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Jurassic radiolarites in a Tethyan continental margin (Subbetic, southern Spain): palaeobathymetric and biostratigraphic considerations

J.M. Molina [a], L. O'Dogherty [b], J. Sandoval [c], J.A. Vera [c,*]

[a] *Depto. Geología, Facultad de Ciencias Experimentales, Universidad de Jaén, 23091-Jaén, Spain*
[b] *Depto. Geología, Facultad de Ciencias del Mar, Universidad de Cádiz, 11510-Puerto Real, Cádiz, Spain*
[c] *Depto. Estratigrafía y Paleontología, Facultad de Ciencias, Universidad de Granada, 18071-Granada, Spain*

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Abstract

A region of the pelagic Subbetic basin within the Southern Iberian Continental Margin is studied in lithostratigraphical and biostratigraphical detail. Jurassic radiolarites (Jarropa Radiolarite Formation, Bathonian–Oxfordian) interbedded with shallow-water marine limestones have been recognized. Underlying the radiolarites (Camarena Formation, Bajocian) are oolitic limestones showing shallowing-upward cycles with karstic surfaces on the top, corresponding to deposition on an isolated carbonate platform on volcanic edifices. The Milanos Formation (upper Kimmeridgian–Tithonian), overlying the radiolarites, contains calciclastic strata with hummocky cross-stratification, which indicate outer carbonate ramp deposition. In the Jarropa Radiolarite Formation some calcisiltite strata with hummocky cross-stratification have been found. The bathymetry of the Subbetic Jurassic pelagic sediments, including the radiolarites, is considered as moderate or shallow in depth. We suggest that the pelagic character of the Jurassic sediments in this margin and their equivalents in other Alpine domains is a consequence of distance from the continent (beyond the pericontinental platform) but not necessarily of depositional depth.

Keywords: radiolarite; bathymetry; Jurassic; Tethys; Betic; Spain

1. Introduction

Significant amounts of pelagic sediments, deposited on the Tethyan continental margins during the Jurassic rifting phases (Bernoulli and Jenkyns, 1974; Hallam, 1975; Jenkyns, 1978; García-Hernández et al., 1980; Vera, 1988), today appear folded in the External Zones of various Alpine mountain chains (Betic, Alps, Apennines, Carpathians, Dinarids, Hellenids, Rif, Tell, etc.).

These pelagic sedimentary rocks do not normally show any direct sedimentary or ecological features allowing their depth of deposition to be pinpointed. They have frequently been compared with recent pelagic sediments and attributed to great depositional depths. The deposition of some lithostratigraphic units (especially for the radiolarite facies) was considered to be located below the Calcite Compensation Depth (CCD) (Grunau, 1965; Gar-

* Corresponding author. Fax: +34 58 248528; E-mail: jvera@goliat.ugr.es

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rison and Fischer, 1969; Garrison, 1974; Bosellini and Winterer, 1975; Winterer and Bosellini, 1981; Ogg, 1981), which during the Jurassic for the western Tethys would have been some 2100–2500 m deep (Bosellini and Winterer, 1975; Winterer and Bosellini, 1981).

Some authors (Hallam, 1975; Seyfried, 1979; Jenkyns, 1980, 1986; Vera, 1981; Jenkyns and Winterer, 1982; Baumgartner, 1987; Santantonio et al., 1996) have questioned these depths, indicating that the deposition of the radiolarite facies (commonly considered the deepest) occurred in areas within the continental margin with very shallow CCD (Jenkyns, 1980, 1986; Jenkyns and Winterer, 1982; Ruiz-Ortiz et al., 1989). Alternatively they considered the deposition of these facies as unrelated with the CCD (Folk in McBride and Folk, 1979; Baumgartner, 1987; Dodona and Farinacci, 1987; Colacicchi et al., 1988; Farinacci, 1988; Cecca et al., 1990; Santantonio, 1993; Santantonio et al., 1996).

In recent years sedimentary, ecological and/or geochemical features in pelagic Jurassic sediments directly related to radiolarites in the Alpine chains have been described, seriously questioning the generalized attribution of great depths for these deposits. Arguments have been put forward in favour of considering that the pelagic character is determined by the distance from the coasts and not by the depth.

Of particular interest in these arguments are: (1) the existence of characteristic sedimentary structures related to storms (especially hummocky cross-stratification) in the Apennines (Cecca et al., 1990; Monaco, 1992, 1994; Santantonio, 1993; Monaco et al., 1994) and in the Betics (Molina and Vera, 1996; Molina et al., 1997; O'Dogherty et al., 1997; Vera and Molina, 1998); (2) the presence of shallow facies intercalated between pelagic facies in the Betics (Molina et al., 1985; Ruiz-Ortiz et al., 1985; Molina, 1987; Rey, 1995; Vera et al., 1997; Vera and Molina, 1998); (3) the recognition of palaeokarst surfaces in stratigraphic discontinuities in the Betics (Seyfried, 1979; Vera et al., 1988; Jiménez de Cisneros et al., 1991, 1993) and in the Apennines (Farinacci et al., 1981; Fazzuoli et al., 1981); (4) the presence of glauconite in red nodular limestones (Rosso Ammonitico) in the Carpathians (Misik and Sucha, 1994); (5) the presence of corals in the Apennines (Santantonio et al., 1996); and (6) inferences from lateral and vertical facies changes, such as those outlined in the Alps (Elmi, 1990), in the Betics (Molina, 1987), in the Apennines (Santantonio et al., 1996) and in the Alpine foreland of Algeria (Ameur and Elmi, 1981).

In this work a stratigraphic section is studied with biostratigraphic precision, with ammonites and/or radiolaria from the middle Toarcian until the end of the Jurassic. In this section, and in others from nearby regions, there is varied and clear evidence, in our judgement, to assert that the Jurassic pelagic deposits (including radiolarites) from the Southern Iberian Continental Margin and presumably those from analogous margins in the Mediterranean Alpine domains were deposited in relatively shallow water, even with local and temporary emersion. The bathymetry of the deposition of the Jurassic pelagic sediments of this continental margin has recently been the object of a discussion (Winterer and Sarti, 1994, 1995; Martín-Algarra and Vera, 1995; Molina et al., 1995), in which two of the authors of this work (Martín-Algarra and Vera, 1995; Molina et al., 1995) participated, defending the relatively shallow nature of these sediments.

2. Geographical and geological settling

The study region is located (Fig. 1) in the proximity of Montejícar village (Granada province, Andalusia, southern Spain). Geologically, this area corresponds to the External Zones of the Betic Cordillera, formed of sedimentary rocks (locally with volcanic rocks) from the Triassic to the Early Miocene that were deposited in the Southern Iberian Continental Margin and deformed later during the continental collision in the Burdigalian (Sanz de Galdeano and Vera, 1992).

Within the Betic External Zones two main geological units have been differentiated (Prebetic and Subbetic, in Fig. 1), corresponding to two palaeogeographic domains according to their position with respect to the emerged region of the Iberian plate. The Prebetic consists of sedimentary rocks deposited in the area nearest the continent during the Jurassic and Cretaceous. It was dominated by shallow marine, coastal and even continental facies. The Subbetic, in contrast, was farther from the continent and had

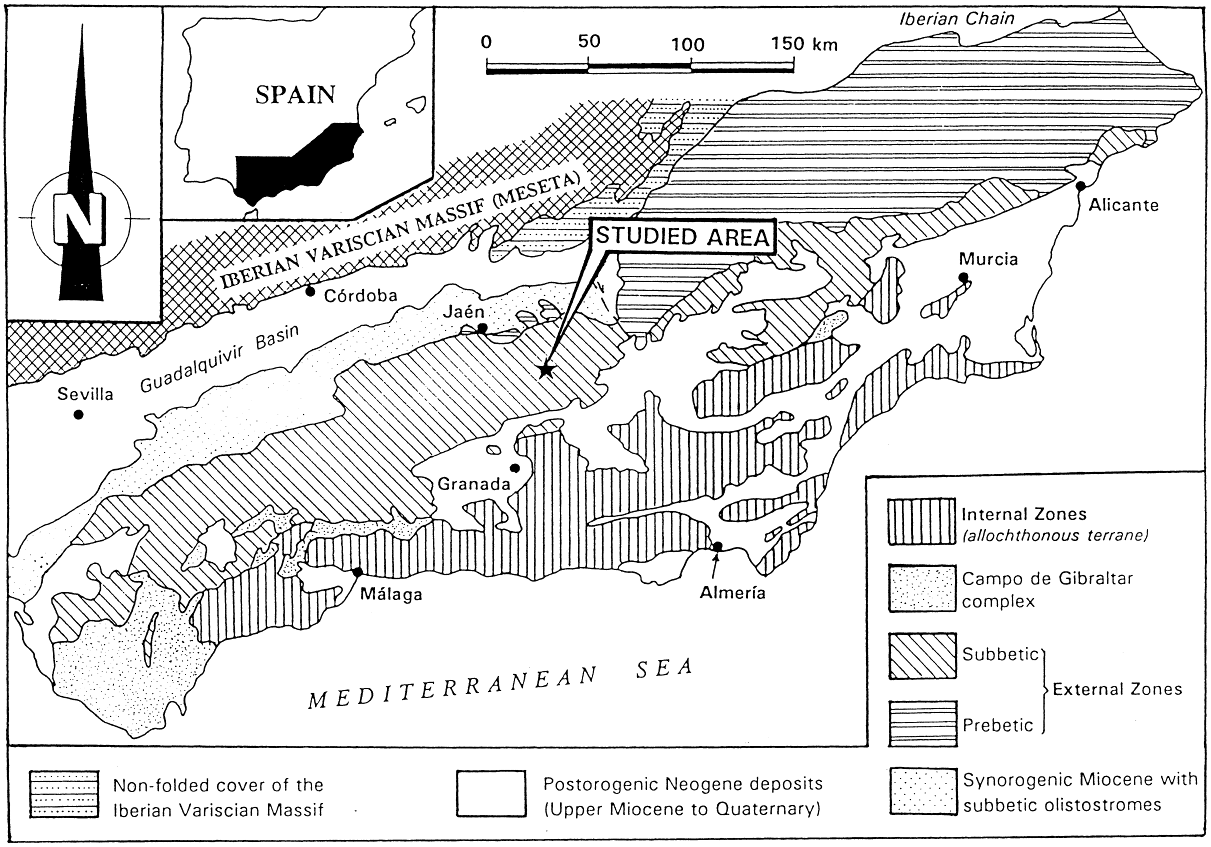


Fig. 1. Geographical and geological locations of the study area (Montejícar, Subbetic, southern Spain).

