rhaetipollis germanicus*. Later, in the same unit, Barrón et al. [2002, 2005, 2006] proposed a Rhaetian age based on different analytical criteria. Barrón et al. [2002] considered the "relative abundance of *Corollina meyeriana* and *Corollina torosus*" and the presence of *Ovalipollis* cf. *pseudoalatus* and *Rhaetipollis germanicus* as indicative of a Rhaetian-late Rhaetian age at the Bárzana section in the Villaviciosa region (Asturias, Spain). Barrón et al. [2005] studied 49 successive samples collected from the Vilorteo and Cantavieyo Diamond Drill Holes, La Camocha Mine area near Gijón (Asturias), and they distinguished three assemblages (PA1, PA2 and PA3) for the Late Triassic-Lower Jurassic time interval. The PA1 assemblage is related to the *Rhaetipollis germanicus* Zone [Orbell, 1973], the third phase of "Grès et Schiste à *Avicula contorta*", to "Argiles de Levallois" [Schuurman, 1977] and the Rhaetian assemblages to NW Europe [Batten and Koppelhus, 1996, Visscher and Brugman, 1981]. The PA2 and PA3 assemblages are associated with the *Heliosporites* Zone of Orbell [1973] and the assemblage of St. Audrie's Bay [Hounslow et al., 2004]. These preliminary palynological studies were finally expanded in Barrón et al. [2006] in a palynological, biostratigraphic, sedimentological and sequence stratigraphy study to characterise the Triassic-Jurassic boundary in Asturias (North Spain). The authors suggested that the PA1 assemblage, which corresponds to the lower part of both boreholes, could be assigned a Rhaetian age due to a similarity with the *Rhaetipollis germanicus* Zone and the presence of *Ovalipollis pseudoalatus* and *Tsugaepollenites pseudomassulae*. However, they could not assign the PA2 assemblage to the Rhaetian or Hettangian due to "the absence of representative palynomorphs of these ages", but the PA3 was interpreted as Hettangian, based on the presence of *Ischyosporites variegatus* and *Cerebropollenites thiergartii*.

Although unable to verify the described taxa due to the partial absence of figures, on the basis of our palynological comparison the presence of *Kraeuselisporites reissingeri*, *Tsugapollenites pseudomassulae* and the genus *Cerebropollenites* in PA3 would be indicative of late Rhaetian or Rhaetian–Hettangian transition. Although *Ischyosporites variegatus* and *Cerebropollenites thiergartii* are considered the best markers for the Triassic-Jurassic boundary, their lowest occurrences have been recorded several meters below the FAD of the ammonite *Psiloceras spelae* defining the base of the Hettangian in the GSSP stratotype Kuhjoch section (Karwendel Mountains, Austria) [Bonis et al., 2009, Cirilli et al., 2018, Hillebrandt et al., 2013, Kürschner and Herngreen, 2010]. However, the PA3 assemblage is equivalent to the one described in the Noto Fm and the Upper Streppenosa Mb (SE Sicily, Italy; Cirilli et al. [2018]) with a Rhaetian age, due to the abundance of *Classopollis* species (*Classopollis meyeriana* and minor *Classopollis torosus*) and other index species such as *Ischyosporites variegatus*, *Porcellispora longdonensis* and *Trachysporites fuscus*. The presence of *Ischyosporites variegatus* in association with *Classopollis* spp., *Porcellispora longdonensis* and *Kraeuselisporites reissingeri*, could indicate a latest Rhaetian age in the PA3 assemblage, as in the case of the upper part of the Upper Streppenosa Mb [Cirilli et al., 2018, Hillebrandt et al., 2013].

The presence of *Kraeuselisporites reissingeri* is reported together with *Carnisporites spiniger*, *Classopollis meyeriana*, *Convolutispora klukiforma*, *Ovalipollis pseudoalatus*, *Taurocusporites verrucatus* and the dinoflagellates *Dapcodinium priscum* and *Rhaetogonyalax rhaetica* in the SC-4 assemblage (late Raethian age) described by Juncal et al. [2018] in the Sancerre-Couy core (Paris Basin). The presence of *Kraeuselisporites reissingeri* and *Tsugapollenites pseudomassulae* is also described in the lower Malanotte Fm of the Triassic–Jurassic transition in the western Southern Alps (Northern Italy; Galli et al. [2007]) in an assemblage that contains *Classopollis torosus, Cerebropollenites macroverrucosus* and the dinoflagellate cysts *Dapcodinium priscum*. A similar microfloral composition is reported at the Rhaetian–Hettangian transition from the St Audrie's Bay section in United Kingdom [Bonis et al., 2010, Hesselbo et al., 2002, 2004, Hounslow et al., 2004, Lindström, 2016, Lindström et al., 017b, Orbell, 1973, Warrington, 1996] and in the intra- and infra-basaltic sediments from different localities at the base of the CAMP lava piles in Morocco [Panfili et al., 2019].

6. Conclusions

We present here a detailed study of four palynological assemblages obtained from three stratigraphical sections and one borehole from the Triassic sedimentary record of the Cantabrian Mountains, North Spain. These data have made it possible to (i) make an accurate correlation of the Triassic record of this area, (ii) integrate the different palynostratigraphic information that already existed but had not been well determined stratigraphically, and (iii) carry out a comparative analysis with other samples studied in Triassic sections from Centre and SW of Europe.

Four assemblages from the Triassic sedimentary record were examined. Three of these were obtained from the Cicera Fm of continental origin (Carmona, San Pedro and Cicera assemblages). A Longobardian age is suggested for the lower (Carmona assemblage) and a Ladinian-Carnian transition for the upper part of this formation (San Pedro and Cicera assemblages). The uppermost part of this formation shows a transition with the overlying Rueda Formation, of shallow marine origin. This transition is indicated by the presence of *Plaesiodictyon mosellanum*, a freshwater-shallow marine environment alga. These palynological assemblages are equivalent to the samples obtained near Verbios village (Palencia Province) and the Tres Mares peak (Cantabrian Province) in the upper part of the “Buntsandstein facies” by Sánchez-Moya et al. [2005].

The last palynological assemblage (Villabona assemblage) has a Lacian-Aulanian age and it was obtained in Transición Fm (mostly of shallow marine origin). This assemblage corresponds to the Norian assemblage obtained in “Keuper facies” in Aguilar de Campoo (Palencia province) by Salvany [990a,b] and to the early-middle Norian assemblage described in the Reinosa area (Cantabria province; Calvet et al. [1993]). Moreover, this assemblage is comparable with the assemblages obtained in laminated gypsum deposits near Poza de la Sal (Cantabrian Province) by Barrón et al. [2001] with an upper Carnian-early Norian age.

The palynological assemblages obtained in this work were compared with the microflora coming from the same paleolatitude (same paleoclimate belt), and they were also compared with the main Triassic palynostratigraphic subdivisions in Central and NW Europe.

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Supplementary data

Supporting information for this article is available on the journal’s website under https://doi.org/10.5802/crgeos.12or from the author.

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