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New stratigraphical data on the Middle–Late Jurassic biosiliceous sediments from the Sicanian basin, Western Sicily (Italy)

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Key words: radiolarians, biostratigraphy, cherts, basalts, Middle–Late Jurassic, Sicily

ABSTRACT

The reported data present the stratigraphy of several sections across a Middle–Late Jurassic Radiolaritic Unit, well exposed in different thrust sheets pertaining to the Maghrebian chain of Southwestern Sicily. The aim was to define the chronostratigraphical distribution of the Jurassic biosiliceous sedimentation in the Sicanian palaeogeographical zone, a deep water basin belonging to the Southern Tethys continental margin.

The radiolarian biostratigraphy indicates that the switching from carbonate to siliceous sedimentation in the Sicanian Basin is referable to the Bajocian, as shown by the section of Campofiorito, near Corleone. The biostratigraphical dataset allows the correlation between the onset of biosiliceous sedimentation and the fall of biodiversity in the Sicanian basin with the carbonate productivity crisis, indicated by the highest eutrophication that affected Western Tethys during Middle Jurassic times.

RIASSUNTO

Sono state studiate alcune sezioni dell'Unità radiolaritica di età Giurassico Medio-Superiore del Bacino Sicano, affioranti nel settore esterno della catena Appenninico-Maghrebide in Sicilia sud-occidentale. Lo scopo di questo lavoro è di definire la distribuzione cronostratigrafica dell'intervallo siliceo in questo settore paleogeografico della Tetide. In queste successioni la distribuzione di ben preservate associazioni a radiolari, consente di riferire la base delle radiolariti al Bajociano (sezione di Campofiorito). Questo dato rafforza l'ipotesi di una possibile crisi di produttività carbonatica, dovuta a eutrofizzazione, di estensione regionale nella Tetide occidentale durante il Giurassico Medio.

Introduction

Sicily is located in the central-western Mediterranean; it lies along the African-European plate boundary and represents a segment that links the African Maghrebides with the Southern Apennines. The Mesozoic and Tertiary sedimentary basins of Sicily are developed in a sector of the African margin as an articulate carbonate platform-basin system that reached the maximum differentiation during Middle Jurassic times (Di Stefano 2002). Several palaeogeographical zones, (also indicated as domains) were defined in the last forty years along the Sicilian thrust and fold belt on the basis of sedimentary and structural features (Ogniben 1960; Mascle 1973; Broquet 1968; Giunta & Liguori 1973; Catalano & D'Argenio 1978; Catalano et al. 1996). They can be divided into i) carbonate platforms that evolved during the Jurassic to pelagic carbonate platforms (i.e. Panormide, Trapanese, Saccense and Hyblean domains), and ii) deeper basins that were distinguishable already in Permian–Triassic times (Imerese and Sicanian basins). The complex Tertiary fragmentation triggered by the Maghrebian orogenesis leaves still uncertain the mutual relationships among different palaeogeographical sectors.

Biosiliceous sediments of Jurassic age were commonly deposited in these basins both on drowned carbonate platforms as intercalations in the "Rosso Ammonitico" sediments or into the deeper parts of the basins. During the past decades their chronostratigraphical distribution has been inferred by the age of the underlying and overlying deposits (Broquet 1968; Wendt 1969; Mascle 1973). Recent biostratigraphical contributions have provided new data for the radiolarites interbedded in the "Rosso Ammonitico" of the Trapanese pelagic carbonate platform: a middle Oxfordian–late Kimmeridgian age for the siliceous interval at the Monte Inici sections has been obtained through ammonite and radiolarian biostratigraphy (Cecca & Savary 2002; Martire 2002; Martire et al. 2002; Pavia et al. 2002; Beccaro 2004, 2006).

