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First record of Anisian deposits in the Betic External Zone of southern Spain and its paleogeographical implications

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A B S T R A C T

In the External Zone of the Betic Cordillera (S Spain), upper Muschelkalk (Ladinian) facies have been known for decades; however, so far there is no stratigraphic record of Anisian deposits. In the present study, new biostratigraphic data from a carbonate succession in the easternmost Subbetic domain reveal a Pelsonian-Illyrian (Anisian) age. The nautiloids *Germanonautilus salinarius* and *Germanonautilus saharonicus* are documented for the first time in the Iberian Peninsula, and together with the brachiopod *Tetractinella trigonella* and the bivalves *Neoschizodus orbicularis* and *Myophoria vulgaris* they represent marker fossils of Anisian deposits previously described from many other basins, both in the Germanic and Alpine realms. The co-occurrence of the nautiloid *G. saharonicus* and the bivalve *Gervillia joleaudi* at the top of the studied succession serves as correlation tool for the first faunal migration event from the Sephardic towards the Subbetic domain. The palynomorph assemblage, including the monosaccate pollen grain *Cristianisporites triangulatus*, provides further evidence of a late Anisian age. An integrated study of fossil assemblages and sedimentary facies reveals tidal and very shallow-marine environments that characterize an extensive epicontinental platform in the western Tethys along the paleo-margin of the Iberian Massif. Two thin shale intervals represent two distinct transgressive phases, correlative to the Pelsonian maximum-flooding zone recorded in other European basins. The new findings contribute to the ongoing paleogeographic reconstruction of epicontinental platform settings which developed during the Middle Triassic in the Peri-Tethyan realm.

1. Introduction

Over the last three decades, sedimentation, tectonics, sea-level changes, climate and the ecological recovery that took place during the Triassic following the end-Permian extinction have been studied globally (e.g., Roest et al., 1992; Payne, 2005; Tong et al., 2007; Song et al., 2011; Holz, 2015; Foster and Sebe, 2017). Additionally, the relationship of events during the Triassic recovery phase and within a period of major changes in paleogeography related to the break-up of Pangaea has been documented in different areas worldwide (e.g., Olsen, 1997; Veevers, 2004; San Mauro et al., 2005; Jordan et al., 2016). In central Europe, sea-level oscillations and tectonics (Szulc, 2000; Feist-Burkhardt et al., 2008b; Matysik, 2019; Matysik et al., 2022) related to the opening of the Tethys to the west and in the context of inter-regional correlation (Götz and Montenari, 2017; Götz and Török, 2018; Liu et al., 2021) have been studied in great detail. Moreover, the reconstruction of faunal immigration routes within changing paleogeographic scenarios is addressed in most recent studies (Rein, 2019; Siegel et al., 2022; Vörös et al., 2022; Pieroni, 2022).

In the Iberian Peninsula, the variety of Triassic deposits – including continental, Alpine and Germanic facies – is related to the break-up of Pangaea and the successive opening of the Tethys to the West (Sopeña et al., 1988; Pérez-Valera and Pérez-López, 2008; López-Gómez et al., 2012; Arche and López-Gómez, 2014; López-Gómez et al., 2019; Pérez-López and Pérez-Valera, 2021). While the Triassic

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paleogeography of the northern Peri-Tethys Basin (Germanic Basin) has become increasingly well defined (e.g., Diedrich, 2009; Götz and Feist-Burkhardt, 2012; Černanský et al., 2018), the Iberian part of the western Tethyan realm needs further investigations to establish high-resolution correlation schemes across the epicontinental margin of the Tethys sea. Furthermore, Anisian rocks are less well documented in the Iberian Peninsula. The knowledge of Anisian outcrops is based on biostratigraphic data obtained by some fossil groups studied in the northeastern Iberian Peninsula and the Balearic Islands (Márquez-Aliaga et al., 2000; Juncal et al., 2017; García-Ávila et al., 2020; Manzanares et al., 2020). On the other hand, recent works carried out in Sardinia (Italy) provide new data to reconstruct the paleogeographic evolution of the central-W Tethys (Stori et al., 2022), adding another puzzle piece.

In the External Zone of the Betic Cordillera, Triassic deposits are developed in Germanic facies (Pérez-López, 1998; Pérez-López and Pérez-Valera, 2007). Middle Triassic epicontinental marine deposits correspond to the upper Muschelkalk of Ladinian age (Pérez-Valera and Pérez-López, 2008; Pérez-Valera et al., 2017) and can be correlated with other Ladinian units of the Iberian and Catalan coastal ranges (M3 unit: Calvet and Tucker, 1988; Márquez-Aliaga et al., 2000; Escudero-Mozo et al., 2015) and the Upper Muschelkalk of Germany (Aigner and Bachmann, 1992).

In the present study we identified for the first time lower Muschelkalk deposits of Anisian age in the Subbetic domain (External Zone of the Betic Cordillera). The new stratigraphic, sedimentological and paleontological data provide a precise age assignment and depositional model for the lower Muschelkalk in this domain, leading to a refined paleogeographic reconstruction. The results of this work are compared with lower Muschelkalk outcrop sections of the Iberian and Catalan Coastal ranges and other European basins, shedding new light on the complex Triassic paleobiogeographic situation.

2. Geological setting

The epicontinental Triassic of the Iberian Peninsula has been subdivided into different paleogeographic domains based on lithological units (Virgili et al., 1977, 1983; Sopeña et al., 1983; López-Gómez et al., 1998; Escudero-Mozo et al., 2015), mainly differentiating between distinct Muschelkalk carbonate units and their age assignment (Fig. 1B):

a) Iberian Triassic: the characteristic feature of this domain is the presence of one carbonate Muschelkalk facies unit of Ladinian age overlying the Buntsandstein facies and underlying the Keuper facies. This domain includes outcrops of the NW-Iberian Ranges, a wide part of the Pyrenees and outcrops of the W-Ebro domain.

b) Mediterranean Triassic: characterized by the presence of two carbonate units of Muschelkalk facies of Anisian and Ladinian age, respectively, separated by an intercalated detritic unit made up of red lutites, sandstones and gypsum beds. This domain includes outcrops of the Catalan Coastal Ranges, the central zone of the Iberian Ranges, the E-Ebro and the Masarac region of the Pyrenees (Virgili et al., 1977; Sopeña et al., 1983).

c) Levantine-Balearic Triassic: represented by a single, thick carbonate unit of middle Anisian-Ladinian age, documenting the disappearance of the detritic intercalation of the Mediterranean Triassic (López-Gómez et al., 1998; Escudero-Mozo et al., 2015). This domain includes outcrops of the Castellón and Valencia provinces (SE Spain) and the Balearic Islands.

The Triassic of the Iberian Peninsula (Fig. 1A), next to or nearby the Variscan basement (Iberian Massif), is characterized, in the north, by continental facies (Hesperian Triassic) with typical redbeds (Ramos et al., 1986; López-Gómez et al., 2002, 2019). In the south, in the Internal Zone of the Betic Cordillera, alpine marine facies are documented (Fontboté, 1986; Delgado et al., 2004). However, the most common Triassic facies present in Iberian outcrops are the Epicontinental-type (López-Gómez et al., 2002, 2019) that comprises the three typical Germanic facies: Buntsandstein, Muschelkalk and Keuper.

The External Zone of the Betic Cordillera crops out extensively to the S and SE of the Iberian Variscan Massif and has been subdivided into two large tectonostratigraphic domains that represent two sectors of the Southiberian paleo-margin: the Prebetic domain proximal to the Iberian Massif, and the distal Subbetic domain (Vera and Martín-Algarra, 2004). The Internal Zone extends across the southernmost sector of the Betic Cordillera and represents the most intensely deformed region of the cordillera, frequently showing metamorphism (e.g., Sanz de Galdeano, 1997). The Internal Zone is composed of allochthonous tectonic units belonging to the Alborán domain and originally located in the Mesomediterranean paleo-margin (Guerrera et al., 2021). The Triassic successions of the Alborán domain units are thicker, they include more marine facies and are generally more alpine in character (Pérez-López and Pérez-Valera, 2007). The outcrop studied in the present work corresponds to the Epicontinental Triassic with Muschelkalk carbonate facies (Pérez-López and Pérez-Valera, 2007) and belongs to the Subbetic domain of the External Zone (Vera and Martín-Algarra, 2004).

In the studied zone, carbonates are exposed surrounded by siliciclastic materials with gypsum-bearing tectonic breccias, together with Upper Cretaceous tectonized rocks forming an extensive shear zone in the southern sector (Fig. 2). The general structure corresponds to a main thrust of the Muschelkalk (lower, middle and upper) carbonate beds, with few meters of Buntsandstein deposits, overlying units of Keuper affinity of a northern and different tectonic unit (Fig. 2). Minor thrusts repeat the Muschelkalk sequence in the Las Atalayas outcrop showing an imbricated geometry (Fig. 2). Additionally, numerous fault contacts and discontinuous Muschelkalk carbonate beds with very different dip directions suggest moderate folding.

3. Material and methods

Previous works addressed Triassic carbonate successions throughout the Betic External Zone, described as upper Muschelkalk deposits (Cehegín Formation) of Ladinian age (Busnardo, 1975; Pérez-López et al., 1991; Pérez-Valera and Pérez-López, 2008; López-Gómez et al., 2019). Here, we present a detailed field study and analyses of fifty-one samples from an outcrop located west of the village of Cehegín (Murcia province), in a sector known as “Las Atalayas” (Fig. 2). The composite “Las Atalayas” outcrop section includes four subsections (A-D) featuring three carbonate units, which are subdivided and described for the first time in the present work. The sedimentological interpretation is based on new data of the “Las Atalayas” section, integrating data from previous works carried out in other regions of the Iberian Peninsula, mainly in the lower Muschelkalk of the eastern sector of the Iberian Cordillera, and studies describing similar facies in different Triassic basins of Europe.

The connection between the four subsections is based on laterally traceable reference beds that have been identified at the base or top of such subsections (Figs. 2, 3). In subsections A and B, an easily identifiable 35 cm thick ochre dolostone bed serves as reference (Fig. 3; Ref. AB). In subsections B and C, a relatively thick bed with evaporite moulds has been identified (Fig. 3; Ref. BC), and the connection between subsection C and D is based on a laterally traceable erosive surface on top of a strongly bioturbated marly limestone below fossil-rich beds (Fig. 3; Ref. CD).

In order to distinguish the different lithofacies types, twenty-nine rock samples were collected for microscopic study from thin sections. For the description of the carbonates, the classification of Dunham (1962) with the modifications of Embry and Klovan (1971) was applied. Alizarin Red S was used to distinguish dolomite from calcite.