the deposition of pelagic facies from the beginning of the main intracontinental rifting phase (190 Ma ago) (García-Hernández et al., 1989). Therefore, in the Middle and Late Jurassic and in the Cretaceous there are rocks with similar facies to those from other Alpine domains (Vera, 1981), including the Jarropa Radiolarite Formation from the Bathonian–Oxfordian (O'Dogherty et al., 1997).

The region studied in this work corresponds to the smaller palaeogeographic domain (Median Subbetic) considered as more subsided within the Subbetic and, frequently, also regarded as the deepest trough during the Middle and Late Jurassic. The main stratigraphic features of this domain during the Jurassic are summarized in Fig. 2. The Lower Jurassic lithostratigraphic unit (Gavilán Formation) corresponds to the shallow-marine platform deposits prior to the main rifting phase. The Zegrí Formation (upper Pliensbachian–Toarcian) is characterized by a limestone/marl rhythmite, with highly variable thicknesses from one sector to another, due to filling of the half-graben. The Aalenian, the Bajocian and locally the Bathonian present quite varied features as in some sectors these stages are totally or partially lacking, and in others they are represented by alternating limestones and marls with notable variations in thickness (Sandoval, 1983; Linares and Sandoval, 1993). In certain sectors of the Median Subbetic, volcanic rocks are intercalated between the sedimentary rocks from the Aalenian to the Bathonian, in which very shallow-marine carbonate sediments have been observed, capping some volcanic edifices (Fig. 2), interpreted as guyots (Vera et al., 1997). The two latest formations of the Jurassic are the Jarropa Radiolarite Formation (O'Dogherty et al., 1997) fundamentally from the Callovian–Oxfordian (locally also the Bathonian) and the Milanos Formation (Kimmeridgian–Tithonian), in which abundant

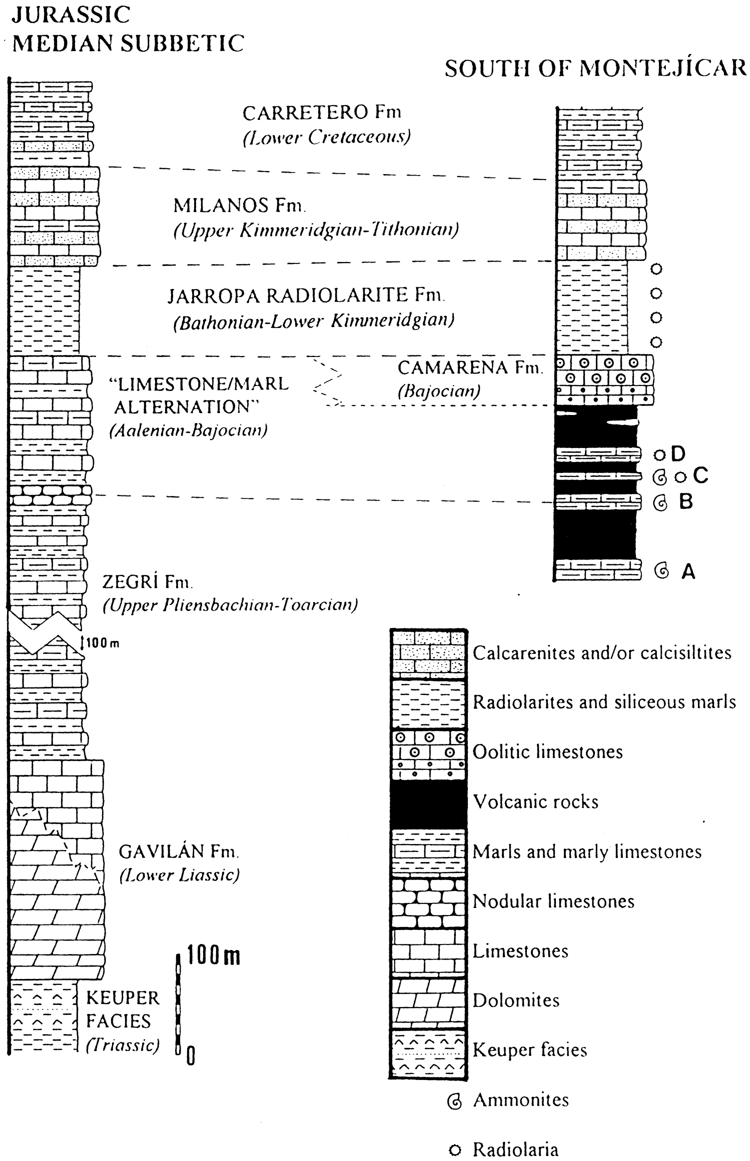


Fig. 2. Jurassic stratigraphic section of most of the palaeogeographical realm termed the Median Subbetic, differentiated into the Subbetic according to subsidence and relative position from the continent. The stratigraphical section of the Montejícar area is represented on the right-hand side, in which oolitic limestones (Camarena Formation) occur at the top of the volcanic edifices. *A*, *B*, *C*, *D*: lithostratigraphic units referred to in the text.

calcisiltite strata with hummocky cross-stratification have been recognized (Molina and Vera, 1996; Vera and Molina, 1998).

The main stratigraphic section studied appears in a geological cross-section one kilometre south of Montejícar village along the highway to Domingo Pérez village. It is located on the north flank of a nearly W–E-striking anticline (Montejícar anticline). The UTM coordinates of the extreme south of the stratigraphic section are 558568 and the extreme north 559576. These observations have been completed with other stratigraphic sections in nearby regions, mainly on the same flank of the anticline, east of the highway. Stratigraphic logs have been made to scale 1 : 100 and sketches of the geometry of the strata and of the contacts have been drawn to the same scale. Previous data on this sector are limited to Comas (1978), Comas et al. (1986) and Diaz de Neira et al. (1991), in which the basic features of the Jurassic stratigraphic section and the presence of interstratified volcanic rocks are described, with limited chronostratigraphic precision. In the paper by Diaz de Neira et al. (1991) the existence of karstification surfaces in the oolitic limestones topping the volcanic rocks was first pointed out, as well as the presence of hummocky cross-stratification in the Milanos Formation, aspects which we discuss in detail below.

The detailed biostratigraphic study has been accomplished with ammonites and/or radiolaria, using the reference biozonations in Fig. 3, in which we also indicate the equivalence between the two ammonite and radiolarian biozones and the chronostratigraphical and geochronological units.

3. Stratigraphical units underlying the radiolarites

Lower and Middle Jurassic sedimentary rocks crop out widely below the radiolarites in the nucleus of an anticline in the study area. They consist of a rhythmic alternation of pelagic marls and marly limestones with ammonites, in which pillow lava flows and pyroclastic beds appear. Four superposed flows can be clearly differentiated (Fig. 4), the lowest and uppermost being thickest. The total thickness of the volcanic flows is over 100 m. Pelagic rocks with ammonites are interbedded between the volcanic flows allowing accurate dating.

The Gavilán Formation (lowermost Jurassic) crops out in areas near to the Montejícar anticline. It was deposited on a shallow-marine platform before the main rifting phase and has very similar characteristics throughout the Subbetic basin.

3.1. Sediments below the volcanic rocks (Zegrí Formation, Toarcian)

The lowest sedimentary rocks cropping out in the Montejícar region correspond to a limestone/marl rhythmite from the Zegrí Formation (A in Fig. 2).