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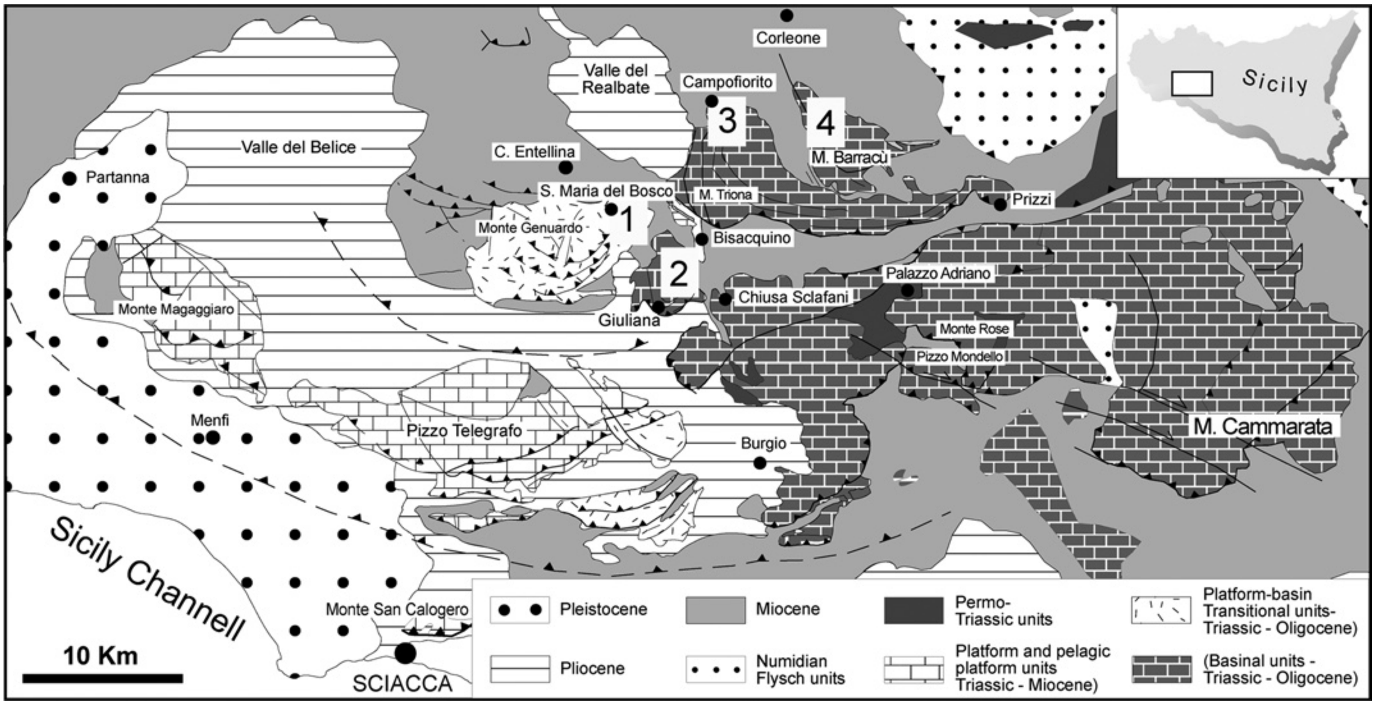

Fig. 1. Structural map of the Monti Sicani (Western Sicily, Italy), with location of the sampled sections: 1, *Casa Gurgo*; 2, *Contrada Lombardia*; 3, *Timpe Rosse*; 4, *Case Paternostro*.

In a recent study of integrated stratigraphy, at the Monte Kumeta sections, Chiari et al. (2004a) reported an early–middle Bathonian to early Kimmeridgian age for the siliceous interval (Membro Radiolaritico Intermedio – MRI). Furthermore, at the Guidaloca section, Caracuel et al. (2002) indicated an early Bathonian to early Kimmeridgian age for the siliceous interval.

For the successions pertaining to the Imerese and Sicanian basins a few data are available. Kito (1989), Kito et al. (1990), Kito & De Wever (1992, 1995) indicated a late Bajocian age for the base of the radiolarites and a late Kimmeridgian–early Tithonian age for the end of the biosiliceous sedimentation at the Monte Cammarata section (Contrada La Ferta, Sicanian Basin).

