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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*

New palynological data in Muschelkalk facies of the Catalan Coastal Ranges (NE of the Iberian Peninsula)

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Abstract. The Middle Triassic (Ladinian) deposits of the Catalan Basin (Spain) are essentially represented by extensive marine carbonate platforms developed in a rift tectonic setting. During the Ladinian, a regional sea-level drop led to a significant paleogeographic reorganisation of the depocentres of eastern Iberia producing a relevant shift in the distribution of the sedimentary environments. To better calibrate the age of the correlative conformity and the associated depositional facies, a new palynological study was carried out in two localities in Tarragona province (Spain). The palynological assemblages suggest a Longobardian–Cordevolian age (Middle–Late Triassic transition) for the materials deposited below and above the correlative conformity. This study allows a refined biostratigraphic and sedimentary correlation between the carbonate sediments in the Catalan Basin and those in the Iberian Ranges and adjacent basins of the Tethys region.

Keywords. Longobardian, Ladinian, Triassic, Palynostratigraphy, Spain.

1. Introduction

The evolution of Iberia during the Upper Permian and Mesozoic can be divided into three rift cycles and post-rift stages. The rift cycle corresponding to the Late Permian–Triassic, mainly affected the eastern part of the Iberian plate giving rise to basins

that were filled with sediments attributed to the Germanic facies during the late Permian and Triassic times [Ramos et al., 1996, Salas and Casas, 1993, Salas et al., 2001].

In Iberia, the Triassic stratigraphic record can be subdivided into the three parts, from the base to the top: Buntsandstein facies (continental clastic sediments and red beds), Muschelkalk facies (marine carbonates, evaporites and red beds) and Keuper facies (tidal and sabkha deposits) [Calvet et al., 1990, Virgili et al., 1983].

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In the Triassic Catalan basin, the Muschelkalk facies (Anisian to Ladinian) is constituted by two marine carbonate sequences with an interstratified evaporite-siliciclastic unit. The second carbonate sequence was recently subdivided into two Transgressive–Regressive sequences corresponding to two fault-block, microbial-dominated carbonate ramps separated by a marked correlative conformity formed in association with a regional sea-level fall [Mercedes-Martín *et al.*, 2013, 014a]. Ammonites, bivalves and palynomorphs have been previously used to constrain the age of these platforms particularly in open marine, deep ramp settings where these organisms are better preserved in organic-rich sediments [Calvet *et al.*, 1990]. However, refined biostratigraphic surveys are needed to: (i) shed light on the age of the correlative conformity which leads to a significant paleogeographic reorganisation of the depocentres of eastern Iberia [Mercedes-Martín *et al.*, 014b], and (ii) identify the Ladinian–Carnian transition in marine sediments. Palynological assemblages can help to temporally constrain the age of these carbonate-shale sequences since palynomorphs are easily well-preserved in organic-rich facies and their remains are abundant in the study area.

1.1. Background

There are previous palynological studies that analyse different assemblages in the Catalan Coastal Ranges. Following the chronostratigraphic order, we have the following data.

For the Lower Muschelkalk facies, in Figaró-Montmany area (Barcelona), Solé de Porta *et al.* [1987] studied a palynological assemblage which was dated as middle Anisian. This assemblage contains *Alisporites grauwogeli*, cf. *Latosaccus latus*, *Microcachryidites doubingeri*, *Microcachryidites fastidioides*, *Platysaccus reticulatus*, *Striatoabieites aytugii*, *Sulcatisporites* cf. *reticulatus*, *Triadispora aurea*, *Triadispora crassa*, *Triadispora falcata*, *Triadispora plicata*, *Voltziaceasporites heteromorpha*, *Alisporites* sp., *Aratrisporites* sp., *Cyclotriletes* sp., *Punctatisporites* sp., *Sulcatisporites* sp., *Triadispora* sp., and unidentified bisaccates.

For the Lower Muschelkalk–Middle Muschelkalk Calvet and Marzo [1994] suggested an Upper

Anisian age, using a palynological assemblage identified in El Figaro (Barcelona): *Alisporites grauwogeli*, *Lunatisporites acutus*, *Microcachryidites doubingeri*, *Praecirculina granifer*, *Striatoabieites aytugii*, *Stellatopollenites thiergartii* (= *Hexasaccites muelleri*), *Cycadopites* sp., *Cyclotriletes* sp., and *Triadispora* sp.

In the base of the Middle Muschelkalk Solé de Porta *et al.* [1987] studied an outcrop in La Riba (Tarragona). This outcrop consists of dark shales, dating by this author as Upper Anisian according to the following palynological assemblage: *Alisporites grauwogeli*, *Cyclotriletes* cf. *granulatus*, *Cyclotriletes* cf. *oligogranifer*, *Cyclotriletes triassicus*, *Kuglerina meieri*, *Lunatisporites acutus*, *Microcachryidites doubingeri*, *Microcachryidites fastidioides*, *Praecirculina granifer*, *Striatoabieites aytugii*, *Stellatopollenites thiergartii* (= *Hexasaccites muelleri*), *Triadispora aurea*, *Triadispora crassa*, *Triadispora falcata*, *Triadispora plicata*, *Triadispora staplinii*, *Triadispora suspecta*, *Alisporites* sp., *Cycadopites* sp., *Cyclotriletes* sp., *Lunatisporites* sp., *Punctatisporites* sp., *Sulcatisporites* sp., and *Triadispora* sp.

