



INSTITUT DE FRANCE
Académie des sciences

Comptes Rendus

Géoscience

Sciences de la Planète

Manuel García-Ávila, Ramon Mercedes-Martín, Manuel A. Juncal
and José B. Diez

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

Volume 352, issue 6-7 (2020), p. 443-454

Published online: 15 July 2020

Issue date: 15 January 2021

<https://doi.org/10.5802/crgeos.8>

Part of Special Issue: Some aspects of current State of Knowledge on Triassic
series on both sides of the Central Atlantic Margin



This article is licensed under the
CREATIVE COMMONS ATTRIBUTION 4.0 INTERNATIONAL LICENSE.
<http://creativecommons.org/licenses/by/4.0/>



*Les Comptes Rendus. Géoscience — Sciences de la Planète sont membres du
Centre Mersenne pour l'édition scientifique ouverte*

www.centre-mersenne.org

e-ISSN : 1778-7025



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)

Manuel García-Ávila^{®*}, ^a, Ramon Mercedes-Martín^b, Manuel A. Juncal^a
and José B. Díez^a

^a Departamento de Xeociencias Mariñas e Ordenación do Territorio, Universidade de Vigo. E-36310, Vigo, Spain

^b SZALAI Grup S.L. 07314 Caimari, Mallorca, Spain

E-mails: manugarcia@uvigo.es (M. García-Ávila), info@ramonmercedes.com (R. Mercedes-Martín), majuncales@uvigo.es (M. A. Juncal), jbdiez@uvigo.es (J. B. Díez)

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].

In the Triassic Catalan basin, the Muschelkalk facies (Anisian to Ladinian) is constituted by two marine carbonate sequences with an interstrat-

* Corresponding author.

ified 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*, *Sulcatissporites cf. reticulatus*, *Triadispora aurea*, *Triadispora crassa*, *Triadispora falcata*, *Triadispora plicata*, *Voltziaceasporites heteromorpha*, *Alisporites sp.*, *Aratrisporites sp.*, *Cyclotriletes sp.*, *Punctatissporites sp.*, *Sulcatissporites 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.*, *Punctatissporites sp.*, *Sulcatissporites 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. grauwogeli*, *Heliosaccus dimorphus*, *Lunatisporites cf. acutus*, *Ovalipollis cf. ovalis*, *Parasaccites cf. korbeensis*, *Punctatissporites 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 depositional model for the T-R Sequence 1 corresponds to a microbial-dominated fault-block carbonate ramp. The T-R Sequence 1 (early Ladinian)