De Wever et al. (1986) and De Wever (1995) studied the S. Anna section, near Sciacca, which belongs to a transitional zone between the Saccense and the Sicanian Domains. These authors indicated the Kimmeridgian/Tithonian boundary as the end of the siliceous sedimentation in this section.

Data presented here concern the stratigraphical study of the Radiolaritic Unit, a complex of silica-rich sediments, in several sections from the Sicanian Basin with the aim to define the age of the biosiliceous sediments in this palaeogeographical zone. Particular attention has been paid to the onset of biosiliceous sedimentation in this basin in order to test a possible correlation to the early Bajocian carbonate productivity crisis recorded in Western Tethys (Bartolini et al. 1996, 1999; Bartolini & Baumgartner 1999; Beaumont et al. 2005).

Geological setting

The Sicanian structural units belong to the external zones of the Maghrebian thrust and fold belt (Catalano et al. 1996). They consist of Permian–Cenozoic successions that were deposited in a deep-water palaeogeographical domain along the African passive continental margin (i.e. the Sicanian Basin sensu Di Stefano 1988, also known as Campofiorito-Cammarata zone, sensu Mascle 1973, and partly corresponding to the Ionides of Finetti 2005) (Fig. 1). Deep-water siliceous sediments of Jurassic age commonly occur within the sedimentary successions of the Sicanian structural units from central-western Sicily. In many localities they overlie basaltic pillow lavas and hyaloclastites related to a widespread Jurassic magmatic event (Lucido et al. 1978; Ferla et al. 2002).

The Figure 2 shows a simplified scheme of the Upper Triassic and Jurassic lithostratigraphy in the Sicanian structural units. A thick (up to 450 m) succession of Upper Triassic *Halobia* cherty limestones (Scillato Formation, Schmidt di Friedberg et al. 1960) marks the lower part of the succession. It overlies Carnian marl/calcilutite alternations (Mufara Formation). Permian–Middle Triassic deep-water sediments, containing carbonate megabreccias can be restored at the base of the succession but at present they occur as independent tectonic imbricates (Di Stefano & Gullo 1997) (Fig. 1).

Differently, the succession at Monte Genuardo consists of Upper Triassic peritidal dolostones (pertaining to the Sciacca Formation, Patacca et al. 1979) laterally grading into reef dolos-