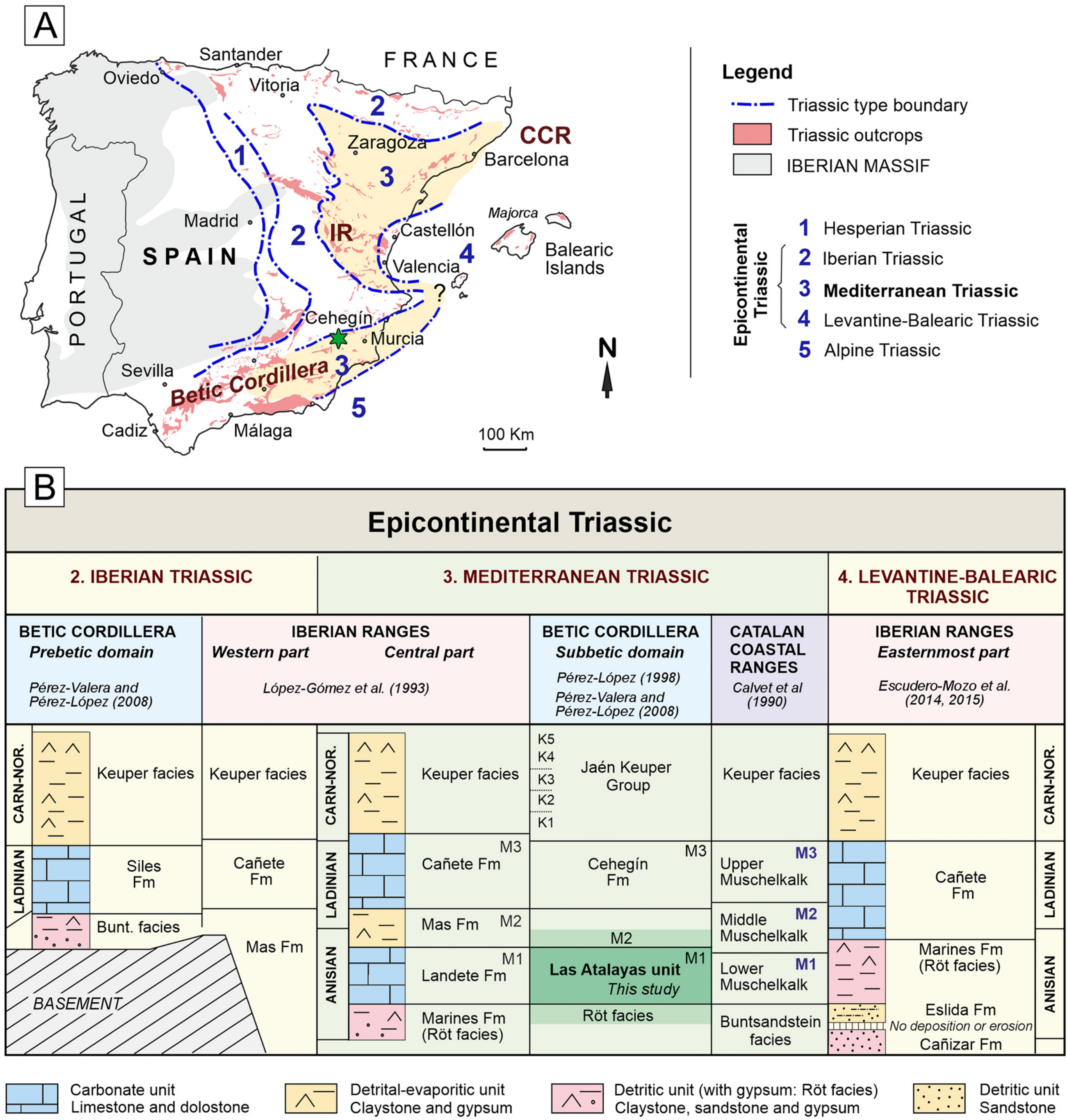
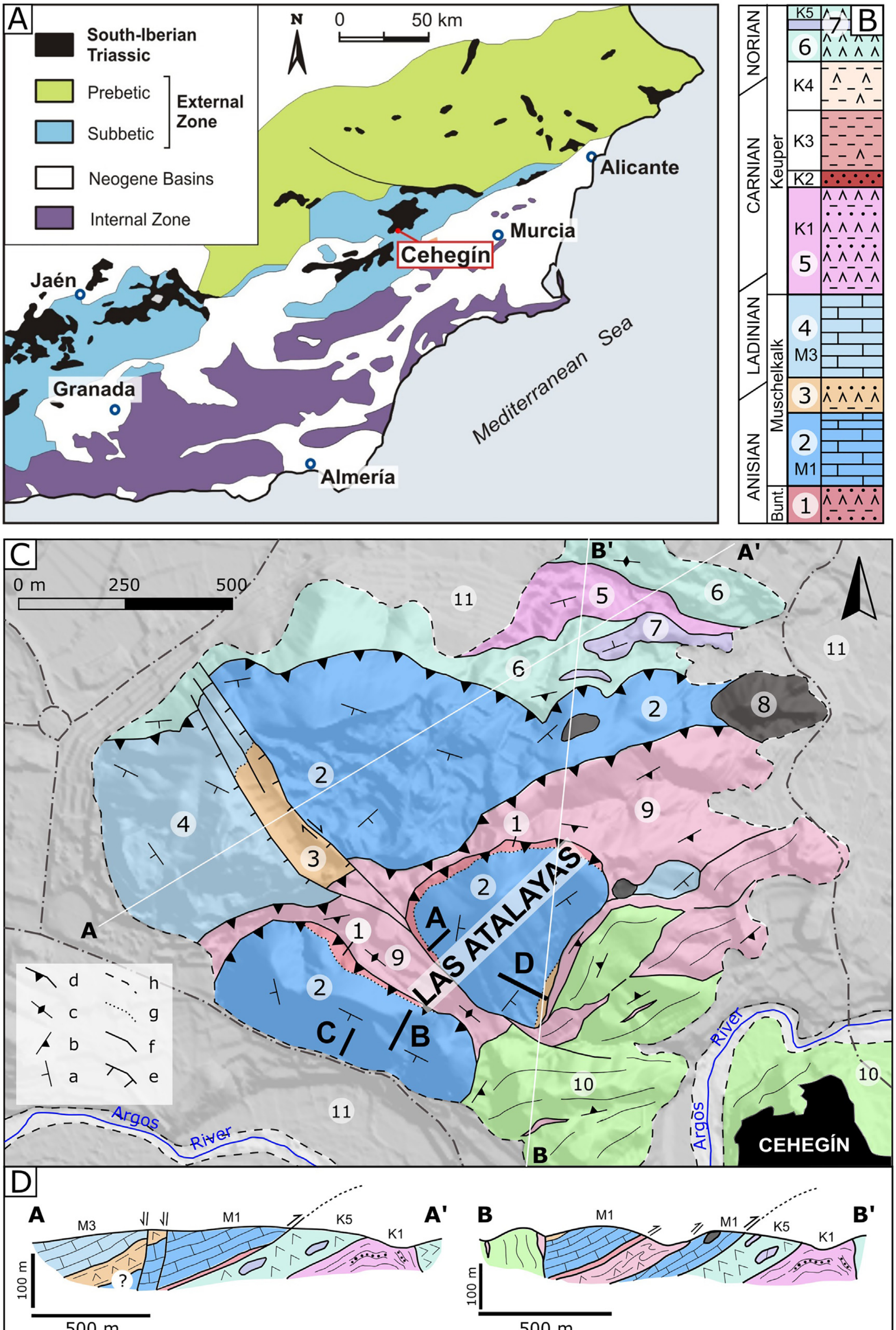


Fig. 1. (A) Triassic paleogeographic domains of the Iberian Peninsula. The study area is indicated by the green star. IR: Iberian Ranges; CCR: Catalan Coastal Ranges. (B) Stratigraphic framework of the Middle-Upper Triassic successions of the different paleogeographic domains (Calvet et al., 1990; López-Gómez et al., 1993; Pérez-López, 1998; Pérez-Valera and Pérez-López, 2008; Escudero-Mozo et al., 2014, 2015). The studied section (Las Atalayas) is indicated by the dark green background. M1, M2, M3 correspond to the lower, middle and upper Muschelkalk, respectively . K1 (lutite and gypsum), K2 (sandstone), K3 (red lutite), K4-K5 (lutite, gypsum and carbonate) correspond to the different units of the Keuper facies.

Several field campaigns were carried out for the sampling of different fossil groups (cephalopods, brachiopods, bivalves) which were later studied in the laboratory. Bivalve specimens collected by the authors are housed in the *Museo Universidad Valencia Historia Natural* (MUVHN). The sampled specimens attributed to *Tetractinella trigonella* and pavement slabs containing this taxon are deposited in the repository of the Earth and Environmental Sciences Department (DCTMA) at the University of Alicante (Spain), labelled under reference numbers CMB.1 to 18 and LAT.1 to 20. The nautiloid specimens are housed in the same department at the University of Alicante (CH1-A1 to 4, CH1-C1 to 3 and CH2-A1 to 4). Nine shale samples were collected for palynological analysis and prepared using standard palynological processing techniques (Wood et al., 1996), including HCl (33 %) and HF (73 %) treatment for dissolution of carbonates and silicates, and saturated $ZnCl_2$ solution (D ≈ 2.2 g/mL) for density separation. Residues were sieved at 15-μm mesh size. Slides have been mounted in Eukitt, a commercial, resin-based mounting medium. Palynological slides were analysed under a Leica DM2000 transmitted light microscope.

Slides are housed in the micropaleontological collection of the *Geozentrum Hannover* (GZH), Germany.

Additionally, thirteen samples were collected for mineralogical analysis, based on X-ray diffraction. Data reduction was carried out using the software written by Martín-Ramos XPowder12. This program uses all XRD patterns to identify mineral components and quantify modal proportions. Automatic acquisition, evaluation, and computation of XRD data were carried out with the XPowder program.



4. Stratigraphy

So far, the Muschelkalk facies of the Betic External Zone have been identified as a carbonate succession of Ladinian age, dominated by marlstones towards the upper part (Busnardo, 1975; Pérez-López, 1998; Pérez-Valera and Pérez-López, 2008). The succession displays an overall thinning-upward trend. Two coeval Ladinian formations, namely the Siles Formation and the Cehegín Formation (Fig. 1), are defined to document the facies and lithostratigraphic variability within the Muschelkalk (Pérez-Valera and Pérez-López, 2008). The Siles Formation features proximal deposits of the Iberian Massif, while the Cehegín Formation comprises a distal and much thicker succession associated with the Subbetic domain. The deposits of both formations represent shallow platform facies. The presence of cephalopods in certain levels indicates a connection with open-marine sedimentary environments (Pérez-Valera and Pérez-López, 2008; Pérez-Valera et al., 2016; Pérez-Valera et al., 2017).

Intense tectonics complicates the study of the numerous partial or truncated carbonate sections that crop out in the study area (López-Gómez et al., 2019). For this reason, it is difficult to establish a complete stratigraphic framework for the Triassic in this region. Nevertheless, for the first time we identified an outcrop exposing lower Muschelkalk deposits of Anisian age in the Betic External Zone (Fig. 2). This succession overlies the lutite and gypsum beds of the Röt facies (Buntsandstein) and is followed by gypsum and red lutite beds (Figs. 2, 3) attributed to the middle Muschelkalk (Fig. 1, M2). Three units have been distinguished from bottom to top: a) A lower unit characterized by an alternation of marl and carbonate beds; b) a middle unit consisting mainly of a bedded limestone package; and c) an upper unit which is the thickest and mainly composed of bedded dolostone with some gypsum beds. The middle and the upper units contain a meter-thick intercalation of thin beds of shaley lutite and marly carbonate, rich in fossils, which are described in the present work (Fig. 3, MID-1, MID-2).

5. Deposits and depositional environments

The sediments exposed in the "Las Atalayas" section represent mainly fine-grained limestones and dolostones as well as marls and gypsum beds, lacking high-energy deposits, except for some thin bioclastic and intraclastic beds.

5.1. Carbonate-marl alternation (lower unit)

The lower part of this succession (17 m thick) is characterized by marls and lutites alternating with limestone, ochre dolostone and marly limestone beds (Fig. 4A). Evaporite moulds, locally with horizontal lamination, are common. Some thin beds display bioclasts. In thin sections, bivalves, gastropods, echinoderms, foraminifera, and intraclasts were identified (sample 22–1). The most frequent texture is mudstone or microsparstone (samples 22–2, 3), although bioclastic packstone/rudstone with intraclasts is also present (sample 21-85b). Carbonates are increasing upwards. In places, a succession of marl, marly limestone and limestone from the base to the top is observed (Fig. 4B).