Also, Diez [2000] analysed the base of the Middle Muschelkalk in the outcrop of “El Figaro”, characterised by an organic-rich interval. This palynological assemblage is constituted by the following species: *Alisporites* cf. *grauvogeli*, *Heliosaccus dimorphus*, *Lunatisporites* cf. *acutus*, *Ovalipollis* cf. *ovalis*, *Parasaccites* cf. *korbeensis*, *Punctatisporites fungosus*, *Triadispora epigona*, *Triadispora falcata*, *Triadispora staplinii*, *Verrucosisporites remyanus*, cf. *Alisporites*, *Alisporites* sp., *Aratrisporites* sp., *Calamospora* sp., cf. *Illinites*, *Microreticulatisporites* sp., and *Platysaccus* sp. Despite the high palynological diversity, this assemblage did not provide detailed chronostratigraphic information.

The palynological content of the Middle Muschelkalk of the Catalan Basin was studied by Visscher [1967] in Pradell (Tarragona) giving an assemblage of poor chronostratigraphic value: *Alisporites grauwogeli*, *Angustisulcites klausii*, *Voltziaceasporites heteromorpha*, and *Triadispora* sp.

Subsequently, Calvet and Marzo [1994] studied the upper part of the Middle Muschelkalk succession in La Riba (Tarragona) suggesting a Ladinian age on the basis of the following assemblage: *Duplicisporites granulatus*, *Duplicisporites scurrilis* (= *Paracirculina scurrilis*), *Ovalipollis ovalis*, *Praecirculina granifer*,

Staurosaccites quadrifidus, and *Triadispora* sp.

Finally, for the Upper Muschelkalk, Solé de Porta *et al.* [1987] studied the microflora of Capafons Unit, in Capafons (Tarragona) which raised a Ladinian microflora constituted by the specimens: *Camerosporites secatus*, *Duplicisporites granulatus*, *Duplicisporites scurrilis* (= *Paracirculina scurrilis*), *Microcachryidites doubingeri*, *Microcachryidites fastidioides*, *Ovalipollis ovalis*, *Praecirculina granifer*, *Rimaesporites potonei*, *Striatoabieites aytugii*, *Triadispora aurea*, *Triadispora crassa*, *Triadispora falcata*, *Triadispora plicata*, *Triadispora suspecta*, *Platysaccus* sp., *Triadispora* sp., and *Verrucosiporites* sp. Also, Calvet and Marzo [1994] studied two palynological assemblages from Rojals and Rasquera Units. The Rojals Unit was recognised at the top of Rojals Unit from la Riera de Sant Jaume (Barcelona) and contains *Camerosporites secatus*, *Duplicisporites scurrilis* (= *Paracirculina scurrilis*), *Ovalipollis cultus*, *Ovalipollis ovalis*, *Praecirculina granifer*, *Triadispora crassa*, *Alisporites* sp., *Calamospora* sp., and *Triadispora* sp. The Rasquera Unit was recognised from marly sediments sampled in Rasquera (Tarragona) yielding *Camerosporites secatus*, *Praecirculina granifer*, *Ovalipollis ovalis*, *Staurosaccites quadrifidus*, *Triadispora crassa*, *Platysaccus* sp., and *Triadispora* sp. An Upper Ladinian age was suggested for both units [Calvet and Marzo, 1994].

Unfortunately, the mentioned previous studies other than that the work of Diez [2000], lack accurate representation of the listed palynomorphs, so a critical motivation of our work was to study similar stratigraphic units in the Catalan Basin to obtain new appropriated data. This study aims at characterising new palynological assemblage from two outcrops located in the surroundings of Falset and Rasquera (Tarragona, Spain), contributing to better constrain the age of the Upper Muschelkalk facies of the Catalan Basin.

2. Geological setting

The study area is located in the Catalan Coastal Ranges, which developed by inversion of the Mesozoic rifts during the Palaeogene [Salas *et al.*, 2001]. The Triassic materials of the Catalan Coastal Ranges are widely distributed in an area about 300 km long and 200 km wide showing a NE-SW orientation. During the Triassic, the basin opened towards the SE into

the Neotethys Sea, with shallow depocentres located towards the western and northern parts of the Spanish Meseta [Calvet *et al.*, 1990].

During the Permian to Middle Triassic times, Iberia experienced the development of graben systems that were closely related to the rapid propagation of the northern Europe-Greenland Sea rift to the south and the propagation of the Neotethys Sea to the west. The late Permian and Mesozoic evolution of Iberia can be divided into four major rift cycles and post-rift stages [Ramos *et al.*, 1996, Salas and Casas, 1993, Salas *et al.*, 2001]. The first of these cycles (late Permian-Triassic rift cycle of Salas and Casas [1993]) broadly affected the eastern part of the Iberian plate (including the Triassic Catalan Basin). This cycle was divided into several syn-rift and post-rift phases [Vargas *et al.*, 2009] providing evidence that the Triassic of Iberia was marked by generalised pulses of rapid syn-rift subsidence which influenced the deposition of extensive carbonate ramps [Mercedes-Martín *et al.*, 2013, 014a, Tucker *et al.*, 1993].

These Triassic graben systems were filled with sediments attributed to Germanic facies during the late Permian and Triassic allowing a tripartite facies subdivision of such deposits. The lower part is made up of continental Buntsandstein siliciclastics and red beds, the middle part is composed of marine Muschelkalk limestones, evaporites and red beds, and the upper part consisting of tidal, sabkha and evaporite deposits of the Keuper facies [Virgili *et al.*, 1983].