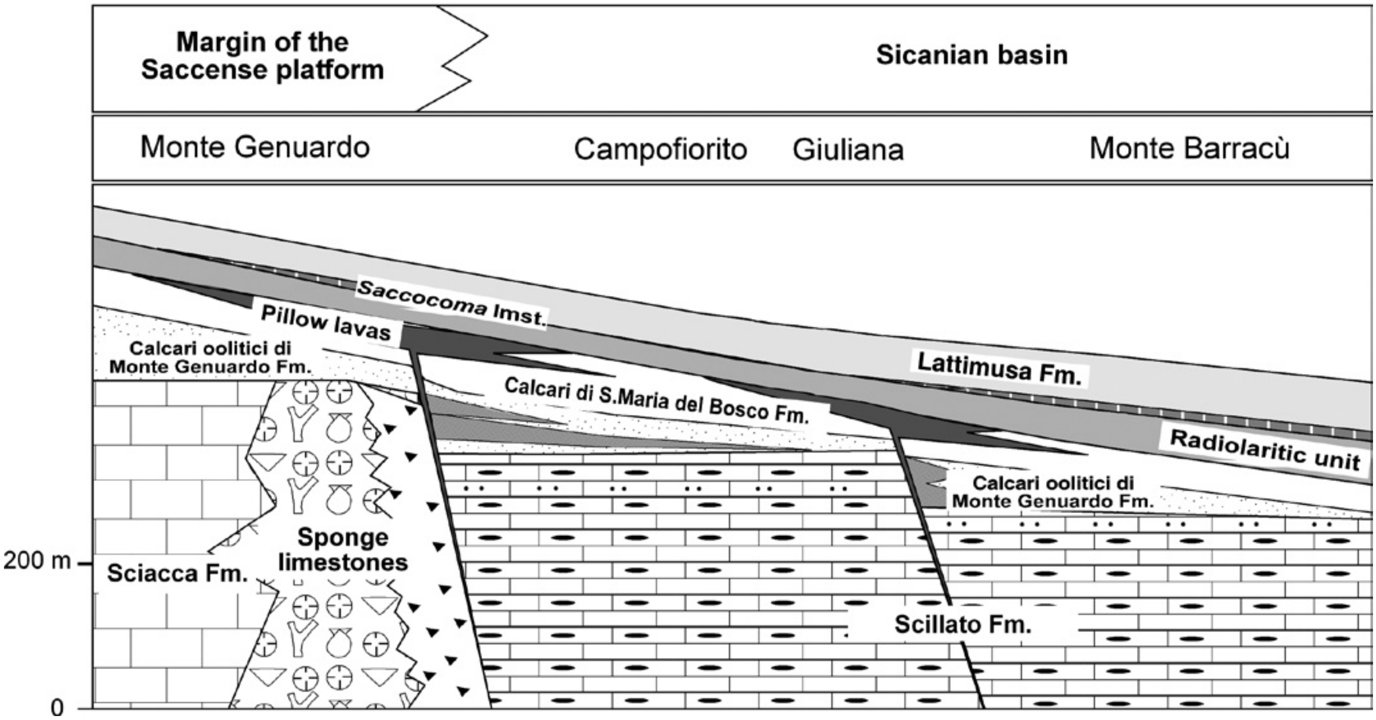

Fig. 2. Lithostratigraphical scheme of the Upper Triassic–Jurassic units from the western Sicani Mountains (modified after Cacciatore et al., in press). Abbreviations: Fm., Formation; lmst., limestone.

tones, followed upward by deeper water, partly clastic, carbonate sediments. This succession records the early drowning of an Upper Triassic carbonate platform margin and its conversion to a slope-to peribasinal area connected to the Sicanian Basin, as a response to the transtensional tectonics about to the Rhaetian–Hettangian boundary (Di Stefano & Gullo 1987).

In all the studied areas the Lower Jurassic succession consists of oolitic-skeletal carbonate turbidites evolving upward to withish cherty calcilutites. These lithostratigraphical units are informally known as Calcari oolitici di Monte Genuardo and Calcari di Santa Maria del Bosco, at the rank of formation respectively (Di Stefano & Vitale 1993) (Fig. 2).

Pillow lavas and hyaloclastites (Figs. 3a, b) occur in the topmost zone of the Calcari di Santa Maria del Bosco in the structural units of Monte Genuardo, Giuliana and Campofiorito, while they are missing at Monte Barracù (Fig. 2). These volcanics are transitional alkali and transitional tholeiitic basalts (Ferla et al. 2002). Besides in the Sicanian basin, the Jurassic magmatism is extensively recorded in several palaeogeographical zones of Sicily (Lucido et al. 1978).

The pillow lavas and hyaloclastites mark the boundary with the overlying siliceous deposits. The latter consist of radiolarian-bearing greenish and reddish siliceous calcilutites alternating to marls and bedded cherts. This lithostratigraphical unit is hereafter informally indicated as Radiolaritic Unit.

At the top of the Radiolaritic Unit discontinuous levels of *Saccocoma* limestone covered by cherty calcilutites with calpionellids (Lattimusa Formation) are present (Fig. 2).

Description of the studied sections

Four sections have been studied for radiolarian biostratigraphical purposes in the Radiolaritic Unit.