5.1.1. Interpretation

The presence of evaporite moulds, intraclasts and laminations is interpreted as intertidal to subtidal facies of very low-energy marine zones (e.g., Flügel, 2004; Adams and Diamond, 2019; Matysik, 2019) with the exception of thin bioclastic beds, which are interpreted as storm deposits (e.g., Kreisa, 1981; Aigner, 1985; Pérez-López and Pérez-Valera, 2012) or lag beds. This unit is very similar to the "lower carbonate-marl alternation" described by Ortí et al. (2020) and Pérez-López et al. (2021) which is recognized in a transgressive phase of the Eastern Iberian Triassic. The increase in carbonate deposits of this lower unit, overlying the Röt facies, and the evolution of characteristic sequences from marls to limestones are interpreted as evidence of transgressive deposits in an evaporitic coastal mud flat environment of a shallow platform setting.

5.2. Bedded limestone package (middle unit)

The "Las Atalayas" succession comprises a limestone package (34 m thick) formed by limestone beds of different thicknesses and bedded marly limestones with nodular structure. The beds are locally massive although mainly thin bedded with lamination (Fig. 4C). The thin-bedded limestones exhibit undulating surfaces with bioturbation (Fig. 4D). A distinctive feature of this unit is the presence of bioturbated nodular limestones with *Planolites* burrows (Fig. 4E). Thin limestone beds with bioclasts are common. The main microfacies of this unit are mudstone/microsparstone and wackestone with foraminifera (*Nodosaria ordinata*) and mollusc fragments (samples 22–11, 21–3, 4). However, at the top of some beds, bioclastic wackestone to packstone (rudstone) occurs (samples 21–7, 8, 9). Another characteristic of this unit is the presence of irregular surfaces associated with bioturbated beds with iron oxides and bioclasts concentrated on these surfaces (Fig. 4F). This unit includes a 0.5 m-thick lutite and marly carbonate intercalation described below in Section 5.4.

5.2.1. Interpretation

The common presence of nodular facies with moderate bioturbation and few bioclasts is interpreted as evidence of a subtidal to lagoonal environment with low-energy conditions. The lagoons could have been more or less restricted and deep (e.g., Pöppelreiter, 2002; Adams and Diamond, 2019). At times storms affected the seafloor and accumulated bioclasts. The thin-bedded limestones with undulating surfaces could correspond to deeper deposits. Compared to the facies described by Pérez-López et al. (2021) in the Eastern Iberian Triassic, showing rare bioclasts and bioturbation structures, they indicate shallow-water and low-energy conditions. Diedrich (2009) studied thin-bedded marly limestones with irregularly undulating surfaces in the Germanic Triassic, which were interpreted as subtidal flat deposits. The thin-bedded limestones with laminations and thin banding formed by different grain sizes are very similar to those described by Chatalov (2017) in the Lower Triassic of the Western Balkanides, interpreted as subtidal sediments. In general, these subtidal and lagoonal deposits are arranged in shallowing-upward sequences, terminating in bioclastic deposits and, in places, the formation of hardgrounds is recognized.

5.3. Bedded dolostone with gypsum beds (upper unit)

These deposits are the thickest of the succession (59 m thick). This unit is characterized by dolostone with some gypsum beds, although limestone beds are also present. Laminated, thin-bedded dolostone and breccia beds are common and, in places, carniolar ochre dolostone deposits occur. The microfacies often consists of dolomicrosparstone (samples 21–10, 22–6, 12, 15), bioclastic packstone is rare (sample

Fig. 2. (A) Geological simplified map of the southeastern Betic Cordillera (after Berrocal-Casero et al., 2023). (B) stratigraphic sketch of the Triassic unit (modified from Ortí et al., 2022) with indication of lithostratigraphic units differentiated in the geological map, and of Triassic facies (Buntsandstein, Muschelkalk and Keuper). (C) Geological map of the "Las Atalayas" outcrop. (D) Geological sections of the "Las Atalayas" outcrop. Legend for the map: 1: Röt facies; 2: M1 unit; 3: M2 unit; 4: M3 unit, 5: K1 unit; 6: K5 unit (gypsum); 7: K5 unit (dolostones); 8: Subvolcanic rocks; 9: Gypsum tectonic breccia; 10: Upper Cretaceous unit; 11: Quaternary deposits; a: dip and dip direction of beds; b: dip and dip direction of cleavage; c: vertical cleavage; d: thrust; e: normal fault; f: tectonic contact; g: stratigraphic contact; h: unconformable contact. The position of the different subsections (A, B, C and D) is also indicated. Geographical coordinates of base of subsection A: 38°06′51″ N; 01°48′37″ W; subsection B: 38°06′04″ N; 01°48′38″ W; subsection C: 38°06′03″ N; 01°48′46″ W; and subsection D: 38°06′36″ N; 01°48′46″ W.

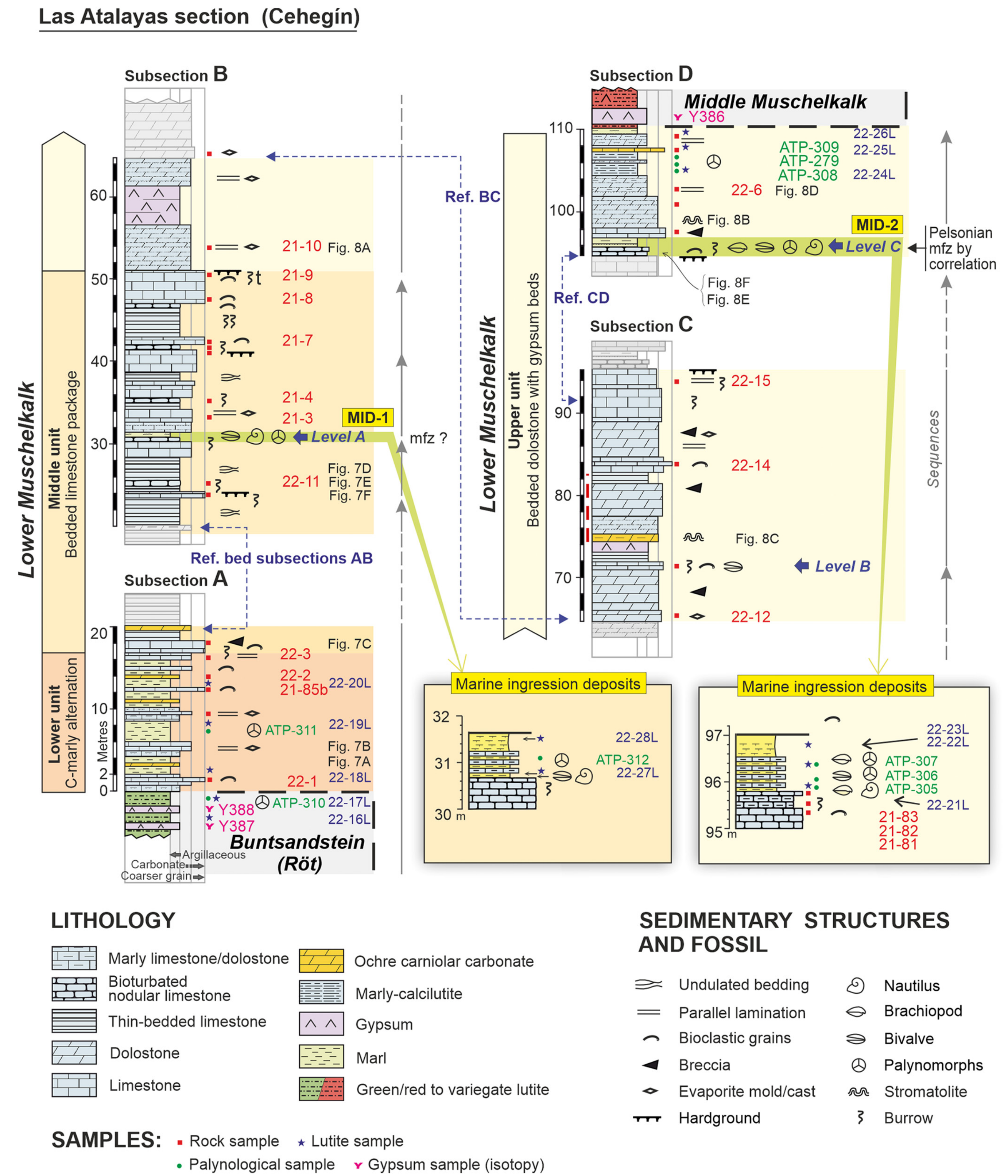


Fig. 3. Lower Muschelkalk composite section from four (A-D) subsections of the "Las Atalayas" outcrop. Different samples are indicated: sediments (21- # or 22- #), bivalves (Level A, B, C), lutite (22- #L) palynomorphs (ATP-#) and previously studied gypsum samples (Ortí et al., 2022) for isotopy (Y#). mfz: maximum-flooding zone. Location see Fig. 2.

22–14), and rudstones represent the breccia beds. The laminated dolostone beds can display evaporite moulds and thin lamination (Fig. 5A). In places, the observed lamination is strongly undulated and forms small domes on the bed top (Fig. 5B). Only in a single case, the undulated lamination is associated with gypsum beds (Fig. 5C). The upper part of this bedded dolostone unit consists of marly carbonate beds which become increasingly shaley towards the top (Fig. 5D), although there are also some intercalations of thin carbonate beds. This unit includes a 1.2 m-thick lutite and marly carbonate intercalation described in Section 5.4.