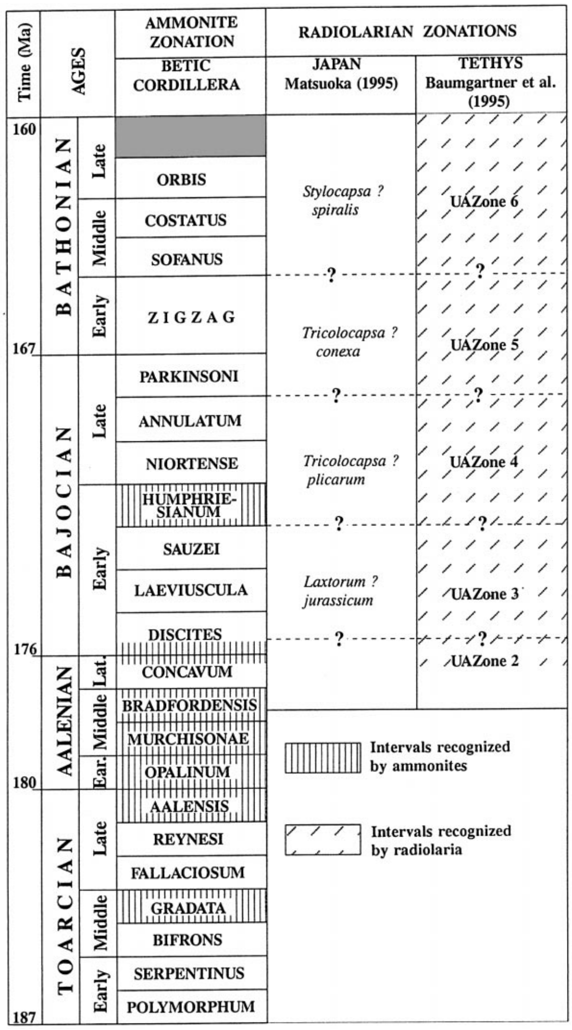


Fig. 3. Radiolarian and ammonite zonations showing the dated stratigraphic intervals in the studied area. Ammonite zones of the Subbetic are from Jiménez and Rivas (1979) for the Toarcian, from Linares and Sandoval (1993) for the Aalenian and from Sandoval (1983) for the Bajocian and Bathonian. Absolute time in million years (Ma) is from Gradstein et al. (1994). Chronostratigraphic position of radiolarian zonal boundaries recalibrated in this paper (see also O'Dogherty et al., 1995, 1997).

The individual thicknesses of the limestone/marl couplets range from 0.5 m to 2 m. These rhythmites crop out in the anticline nucleus, under the earliest lava flow, and show a similar facies in most regions of the Subbetic. The mudstone and wackestone assemblage is characterized by calcitized radiolaria and remains of thin-shelled pelecypods. In

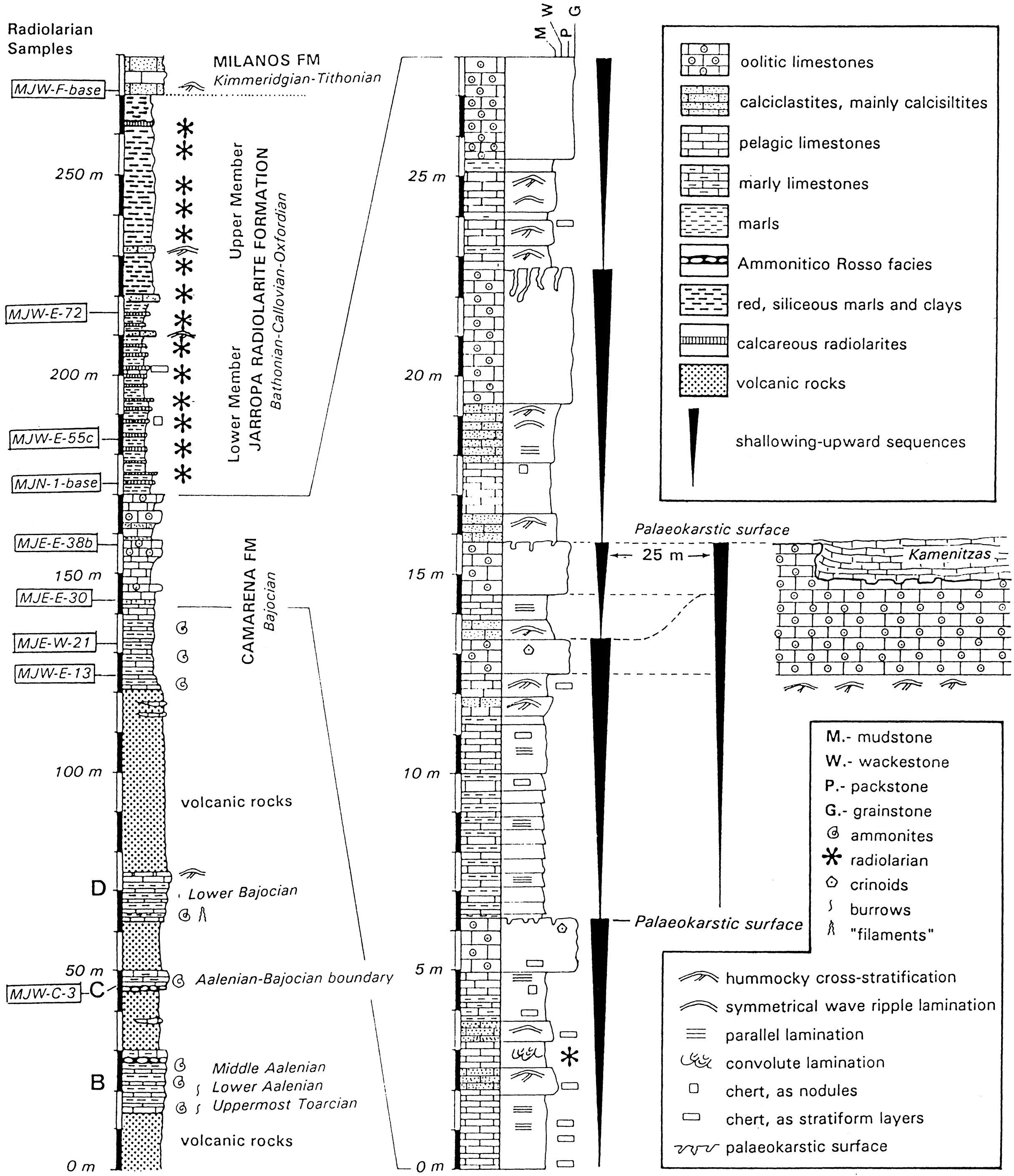


Fig. 4. Stratigraphical section of the Jurassic (from the Toarcian to the Kimmeridgian) in the Montejícar area (Subbetic, southern Spain).

some beds, *Bositra buchi* Roemer is very abundant. In the Montejícar sections centimetre-scale strata of yellow-brown clays with a pyroclastic appearance occur. There are also beds with slumps and synsedimentary small faults. Abundant ammonites [*Polyplectus discoides* (Zieten), *Merlaites alticarinatus* (Merla), *Geczyceras bonarelli* (Parish and Viale) and *Alocolytoceras* sp.] have been collected. This fossiliferous association is typical of the upper part of the middle Toarcian (Gradata zone) according to Jiménez and Rivas (1979) and Goy et al. (1988).

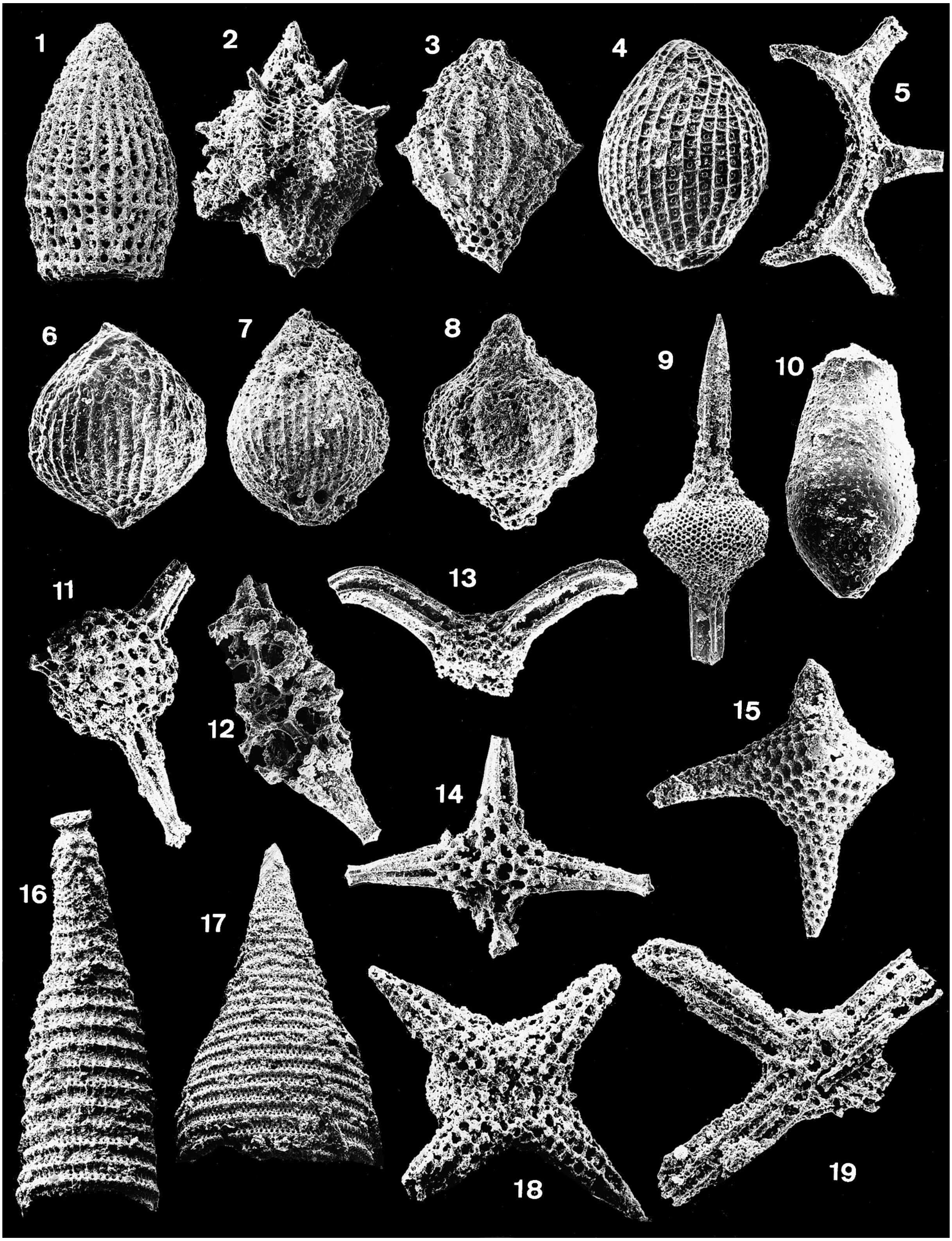
3.2. Sediments interbedded in volcanic rocks (upper Toarcian–Aalenian)

There are three main sedimentary intercalations (termed B, C and D from bottom to top in Figs. 2 and 4) between the volcanic rocks. They can be dated with ammonites and/or radiolarians, and show continuity towards nearby sectors. Several small sedimentary intercalations (up to 1 m thick), mainly discontinuous, can also be recognized.