Monte Genuardo – Casa Gurgo section

This section was sampled in the northern slope of Monte Genuardo, along a road connecting Sambuca di Sicilia to the S. Maria del Bosco Abbey. Near the locality *Casa Gurgo* (Fig. 1), the road cut exposes a succession of about 8.5 m of slightly folded greenish siliceous limestones alternating with marls and bedded cherts. Thickness of beds ranges from a few to 10 cm. The general dip of the succession is about 10° N. Moving downsection (southward) colluvial deposits cover the contact with the underlying basalts and pillow lavas that are largely exposed in the area. The covered stratigraphical thickness from the basalt top to the base of the sampled section can be evaluated at about 5 m. The studied section thus represents the lower portion of the Radiolaritic Unit in this area (Fig. 4).

Giuliana – Contrada Lombardia section

The *Contrada Lombardia* section was sampled close to the village of Giuliana, along the road to Sambuca di Sicilia (Fig. 1). The road cut exposes a few meter section across the upper portion of the basaltic unit and the basalmost one of the Radiolaritic Unit. It comprises about 5 m of altered pillow lavas and

Fig. 3. a) Pillow lavas along the road Santa Maria del Bosco – *Casa Gurgo* section. b) detail of (a).

hyaloclastites that are covered by 1 m of tectonized bedded cherts. They are followed in turn by about 2.5 m of well bedded greenish radiolarian cherts and greenish-graysh siliceous limestones alternated with thin marly layers (Fig. 4). In this section, the observed intense deformation along the contact between basalts and radiolarites appears to be to a Tertiary shear zone.

Campofiorito – Timpe Rosse section

In the *Timpe Rosse* section, near the village of Campofiorito (Fig. 1) the Radiolaritic Unit covers a 20 m thick unit of basaltic pillow lavas and hyaloclastites, resting in turn on Lower Jurassic cherty calcilutites and marls (Calcari di S. Maria del Bosco Formation) (Fig. 4). The lithologies of the Radiolaritic Unit consist of a lower part (about 8 m) of wellbedded greenish-gray cherty calcilutites alternating to chert layers and thin levels of siliceous marls. Upsection, about 12 m of similar alternating litologies with a reddish color and a little increase of the cherty layers follow. On top of this unit, a thin transitional portion indicates the change to the calpionellid cherty limestones (Lattimusa Formation).

Monte Barracù – Case Paternostro section

At Monte Barracù the Radiolaritic Unit is well exposed along a spectacular outcrop at km-scale exposed along the N–S trending western slope. The section was sampled in a zone of the slope close to the locality of Case Paternostro (Fig. 1). Here the Radiolaritic Unit reaches a thickness of about 49 m and consists of well bedded radiolarian-bearing cherty calcilutites alternating with cherts and levels of siliceous marls (Fig. 4). As at Campofiorito, the lower part of the unit has a greenish-gray color, while the upper one is reddish. This unit covers uppermost Triassic–Lower Jurassic cherty calcilutites (Scillato Formation and Calcari di S. Maria del Bosco Formation) through a large-scale stepped unconformity of submarine origin (Di Stefano et al. 2004). The upper boundary (affected, in places by synsedimentary deformations) is transitional to a thin unit (about 2 m) of red limestones with *Saccocoma,* grading upwards to pink to whitish calpionellid cherty limestones (Lattimusa Formation).

Radiolarian biostratigraphy

The samples have been etched with hydrochloric and hydrofluoric acids, using the method proposed by Dumitrica (1970), Pessagno and Newport (1972), Baumgartner et al. (1981), De Wever (1982) and Chiari et al. (2004b).

The radiolarian zonation adopted for the studied samples is based on the Unitary Association Zones (UAZ., Zones 95 scale) proposed by Baumgartner et al. (1995b) that spans the Aalenian–early Aptian time interval (Middle Jurassic–Early Cretaceous). The occurrence of the radiolarians in the examined samples is reported in Figure 5 while the stratigraphical distribution of the most significant radiolarian taxa is shown in Figure 6. Furthermore, in the following paragraphs we discuss the range of some taxa that were either not considered or reported with a different age range in Baumgartner et al. (1995a); the principal radiolarian markers are illustrated in Plates I and II.