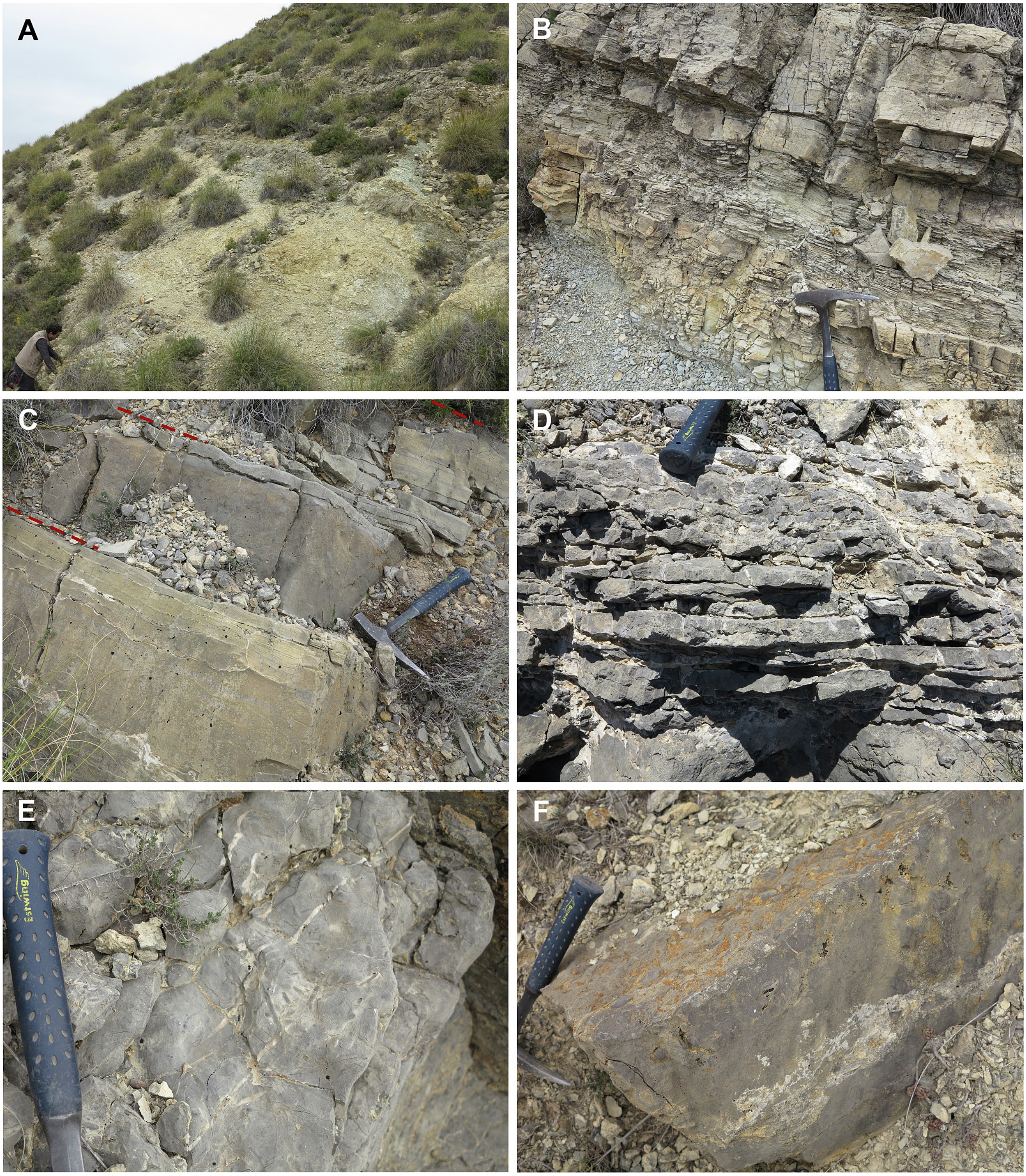


Fig. 4. Lithofacies in outcrops of the lower and middle units. (A) Lutites, marl and marly limestone of the lower unit. (B) Sedimentary sequence of the lower unit where an upward increase of carbonate is observed. (C) Bedded limestone of the middle unit, with laminations or thin banding which are formed by different fine-grain sizes (sequence boundaries are indicated). (D) Thin-bedded limestone of the middle unit with undulating surfaces and bioturbation level. (E) Bioturbated nodular limestone with *Planolites* burrows, characteristic of the middle unit. (F) Hardground with bioclasts on the top of a limestone, occurring in the middle unit.

5.3.1. Interpretation

The thin-bedded dolostones with evaporite moulds and laminations, and in places domes, are interpreted as tidal flat deposits with algal mats and/or stromatolites (e.g., Jahnert and Collins, 2012; Zhang et al., 2019). The gypsum corresponds to ponds or ephemeral lagoons (Ortí et al., 2017). The presence of dolomitic breccias is interpreted to represent supratidal deposits. These facies, locally associated with carniolar ochre dolostones, indicate a restricted inner-ramp setting characterized by frequent emersion events (Bodzioch and Kwiatkowski, 1992; Szulc, 2000). In general, these deposits are related to a carbonate tidal flat setting with ponds and very shallow restricted lagoons under arid conditions (Ortí et al., 2017).

Fig. 5. Lithofacies in outcrops of the upper unit. (A) Laminated dolostone bed with evaporite moulds. (B) Dome forms on top of dolostone which are interpreted as stromatolites. (C) Stromatolitic marly limestone above gypsum beds. (D) Laminated marly limestone (dolomicrosparstone). (E) Alternation of shaley lutite and marly carbonate (marine ingression deposits), which underlies laminated dolostone beds. (F) Detail of shaley and marly carbonate alternation (camera lens cap: 4.5 cm).

5.4. Significant intercalations of shaley lutite and marly carbonate

In the middle and upper units of the succession, shaley lutite and marly carbonate intercalations are documented (Fig. 3). These intercalations of 0.5 and 1.2 m thickness, respectively, consist of thin grey, shaley lutite and nodular, marly limestone beds with bioclasts and fossils (Fig. 5F). In the middle unit, nautiloids and bivalves are present, and in the upper unit a diverse fauna of brachiopods, bivalves and nautiloids is recorded. Palynological and mineralogical data of the grey shales show a striking similarity between the two intercalations, although marine phytoplankton (acritarchs) is more abundant in the upper one. The intercalations become more marly towards the top and are overlain by laminated carbonates with evaporite moulds and intraclasts (Fig. 5E). These fossil-rich levels are described separately (see Section 7).

5.4.1. Interpretation

These two intercalations correspond to relatively deeper sediments within the two units that comprise facies of very shallow sedimentary environments, especially in the upper unit. They represent two marine ingression events (MID-1 and MID-2) characterized by open-marine faunal elements in the flooded areas of the lagoon: cephalopods and bivalves in the middle and upper unit and brachiopods in the upper unit. At times, there was a connection with the open sea, but depositional conditions remained low-energy, as barriers (emerged zones) must have continued to exist in areas far from the study area within the Triassic epicontinental platform (Pérez-López et al., 2011; Pérez-López et al., 2021).

6. Mineralogy of lutites

X-ray diffraction (XRD) has been carried out in order to better understand the depositional environment of prominent lutite beds (Fig. 6). The studied lutites comprise: a) the lower beds of the Röt facies and the lower part of the carbonate succession, representing a transgressive phase; b) the intermediate shaley lutite intervals between the carbonate beds; in particular beds that have been identified as deposits related to marine ingression (MID); and c) the upper lutite beds representing a regressive phase. Quartz and illite are predominant in the lutites listed under a) and b). Clearly, the upper shaley lutites are much more carbonated, with hardly any silicates. The influence of carbonate production at the end of the lower Muschelkalk deposits is noticeable (samples 22-24 L, 25 L, 26 L). Glauconite is present early in the transgressive phase (samples 22-16 L, 17 L, 19 L), in the Röt facies and in the lower unit, and reaches its maximum in the dark levels associated with the MID (samples 22-21 L, 22 L, 23 L). In the upper beds, during the regressive phase, the glauconite content is very low.

These data corroborate the interpretation that the lower shale levels, more continental in character, changed to more marine (carbonate) deposits, due to the onset of a transgressive phase. The dark levels associated with the shaley lutite intervals (MID) represent short phases of carbonate production depletion and the onset of reducing conditions, when the sedimentation rate was very low. Several studies showed that the formation of glauconite is related to low sedimentation rates in response to rapid marine transgressions (Tounekti et al., 2021; Baioumy et al., 2020; Roy Choudhury et al., 2022), and in environments with conditions that are not strongly reducing and not necessarily in very deep water (Tribovillard et al., 2022). In the levels corresponding to the MID it can be observed how, at the same time, they contain a higher proportion of quartz from the hinterland as aeolian sediment input (Calvert and Pedersen, 2007). The uppermost deposits of the upper unit show much more carbonate related to a carbonate sabkha as documented from other Iberian basins (Pérez-López et al., 2021).

7. Paleontological data

7.1. Cephalopods (Nautiloids)

Generally, nautiloids are rare in the "Las Atalayas" section, however some specimens have been found in two fossiliferous levels, some of which are documented for the first time in the Triassic of the Iberian Peninsula (*Germanonautilus salinarius* and *Germanonautilus saharonicus*). They occur in association with bivalves in level A, and with bivalves and brachiopods in level C (Figs. 3, 7).

In level A, the lower fossiliferous level in the section, several specimens of nautiloids can be assigned to *Germanonautilus salinarius* (Mojsisovics, 1882) and *Grypoceras* cf. *quadrangulum* (Beyrich, 1866). In contrast, the upper fossiliferous level (level C) is characterized by the monospecific presence of *Germanonautilus saharonicus* (Parnes, 1986) (Fig. 7).

7.2. Brachiopods

This group is represented solely by the athyridoid brachiopod *Tetractinella trigonella* (Schlotheim, 1820). This taxon has a strongly differentiated morphology mainly consisting of a pentagonal outline with four prominent and restricted diagnostic plications with opposing pairs of costae on each valve, and flat and gently depressed intercostal areas. This structure leads to anterior rectimarginate (virtually bilobate) shells.

In the "Las Atalayas" section, *T. trigonella* represents monospecific assemblages, either as isolated individuals recorded in the marly levels or forming very small patches in condensed pavements (Fig. 8). Most of the specimens show taphonomic alterations, with recurrent disarticulation, fragmentation, and distorted shells.

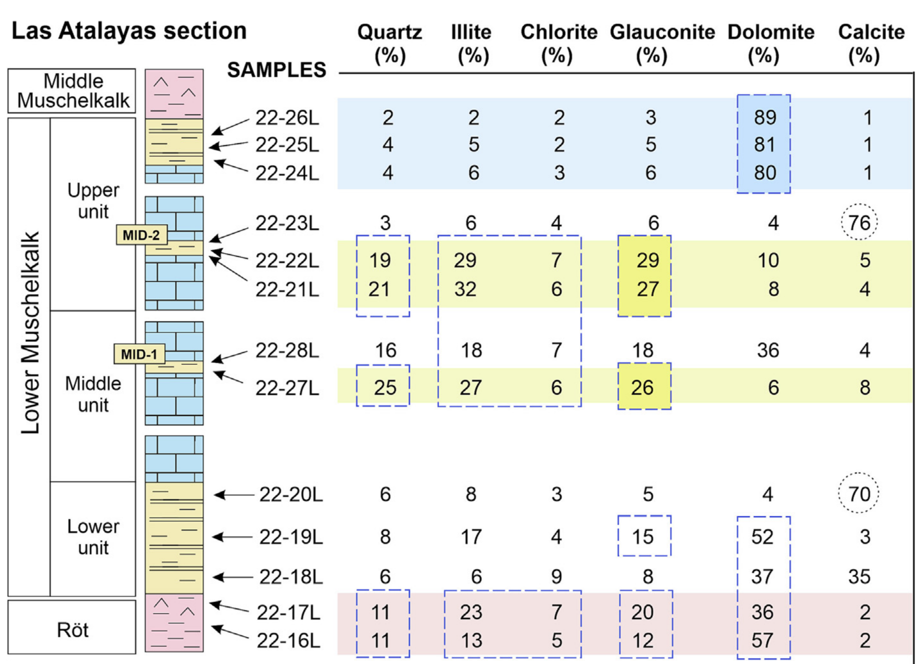


Fig. 6. Mineralogy of the main lutite beds of the "Las Atalayas" section.