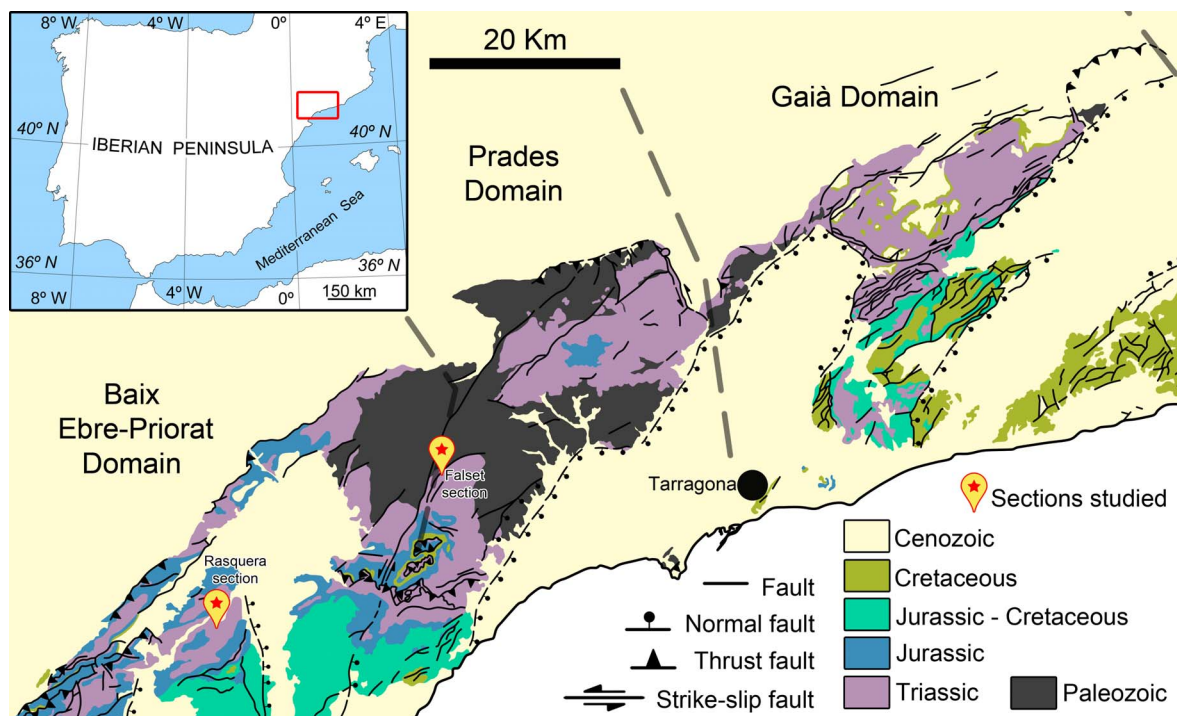


Figure 1. Geographical and geological location of the study area.

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 Benifallet 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 stromatolites 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

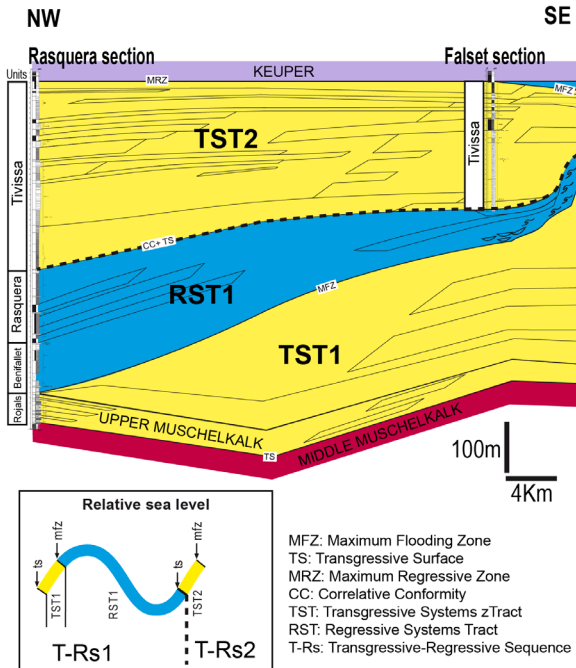


Figure 2. Depositional profile and sequence stratigraphic interpretation of the Upper Muschelkalk rocks in the Catalan Basin (Baix Ebre-Priorat domain). Note the location of the studied sections (Rasquera and Falset) and the lithological units of Calvet *et al.* [1987]. The black dotted line represents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

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 shaly 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 identified 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