Monte Genuardo **–** *Casa Gurgo section*

In this sections eight samples were collected in the Radiolaritic Unit for radiolarian analyses (Fig. 4). Seven samples yielded very well preserved radiolarian assemblages:

Sample 4065. It was collected at the base of the section. The radiolarian assemblage is assigned to the UAZ. 4–5 (latest Bajocian–early Bathonian) by co-occurrence of *Saitoum levium* De Wever, *Saitoum pagei* Pessagno with *Hexasaturnalis suboblongus* (Yao). After Baumgartner et al. (1995a), the range of *H. suboblongus* is UAZ. 3–11 (early–middle Bajocian to late Kimmeridgian–early Tithonian). Dumitrica & Dumitrica-Jud (2005) considered a more restricted range for this taxon, only Bajocian (UAZ. 3–4). Chiari et al. (2007) found *H. suboblongus*

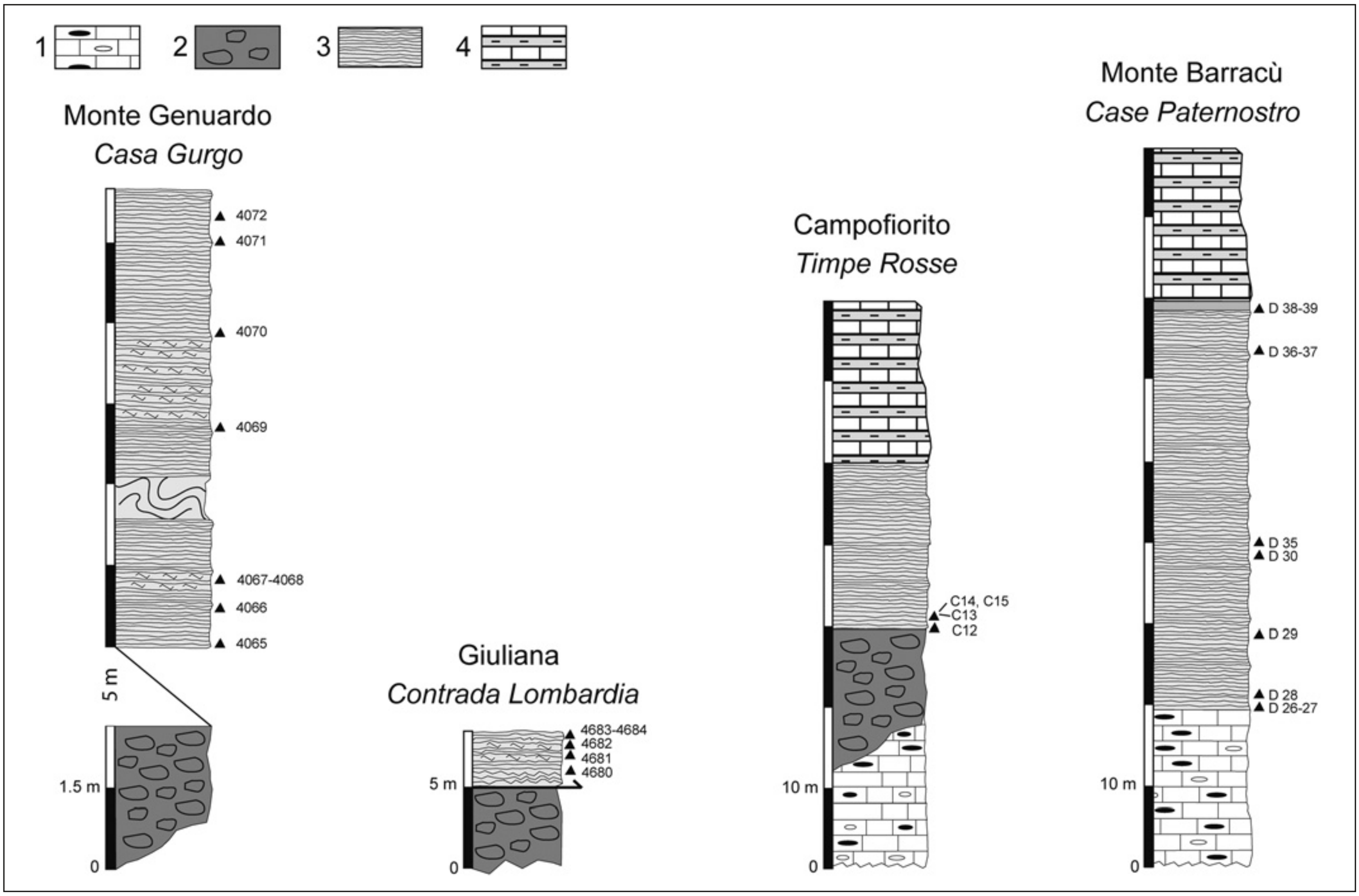

Fig. 4. Columnar sections of the studied successions, with position of the reported samples (triangles) along the Radiolaritic Unit. 1) Calcari di S. Maria del Bosco Formation; 2) Pillow lavas; 3) Radiolaritic Unit; 4) Lattimusa Formation.

after the first occurrence of *Watznaueria barnesae*. The first occurrence (FO) of *W. barnesae* (Black) Perch-Nielsen is referable to earliest Bathonian (Mattioli & Erba 1999) and therefore the range of *H. suboblongus* could be tentatively assigned to the UAZ. 3–5 (early–middle Bajocian to latest Bajocian–early Bathonian). In this sample also *Emiluvia splendida* Carter occurs. The range of this taxon, after Baumgartner et al. (1995a), is restricted to UAZ. 1–3 (early–middle Aalenian to early–middle Bajocian). According to the age of sample 4065 we could extend the range of *E. splendida* to UAZ. 4 or UAZ. 5.