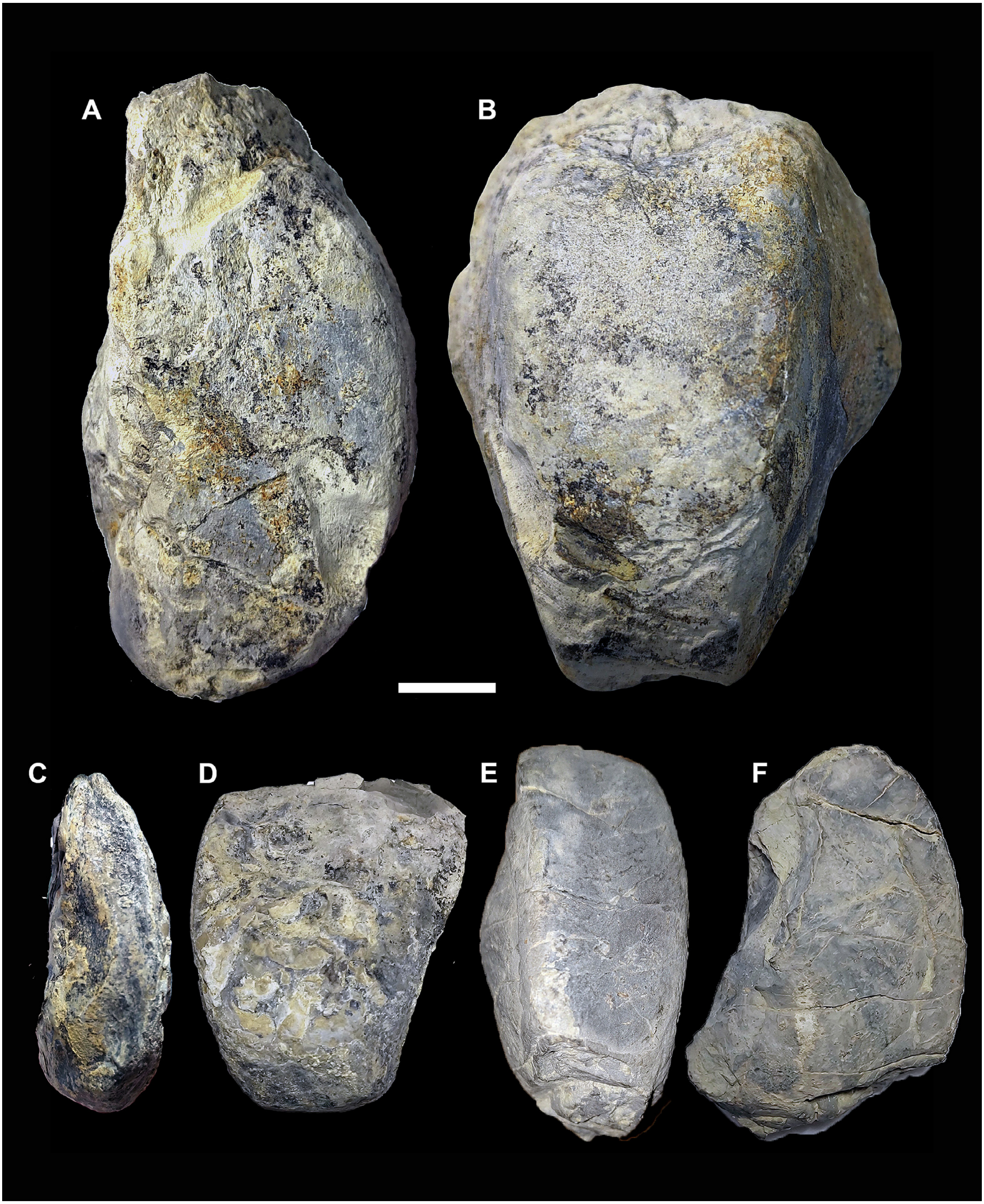


Fig. 7. Nautiloids from the "Las Atalayas" section. *Germanonautilus saharonicus* Parnes, 1986, (CH-2A-1), lateral (A) and ventral (B) views (Level C). *Germanonautilus salinarius* (Mojsisovics, 1882) (CH-1A-4), lateral (C) and ventral (D) views (Level A). *Grypoceras* cf. *quadrangulum* (Beyrich, 1866) (CH-1A-2), lateral (E) and ventral (F) views (Level A). All specimens correspond to body chamber. Scale bar represents 2 cm.

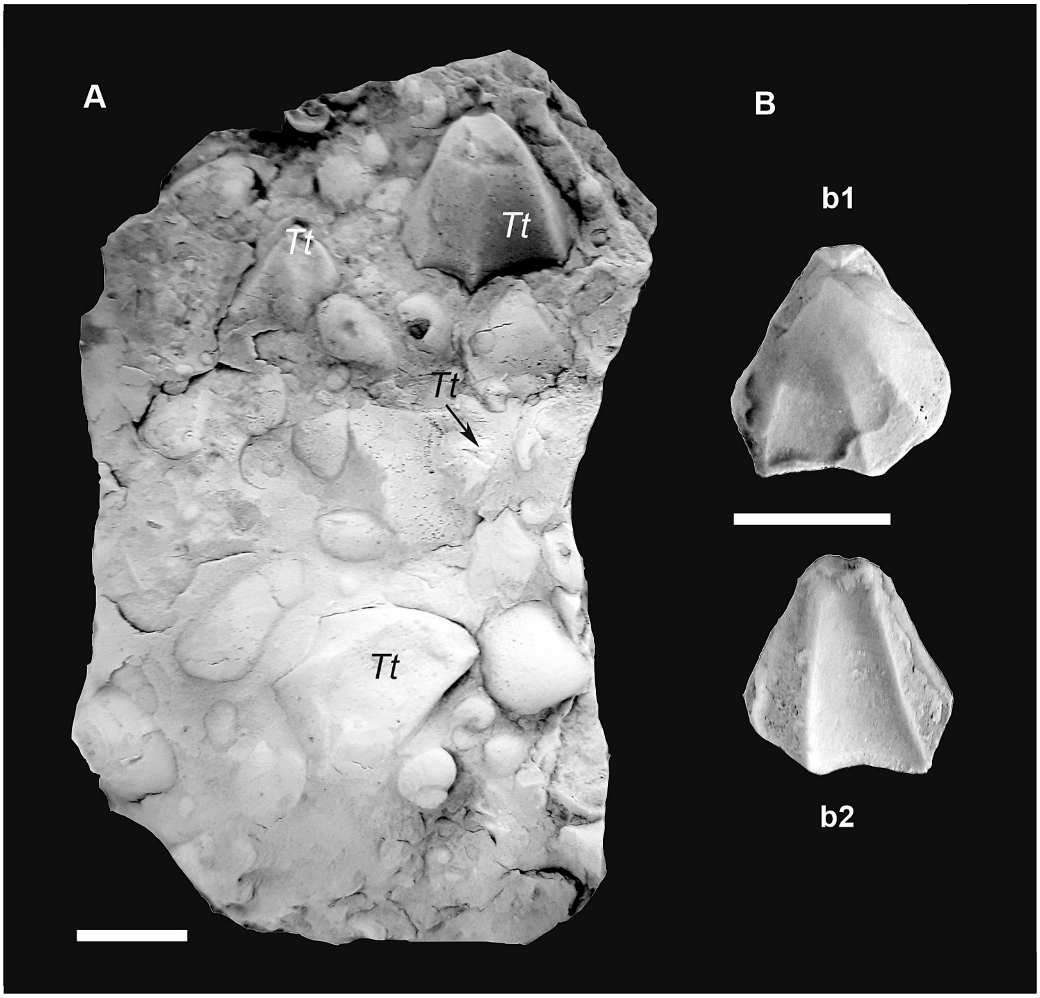


Fig. 8. (A) Slab showing condensed pavement with *Tetractinella trigonella* (Tt) among the common benthic biota recorded in this level. (B) *Tetractinella trigonella*, isolated CMB.1 specimen showing dorsal (b1) and ventral (b2) views. Scale bars represent 1 cm.

7.3. Bivalves

Three thin levels of marly limestones and marls (A, B and C) were sampled (Fig. 3) comprising several species belonging to the families Myophoridae, Mytilidae, Halobiidae, Pectinidae and Bakeveliidae, among others (Table 1). *Myophoria vulgaris* (Schlotheim, 1820) and *Neoschizodus orbicularis* (Bronn, 1837) (Fig. 9C, D) are the most abundant species and the only ones found in the lower two levels (A and B). This association is characterized by its low diversity and is often composed of the dominant cosmopolitan specimens. These two species are also present in level C, although in this level the diversity is much higher. *Pleuromya elongata* (Schlotheim, 1822), *Unionites fassaensis* (Wissmann, 1841) and *Daonella moussoni* (Merian, 1853) have been identified in this upper level. *Chlamys schroeteri* (Giebel,

Table 1
Abundance of bivalve species recorded in the "Las Atalayas" section with indication of life habits of each species. Bivalve life habits adopted: epifaunal attached (epibyssate), semi-infaunal attached (endobyssate), infaunal shallow-burrower, infaunal deep-burrower, epifaunal free-living (recliner). All species are suspension feeders.

Level	Family	Species	Number of specimens	Mode of life
A	Myophoridae	*Myophoria vulgaris* (Schlotheim)	8	Shallow burrower
		Neoschizodus orbicularis (Bronn)	18	Shallow burrower
		Myophoria sp. aff. *cardisoides* (Alberti)	2	Shallow burrower
B		*Myophoria vulgaris* (Schlotheim)	45	Shallow burrower
C	Mytilidae	*Modiolus* sp.	4	Endobyssate
	Myophoridae	*Myophoria vulgaris* (Schlotheim)	4	Shallow burrower
		Neoschizodus laevigatus (Goldfuss)	3	Shallow burrower
		Neoschizodus orbicularis (Bronn)	1	Shallow burrower
	Halobiidae	*Daonella moussoni* (Merian)	7	Epifaunal recliner
	Pectinidae	*Chlamys schroeteri* (Giebel)	2	Epibyssate
	Bakevelliidae	*Gervillia joleaudi* (Schmidt)	6	Endobyssate
		Bakevellia modioliformis (Giebel)	3	Endobyssate
	Trigonodidae	*Unionites fassaensis* (Wissmann)	9	Shallow burrower
	Pleuromyidae	*Pleuromya elongata* (Schlotheim)	16	Deep burrower
	Mactromyidae	*Unicardium schmidii* (Geinitz)	1	Deep burrower