In the Catalan Basin, the Muschelkalk facies (Anisian to Ladinian, Middle Triassic) consist of two marine carbonate units separated by a siliciclastic-evaporite unit. The second carbonate unit (Upper Muschelkalk) records paleogeographical thickness variations between the shallowest carbonate deposits, located in the Gaià domain, and the deeper carbonate-shale deposits, located in the Baix Ebre-Priorat domain [Calvet *et al.*, 1987, Calvet and Tucker, 1988] (Figure 1). The outcrops studied in this work belongs to the Baix Ebre-Priorat domain.

The Ladinian sedimentary record of the Triassic Catalan Basin has been recently divided into two transgressive-regressive (T-R) sequences by [Mercedes-Martín *et al.*, 014a]. The two T-R sequences represent examples of carbonate ramps, with low-gradient depositional angles and clearly recognised lateral relationships of facies belts. The

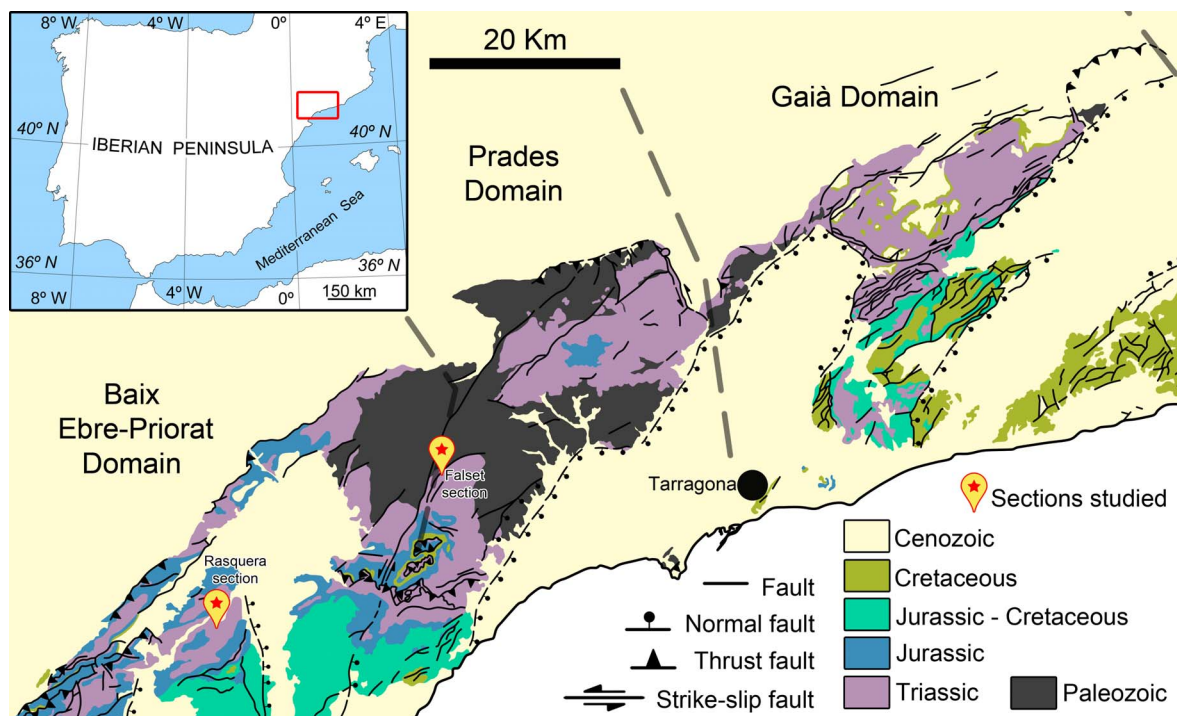


Figure 1. Geographical and geological location of the study area.

depositional model for the T-R Sequence 1 corresponds to a microbial-dominated fault-block carbonate ramp. The T-R Sequence 1 (early Ladinian) contains widespread microbial carbonate deposits: stromatolites in the inner ramp (up to 10 m thick) and thrombolytic biostromes and mounds in the middle ramp (up to 70 m thick). However, the T-R Sequence 2 (late Ladinian) is made up of oolitic stromatolites in the inner ramp, and internal shoals and sheltered lagoons in the middle-outer ramp [Mercedes-Martín *et al.*, 2013, 014a,b].

Both T-R sequences are bounded by a prominent correlative conformity associated with incised-valley erosional features and collapse breccia fillings. The correlative conformity was interpreted as formed by a significant sea-level drop of at least 50 m [Mercedes-Martín *et al.*, 2013, 014a]. The deep-water expression of such surface is the correlative conformity, which was recognised in the Rasquera section (Figure 2).

2.1. Stratigraphy of the Baix Ebre-Priorat domain

From a lithostratigraphic perspective, the Upper Muschelkalk is constituted by different units in the Baix Ebre-Priorat domain (Figure 2). Calvet *et al.* [1987] and Calvet and Tucker [1988] recognised five units, which from base to top are: (1) the Rojals Unit, (2) the Benifalset Unit, (3) the Rasquera Unit, (4) the Tivissa Unit, and (5) the Capafons Unit. Collectively, the sedimentary sections studied in this work (Falset and Rasquera, Figures 2, 3) contain the lithological units 1 to 4 which have been placed in the stratigraphic sequence framework provided by Mercedes-Martín *et al.* [2013].