The first sedimentary intercalation (B in Fig. 4) is 15 m thick in the main stratigraphic section at the Montejícar anticline, thinning 10 m in another stratigraphic section 1 km eastwards. It is composed of a grey limestone/marl rhythmite with individual cycle thicknesses ranging from 0.5 to 2 m. Near the top, a red nodular limestone (marly Rosso Ammonitico facies) with ammonites appears. In the lower part of this first intercalation we have collected abundant well-preserved ammonites. The association comprises *Phylloceras* sp., *Alocolytoceras* sp., *Pleydellia mactra* (Dumortier), *P. subcompta* (Branco), *P. aalensis* (Zieten), *P. falcifer* Maubeuge, *P*. aff. *buckmani* Maubeuge, *Cotteswoldia bifax* Buckman, *C. costulata* (Zieten), *C. limatula* Buckman and *Bredyia* sp. This association is characteristic of the latest Toarcian, Aalensis Zone (Matra and Aalensis subzones) (Jiménez and Rivas, 1979; Goy et al., 1988, 1994, 1996; García-Gómez et al., 1995). In the middle part of the first intercalation containing grey marls and marly limestones there are also abundant ammonites. We have identified *Calliphylloceras nilsoni* (Hebert), *Holcophylloceras ultramontanum* (Neumayr), *Alocolytoceras ophioneum* (Benecke), *Leioceras lineatum* Buckman, *L. comptum* (Reinecke), *Tmetoceras scissum* (Benecke), *Erycites* sp. and *Abbasitoides*? sp. This association corresponds to the early Aalenian (Opalinum Zone) according to Linares and Sandoval (1993), García-Gómez et al. (1995) and Goy et al. (1994, 1996). In the upper part of the first intercalation a marly Rosso Ammonitico facies contains scarce ammonites, but there is a very significant association consisting of *Calliphylloceras nilsoni* (Hebert), *Ancolioceras opalinoides* (Mayer), *Brasilia bradfordensis* (Buckman), *Erycites fallifax* Arkel, *Spinammatoceras tenax* (Vacek), *S. schindewolfi* Linares and Sandoval and *Abbasitoides modestum* (Vacek). This association corresponds to the middle Aalenian, specifically the Murchisonae and Bradfordensis zones (Linares and Sandoval, 1993; Henriquez et al., 1996).

The second sedimentary intercalation (C in Fig. 4) is 6 m thick in the Montejícar stratigraphic section (Fig. 4), changing towards the east (1 km) where it is composed of two sedimentary intercalations 3.5 m and 8 m in thickness, and an interbedded volcanic flow 3.5 m thick. In both sections it comprises a grey limestone/marl rhythmite in which the individual thickness of the cycles ranges from 0.5 to 2 m. Several small synsedimentary faults have been observed. Near the bottom there is a red and violet marly nodular limestone (marly Rosso Ammonitico facies) with ammonites. The macrofauna is composed mainly of *Bositra buchi* Roemer, but there are also belemnites and scarce ammonites. We have recognized *Haplopleuroceras mundum* Buckman, an ammonite specimen characteristic of the Aalenian–Bajocian boundary and very abundant in the Subbetic (Linares and Sandoval, 1993, 1996). The first samples yielding well preserved radiolarians occur in this interval. In sample MJW-C-3 we have noted the occurrence of *Linaresia rifensis* El Kadiri, *Ristola praemirifusus* Baumgartner and Bartolini, *Mirifusus proavus* Tonielli, *Triactoma jakobsae* Carter, *Aconthoarcus suboblongus* (Yao), *Eucyrhdiellun unumaense* (Yao), *Parahsuum*? *grande* Hori and Yao and *P*.? *olorizi* El Kadiri (16 in Fig. 5). This association is characteristic of the latest Aalenian and earliest Bajocian (approximately UAZone 3 of Baumgartner et al., 1995).

The third sedimentary intercalation (D in Fig. 4) is 12 m thick and is very similar in lithology and thickness to other stratigraphic sections from nearby regions. It consists of grey limestone/marl rhyth-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mite. The limestone strata contain cherts occurring as beds or in nodules. In several limestone beds parallel lamination and symmetrical wave ripples can be observed. The uppermost bed of this sedimentary intercalation is easily recognized throughout the study area, because it is a characteristic grey calcisiltite with peloids, showing hummocky cross-stratification.

The D intercalation with poorly preserved radiolarians have no ammonites, even though it has strong affinities with the association of the C intercalation. An early Bajocian age is attributable to this third intercalation.

All the sedimentary intercalations under the microscope correspond to mudstones and wackestones with radiolarians, remains of thin-shelled pelecypods (usually termed 'filaments'), sections of Aptychus and small unidentifiable bioclasts. The limestones in contact with the volcanic rocks are virtually unaltered, with the exception of small changes in colour. In only one sample under the microscope is it possible to see microcrystalline carbonate with a characteristic mottled texture due to thermal metamorphism.

3.3. Sediments above the volcanic rocks (Camarena Formation, Bajocian)

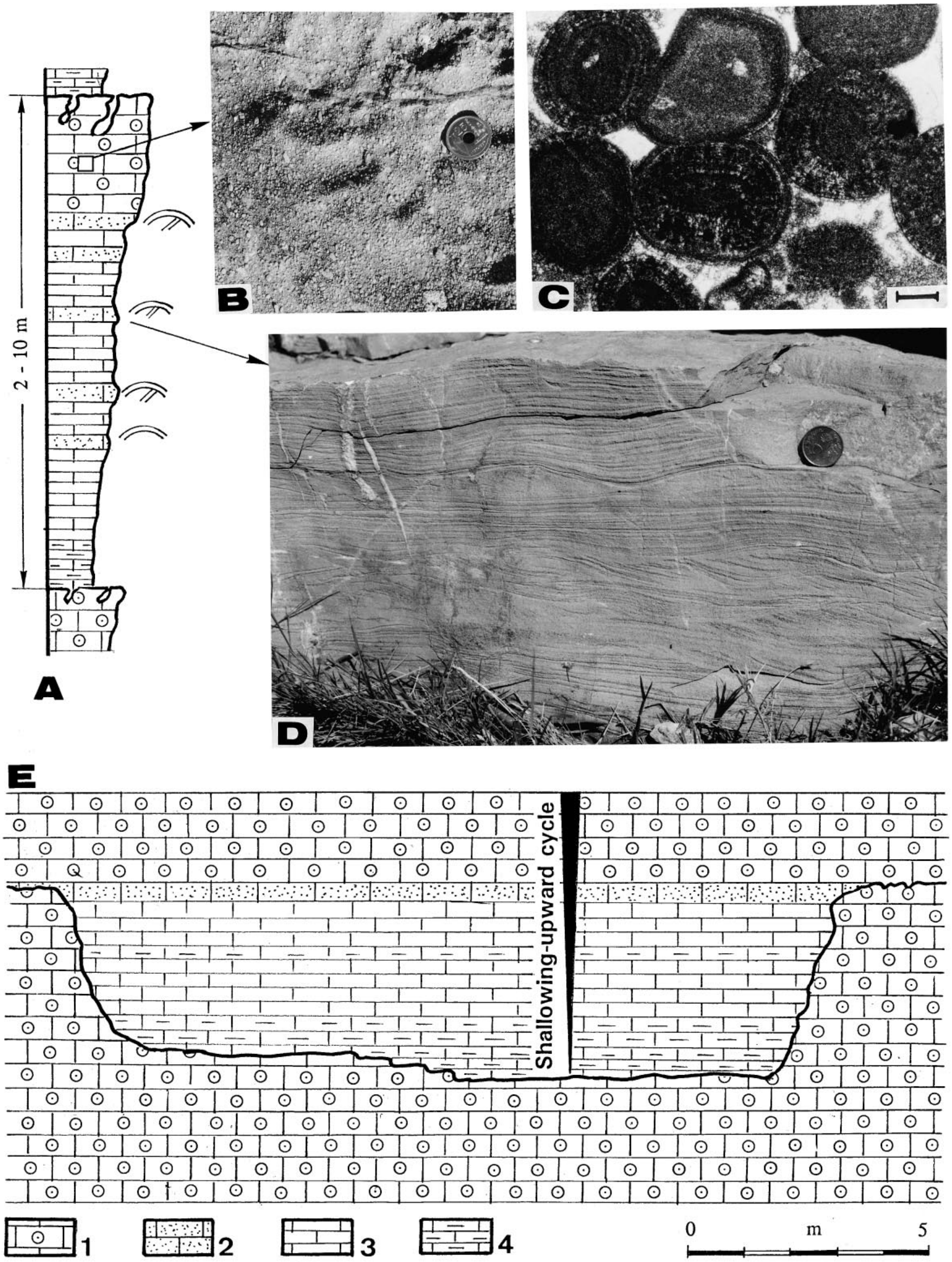
A lithostratigraphic unit 50 m thick overlies the youngest volcanic flow (Fig. 4). It is characterized by oolitic limestones in the upper half, which are included in the Camarena Formation (Molina, 1987). Similar oolitic limestone facies have been recognized in other regions from the Median Subbetic capping volcanic edifices, forming guyots (Vera et al., 1997).