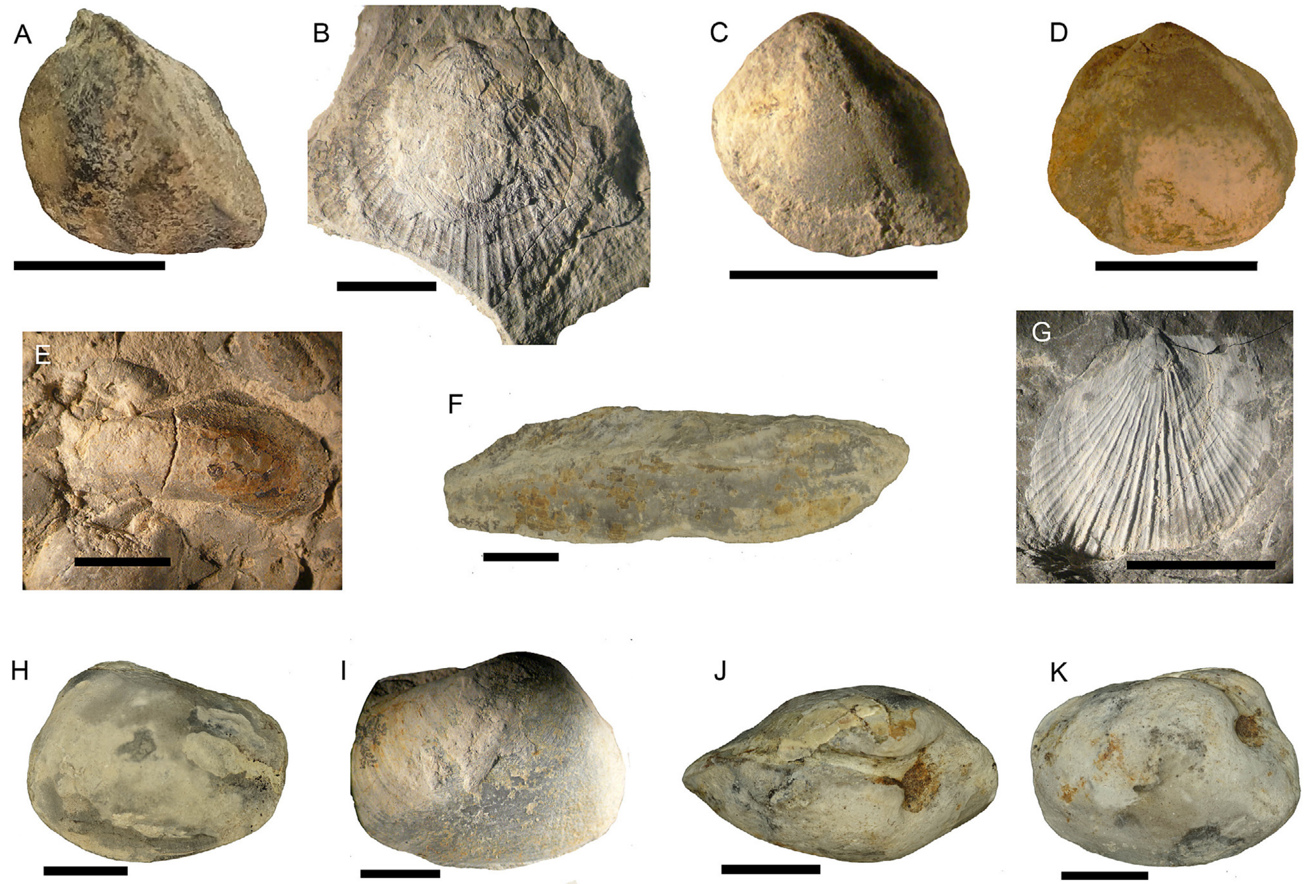


Fig. 9. Most significant bivalves present in the lower Muschelkalk of the "Las Atalayas" section. (A) *Neoschizodus laevigatus* (Goldfuss), MGUV-39682, internal mould, left valve, level C. (B) *Chlamys schroeteri* (Giebel), MGUV-39673, internal mould with shell remains, left valve, level C. (C) *Myophoria vulgaris* (Schlotheim), MGUV-39676, internal mould, left valve, level A. (D) *Neoschizodus orbicularis* (Bronn), MGUV-39674, internal mould, left valve, level A. (E) *Bakevellia modioliformis* (Giebel), MGUV-39675, internal mould with shell remains, left valve, level C. (F) *Gervillia joleaudi* (Schmidt), MGUV-39680, internal mould with shell remains, left valve, level C. (G) *Daonella moussoni* (Merian), MGUV-39679, left valve, level C. (H) *Unionites fassaensis* (Wissmann), MGUV-39681, internal mould, left valve, level C. (I) *Unicardium schmidii* (Geinitz), MGUV-39684, internal mould, right valve, level C. (J, K) *Pleuromya elongata* (Schlotheim), MGUV-39683, internal mould, level C, right valve (K) and dorsal (J) views.

1856), *Bakevellia modioliformis* (Giebel, 1856), *Unicardium schmidii* (Geinitz, 1842) and *Gervillia joleaudi* (Schmidt, 1935) are also present (Fig. 9, Table 1). All these species have been described in Márquez-Aliaga (1985) and Plasencia et al. (2007), with the exception of *Daonella moussoni*, since it is the first record of this species in the Iberian Peninsula, and it is in accordance with the descriptions published by Stoppani (1858).

7.4. Palynomorphs

Nine samples of the "Las Atalayas" section have been collected for palynological analysis (Fig. 3). Each sample yielded moderately to well-preserved palynomorphs. An Anisian palynomorph assemblage is identified, including index taxa such as *Illinites chitonoides*, *Stellapollenites thiergartii*, *Tsugaepollenites oriens*, *Cristianisporites triangulatus*, and *Triadispora crassa* (Fig. 10, Table 2). Additionally, maximum abundance of marine phytoplankton (acritarchs) is recorded in samples ATP-305 and ATP-306 (Fig. 3).

8. Discussion

8.1. Age assignment

An important goal of this study is the age assignment of the studied Middle Triassic succession of the "Las Atalayas" section. Based on the first clear biostratigraphic data presented here, Anisian deposits are identified for the first time in the Subbetic domain of the Betic Cordillera (Fig. 11).

8.1.1. Nautiloids

As described above, the nautiloid association found in the "Las Atalayas" section is indicative of a late Anisian (Pelsonian-Illyrian) age and has been reported in Anisian deposits of other Triassic areas from Austria, Egypt, Israel, and North America (Beyrich, 1866; Mojsisovics, 1882; Kummel, 1953; Kummel, 1960; Parnes, 1986). In terms of biostratigraphy, *G. salinarius* (Mojsisovics) is a relatively common species known in the Alpine-Mediterranean realm and has been documented in the Lower Muschelkalk of Germany (Mundlos and Urlichs, 1984), the upper Anisian (Illyrian) of Israel (Kummel, 1960; Parnes, 1986), and the upper Anisian (Pelsonian-Illyrian) of the Balaton Highlands (Vörös, 2001; Vörös et al., 2022). *G.* cf. *quadrangulum* has been also reported from the lower Ladinian (Fassanian) successions of the Subbetic domain (Cehegín Fm.; Pérez-Valera et al., 2017), but its biostratigraphic range includes the Anisian, with its first occurrence datum (FOD) in the late Anisian of Israel (Parnes, 1986). Moreover, *G.* cf. *quadrangulum* (Beyrich) is known from the upper Anisian in the Alps (Beyrich, 1866; Mojsisovics, 1882; Kummel, 1953). On the other hand, *G. saharonicus* (Parnes), the only nautiloid species identified in level C, was identified for the first time in the upper Anisian (Illyrian) of Israel (Parnes, 1986), representing a characteristic taxon of the Sephardic province although it is also known from the upper Anisian of Oman (Ali, 2001). Recently, Rein (2019) included *G. salinarius*

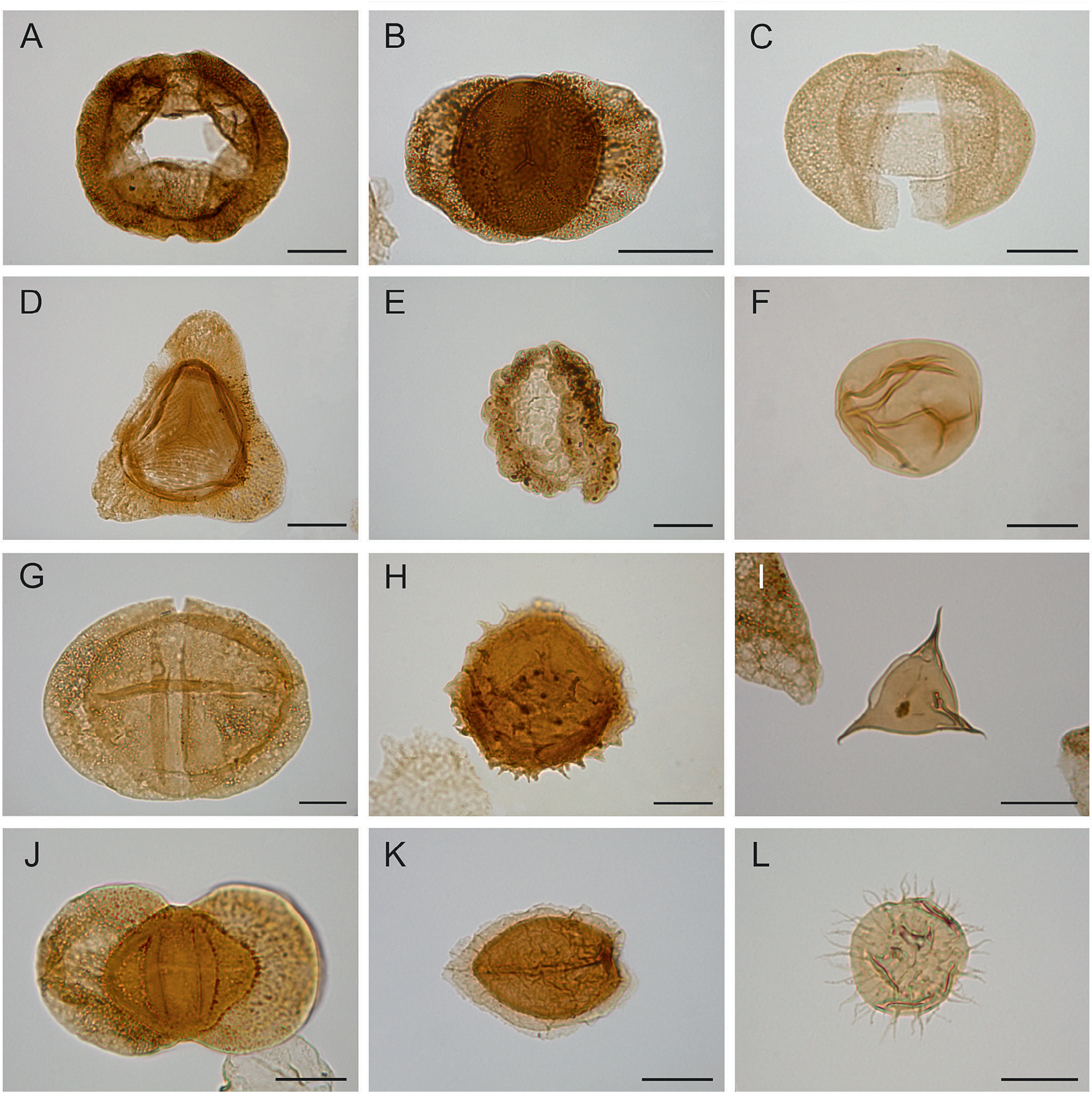


Fig. 10. Selected palynomorphs of the "Las Atalayas" section. Taxon name is followed by the sample number and stage coordinates for a Leica DM2000 microscope. Scale bar is 20 μm on all photomicrographs. (A) *Stellapollenites thiergartii* (Mädler) Clement-Westerhof et al., 1974; ATP-312, 27.6/116.3. (B) *Triadispora crassa* Klaus, 1964; ATP-306, 31.4/102.2. (C) *Lunatisporites* sp.; ATP-307, 34.5/117.3. (D) *Cristianisporites triangulatus* Antonescu, 1969; ATP-308, 21.2/112.3. (E) *Tsugaepollenites oriens* Klaus, 1964; ATP-311, 32.1/108.4. (F) *Calamospora tenera* (Leschik) de Jersey, 1962; ATP-311, 24.8/110.5. (G) *Illinites chitonoides* Klaus, 1964; ATP-307, 18.2/105.4. (H) *Kraeuselisporites* sp.; ATP-309, 26.1/118.7. (I) *Veryhachium* sp.; ATP-305, 31.5/102.8. (J) *Angustisulcites klausii* (Freudenthal) Visscher, 1966; ATP-308, 29.5/116.5. (K) *Aratrisporites reticulatus* Brugman, 1986; ATP-279, 34.8/115.2. (L) *Michrystridium* sp.; ATP-306, 24.2/106.4.

(Mojsisovics) and *G. saharonicus* (Parnes) in the new genus *Sephardonautilus* Rein, 2019, establishing connections between the Germanic, Alpine and Sephardic faunas from the upper Anisian (Illyrian).

8.1.2. Brachiopods

The shorter stratigraphic range of brachiopods recorded in the "Las Atalayas" section makes this group a better tool for the age calibration. *Tetractinella trigonella* (Schlotheim, 1820) has been described as a marker species from different Pelsonian-Illyrian successions in numerous basins of the Tethys bioprovince (e.g. Pálfy, 2003). Among the common records of *T. trigonella* from European basins, the Betic material reveals strong affinities with that depicted by Mantovani (2002) from the Anisian type area (Tarnowitz), which display the plicae exceeding the anterior commissure, thus extending the length of the anterior margin. The characteristic morphology of this species and its common record in the Western Tethys make it a useful correlation tool. Thus, it can be considered as a distinctive Anisian marker from the Northern Alps (e.g. Bittner, 1890), the Western Caucasus (Ruban, 2006) and, remarkably, most of the occurrences are restricted to the Pelsonian substage, even typifying a marker horizon ("*Tetractinella*-Bank" or

Table 2
Alphabetical list of identified palynomorph taxa.