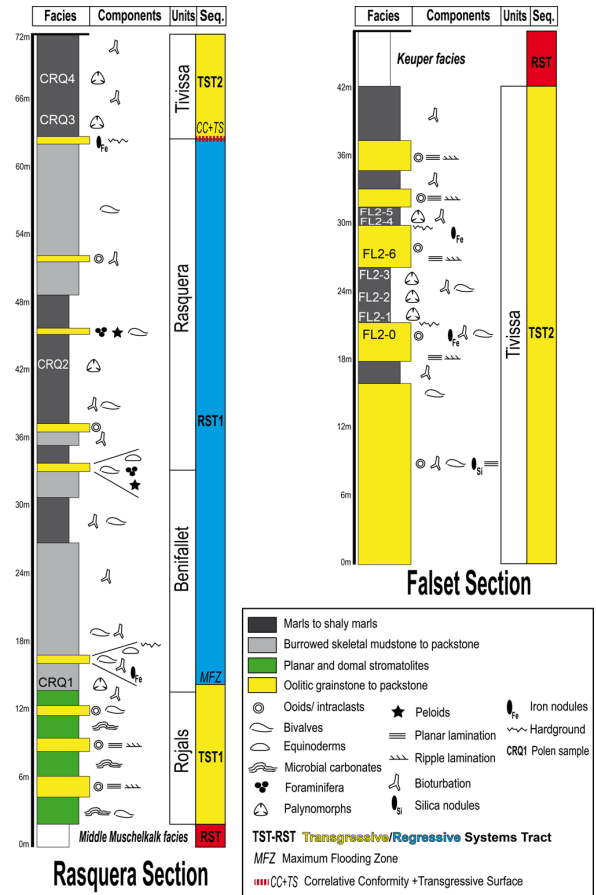


Figure 3. Stratigraphic sections studied (Rasquera and Falset) displaying the main lithological, sequence stratigraphical, and paleontologic characteristics (modified from Mercedes-Martín *et al.* [014a]).

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 steinmann*, *P. hispanicum*, *Hungarites pradoi*) and conodonts (*Metapolygnathus mungoensis*, *Pseudofurnishius murcianus*) [Calvet *et al.*, 1987, Calvet and Tucker, 1988]. However, a 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*, *Protrachyceras 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 fastidioides* Klaus 1964, *Ovalipollis cultus* Scheuring 1970, *Ovalipollis ovalis* (Kruttsch 1955) Scheuring 1970, *Ovalipollis pseudoalatus* (Thiergart) Schuurman 1976, *Palaeosporangium 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, *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., *Verrucosporites* sp., *Cymatiosphaera* sp., *Tasmanites* sp., and foraminiferal test lining.