Sample 4066 (0.70 m upsection). The co-occurrence of *Hexasaturnalis suboblongus* (Yao) with *Unuma michelei* Chiari, Marcucci & Prela indicates UAZ. 5 (latest Bajocian to early Bathonian), the range of *U. michelei* is referable to the UAZ. 5 as proposed by Chiari et al. (2002). In the present paper we consider a broader range for *Striatojaponocapsa synconexa* O'Dogherty, Gorican & Dumitrica (*S. plicarum* ssp. A in Baumgartener et al. 1995a): UAZ. 4–6 (late Bajocian to middle Bathonian) as indicated by Prela et al. (2000).

Sample 4067 (0.5 m upsection). The most important taxa are *Saitoum levium* De Wever and *Hexasaturnalis suboblongus* (Yao) that indicate the UAZ. 4–5 (late Bajocian to latest Bajocian to early Bathonian). We also found in this sample *Parvicingula schoolhousensis* gr. Pessagno & Whalen. After Baumgartner et al. (1995a), the range of this taxon is restricted to the UAZ. 3 (early–middle Bajocian). The age of the sample 4067 is referable to UAZ. 5 (latest Bajocian to early Bathonian) considering its stratigraphical position so the LAD (last appearance datum) of *P. schoolhousensis* gr. could be extended to the UAZ. 5. *Unuma echinatus* Ichikawa & Yao was also found in this sample, Baumgartner et al. (1995a) report the UAZ. 1–6 range (early–middle Aalenian to middle Bathonian) for this taxon. After Beccaro et al. (2002) the LAD of *Unuma echinatus* could be in UAZ. 7 (late Bathonian–early Callovian).