Palynomorph taxa
Pollen grains
Angustisulcites grandis (Freudenthal) Visscher, 1966
Angustisulcites klausii (Freudenthal) Visscher, 1966
Angustisulcites spp.
Cristianisporites triangulates Antonescu, 1969
Cycadopites spp.
Illinites chitonoides Klaus, 1964
Illinites sp.
Lunatisporites spp.
Protodiploxypinus sittleri Klaus, 1964
Protodiploxypinus spp.
Stellapollenites thiergartii (Mädler) Clement-Westerhof et al., 1974
Striatoabieites spp.
Triadispora crassa Klaus, 1964
Triadispora spp.
Tsugapollenites oriens Klaus, 1964
Spores
Aratrisporites reticulatus Brugman, 1986
Aratrisporites spp.
Calamospora tenera (Leschik) de Jersey, 1962
Calamospora sp.
Kraeuselisporites spp.
Punctatisporites sp.
Verrucosisporites sp.
Marine phytoplankton
Michrystridium spp.
Veryhachium sp.

"Brachiopoden-Bank" sensu Gaetani, 1969; Ockert and Rein, 2000; Mantovani, 2002; Dynowski and Nebelsick, 2011). The Pelsonian occurrence of *T. trigonella* is also well documented in the Balaton Highland (Török, 1993; Pálfy, 2003), Romania (Iordan, 1993), the Southern Italian Alps (e.g., Gaetani, 1969; Mantovani, 2002), Upper Silesia (Kaim, 1997), the Dolomites (Mantovani, 2002), and the Stara Planina, Bulgaria (Benatov et al., 1999).

8.1.3. Bivalves

The identified Middle Triassic bivalve taxa have long biostratigraphic ranges. Most of them are cosmopolitan (Tethyan and Germanic) lower Muschelkalk species, very common in the Middle Triassic. These taxa have been recorded in the upper Anisian and lower Ladinian in some localities of the Iberian and Catalan Coastal Ranges (Márquez-Aliaga et al., 2008; Escudero-Mozo et al., 2015). *Neoschizodus orbicularis* (Fig. 9D) and *Myophoria vulgaris* (Fig. 9C) are recorded in Anisian associations of the Landete Formation (Mediterranean Triassic domain), at the base of the Cañete Formation (Levantine-Balearic Triassic domain) (Márquez-Aliaga et al., 2001, 2002, 2008), and in the lower Muschelkalk of the Catalan Coastal Ranges (Escudero-Mozo et al., 2015). *Unionites fassaensis* (Fig. 9H), *Pleuromya elongata* (Fig. 9J, H) and *Neoschizodus laevigatus* (Goldfuss, 1837) (Fig. 9A) are common forms in the Anisian at the base of the Cañete Formation of Serra (Valencia) (Márquez-Aliaga et al., 2008). *Chlamys schroeteri* (Fig. 9B) is very common in the Lower Muschelkalk of Germany (Giebel, 1856), and it has been reported from Calasparra (Murcia), Betic Cordillera in the early Ladinian (Plasencia et al., 2007). This association is characteristic of the late Anisian and very common in the Germanic Lower Muschelkalk (Schmidt, 1928). *Gervillia joleaudi* (Fig. 9F), typical of the Sephardic bioprovince (southern Tethys margin), has been reported from the Anisian of Ramon (Israel) (Lerman, 1960) and it is very common in the early Ladinian (Fassanian) of Spain. The cosmopolitan *Daonella moussoni* is recorded for the first time in the Iberian Peninsula, but it is frequent in the Anisian of the Italian Alps, southern China and Nevada (USA) (Stoppani, 1858; Kittl, 1912; Silberling and Nichols, 1982; Chen et al., 1992). Thus, the bivalve association is indicative of a late Anisian-early Ladinian age.

8.1.4. Palynomorphs

The presence of species such as *Stellapollenites thiergartii* and *Tsugaepollenites oriens* clearly indicates an Anisian age (Orłowska-Zwolińska, 1977, 1985; Visscher and Brugman, 1981; Reitz, 1985; Brugman, 1986; Hochuli, 1998). Based on the zonation scheme of Kürschner and Herngreen (2010), the palynomorph assemblage of the "Las Atalayas" section represents the *S. thiergartii* zone comprising the entire Anisian. The palynozonation of the Germanic Basin (Heunisch, 1999, 2020; Heunisch and Wierer, 2021) distinguishes three zones (GTr7 – GTr9) within the Anisian and the "Las Atalayas" assemblage shows a strong similarity to the GTr8 assemblage of the Lower Muschelkalk series of Bithynian to early Illyrian age. Whereas most of the identified palynomorphs are long-ranging taxa of the Anisian, *Cristianisporites triangulatus* has been attributed to the Pelsonian (Antonescu, 1969, 1970; Antonescu et al., 1975), and according to Roghi (1995) and Kustatscher and Roghi (2006) this species is constricted to the late Pelsonian. More recently, Hochuli et al. (2020) reported its range from the Pelsonian to the early Illyrian.

Additionally, maximum abundance of marine phytoplankton (acritarchs) recorded in samples ATP-305 and ATP-306 points to a Pelsonian age, as Pelsonian acritarch peaks have been reported across the Tethys shelf and the northern Peri-Tethys Basin (Germanic Basin), documenting a major flooding event (e.g., Götz and Feist-Burkhardt, 2012).

8.1.5. Vertebrates

The Anisian age assignment of the studied carbonates, i.e., the presence of lower Muschelkalk deposits in the study area, is confirmed by the presence of an Anisian marine reptile (sauropterygian) recently found in the "Las Atalayas" section (Berrocal-Casero et al., 2023).

8.1.6. Isotopic signatures

Further evidence of an Anisian age is provided by the $\delta^{34}S$ values of the gypsum samples taken from the Buntsandstein facies (samples 387, 388) and in the overlying carbonates (sample 386) of the presumed middle Muschelkalk (Fig. 3). The $\delta^{34}S$ values obtained by Ortí et al. (2022) in these beds are between 17.5 and 17.9, characteristic of the Anisian of the Iberian Peninsula. These values are in agreement with the global $\delta^{34}S$ curve (Bernasconi et al., 2017) of the Anisian of the Germanic Basin and the Alpine-Apennine domains.

8.2. Transgressive stages of the epicontinental platform during the Middle Triassic

The stratigraphic results of the present study enable us to deduce that the two major Middle Triassic transgression-regression cycles defined at the northwestern margin of the Tethys sea (e.g., López-Gómez et al., 2002; Vecsei and Duringer, 2003) and correlated with the Alpine basins (Aigner and Bachmann, 1992; Gianolla et al., 1998; Szulc, 1999) span the two Middle Triassic units of Muschelkalk facies (lower and upper Muschelkalk) in the Subbetic domain of the Betic Cordillera: (1) Röt-lower Muschelkalk and (2) middle-upper Muschelkalk. Furthermore, the presence of lower Muschelkalk deposits in the studied outcrop implies that the studied intermediate unit of lutite and gypsum corresponds to the middle Muschelkalk (M2), which overlies the lower Muschelkalk unit and has $\delta^{34}S$ values characteristic of the M2 unit (Ortí et al., 2022). This unit was also identified in other Iberian basins (Virgili, 1958; Ortí et al., 2018) and interpreted as regressive deposits. At an interregional scale, the M2 unit can be correlated, for example, with the fine-grained clastic and evaporitic middle Muschelkalk of Luxembourg and SW Germany and with the "Couches Grises" in France (Vecsei and Duringer, 2003). Also, the M2 unit can be correlated by age and lithofacies type with the "Anhydritgruppe" of Switzerland, included in the Zeglingen Formation (Jordan, 2016), at the southwestern margin of the Germanic Basin. At a regional scale, an east-west transgression

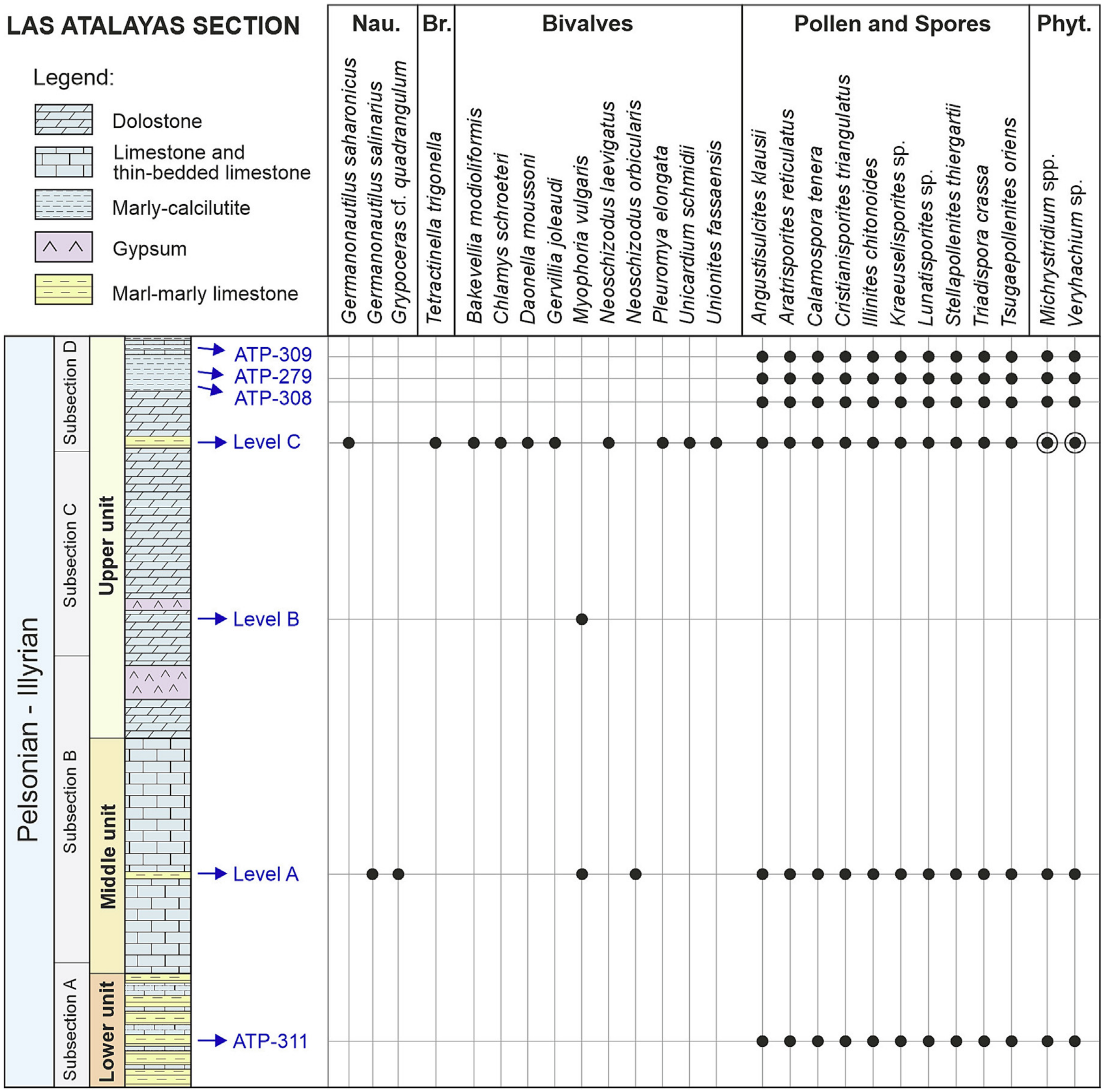


Fig. 11. Distribution of fossils in the synthetic stratigraphic column of the "Las Atalayas" outcrop. The position of the most important fossils (nautiloids, brachiopods, bivalves, pollen grains, spores and marine phytoplankton) is indicated. Maximum abundance of marine phytoplankton (*Michrystridium* spp., *Veryhachium* sp.) is highlighted with a circle above the dot.

during the Anisian-Ladinian is interpreted (Bourquin et al., 2011), documented by the different Muschelkalk units (M1, M2 and M3).