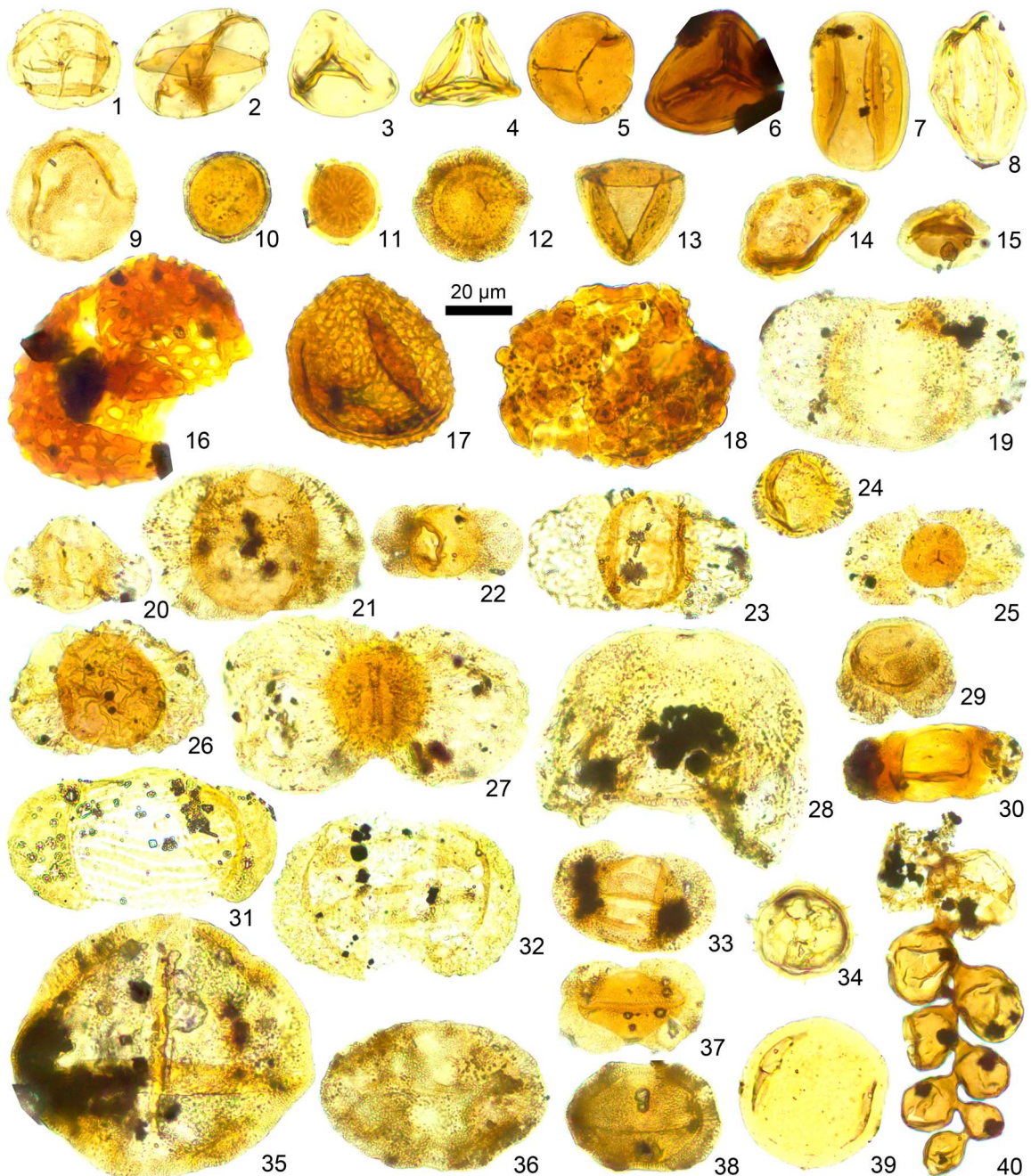


Figure 4. Synthesis of the palynomorphs found in the Falset and Rasquera sections. (1) *Calamospora* sp., (2) *Calamospora tener*, (3) *Deltoidospora* sp., (4) *Concavisporites* sp., (5) *Retusotriletes* sp., (6) *Camarozonosporites laevigatus*, (7) *Chasmatosporites* sp., (8) *Ephedripites* sp., (9) *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.

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, *Camarozonosporites 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 quadridus* Dolvy 1976, *Striatoabieites ayugii* (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., *Retusotriteles* 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; Eshet, 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 vigens*/*Enzonolasporites vigens* – *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 oryctocoenosis 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 makes impossible, as in most cases, the statistical use of the data in the deduction of paleoclimatic evolution.

Acknowledgements

The authors are grateful to the anonymous reviewers for helpful and constructive suggestions, and the

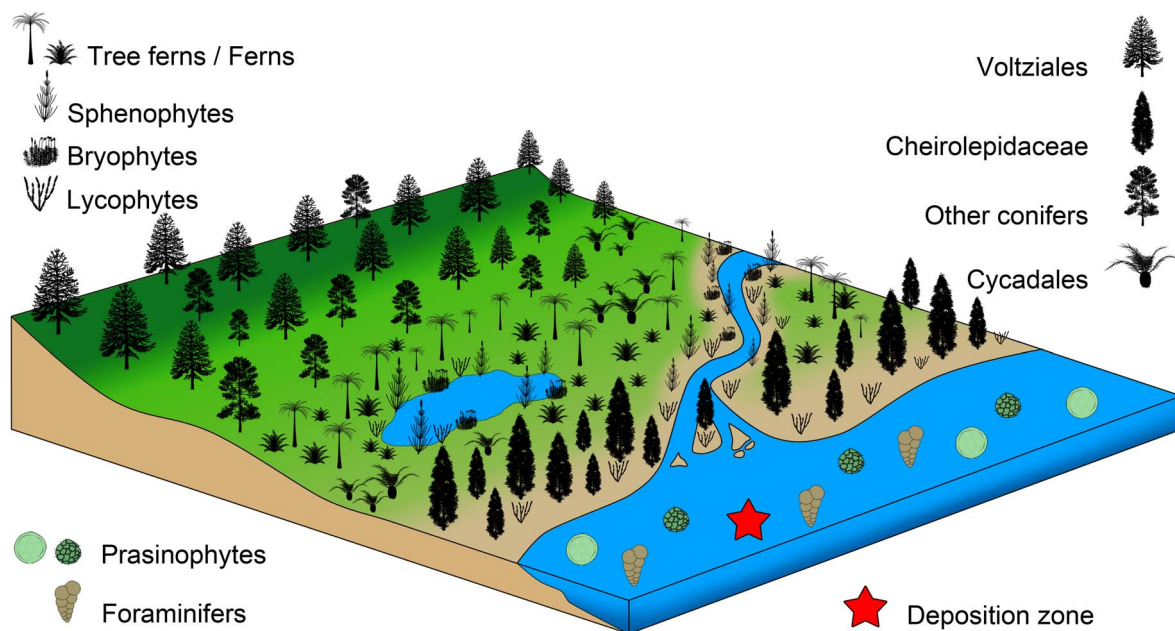


Figure 5. Paleoenvironmental reconstruction based on palynomorphs assemblages.