The lower half, 22 m thick, is represented by a marl/limestone rhythmite, with ammonites and radiolarians. The ammonites are very scarce and we have only collected one specimen of *Stephanoceras* sp. from the top of this lower half (immediately below the first oolitic limestone bed), which indicates an early Bajocian age.

The upper half, 28 m thick, presents features of great interest that have therefore been analysed at a smaller scale (Fig. 4), highlighting six oolitic limestone beds varying in thickness from 1 m to 4.5 m, intercalated in strata of micritic limestones, calcisiltites with hummocky cross-stratification (Fig. 6D) and scarce marls. The oolitic limestones are oolitic grainstone with peloids, oncoids, foraminifera (*Nautiloculina, Protopeneroplis, Trocholina, Pfenderina, Valvulina*), crinoids and corals. There are no fragmentary textural elements (Fig. 6C) and therefore redeposition can be discarded. Several of the oolitic limestone beds show very characteristic karstic morphology at the top. Some of these data are extensively discussed below in the section on palaeobathymetric criteria.

This interval (samples MJW-E-13, MJW-E-21, MJE-E-30 and MJE-E-38b, see Fig. 4 and Table 1) has yielded the best-preserved and diversified radiolarian fauna, mostly pyritized specimens (Fig. 5). The

Fig. 5. Jurassic radiolarians from the Montejícar area (Subbetic). 1: *Parahsuum izeense* (Pessagno and Whalen), specimen 17479, sample MJE-E-30, lower Bajocian, Humphriesianum zone, ×210. 2–3: *Unuma echinatus* Ichikawa and Yao (2 is specimen 17552, sample MJE-E-30, lower Bajocian, Humphriesianum zone, ×210; 3 is specimen 17560, sample MJE-E-30, lower Bajocian, Humphriesianum zone, ×230). 4: *Tricolocapsa conexa* Matsuoka, specimen 17819, sample MJN-1-base, Bathonian, ×300. 5: *Hexasaturnalis tetraspinus* (Yao), specimen 17904, sample MJW-E-13, lower Bajocian, ×150. 6: *Tricolocapsa plicarum* ssp. A in Baumgartner et al. (1995), specimen 17817, sample MJE-E-30, lower Bajocian, Humphriesianum zone, ×900. 7. *Tricolocapsa plicarum plicarum* Yao, specimen 17553, sample MJW-E-30, lower Bajocian, Humphriesianum zone, ×230. 8: *Unuma latusicostatus* (Aita), specimen 17656, sample MJW-E-72, Bathonian, ×230. 9: *Xiphostylus* sp., specimen 17644, sample MJW-E-30, lower Bajocian, Humphriesianum zone, ×135. 10: *Guexella nudata* (Kocker), specimen 17790, sample MJN-1-base, Bathonian, ×300. 11: *Acaeniotylopsis variatus* (Ozvoldova), specimen 17531, sample MJE-E-30, Lower Bajocian, Humphriesianum zone, ×110. 12: *Perispyridium ordinarium* (Pessagno), specimen 17629, sample MJE-E-30, lower Bajocian, Humphriesianum zone, ×200. 13: *Bernoulluis cristatus* Baumgartner, specimen 17568, sample MJE-E-30, lower Bajocian, Humphriesianum zone, ×160. 14: *Emiluvia lombardensis* Baumgartner, specimen 17618, sample MJE-E-30, lower Bajocian, Humphriesianum zone, ×160. 15: *Podocapsa amphitreptera* Foreman, specimen 17744, sample MJW-F-1, upper Kimmeridgian–early Tithonian, ×100. 16: *Parahsuum*? *olorizi* El Kadiri, specimen 17467, sample MJE-E-30, lower Bajocian, Humphriesianum zone, ×110. 17: *Mirifusus fragilis* Baumgartner, specimen 17458, sample MJE-E-30, lower Bajocian, Humphriesianum zone, ×110. 18: *Higumastra wintereri* Baumgartner, specimen 17912, sample MJE-E-13, lower Bajocian, ×180. 19: *Archaeohagiastrum longipes* Baumgartner, specimen 17903, sample MJE-E-13, lower Bajocian, ×150.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latest early Bajocian and the late Bajocian (approximately UAZone 4 of Baumgartner et al., 1995) are recognized by the co-existence of the following radiolarian species: *Hexasaturnalis tetraspinus* (Yao) (5 in Fig. 5), *Higumastra wintereri* Baumgartner, *Hsuum matsuokai* Isozaki and Matsuda, *Parahsuum*? *grande* Hori and Yao, *Parahsuum*? *olorizi* El Kadiri (16 in Fig. 5), *Parahsuum izeense* (Pessagno and Whalen) (1 in Fig. 5), *Parasaturnalis diplocyclis* (Yao), *Tricolacapsa plicarum plicarum* Yao (7 in Fig. 5), *Unuma echinatus* Ichikawa and Yao (1 in Fig. 5), *Xiphostylus* sp. (9 in Fig. 5) and *Zartus dickinsoni* Pessagno and Blome (see distribution in Table 1).

4. Radiolarites

The Jurassic radiolarites of the Median Subbetic have recently been re-examined and defined as a formal lithostratigraphic unit termed Jarropa Radiolarite Formation (O'Dogherty et al., 1997). It is very similar to Jurassic radiolaritic units in other Alpine chains such as the Apennines (*Calcari Diasprigni*), Southern Alps (*Radiolariti Formation* or *Selcifero Lombardo Formation*), Dinarids (*Lastva Radiolarite Formation*), Carpathians, etc.

The type section of this formation is located 10 km to the west of the locality described here. In the type locality, where there are no volcanic rocks intercalated in the Jurassic pelagic rocks, the unit underlying the radiolarite is a rhythmite of marls and limestones with ammonites so that the boundary with the Jarropa Radiolarite Formation is gradual and is established by conventional criteria (O'Dogherty et al., 1997). In contrast, in the Montejícar area the underlying rocks are the oolitic limestone of the Camarena Formation, deposited on a volcanic high, forming a guyot (Vera et al., 1997), so that the transition of one unit to the other is very clear.

In the Jarropa Radiolarite Formation in this area, as in that of the type section and reference sections, two members are differentiated. The lower member, 50 m thick, is composed of calcareous radiolarites, radiolaritic limestones and green marls; the beds with the greatest concentration of radiolaria have centimetric thickness. Calcisiltites with hummocky cross-stratification are interbedded in the upper part of this member. The upper member, also 50 m thick, is formed of red siliceous clays and marls, with centimetric beds of radiolarites. Levels of calcisiltites 30 to 40 cm thick with symmetrical wave ripples (Fig. 7D) and small-scale hummocky cross-stratification (Fig. 7B,C) have been found interbedded in this member.

The lower member of the Jarropa Radiolarite Formation (samples MJN-1-base, MJW-E-55c and MJW-E-72 in Fig. 4 and Table 1) is characterized by the co-occurrence of *Amphipyndax durisaeptum* Aita, *Dictyomitra*? *amabilis* (Aita), *Palinandromeda podbielensis* (Ozvoldova), *Protunuma turbo* Matsuoka, *Stichomitra*? *takanoense* (Aita), *Theocapsoma*? *cordis* Kocher, *Tricolocapsa conexa* Matsuoka (4 in Fig. 5) and *T. tetragona* Matsuoka. This association allows the assignment of an early Bathonian age for this interval (approximately UAZone 5 of Baumgartner et al., 1995). Interbedded in this member near the top are levels of calcisiltites (20–40 cm thick) with hummocky cross-stratification and symmetrical wave ripples.

In the upper member of the Jarropa Radiolarite Formation the radiolaria are not well preserved in this stratigraphic section. In the holostratotype of this formation (10 km west) this member contains radiolarian associations (O'Dogherty et al., 1997) corresponding to the Oxfordian and lowermost Kimmeridgian. This age can be attributed to the upper member in this stratigraphic section.

As already established by O'Dogherty et al. (1997), the age of the formation bottom and the boundary between the two members is highly variable. In the holostratotype the age of the base is late Callovian and the boundary between the two mem-

Fig. 6. Shallowing-upward cycles and palaeokarstic features below the radiolarites. (A) Shallowing-upward cycles in the Camarena Formation. (B) Close-up of the oolitic limestone outcrop of the Camarena Formation. (C) Microfacies of the Camarena Formation oolitic limestones (sample MJE-37C, scale is 0.2 mm). (D) Hummocky cross-stratification in the calcisiltite beds in shallowing-upward cycles (Camarena Formation) below the radiolarites. Coin for scale is 18 mm in diameter. (E) Detailed sketch of a palaeosinkhole showing the karstic morphology at the top of a shallowing-upward cycle and its filling composed by another shallowing-upward cycle. Key: *1* = oolitic limestones; *2* = calcisiltites; *3* = micritic limestones (mudstone with radiolaria and pelagic bioclasts); *4* = marly limestones.