Rojals Unit. It is made up to 14 m thick carbonate succession sharply lying on top of the Middle Muschelkalk siliciclastic-evaporitic deposits. Rojals Unit is composed of several alternating facies: grey massive bioturbated mudstone; grey laminated mudstone-wackestone with mud-cracks and evaporitic moulds; grey wackestone with ripple lamination; white oolitic grainstone showing ripple, herringbone, planar, and wavy laminations; planar to domal stro-

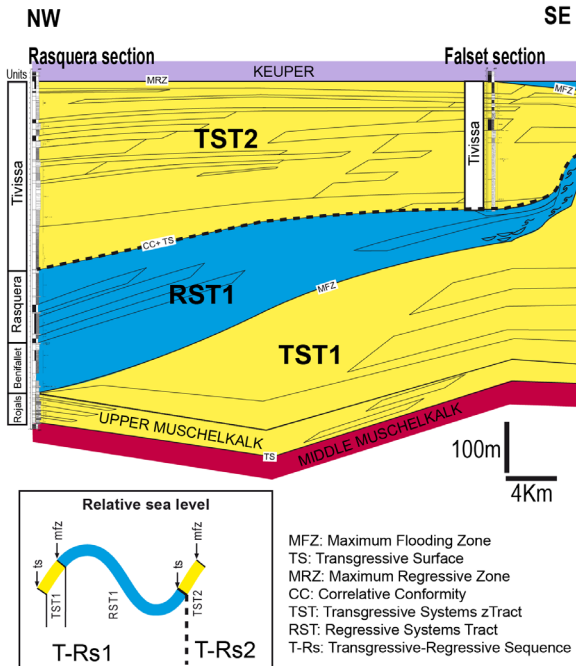


Figure 2. Depositional profile and sequence stratigraphic interpretation of the Upper Muschelkalk rocks in the Catalan Basin (Baix Ebre-Priorat domain). Note the location of the studied sections (Rasquera and Falset) and the lithological units of Calvet *et al.* [1987]. The black dotted line represents the correlative conformity (see text for more details).

matolites with occasional flat-pebble intraclasts and bivalve fragments [Calvet *et al.*, 1987]. The Rojals Unit represents the Transgressive Systems Tract of the T-R sequence 1 of [Mercedes-Martín *et al.*, 2013] dated as early Ladinian. This unit is outcropping in Rasquera section (Figures 2, 3).

Benifallet Unit. It is composed by up to 20 m of a carbonate succession sharply lying on top of the Rojals Unit. Benifallet Unit is constituted by an array of facies: grey to greenish skeletal mudstone to wackestone with echinoid and bivalve allochems; massive to bioturbated mudstone to wackestone with occasional ripple and herringbone lamination; marly to shaley dolostones with evidence of bioturbation and bivalve fauna. A change from the Rojals Unit (shallow water stromatolitic facies) to Benifallet Unit (deeper water burrowed mudstone to wackestone) was iden-

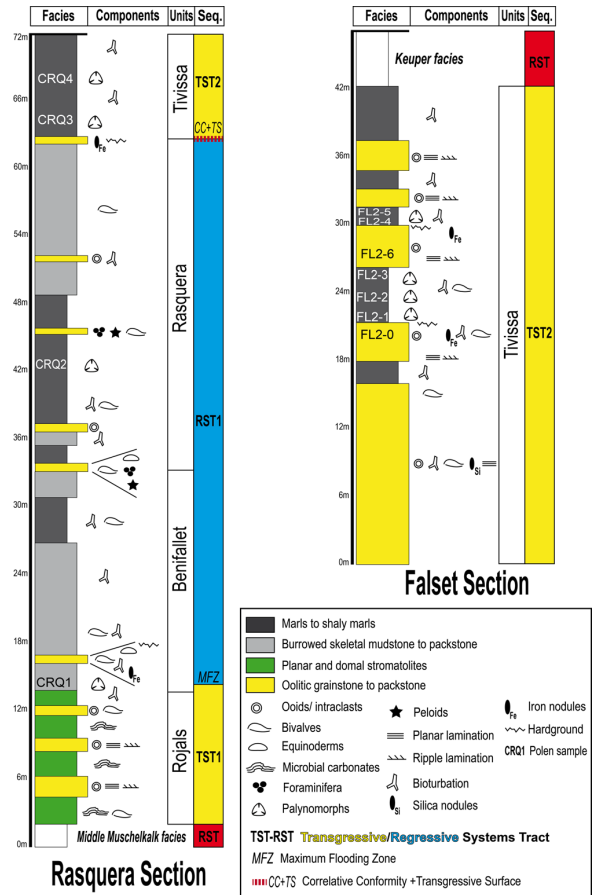


Figure 3. Stratigraphic sections studied (Rasquera and Falset) displaying the main lithological, sequence stratigraphical, and paleontologic characteristics (modified from Mercedes-Martín *et al.* [014a]).

tified as the Maximum Flooding Zone of the T-R sequence 1. Thus, Benifallet Unit was interpreted to be the lower portion of the Regressive Systems Tract of the T-R sequence 1 of Mercedes-Martín *et al.* [2013], and it was dated as early Ladinian. This unit is outcropping in Rasquera section (Figures 2, 3).