editor Dr. Sylvie Bourquin for her valuable recommendations. This work was supported by projects CGL2014-52699P (Spanish Ministry of Economy) and GRC 2015/020 (Xunta de Galicia) and a Percy Sladen Memorial Fund Grant of the Linnean Society of London (RM-M).

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.

References

- Arche, A., López-Gómez, J., Herranz, P., Márquez-Aliaga, A., and Solé de Porta, N. (1995). The Permian and Triassic sediments of the Teruel area, SE Iberian Ranges, Spain. *Sci. Geol. Bull.*, 48(1–3):101–117.
- Brugman, W. A., Van Bergen, P. R., and Kerp, J. H. E. (1994). A quantitative approach to Triassic palynology: the Lettenkeuper of the Germanic Basin as an example. In Traverse, A., editor, *Sedimentation of Organic Particles*, pages 409–429. Cambridge University Press.
- Calvet, F., March, M., and Pedrosa, A. (1987). Estratigrafía, sedimentología y diagénesis del Muschelkalk superior de los Catalánides. *Cuad. Geol. Ibérica*, 11:171–198.
- Calvet, F. and Marzo, M. (1994). *El Triásico de las Cordilleras Costero-Catalanas. Estratigrafía, Sedimentología y Análisis Secuencial*. Gráficas Cuenca, S.A., Cuenca, Spain.
- Calvet, F. and Tucker, M. E. (1988). Outer ramp cycles in the Upper Muschelkalk of the Catalan Basin, northeast Spain. *Sediment. Geol.*, 57:185–198.
- Calvet, F., Tucker, M. E., and Henton, J. M. (1990). Middle Triassic carbonate ramp systems in the Catalan Basin, Northeast Spain: facies, systems tracts, sequences and controls. *Carbonate Platforms, Facies, Seq. Evol.*, 9:79–108.
- Cirili, S. (2010). Upper Triassic-lowermost Jurassic palynology and palynostratigraphy: a review. In Lucas, S. G., editor, *Triassic Timescale*, Special Publications 334, pages 285–314. Geological Society of London, London, United Kingdom.
- Diez, J. B. (2000). *Geología y Palaeobotánica de la*