Table 1
Radiolarian species recorded in the samples from the Jurassic in the Montejícar section

Radiolarian species	Samples								
	MJW C 3	MJW E 13	MJW E 21	MJE E 30	MJE E 38b	MJW E 55c	MJN 1	MJWLW E 72	MJW F base
Acaeniotylopsis ? *splendens* Kito and De Wever				•					
Acaeniotylopsis variatus (Ozvoldova)			•	•			•		
Acanthocircus suboblongus (Yao)	•	•	•	•	•	•	•		•
Acanthocircus trizonalis (Rüst)									•
Actinomma siciliensis Kito and De Wever				•					
Alievium sp. 1				•					
Amphipyndax durisaeptum Aita								•	
Angulobracchia biordinalis Ozvoldova									•
Angulobracchia digitata Baumgartner				•					
Angulobracchia ? *portmani* Baumgartner									•
Angulobracchia purisimaensis (Pessagno)				•					•
Angulobracchia sicula Kito and De Wever		•	•						
Archaeohagiastrum longipes Baumgartner		•				•			
Bernoullius cristatus Baumgartner				•					
Bernoullius dicera (Baumgartner)									•
Bernoullius rectispinus Kito					•				
Cinguloturris carpatica Dumitrica							•		•
Crucella theokaftensis Baumgartner									•
Orbiculiforma heliotropica (Baumgartner)		•	•					•	
Cyrtocapsa kisoensis Yao			•			•			
Cyrtocapsa mastoidea Yao						•			
Dictyomitra ? *amabilis* (Aita)						•	•	•	
Dictyomitra excellens (Tan)									•
Dictyomitra sp. 1		•							
Dictyomitra sp. 2								•	
Dictyomitrella ? *kamoensis* Mizutani and Kido		•				•	•	•	
Emiluvia chica Foreman			•	•	•				
Emiluvia lombardensis Baumgartner			•	•					
Emiluvia ordinaria Ozvoldova									•
Emiluvia orea ultima Baumgartner and Dumitrica									•
Eucyrtidiellum ptyctum (Riedel and Sanfilippo)									•
Eucyrtidiellum semifactum Nagai and Mizutani				•					
Eucyrtidiellum unumaense (Yao)	•	•	•			•	•	•	
Fultacapsa sphaerica (Ozvoldova)									•
Gongylothorax aff. *favosus*							•		
Gorgansium spp.						•			
Guexella nudata (Kocher)					•			•	
Hexasaturnalis ? sp. 1		•							
Hexasaturnalis hexagonus (Yao)				•					
Hexasaturnalis tetraspinus (Yao)	•	•	•						
Higumastra wintereri Baumgartner		•							•
Hiscocapsa aff. *funatoensis* (Aita)								•	
Hiscocapsa funatoensis (Aita)				•		•			
Hiscocapsa leiostraca (Foreman)									•
Hiscocapsa pseudouterculus (Aita)									•
Hiscocapsa sp. 2								•	
Homoeoparonaella argolidensis Baumgartner									•
Hsuum matsuokai Isozaki and Matsuda	•	•	•						
Hsuum mirabundum Pessagno and Whalen				•					
Hsuum sp. 1		•				•	•		

Table 1 (continued)

Radiolarian species	Samples								
	MJW C 3	MJW E 13	MJW E 21	MJE E 30	MJE E 38b	MJW E 55c	MJN 1	MJWLW E 72	MJW F base
Leugeo hexacubicus (Baumgartner)							•		
Linaresia chrafatensis El Kadiri	•		•						
Acaeniotylopsis ? *splendens* Kito and De Wever				•					
Acaeniotylopsis variatus (Ozvoldova)			•	•			•		
Acanthocircus suboblongus (Yao)	•	•	•	•	•	•	•		•
Acanthocircus trizonalis (Rüst)									•
Linaresia rifensis El Kadiri	•								
Mirifusus dianae s.i. (Karrer)								•	
Mirifusus fragilis Baumgartner	•			•				•	
Mirifusus proavus Tonielli	•		•						
Napora boneti Pessagno, Whalen and Yeh									•
Palinandromeda depressa (De Wever and Miconnet)		•	•						
Palinandromeda podbiliensis (Ozvoldova)						•		•	
Palinandromeda praepodbiliensis (Baumgartner)		•							
Pantanellium riedeli Pessagno				•					•
Pantanellium squinaboli (Tan)						•			
Parahsum sp. S in Baumgartner et al., 1995		•		•					
Parahsum ? *grande* Hori and Yao	•		•	•					
Parahsuum ? *hiconocosta* Baumgartner and De Wever			•			•			
Parahsuum ? *magnum* Takemura		•							
Parahsuum ? *olorizi* El Kadiri	•		•	•					
Parahsuum izeense (Pessagno and Whalen)	•			•					
Parahsuum aff. *izeense* (Pessagno and Whalen)			•				•		
Parahsuum officerense (Pessagno and Whalen)		•	•						
Parasaturnalis diplocyclis (Yao)				•					
Paronaella kotura Baumgartner				•					
Paronaella sp.		•							
Parvicingula dhimenaensis Baumgartner						•		•	
Parvicingula spinata (Vinassa)		•	•			•		•	
Parvicingula mashitaensis Mizutani									•
Parvicingula sp. 1		•		•					
Parvicingula sp. 2				•					
Perispyridium ordinarium (Pessagno)				•					•
Podobursa helvetica (Rüst)								•	
Podobursa polyacantha (Fischli)				•			•		
Podobursa aff. *quadriculeata* Steiger									•
Podobursa sp. 1									•
Podocapsa amphitreptera Foreman									•
Protunuma japonicus Matsuoka and Yao								•	•
Protunuma turbo Matsuoka						•	•	•	
Pseudoeucyrtis reticularis Matsuoka and Yao									•
Pseudoeucyrtis sp. J in Baumgartner et al., 1995								•	
Quarticella ovalis Takemura						•			
Ristola altissima major Baumgartner and De Wever								•	
Ristola praemirifusus Baumgartner and Bartolini	•								
Ristola sp. 1		•							
Saitoum elegans De Wever									•
Saitoum levium De Wever						•		•	
Stichocapsa convexa Yao	•	•	•		•		•	•	
Stichocapsa himedaruma Aita								•	
Stichocapsa japonica Yao	•		•				•	•	

Table 1 (continued)

Radiolarian species	Samples								
	MJW C 3	MJW E 13	MJW E 21	MJE E 30	MJE E 38b	MJW E 55c	MJN 1	MJWLW E 72	MJW F base
Stichomitra ? *takanoense* (Aita)						•	•	•	
Spongocapsula palmerae Pessagno							•	•	•
Spongocapsula perampla (Rüst)									•
Suna echiodes (Foreman)									•
Acaeniotylopsis ? *splendens* Kito and De Wever				•					
Acaeniotylopsis variatus (Ozvoldova)			•	•			•		
Acanthocircus suboblongus (Yao)	•	•	•	•	•	•	•		•
Acanthocircus trizonalis (Rüst)									•
Syringocapsa sp. A in Baumgartner et al., 1995				•					
Teraditryma corralitosensis corralitosensis (Pessagno)		•			•				•
Tetratrabs pseudoplena Baumgartner									•
Theocapsoma ? *cordis* Kocher							•	•	
Theocapsoma ? *cucurbiformis* Baumgartner							•		
Theocapsoma ? *operculi* (Yao)								•	
Theocapsoma ? sp. 1							•		
Transhsuum brevicostatum (Ozvoldova)						•	•		
Transhsuum hisuikyoense (Isozaki and Matsuda)			•	•					
Triactoma cornuta Baumgartner									•
Triactoma jakobsae Carter	•		•	•					
Triactoma jonesi (Pessagno)									•
Tricolocapsa conexa Matsuoka (1995)							•	•	
Tricolocapsa fusiformis Yao		•	•						
Tricolocapsa plicarum ssp. A				•			•		
Tricolocapsa plicarum plicarum Yao				•			•	•	
Tricolocapsa tetragona Matsuoka								•	
Tricolocapsa sp. S in Baumgartner et al., 1995				•			•		
Tricolocapsa sp. 1								•	
Tritrabs hayi (Pessagno)									•
Tritrabs simplex Kito and De Wever		•	•		•				
Unuma echinatus Ichikawa and Yao	•	•	•	•	•	•		•	
Unuma latusicostatus (Aita)					•	•		•	
Unuma typicus Ichikawa and Yao					•	•			
Williriedellum carpathicum Dumitrica									•
Williriedellum sp. 1				•			•	•	
Xiphostylus spp.	•	•	•	•	•				
Yamatoum spp.		•	•						
Zartus dickinsoni Pessagno and Blome	•	•	•	•	•				
Zartus imlayi Pessagno and Blome		•	•						

The stratigraphic location of the samples is marked in Fig. 4 (sample MJW-C-3 is the oldest, Aalenian–Bajocian boundary, and sample MJW-F-base is the youngest, late Kimmeridgian–early Tithonian).

bers is located in the early Oxfordian. In the section studied here the base of the formation is older (uppermost Bajocian), while the age of the boundary between the two members can be similar to the type section. In one of the two reference sections (Sierra Pelada, O'Dogherty et al., 1997) the bottom of the formation was also dated as late Bajocian.