Rasquera Unit. It is made up of at least 40 m of a carbonate-marly succession sharply lying on top of the Benifallet Unit. Rasquera Unit is characterised by a wide range of lithofacies including alternation of grey skeletal mudstone-wackestone (with bivalves as *Daonella*, brachiopods, peloids, foraminifera and ostracods) with dark marls/shales forming nodular and continuous beds; grey bioturbated mudstone-

wackestone with bivalves arranged in massive to nodular layers; wackestone-packstone with echinoids, foraminifera, peloids, and brachiopods organised in massive beds exhibiting cross-bedded laminations. Rasquera Unit was interpreted to be the upper portion of the Regressive Systems Tract of the T-R sequence 1 of Mercedes-Martín *et al.* [2013], and it was dated as late Ladinian on the basis of ammonoids (*Prothachyceras steinmanni*, *P. hispanicum*, *Hungarites pradoi*) and conodonts (*Metapolygnathus mungoensis*, *Pseudofurnishius murcianus*) [Calvet *et al.*, 1987, Calvet and Tucker, 1988]. However, an early Ladinian age was determined by Mercedes-Martín *et al.* [2013] by the stratigraphic relationships and lateral facies distributions. This unit is outcropping in Rasquera section (Figures 2, 3).

Tivissa Unit. It is composed of at least 42 m-thick of a coarse-grained carbonate succession alternating with shale/marl-rich intervals. The base of this unit is characterised by an iron-rich hardground containing abundant ammonite fauna. This unit is made up of the following facies: bioturbated marlstone-shale; marlstone with thin-bedded bioturbated limestones; thick-bedded and massive mudstone and wackestone; bioclastic packstone-grainstone with ooids, echinoids, peloids and molluscs with evidence of ripple and planar laminations, and silica or iron nodules. This unit is interpreted as the Transgressive Systems Tract of the T-R sequence 2 [Mercedes-Martín *et al.*, 2013] which is bounded by a composite stratigraphic surface (correlative conformity and transgressive surface). The Tivissa Unit was dated as late Ladinian by ammonite fauna (*Hungarites pradoi*, *Prothachyceras hispanicum*, *P. ibericum*, *P. batalleri*, and *P. vilanovae*), and conodonts (*Metapolygnathus mungoensis*, *Pseudofurnishius murcianus*) [Calvet and Tucker, 1988, Calvet *et al.*, 1987]. This unit is cropping out both in Rasquera and Falset sections (Figures 2, 3).

3. Materials and methods

In this paper, we have studied two stratigraphic sections close to Falset and Rasquera, in the province of Tarragona (Spain).

In the Rasquera Section (40° 59' 41.40" N, 0° 34' 6.12" E) four samples were collected in marly levels. Sample CRQ-1 and CRQ-2 were collected below the correlative conformity (see Figure 3), while

samples CRQ-3 and CRQ-4 were collected above. In the Falset section (41° 9' 2.66" N, 0° 51' 35.30" E) five samples were sampled (FL2-1 to FL2-5) above the correlative conformity. All the samples contained palynomorphs. Due to the positive results of the marly levels, two new complementary samples were subsequently collected in the Falset section (FL2-0 and FL2-6) in limestone levels. Both samples were negative in both marine and continental palynomorphs.

Palynological samples were processed using HCl-HF-HCl attack techniques as described by Wood *et al.* [1996] in the palynological Laboratory of Geosciences Department at the University of Vigo. A dispersing agent was added to facilitate filtering and sieving at 10 µm. The palynological slides were studied under a Leica DM 2000 LED, and the photomicrographs were taken with a Leica ICC50 W camera using ×1000 magnification.

The slides are stored in the palynological Laboratory of Geosciences Department at the University of Vigo.

4. Results

Two palynological assemblages were considered (Supplementary Table 1), and a synthetic assemblage is shown in Figure 4. The isolated and complete assemblages of each section are shown in the Supplementary data.

The samples CRQ-1 to CRQ-4 in the Rasquera section contain: *Aratrisporites granulatus* (Klaus 1960) Playford and Dettmann 1965, *Calamospora tener* (Leschik) Mädler 1964, *Camerosporites secatus* Leschik 1956, *Duplicisporites granulatus* (Leschik) Scheuring 1970, *Ellipsovelatisporites rugosus* Scheuring 1970, *Lunatisporites noviaulensis* (Leschik 1956) de Jersey 1979, *Microcachryidites doubingeri* Klaus 1964, *Microcachryidites fastidoides* Klaus 1964, *Ovalipollis cultus* Scheuring 1970, *Ovalipollis ovalis* (Kruttsch 1955) Scheuring 1970, *Ovalipollis pseudoalatus* (Thiergart) Schuurman 1976, *Palaeospongisporis europaeus* Schulz 1965, *Paracirculina tenebrosa* Scheuring 1970, *Patinasporites densus* Leschik 1955, *Platysaccus papilionis* Potonié and Klaus 1954, *Praecirculina granifer* (Leschik) Klaus 1960, *Striatoabieites aytugii* (Visscher) Scheuring 1970, *Triadispora crassa* Klaus 1964,