- Facies Buntsandstein en la Rama Aragonesa de la Cordillera Ibérica. Implicaciones bioestratigráficas en el Peritethys Occidental.* PhD thesis, Universidad de Zaragoza (Spain)/Université Paris VI (France).
- Diez, J. B., Arche, A., Broutin, J., Bourquin, S., De la Horra, R., Ferrer, J., García-Gil, S., and López-Gómez, J. (2014). Palynostratigraphic Data for the Buntsandstein and Muschelkalk Facies from the Iberian Ranges (Spain). In Rocha, R., Pais, J., Kullberg, J. C., and Finney, S., editors, *Strati 2013*. Springer, Switzerland.
- Doubinger, J. and Adloff, M. C. (1983). Triassic palynomorphs of the mediterranean area. Centre de Sédimentologie et Géochimie de la Surface, Strasbourg, France (unpublished).
- Doubinger, J. and Bühmann, D. (1981). Röt bei Borken und bei Schlüchtern (Hessen, Deutschland): Palynologie und Tonmineralogie. *Z. Dtsch. Geologischen Ges.*, 132(1):421–449.
- Eshet, Y. (1990). The palynostratigraphy of the Permian Triassic boundary in Israel: two approaches to biostratigraphy. *Israel J. Earth Sci.*, 39:1–15.
- García-Royo, J. F., Arche, A., and Doubinger, J. (1989). Palinomorfos del Triásico de la región Nuevalos-Cubel (provincia de Zaragoza). *Rev. Espa nola de Micropaleontología*, 21(1):125–137.
- Herngreen, G. F. W. (2005). Triassic sporomorphs of nw europe: taxonomy, morphology and ranges of marker species with remarks on botanical relationship and ecology and comparison with ranges in the alpine triassic. Kenniscentrum Biogeology (UU/TNO)—TNO report, NITG 04–176-C, Ned Inst Toegepaste Geowet TNO, Utrecht.
- Heunisch, C. (1999). Die Bedeutung der Palynologie für Biostratigraphie und Fazies in der Germanischen Trias. In Hauschke, N. and Wilde, V., editors, *Trias, Eine ganz andere Welt, Mitteleuropa im frühen Erdmittelalter*, pages 207–220. Pfeil Verlag, München.
- Juncal, M., Bourquin, S., Beccalotto, L., and Diez, J. B. (2018). New sedimentological and palynological data from the Permian and Triassic series of the Sancerre-Couy core, Paris Basin, France. *Geobios*, 51(6):517–535.
- Kürschner, W. M. and Herngreen, G. F. W. (2010). Triassic palynology of central and northwestern Europe: a review of palynofloral diversity patterns and biostratigraphic subdivisions. In Lucas, S. G., editor, *Triassic Timescale*, Special Publications 334, pages 263–283. Geological Society of London, London, United Kingdom.
- Kustatscher, E., Ash, S., Karasev, E., Pott, C., Vajda, V., Yu, J., and McLoughlin, S. (2018). Flora of the Late Triassic. In Tanner, L. H., editor, *The Late Triassic World*, Topics in Geobiology 46, pages 545–622. Springer, Cham.
- Mercedes-Martín, R., Arenas, C., and Salas, R. (2014a). Diversity and factors controlling wide-spread occurrence of syn-rift Ladinian microbialites in the western Tethys (Triassic Catalan Basin, NE Spain). *Sediment. Geol.*, 313:68–90.
- Mercedes-Martín, R., Salas, R., and Arenas, C. (2013). Facies heterogeneity and depositional models of a Ladinian (Middle Triassic) microbial-dominated carbonate ramp system (Catalan Coastal Ranges, NE Spain). *Mar. Pet. Geol.*, 46:107–128.
- Mercedes-Martín, R., Salas, R., and Arenas, C. (2014b). Microbial-dominated carbonate platforms during the Ladinian rifting: sequence stratigraphy and evolution of accommodation in a fault-controlled setting (Catalan Coastal Ranges, NE Spain). *Basin Res.*, 26:269–296.
- Orłowska-Zwolińska, T. (1983). Palynostratigraphy of the upper part of Triassic Epicontinental sediments in Poland. *Prace Instytutu Geologicznego*, 104:1–89.
- Orłowska-Zwolińska, T. (1985). Palynological zones of the Polish epicontinental Triassic. *Bull. Pol. Acad. Sci. Math., Earth Sci.*, 33(3–4):107–117.
- Orłowska-Zwolińska, T. (1988). Palynostratigraphy of Triassic deposits in the vicinity of Brzeg (SE part of the Fore-Sudetic Monocline). *Kwart. Geologiczny*, 32(2):349–366.
- Ramos, A. (1979). *Estratigrafía y paleogeografía del Pérmico y Triásico al oeste de Molina de Aragón*. PhD thesis, Universidad Complutense, Madrid (Spain).
- Ramos, A., Sopena, A., Sánchez-Moya, A., and Muñoz, A. (1996). Subsidence analysis, maturity modelling and hydrocarbon generation of the Alpine sedimentary sequence in the NW of the Iberian Ranges (Central Spain). *Cuad. Geol. Ibérica*, 21:23–53.
- Roghi, G. (1995). *Analisi palinologica del Trias medio del Sudalpino*. PhD thesis, Univ. Padova.
- Roghi, G. (2004). Palynological investigations in the Carnian of the Cave del Predil area (Julian Alps, NE Italy). *Rev. Palaeobot. Palynol.*, 132:1–35.
- Roghi, G., Gianolla, P., Minarelli, L., Pilati, C., and