5. Stratigraphical units overlying the radiolarites

In extensive sectors of the Median Subbetic, the Milanos Formation (Kimmeridgian–Tithonian) overlies the Jarropa Radiolarite Formation. In the area studied here the transition from the Jarropa Radiolarite Formation to the Milanos Formation is indicated by a colour change, from red to grey, and the appearance of metre-thick beds of cherty limestones. The clayey beds at the base of this formation have yielded the following radiolarian assemblage: *Angulobracchia biordinalis* Ozvoldova, *Dictyomitra excellens* (Tan), *Emiluvia ordinaria* Osvoldova, *Fultacapsa sphaerica* (Ozvoldova), *Podocapsa amphitreptera* Foreman (15 in Fig. 5) and *Williriedellum carpathicum* Dumitrica. This association characterizes a late Kimmeridgian–early Tithonian age (approximately UAZones 10–11 of Baumgartner et al., 1995).

In its lowest 25 m the Milanos Formation is characterized by the presence of cherty limestones, with strata 0.5 to 1 m thick, with planar lamination, symmetrical wave lamination and, in two of the beds, hummocky cross-stratification. The top of some beds shows symmetrical wave ripples. Cycles occur between 14 m to 24 m above the base, changing from wackestone to grainstone, frequently oolitic in the upper part, several with symmetrical wave ripples. Five metres from the bottom a calcarenite bed with large-scale planar cross-bedding occurs (Fig. 7F,G).

6. Palaeobathymetric arguments

The fossil associations recognized in different pelagic sediments of the Subbetic Jurassic (included the radiolarites) in the analysed sector do not provide any indication of a specific depth, mainly because benthonic organisms meaningful from a palaeobathymetric point of view do not occur. The same fossils occur in Jurassic pelagic sedimentary rocks of similar age in other Alpine domains, corresponding to Tethyan continental margins. Therefore, and due also to the lack of sedimentological arguments, indirect arguments based on comparisons with recent pelagic sedimentation have been invoked by many authors.

However, in the authors' judgement, several of the sedimentary data described above provide weighty palaeobathymetric arguments for the radiolarite deposition (Jarropa Radiolarite Formation) and especially for the underlying and overlying sedimentary rocks (Camarena and Milanos Formations, respectively). This discussion centres on the validity and usefulness of these criteria in estimating the depositional depth.

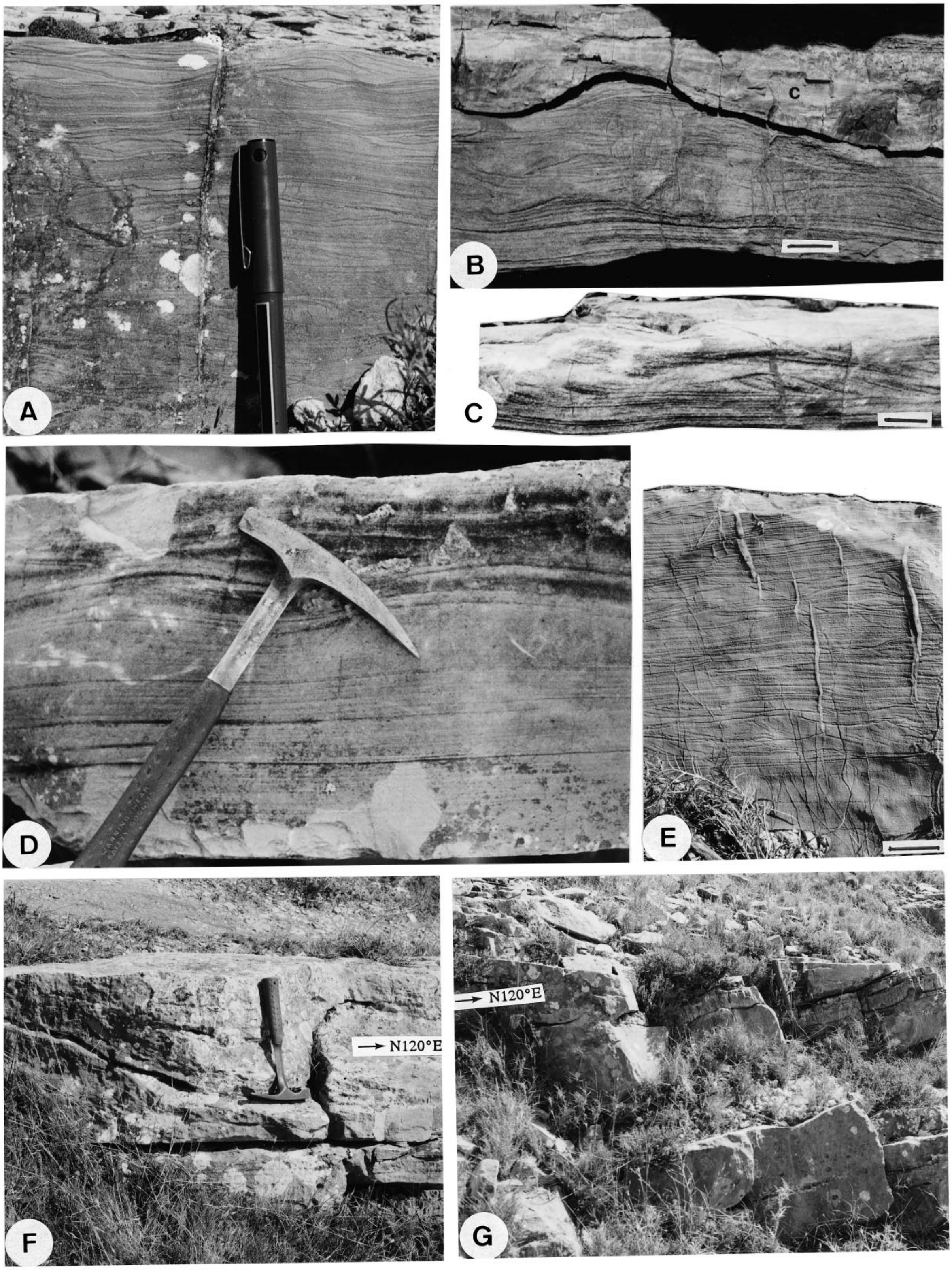
6.1. Shallowing-upward cycles with palaeokarstic surfaces at the top

These cycles appear in the sedimentary rocks immediately below the radiolarites, in the highest beds of the Camarena Formation (Fig. 6A). In the lower part of each cycle there are pelagic limestones and marls (with sections of *Bositra*), interbedded with calcisiltites with hummocky cross-stratification (Fig. 6D and Fig. 7A). In the upper part of each cycle there are massive oolitic limestones, frequently with abundant crinoids. These oolitic limestones are mainly composed of Bahamian ooids, with well-developed tangential and radial structures (Fig. 6B,C), and without the 'pelagic ooids' characteristic referred by Bernoulli and Jenkyns (1974). The textural features and skeletal grains and fossils in these oolitic limestones are typical of very shallow-water marine environments.

On the top of these oolitic beds are palaeokarstic surfaces varying in degree of development. In some cases they are corrosion surfaces with centimetre-scale karstic cavities, while in others there are cavities of irregular shape penetrating more than a metre into the underlying oolitic limestones and which are filled by more recent pelagic sediments, forming neptunian dykes. In the cases of greater development palaeosinkholes appear, treated separately in the paragraph below. In the stratigraphic section of Fig. 4 six cycles have been recognized, laterally changing to five by progressive thinning of the lower beds of a cycle and the joining of two beds of oolitic limestones. The shallowing-upward cycles that end with palaeokarstic surfaces clearly indicate sedimentation in a very shallow-marine environment in which the initial stages were below the fair-weather wave base and subsequent temporary emersion of the isolated carbonate platforms would have occurred.

6.2. Palaeosinkholes in the oolitic limestones with filling of pelagic sediments

Palaeosinkholes also appear in the limestones underlying the radiolarites, in the higher part of the Camarena Formation, at the top of some of the afore-mentioned shallowing-upward cycles. Several irregularly shaped cavities at the top of the oolitic beds have been observed and measured in detail.


A
B
c
C
D
E
F
N120°E
G
N120°E

There are several examples of palaeosinkholes, the most significant of which (Fig. 6E) is more than 30 m long (horizontal or parallel to the stratification) and up to 6.5 m high (vertical or perpendicular to the stratification). Their morphology, with almost vertical walls and nearly flat bottoms, although with numerous irregularities in detail, is clearly karstic. In some instances, at the bottoms there are kamenitzas typical of coastal karst (Esteban and Klappa, 1983). The cavities are filled by sedimentary rocks from the uppwer to the lower part of the overlying shallowing-upward cycle. In some instances the lower strata of the fill have slump structures indicating sliding-down towards the interior of the cavity. These palaeosinkholes constitute one of the most important pieces of evidence in favour of the existence of emersion stages of the isolated platform in the sedimentary rocks underlying the radiolarites. These isolated carbonate platforms on volcanic edifices (guyots in the sense of Vera et al., 1997) disappeared when the deposition of the radiolarites began.

6.3. Shallowing-upward cycles without palaeokarst surfaces

These cycles are observed below and above the radiolarites as shallowing-upward cycles showing textural changes from wackestone–packstone at the base to oolitic grainstone at the top. In the sedimentary rocks underlying the radiolarites these cycles are similar to those described in Section 6.1, differing only in the absence of palaeokarst features at the top (Vera and Molina, 1998). They are interpreted as shallowing-upward cycles formed by the migration of oolitic shoals in a shallow platform, without emersion, but in which the depositional depth was shallow (Vera and Molina, 1998). Current oolite lithofacies are best developed in wave-influenced and tidally influenced marine areas where depths are less than 3 m (Wright and Burchette, 1996, p. 334).