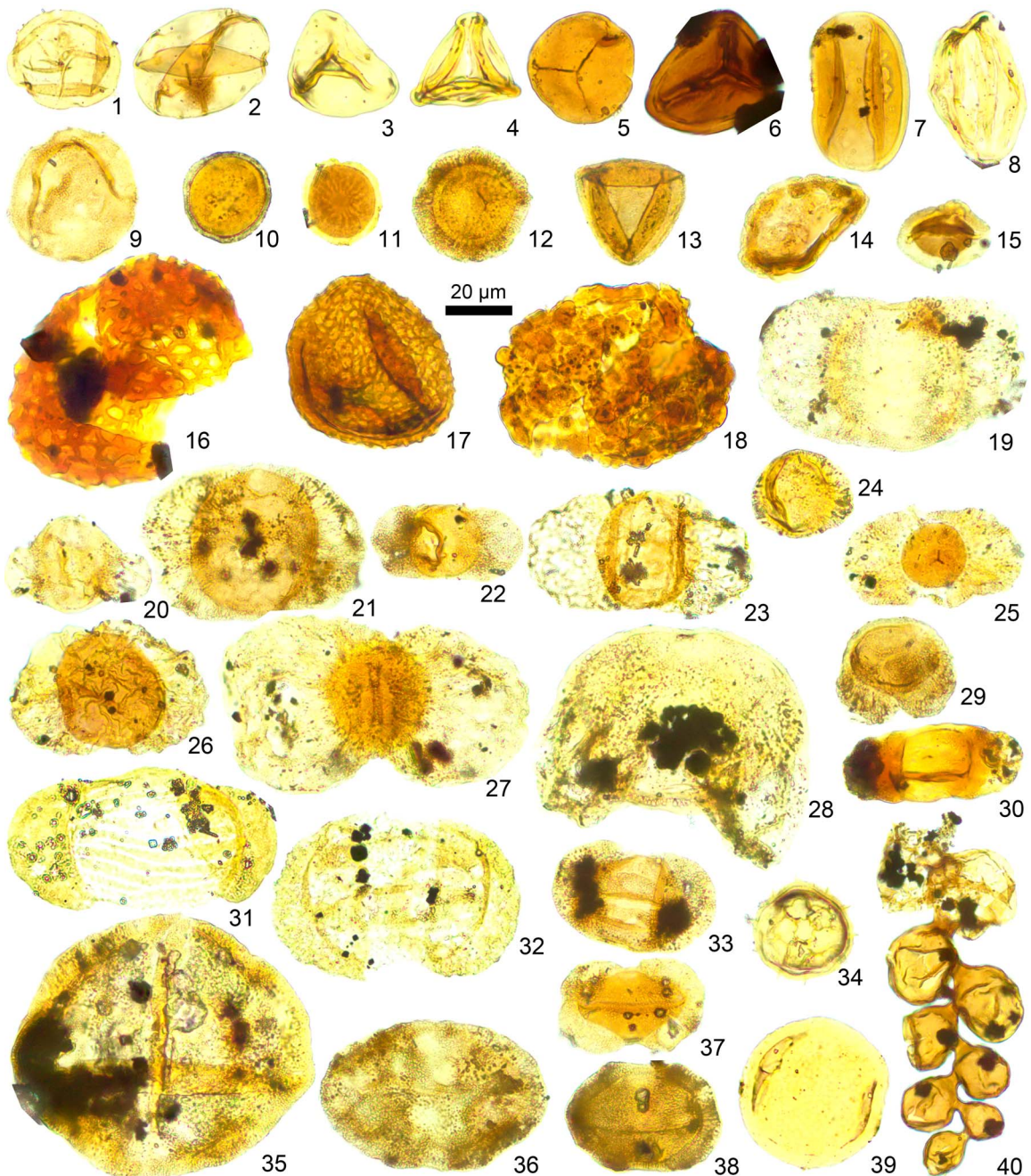


Figure 4. Synthesis of the palynomorphs found in the Falset and Rasquera sections. (1) *Calamospora* sp., (2) *Calamospora tener*, (3) *Deltoidospora* sp., (4) *Concavisporites* sp., (5) *Retusotriletes* sp., (6) *Camarozonosporites laevigatus*, (7) *Chasmatosporites* sp., (8) *Ephedripites* sp., (9) *Praecirculina granifer*, (10) *Paracirculina scurrilis*, (11) *Paracirculina tenebrosa*, (12) *Patinasporites densus*, (13) *Duplicisporites granulatus*, (14) *Camerosporites secatus*, (15) *Aratrisporites granulatus*, (16) *Palaeospongisporis europaeus*, (17) *Maculatasporites* sp., (18) *Verrucosisporites* sp., (19) *Alisporites* sp., (20) *Triadispora falcata*, (21) *Triadispora plicata*, (22) *Triadispora crassa*, (23) *Triadispora staplinii*, (24) *Triadispora epigona*, (25) *Triadispora suspecta*, (26) *Ellipsovelatisporites rugosus*, (27) *Platysaccus papilionis*, (28) *Microcachryidites fastidioides*, (29) *Microcachryidites doubingeri*, (30) *Chordasporites* sp., (31) *Striatoabieites ayugii*, (32) *Lunatisporites noviaulensis*, (33) *Lunatisporites acutus*, (34) *Cymatiosphaera* sp., (35) *Staurosaccites quadrifidus*, (36) *Ovalipollis pseudoalatus*, (37) *Ovalipollis cultus*, (38) *Ovalipollis ovalis*, (39) *Tasmanites* sp., (40) foraminiferal test lining.

Triadispora epigona Klaus 1964, *Triadispora falcata* Klaus 1964, *Triadispora plicata* Klaus 1964, *Triadispora staplinii* (Jansonius) Klaus 1964, *Triadispora suspecta* Scheuring 1970, *Chordasporites* sp., *Concavisporites* sp., *Deltoidospora* sp., *Maculatasporites* sp., *Microcachryidites* sp., *Paracirculina* sp., *Retusotriletes* sp., *Triadispora* sp., *Verrucosisporites* sp., *Cymatiosphaera* sp., *Tasmanites* sp., and foraminiferal test lining.