In the Betic External Zone, there is a striking trend in facies evolution in the upper Muschelkalk (M3). A lower member of transgressive character followed by an upper member documenting a progradation of shallow depositional environments is overlain by the detrital-evaporitic facies of the Keuper unit (Pérez-Valera and Pérez-López, 2008). In the present study, the lower Muschelkalk (M1) depositional sequences are difficult to determine, since there is no distinct pattern of systems tracts. The occasional presence of nautiloids within shallower and more restricted environments indicates short intervals of more open-marine conditions (e.g., Chirat et al., 2006; Pérez-Valera et al., 2017), although the influence of storm events, which could have displaced shells towards the relatively shallower areas, cannot be ruled out. Additionally, two fossil-rich intervals (MID-1 and MID-2; Fig. 3), documenting transgressive events, are identified as useful stratigraphic horizons to perform correlations with other European basins. The age assignment (Pelsonian-Illyrian) provided herein suggests that these intervals most probably correspond to the Pelsonian maximum-flooding zone (mfz) identified in several basins across Europe (Szulc, 2000; Rameil et al., 2000; Götz et al., 2003, 2005; Götz and Török, 2008, 2018; Götz and Feist-Burkhardt, 2012; Chatalov, 2013, 2018; Ajdanlijsky et al., 2019, 2020). Furthermore, thin, dark grey beds of the shaley interval MID-2 reveal maximum abundance of marine acritarchs. This striking signature was also recognized in the Pelsonian of the Germanic Basin (Götz and Feist-Burkhardt, 2012) and the northwestern Tethyan realm (Götz et al., 2003, 2005; Götz and Török, 2008; Ajdanlijsky et al., 2019).

8.3. Depositional platform model

A characteristic feature of the studied Anisian succession is the absence of high-energy deposits related to banks or barriers, reefs, etc., which have been described in the Anisian sections from other regions (Pérez-López et al., 2021). These lower Muschelkalk carbonates are, in general, of shallower facies than the upper Muschelkalk carbonates (Pérez-Valera and Pérez-López, 2008), as observed in other Triassic sub-basins of the Iberian Peninsula (Escudero-Mozo et al., 2015; Pérez-López et al., 2021). However, they are, in any case, low-energy deposits associated with more or less restricted environments.

Nevertheless, the platform communicated with open-marine areas, as documented by deposits with nautiloids and the thin shaley intercalations with glauconite and abundant acritarchs (MID-1, MID-2; Fig. 3).

The continuous deposition of fine-grained sediments, associated with a low-energy environment, can be explained by a large "compartmentalized" epicontinental platform setting, as may have occurred during the Middle Triassic (Pérez-López et al., 2011, 2021). At times, as the sea level rises, the platform becomes flooded, allowing faunal immigration from the Tethys ocean, although the platform remains rather shallow and with low hydrodynamic conditions. A relative sea-level fall immediately causes the development of coastal mud with tidal flats and, most probably, the formation of restricted lagoons, sometimes evaporitic ponds or sulfate lagoons (Ortí et al., 2017). This facies development is well documented in the lithofacies of the studied succession (evaporites, laminites, evaporite moulds and stromatolites). To some extent, a similar situation is described in the semi-closed Germanic Basin, where major flooding occurred during the Pelsonian, as recorded by the presence of open-marine faunal elements (Feist-Burkhardt et al., 2008a). However, differences in the platform evolution and cyclicity are also controlled by local tectonics (Szulc, 1999, 2000) and, obviously, the facies change from proximal to distal environments.

8.4. Fossil associations and Anisian paleogeography of the western Peri-Tethyan realm

Previous works on the Triassic of the Betic External Zone, i.e., on the Muschelkalk carbonates (Cehegín and Siles formations) of Ladinian age (Márquez-Aliaga, 1985; Márquez-Aliaga et al., 1986; Pérez-López et al., 1991; Pérez-Valera et al., 2005; Pérez-Valera, 2015, among others), have described some species (bivalves, ammonoids and conodonts) typical of the Sephardic domain that extends from Spain and North Africa to the Middle East and develops to the S and SW of the Tethys (Hirsch, 1977). Some cosmopolitan species present in the Germanic domain have also been described, as well as some species from the Tethys bioprovince (Márquez-Aliaga and Ros, 2003). However, all these data from the upper Muschelkalk (Ladinian) suggest an influence on the fauna, especially from the Sephardic domain during the Ladinian, in the central-eastern platforms of Iberia via the Betic basin during the major transgressive phase (Hirsch and Márquez-Aliaga, 1988; Márquez-Aliaga and Hirsch, 1988; Pérez-López and Pérez-Valera, 2007; Escudero-Mozo et al., 2016) or in the Catalan Coastal Ranges (Escudero-Mozo et al., 2014) and in Sardinia (Costamagna and Piros, 2022; Stori et al., 2022).

In the present study, the Anisian fossils found in the lower Muschelkalk of the "Las Atalayas" section suggest a major connection with the Tethys bioprovince, as similar forms to those described by other authors have been found in Tethyan sub-basins as described below. Most of the bivalve taxa are present in the Germanic Basin and have their origin in the Tethys bioprovince. It is important to note that the bivalves *N. orbicularis* and *M. vulgaris* of Germanic character are typical of the Paleotethys in the Iberian Peninsula (Escudero-Mozo et al., 2015). The brachiopod *Tetractinella trigonella* found in the studied section also indicates a connection with the Tethys bioprovince, since it is a fossil described also from several alpine outcrops (e.g., Mantovani, 2002). The faunal affinity between the "Mediterranean Triassic" and the Tethys domain coincides with the observations made by Márquez (2005) on foraminifera. This author identified assemblages of clear Tethyan affinities in Anisian carbonates, e.g., *Hoyenella sinensis* (Ho), *Endoteba kueperi* (Oberhauser), *Paulbronnimannia judicariensis* (Premoli-Silva).

Consequently, all the faunal elements found suggest a prominent connection of the Subbetic domain towards the NE with the Paleotethys (Fig. 12, red arrows). Additionally, the presence of the nautiloid *Germanonautilus saharonicus* and the bivalve *Gervillia joleaudi*, both characteristic of the Sephardic province and appearing only in the upper part of the section (level C; Fig. 3), coinciding with MID-2

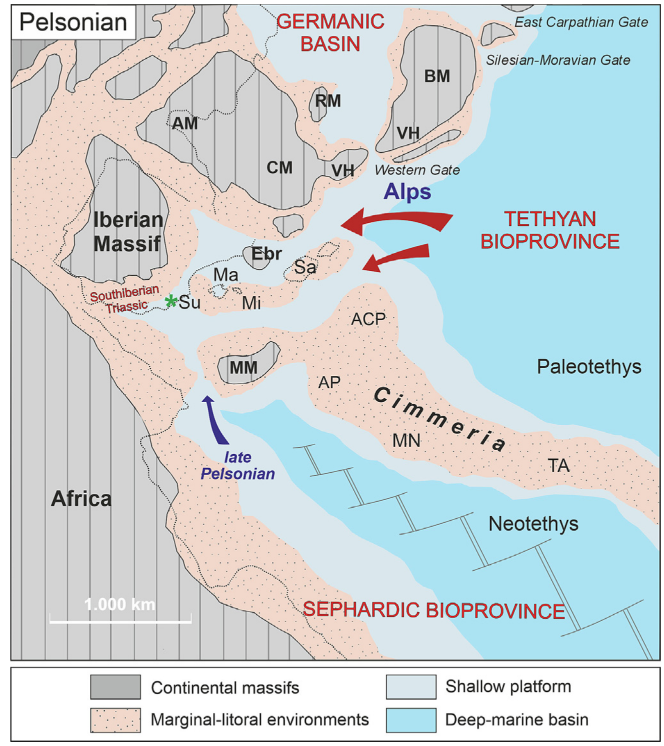


Fig. 12. Paleogeographical reconstruction of the westernmost Tethys region during the Anisian. Faunal immigrations are indicated with arrows. Green star indicates the study area. ACP: Apennine Carbonate Platform; AM: Armorican Massif; AP: Apulia; BM: Bohemian Massif; CM: Central Massif; Ebr: Ebro Massif; Ma: Majorca; MN: Mani; MM: Mesomediterranean Massif; Mi: Minorca; RM: Rhenish Massif; Sa: Sardinia; Su: Subbetic domain; TA: Taurus; Ma: Majorca; VH: Vindelician High. The paleogeographic map is modified from Costamagna and Barca (2002), Diedrich (2009), Stampfli and Kozur (2006), Pérez-López and Pérez-Valera (2007), Martín-Algarra et al. (2009), Götz and Feist-Burkhardt (2012), Černanský et al. (2018), López-Gómez et al. (2019) and Stori et al. (2022).

(Fig. 3), may indicate the first migration event of the Sephardic fauna towards the Betic Basin (Fig. 12, blue arrow). This faunal immigration occurred during the late Anisian and developed more extensively during the Ladinian (Pérez-Valera et al., 2017). The migration of the Sephardic fauna was recognized in the lower Illyrian for the Germanic Basin, where Sephardic species of cephalopods (ammonoids and nautiloids) arrived to the Germanic Basin from the south to constitute the ancestors of the mostly endemic fauna of the Upper Muschelkalk of Germany (Rein, 2019). Moreover, Sephardic nautiloids (*Germanonautilus* aff. *ellipticus* Parnes, 1986) have recently been reported from the Illyrian of the Southern Alps (Monte San Giorgio; Pieroni, 2022), which also suggests the presence of Sephardic fauna in the Alpine realm at this time.

At this point it is important to note that all the epicontinental basins with Germanic facies of the Iberian Peninsula were at some point in their history connected with the Tethys ocean. Based on the fossil record, the most prominent connection occurred during the Anisian and, most probably, the Rhaetian (Pérez-López et al., 1992; Márquez, 2005). In the late Anisian, a communication with the Tethys and the Sephardic domain was possible up to the Subbetic domain (Fig. 12), more extensively than previously thought with the first identification of lower Muschelkalk deposits in this domain of the Betic Cordillera.

9. Conclusions

The first record of lower Muschelkalk deposits in the Subbetic domain of the Betic External Zone enables to distinguish an evaporitic detrital unit (M2) between the lower and upper carbonate units (M1 and M3). These units document the Mediterranean Triassic of the Iberian

Peninsula, representing major transgressive phases of the Middle Triassic within the western Peri-Tethyan realm.

The age assignment of the lower Muschelkalk unit as Pelsonian-Illyrian is based on new biostratigraphic data. The nautiloids *Germanonautilus salinarius* and *Germanonautilus saharonicus* and the brachiopod *Tetractinella trigonella* are reported for the first time from the Iberian Peninsula. Moreover, a bivalve association including Anisian index taxa such as *Neoschizodus orbicularis*, *Unicardium schmidii, Daonella moussoni* and *Chlamys schroeteri* has been recorded. An Anisian palynomorph assemblage is reported for the first time from the Betic Cordillera. These new paleontological data, including many forms characteristic of the Germanic Basin, suggest a link between the Middle Triassic platform of southern Spain and the Paleotethys bioprovince. During the late Anisian, a gateway to the Sephardic domain began to open.

The lower Muschelkalk sediments of the Subbetic domain are interpreted as very shallow platform deposits. Two intervals of fossil-rich shale and marly limestones document prominent marine transgression events, corresponding to the Pelsonian maximum-flooding zone identified in other European basins. So far, it remains difficult to establish a high-resolution sequence stratigraphic framework, as regional tectonics have to be considered. Ongoing research will also rely on the further identification of Anisian successions in the Subbetic domain to study lateral sequence patterns at basinal scale and to unravel the interregional platform development within the western Peri-Tethyan realm.

Data availability

All data are provided in the article.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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