6.4. Hummocky cross-stratification

Small-scale hummocky cross-stratifications are present in most of the stratigraphic section. The oldest are observed at the top of the strata in a sedimentary intercalation within the volcanic rocks (Fig. 4). They are very abundant in the middle part of the Camarena Formation, particularly in calcisiltite levels appearing in the lower part of the shallowing-upward cycles (Fig. 6D and Fig. 7A). They appear also in the calcisiltite beds, interbedded in the Jarropa Radiolarite Formation (Fig. 7B,C,D). Finally, they are abundant in the lower beds of the Milanos Formation, as described for numerous localities in the Median Subbetic (Vera and Molina, 1998). The presence of this structure is an important criterion for the recognition of tempestites, and indicates that deposition occurred in a relatively shallow environment, as its genesis demands storm waves affecting the bottom (Cheel and Leckie, 1993; Monaco, 1994), which occurs in a middle ramp and less frequently in an outer ramp (Burchette and Wright, 1992). The diagnostic criteria between calciclastic beds from steep carbonate platforms and gentle (ramp) carbonate platforms has been recently analysed by Vera and Molina (1998). According to their criteria the calcisiltite beds with hummocky cross-stratification studied here are clearly storm deposits deposited on a gentle (ramp) carbonate platform.

6.5. Symmetrical wave ripples

This structure is usually related to that described above in beds of calcareous tempestites. It has been recognized at the tops of many strata, in some cases clearly calcareous tempestites with hummocky cross-stratification. They have been observed in the calcisiltite strata interbedded in sedimentary rocks underlying the radiolarites (corresponding to the Camarena Formation) as well as in the overlying Mi-

Fig. 7. Sedimentary structures in the calciclastic levels. (A) Small-scale hummocky cross-stratification in the Camarena Formation in the lower part of the shallowing-upward cycles. (B) Hummocky cross-stratification in a calcisiltite level in the Jarropa Radiolarite Formation (c = chert; scale bar is 2 cm). (C) Small-scale hummocky cross-stratification in the Jarropa Radiolarite Formation (scale bar is 2 cm). (D) Symmetrical wave ripples at a calcisiltite level in the Jarropa Radiolarite Formation. (E) Small-scale hummocky cross-stratification in a calcisiltite level in the Milanos Formation (scale bar is 3 cm). (F) Large-scale cross-stratification in a calcarenite bed near the bottom of the Milanos Formation, with palaeocurrent indicated. (G) Calcarenite bed (more than 1 m thick) with large-scale cross-bedding, with palaeocurrent indicated, in the lower part of the Milanos Formation.

lanos Formation (Fig. 7E). This structure has also been recognized at the top of calcisiltite strata with hummocky cross-stratification in the Jarropa Radiolarite Formation (Fig. 7B,C). The most frequent wavelength values range between 0.2 m and 0.6 m and heights vary from 2 cm to 10 cm. This structure, although not indicative of only one sedimentary environment, is especially abundant in very shallow-water marine environments.

6.6. Calcarenites with large-scale cross-stratification

These calcarenites have been exclusively observed in a bed located 5 m above the bottom of the Milanos Formation. It is more than 1 m thick, and shows good examples of large-scale planar cross-bedding (Fig. 7F,G). Measurements of palaeocurrent directions indicate currents travelling towards Nº90E–N130ºE, mainly N120ºE. Structures of this type and mainly of this scale in calcarenite beds are indicative of traction currents moving a huge volume of allochems and bioclasts. Such currents are especially frequent in very shallow-water marine platform environments.

7. Discussion and conclusions

These palaeobathymetric arguments allow us to affirm that the sedimentary rocks underlying the radiolarites were deposited in a very shallow-water marine environment in which even emersion stages occurred. During these stages karstic reliefs (kamenitzas and palaeosinkholes) developed, recognized on the top of some of the shallowing-upward cycles. In addition we can assert that the sedimentary rocks overlying the radiolarites were deposited on a carbonate ramp at depths at which the bottom was sporadically affected by storm waves (Vera and Molina, 1998).

This discussion is based on the depositional bathymetry of the Jurassic Subbetic radiolarites (Jarropa Radiolarite Formation) and their equivalent facies in other Alpine margins. In Section 1 the ‘classic’ interpretation of Bosellini and Winterer (1975) was presented, according to which radiolarites are the deepest deposits of the Alpine continental margins, below the CCD, and more than 2000 m in depth. Alternative interpretations were also presented suggesting that the Jurassic pelagic sediments of the margins (including the radiolarites) could be notably shallower (Folk, in McBride and Folk, 1979; Seyfried, 1979; Vera, 1981, 1988, 1998; Baumgartner, 1987; Dodona and Farinacci, 1987; Farinacci, 1988; Santantonio et al., 1996).

The first fact attracting attention in the region analysed is that the radiolarites are interbedded between sedimentary rocks deposited in very shallow-marine environments, that in the case of the underlying unit (Camarena Formation) can even signify a temporary emergence. It is therefore highly improbable that a rise and a fall in relative sea level occurred, both approximately 2000 m, before and after the deposition of the radiolarites, respectively.

The radiolarites analysed (Jarropa Radiolarite Formation) overlie the Camarena Formation, and the boundary between the two formations is a stratigraphic discontinuity recognizable in broad areas of the Subbetic basin and corresponding to a sedimentary gap followed by a deepening stage (Vera, 1988; García-Hernández et al., 1989). This increase in depth was originated by a fracturing stage of the continental margin in its extensional phase, in which half-grabens were generated, with a tendency to be filled by sediments in the subsequent stages, leading to progressive levelling of the marine bottom (Vera, 1998). The radiolarites were deposited in the more sunken parts and on the flanks of the tilted blocks, with marked diachronism at the beginning of their sedimentation. The commencement of radiolaritic sedimentation changed from later Bajocian to the Callovian in different sections (O’Dogherty et al., 1997). De Wever et al. (1994, pp. 354–355) have confirmed a diachronous onset of radiolarite sedimentation in the Tethys for the Middle and Late Jurassic which they have explained as due to the triangular shape of the western edge of the Tethys at this time. This triangular border of the Tethys was open to the east and mainly located in tropical areas, conditioning the distribution of the marine currents.

In those areas of the Subbetic basin with radiolarites containing calcisiltite strata with hummocky cross-stratification deposition was relatively shallow. This same fact has already been stated in other stratigraphic sections of the Subbetic radiolarites

(O'Dogherty et al., 1997; Vera and Molina, 1998) and was considered as a criterion of shallow depth during their deposition, since this type of structure develops mainly in marine environments at depths above 50 m (see discussion in Vera and Molina, 1998). The occurrence of the symmetrical wave ripples also favours an interpretation of deposition in a shallow-water marine environment.

It is difficult to calculate the depositional palaeobathymetry of the radiolarite intervals without hummocky cross-stratification and therefore without direct palaeobathymetric criteria, in which the estimation of the depositional depth must be made by indirect criteria, mainly based on the study of the lateral and vertical relations with rocks having facies of known bathymetry.

The existence of beds with hummocky cross-stratification in some areas and their absence in nearby areas, for rocks of the same age and same general lithological appearance, indicates a temporary association between the two types of facies. Likewise, the existence of this type of structure in the upper part of the formation and its absence in the lower part denotes a clear vertical relationship between the rocks presenting this structure and those that do not. These facies changes alone are criteria for establishing that the deposition of the radiolarites without these structures occurred in a marine environment below, but relatively close to, the storm wave base.

An important item of discussion is the existence or not of stratigraphic continuity between the radiolarites and the overlying rocks. The change between the two formations (Jarropa Radiolarite and Milanos) in the study area is gradual. The age of the top of the radiolarites and the bottom of the overlying formation changes in detail from some areas to others, indicating a clear heterochronous character of the boundary between the two formations. In both formations there is usually a gradual change of facies in different areas of the Subbetic (Vera and Molina, 1998). These arguments indicate that between the radiolarites (Jarropa Radiolarite Formation) and the overlying sedimentary rocks there are facies changes such as those described by Santantonio et al. (1996) in the Apennines. We can state that throughout the Subbetic the radiolarites are included in a shallowing megasequence comprising the two formations (Vera and Molina, 1998).

It is not easy to determine the maximum depths of radiolarite deposition, as the only criterion used, until now, is that they should be below storm wave base, without any criteria for establishing this maximum value. The deeper radiolaritic facies should be those deposited in the lowest parts of the tilting blocks, after the fracturing stage of the margin (during the Bathonian). In view of the tendency of sedimentation to level the bottom, the depth difference between the deepest and shallowest parts of the tilted blocks is equivalent to the thickness of the sediments filling the half-grabens. In the Subbetic, these depths reach a few hundreds of metres, normally 150–250 m, exceptionally reaching 500 m in the more subsided troughs. A generalized deepening of the basin from a very small bathymetry (near sea level) up to values over 2000 m can be discarded completely. Based on the palaeoecologic interpretation of corals, Santantonio et al. (1996) considered that the deposition of the radiolarites in the Umbria–Marche Apennines region occurred within, or very close to, the photic zone, estimating the depth between 150 and 250 m. In our case we have no direct criteria to estimate with comparable precision the maximum depth, but according to the sedimentary continuity with the overlying rocks it is estimated that analogous values (a few hundreds of metres) are very likely.

The possibility is raised that similar palaeobathymetric interpretations could be applied to the Jurassic radiolarites deposited in other passive continental margins around the Tethys, in some of which (the Apennines) very substantial arguments have already been presented with the same idea. Accordingly, we propose to abandon the dominant hypothesis over the two last decades according to which Jurassic radiolaritic facies of the External Zones of the Alpine domains were deposited more than 2000 m in depth, below the CCD, in the Jurassic Tethyan continental margins.

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