The samples FL2-1 to FL2-5 in the Falset section contain: *Aratrisporites granulatus* (Klaus 1960) Playford and Dettmann 1965, *Calamospora tener* (Leschik) Mädler 1964, *Camerozonosporites laevigatus* Schulz 1967, *Camerosporites secatus* Leschik 1956, *Duplicisporites granulatus* (Leschik) Scheuring 1970, *Lunatisporites acutus* Leschik 1956, *Microcachryidites doubingeri* Klaus 1964, *Microcachryidites fastidioides* Klaus 1964, *Ovalipollis cultus* Scheuring 1970, *Ovalipollis pseudoalatus* (Thiergart) Schuurman 1976, *Paracirculina scurrilis* Scheuring 1970, *Paracirculina tenebrosa* Scheuring 1970, *Patinasporites densus* (Leschik) Scheuring 1970, *Platysaccus papilionis* Potonié and Klaus 1954, *Praecirculina granifer* (Leschik) Klaus 1960, *Staurosaccites quadrifidus* Dolvy 1976, *Striatoabieites aytugii* (Visscher) Scheuring 1970, *Triadispora crassa* Klaus 1964, *Triadispora epigona* Klaus 1964, *Triadispora falcata* Klaus 1964, *Triadispora suspecta* Scheuring 1970, *Alisporites* sp., *Calamospora* sp., *Chasmatosporites* sp., *Concavisporites* sp., *Ephedripites* sp., *Maculatasporites* sp., *Microcachryidites* sp., *Retusotriletes* sp., *Triadispora* sp. and *Verrucosisporites* sp. We also identified *Tasmanites* sp. and foraminiferal test lining.

5. Discussion

5.1. Age assessment

The First Appearance Datum (FAD) of *Camerosporites secatus* is documented in the early Fassanian (early Ladinian) of alpine Domaine of Europe [Roghi, 1995, Stockar *et al.*, 2012, Van Der Eem, 1983, Visscher and Brugman, 1981], and the FAD of *Duplicisporites granulatus* raises a middle Fassanian age in central and northwestern Europe [Kürschner and Herngreen, 2010]. By the other hand, the bisaccate pollen grains like *Lunatisporites noviaulensis*, *Microcachryidites doubingeri*, and *Microcachryidites*

fastidioides are characteristic of the Early-Middle Triassic and rarely appear in early Carnian assemblages (e.g. Doubinger and Bühmann, 1981, in Germany; Doubinger and Adloff, 1983, in the Mediterranean area; Orłowska-Zwolińska, 1983, 1985, in Poland; Eschet, 1990, in Israel; Kürschner and Herngreen, 2010 in central and northwestern Europe). The Last Appearance Datum (LAD) of *Protodiploxypinus fastidioides* (= *Microcachryidites fastidioides*) is reported in the middle Longobardian of central and northwestern Europe [Kürschner and Herngreen, 2010].

Van Der Eem [1983] in Wester Dolomites (Italy), Scheuring [1970] in Solothurner Jura (Switzerland) and Kürschner and Herngreen [2010] in Central and northwestern of Europe placed the first appearance of *Patinasporites densus* to the base of the early Carnian. Cirili [2010] in the revision of the Upper Triassic materials in Central and Northwestern of Europe suggested for this taxon a Carnian–early Norian age. Scheuring [1970] in Solothurner Jura (Switzerland) linked the presence of *Ellipsovelatisporites rugosus* to Gipskeuper, with an late Ladinian–early Norian age.

The two assemblages correspond to the intervals between *Camerosporites secatus*–*Enzonolasporites vigeni*/*Enzonolasporites vigeni* – *Patinasporites densus* phases [Van Der Eem, 1983], the *Heliosaccus dimorphus*/*Porcellispora longdonensis* Zones of Orłowska-Zwolińska [1983, 1985, 1988] amended by Herngreen [2005], zones GTr 11 and 12 in the palynostratigraphical subdivision of the Germanic Basin [Heunisch, 1999], and the *Heliosaccus dimorphus*/*Camerosporites secatus* zones [Kürschner and Herngreen, 2010].

The palynological assemblages studied in the Upper Muschelkalk of the Catalan Coastal Ranges are comparable with other assemblages recognised in the middle-upper part of Royuela Formation in Torrecilla and Arroyo de San Roman (Guadalajara, Spain; Ramos 1979), the Upper Muschelkalk of Alcalá de la Selva and Barranco del Contador, Cañete Formation (Teruel, Spain; Arche *et al.* 1995), the Upper Muschelkalk of Pantano de la Tranquera (Zaragoza, Spain. García-Royo *et al.* 1989), and the assemblage SC-2 of Juncal *et al.* [2018] in the Paris Basin.

Thus, the palynomorph assemblages identified from Falset and Rasquera sections raise a Longobardian–Cordevolian age.

This palynological dating is consistent with the

age provided by ammonite fauna and conodonts from Rasquera and Falset Units [Calvet and Tucker, 1988, Calvet *et al.*, 1987] and is coherent with previous biostratigraphical and sedimentological correlations between the Muschelkalk of the Catalan Basin and the Iberian Ranges [Diez *et al.*, 2014].

5.2. *Paleoenvironmental and paleoecological remarks*

The lithostratigraphical data suggest deposition in the middle to outer carbonate ramp environments with a predominant increase in water depth towards Rasquera section, where marls and shaly marls are more abundant [Mercedes-Martín *et al.*, 2013, 014b]. Despite the marine character of the sediments, the overall palynological assemblage found in marly levels, present a clear dominance of continental palynomorphs. Notwithstanding, although scarce, some samples show the presence of autochthonous marine prasinophytes (*Tasmanites* and *Cymatiosphaera*), and foraminiferal test linings indicating that mixing of marine and continental associations occurred at least in the more proximal parts of the basin.