- Preto, N. (2010). Palynological correlation of Carnian humid pulses throughout western Tethys. *Palaeogeogr. Palaeoclimatol. Palaeoecol.*, 290:89–106.
- Salas, R. and Casas, A. (1993). Mesozoic extensional tectonics, stratigraphy and crustal evolution during the Alpine cycle of the eastern Iberian basin. *Tectonophysics*, 228:33–55.
- Salas, R., Guimera, J., Mas, R., Martín-Closas, C., Melendez, A., and Alonso, A. (2001). Evolution of the Mesozoic Iberian Rift System and its Cainozoic inversion (Iberian chain). In Ziegler, P. A., Cavazza, W., Robertson, A. H. F., and Crasquin-Soleau, S., editors, *Peri-Tethys Memoir 6: Peri-Tethyan Rift/Wrench Basins and Passive Margins*, Mem. Mus. Hist. Natl. 186, pages 145–185. ISBN: 2-85653-528-3.
- Scheuring, B. W. (1970). Palynologische und palynostratigraphische Untersuchungen des Keupers im Bölchentunnel (Solothurner Jura). *Schweiz. Paläontol. Abh.*, 88:1–187.
- Scheuring, B. W. (1978). Mikroflora aus den Meridalken des Mte. San Giorgio (Kanton Tessin). In *Schweizerische Paläontologische Abhandlungen*, volume 100.
- Solé de Porta, N., Calvet, F., and Torrentó, L. (1987). Análisis palinológico del Triásico de los Catalánides (NE España). *Cuadernos Geología Ibérica*, 11:237–254.
- Stockar, R., Baumgartner, P. O., and Condon, D. (2012). Integrated Ladinian biostratigraphy and geochronology of Monte San Giorgio (Southern Alps, Switzerland). *Swiss. J. Geosci.*, 105:85–108.
- Tucker, M. and Marshall, J. (2004). Diagenesis and geochemistry of Upper Muschelkalk (Triassic) buildups and associated facies in Catalonia (NE Spain): a paper dedicated to Francesc Calvet. *Geol. Acta*, 2(4):257–269.
- Tucker, M. E., Calvet, F., and Hunt, D. (1993). Sequence stratigraphy of carbonate ramps: systems tracts, models and application to de Muschelkalk carbonate platforms of eastern Spain. *Spec. Publ. Int. Assoc. Sediment.*, 18:397–415.
- Van Der Eem, J. G. L. A. (1983). Aspects of Middle and Late Triassic Palynology: 6. Palynological investigations in the Ladinian and Lower Karnian of the Western Dolomites, Italy. *Rev. Palaeobot. Palynol.*, 39:189–300.
- Vargas, H., Gaspar-Escribano, J. M., López-Gómez, J., Van Wees, J. D., Cloetingh, S., de La Horra, R., and Arche, A. (2009). A comparison of the Iberian and Ebro Basins during the Permian and Triassic, eastern Spain: a quantitative subsidence modelling approach. *Tectonophysics*, 474:160–183.
- Virgili, C., Sopena, A., Arche, A., Ramos, A., and Hernandez, S. (1983). Some observations on the Triassic of the Iberian Peninsula. *Neue Beitr. Biostratigr. Tethys-Trias, Schriftenr. Erdwiss. Komrn.*, 5:287–294.
- Visscher, H. (1967). Permian and Triassic palynology and the concept of “Tethys twist”. *Palaeogeogr. Palaeoclimatol. Palaeoecol.*, 3:151–166.
- Visscher, H. and Brugman, W. A. (1981). Ranges of selected palynomorphs in the Alpine Triassic of Europe. *Rev. Palaeobot. Palynol.*, 34:115–128.
- Visscher, H., Van Route, M., Brugman, W. A., and Poort, R. J. (1994). Rejection of a Carnian (Late Triassic) “pluvial event” in Europe. *Rev. Palaeobot. Palynol.*, 83:217–226.
- Wood, D. G., Gabriel, A. M., and Lawson, J. C. (1996). Palynological techniques – processing and microscopy. In Jansonius, J. and McGregor, D. C., editors, *Palynology: Principles and Applications*, volume 1, pages 29–50. AASP Foundation, Dallas, Texas, USA.
- Zavialova, N. E. and Roghi, G. (2005). Exine morphology and ultrastructure of *Duplicisporites* from the Triassic of Italy. *Grana*, 44:337–342.