Moreover, as mentioned previously, the absence of palynomorphs in the sampled coarse-grained carbonate intervals could be due to deposition of these sediments in moderate to high energy and oxygenated environments which can encourage the rapid disintegration of the organic remains. The limited tissue preservation of the studied carbonates can also be attributed to the pervasive post-depositional dolomitisation that these rocks have suffered [Tucker and Marshall, 2004]. Consequently, the taphonomic bias produced should be kept in mind when carrying out the approximate hinterland and coastal floral reconstruction. This same bias makes it impossible to make percentage variation graphs of palynomorphs to try to discern the paleoclimatic evolution of the study area.

The composition of the microfloras of the Falset and Rasquera assemblages reflects a flora dominated by xerophytic species whose pollen grains were transported by wind and water currents to the deposition zone. The presence of *Triadispora* spp. indicates an influx of hinterland elements also with saline mudflats [Brugman *et al.*, 1994, Roghi

et al., 2010]. In addition, the occurrence of *Duplicisporites*, *Camerosporites*, *Paracirculina* and *Praecirculina* (Circumpolles group) could represent a xerophytic coastal vegetation [Roghi *et al.*, 2010] due to their Cheirolepidiaceae affinity [Roghi, 2004, Scheuring, 1970, 1978, Visscher *et al.*, 1994, Zavialova and Roghi, 2005]. Although the Cheirolepidiaceae could live in a wide variety of habitats, the presence of this group in the Falset and Rasquera assemblages could indicate a drier and/or saline influence [Kustatscher *et al.*, 2018].

Although scarcer, the occurrence of spores could indicate the presence of hygrophytic vegetation. In addition, coastal, swamp and freshwater environments could have sourced different lycophytes (*Ara-trisporites*) to marine settings. Small and larger ferns (e.g. *Verrucosisporites*, *Deltoidospora* and *Concavisporites*) are typically associated to more humid environments in the hinterland, while bryophytes (*Maculatasporites*), and horsetail specimens (*Calamospora*) could have been sourced from wetter areas and along a small river.

Based on the probable parent plant affinities of the palynological record (see Supplementary data) in combination with sedimentological data, we can propose an approximate paleoenvironmental reconstruction of the study area (Figure 5).

6. Conclusions

The palynological assemblages recognised from Rasquera and Falset Sections give a Longobardian–Cordevolian age.

Our data are in agreement with the marine previous biostratigraphical data published, providing the most complete and recent figuration of the palynomorphs of the Catalan Basin. This refined calibration helps to constrain the age of the Upper Muschelkalk sediments themselves, and the overlying Keuper facies (Ladinian–Carnian) in the Catalan Coastal Ranges and the stratigraphical correlation with the Iberian Ranges, and adjacent basins of the Tethys region.

Although taphonomic bias is important, the composition of the recovered cryptocoenosis makes it possible to sketch the composition of the continental flora in the source sedimentary area. However, the decrease in preservation due to the increase in the proportion of carbonates indicates that the bias

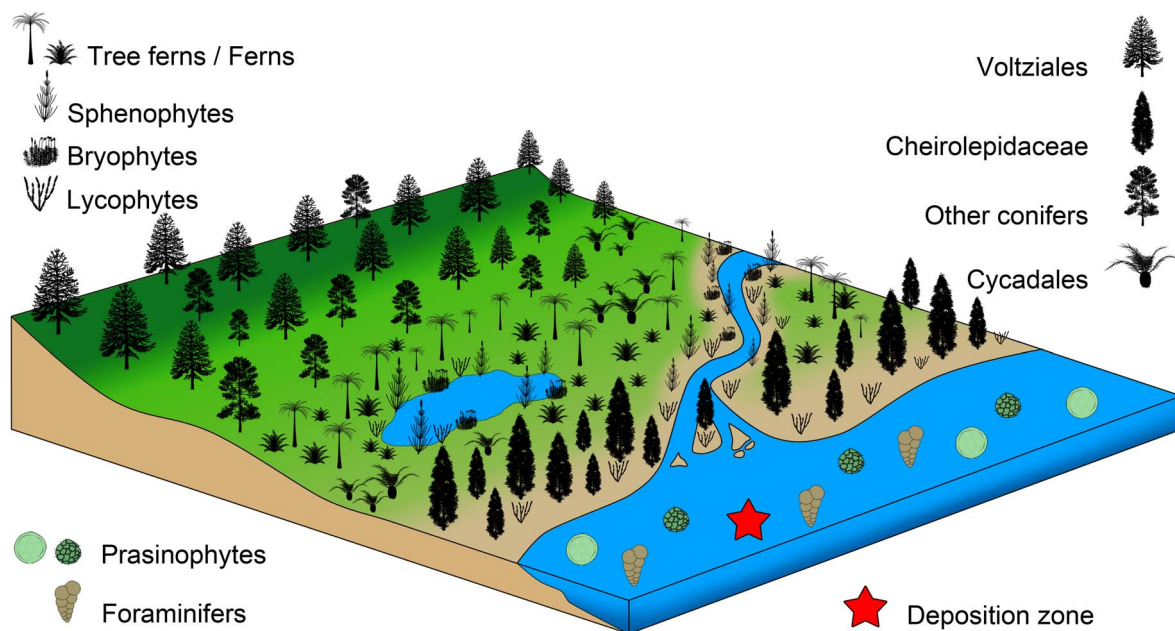


Figure 5. Paleoenvironmental reconstruction based on palynomorphs assemblages.

makes impossible, as in most cases, the statistical use of the data in the deduction of paleoclimatic evolution.

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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.8> or from the author.

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