Sample 4069 (2.8 m upsection). The co-occurrence of *Tethysetta dhimenaensis* ssp. A (Baumgartner, O'Dogherty, Gorican, Dumitrica-Jud, Dumitrica, Pillevuit, Urquhart, Matsuoka, Danelian, Bartolini, Carter, De Wever, Kito, Marcucci & Steiger) with *Hexasaturnalis suboblongus* (Yao) indicates the UAZ. 3–5 (early–middle Bajocian to latest Bajocian–early Bathonian). *Tethysetta dhimenaensis* ssp. A occurs also in Carpathian up to Tithonian (P. Dumitrica, pers. comm.). Its LAD could be extended to the UAZ. 11.

SECTIONS	CASA GURGO							CONTRADA LOMBARDIA				TIMPE ROSSE			CASE PATERNOSTRO			
TAXA \ SAMPLES	4065	4066	4067	4069	4070	4071	4072	4680	4681	4682	4683	C12	C13	C14	D27	D35	D36	D39
UAZ.	4-5	5	4-5	3-5	5	5	5	5/6-10	7-8	7-11	8-11	3-5	4	3-5	4	8	8-10	9-11
Archaeodictyomitra apiarium (RÜST)																■		
Ares cylindricus flexuosus (TAKEMURA)													■		■			
Bernoullius dicera (BAUMGARTNER)																	■	
Bernoullius rectispinus delnortensis PESSAGNO, BLOME & HULL						■												
Emiluvia orea orea BAUMGARTNER																■		
Emiluvia sp. cf. *E. orea ultima* BAUMGARTNER & DUMITRICA									■									
Emiluvia pentaporata STEIGER & STEIGER																■	■	
Emiluvia splendida CARTER	■																	
Eucyrtidiellum (?) *quinatum* TAKEMURA													■		■			
Eucyrtidiellum unumaense pustulatum BAUMGARTNER																■		
Gorgansium spp. in Baumgartner et al. (1995)																■		
Hexasaturnalis minor (BAUMGARTNER)								■	■		■					■		■
Hexasaturnalis nakasekoi DUMITRICA & DUMITRICA-JUD																■		■
Hexasaturnalis suboblongus (YAO)	■	■	■	■	■	■	■					■		■				
Hexastylus (?) sp. cf. *H.* (?) *tetradactylus* CONTI & MARCUCCI			■															
Hsuum altile HORI & OTSUKA													■					
Hsuum matsuokai ISOZAKI & MATSUDA														■				
Kilinora spiralis gr. (MATSUOKA)																■		
Linaresia chrafatensis EL KADIRI													■					
Mirifusus dianae s.l. (KARRER)										■						■	■	
Mirifusus fragilis praeguadalupensis BAUMGARTNER & BARTOLINI			■						■									
Mirifusus guadalupensis PESSAGNO					■	■			■									
Mirifusus proavus TONIELLI												■	■					
Napora lospensis PESSAGNO											■						■	
Napora sp. cf. *N. nipponica* TAKEMURA			■															
Palinandromeda podbielensis (OZVOLDOVA)						■			■									
Palinandromeda sp. cf. *P. sognoensis* BAUMGARTNER														■				
Parvicingula schoolhousensis gr. PESSAGNO & WHALEN			■									■						
Perispyridium ordinarium gr. (PESSAGNO)									■		■							
Podobursa chandrika (KOCHER)										■								
Podobursa spinosa (OZVOLDOVA)											■							
Podocapsa amphitreptera FOREMAN																		■
Ristola altissima altissima (RÜST)										■	■						■	
Ristola procera (PESSAGNO)						■			■									
Saitoum levium DE WEVER	■		■		■											■		
Saitoum pagei PESSAGNO	■															■		
Spongocapsula perampla (RÜST)										■	■							
Striatojaponicapsa synconexa O'DOGHERTY, GORICAN & DUMITRICA		■			■													
Tethysetta dhimenaensis ssp. A (BAUMGARTNER ET AL.)			■	■	■													
Tetratrabs bulbosa BAUMGARTNER									■		■							
Theocapsomma cordis KOCHER							■											
Transhumm maxwelli gr. (PESSAGNO)			■		■			■	■									
Triactoma blakei (PESSAGNO)									■		■						■	
Triactoma jonesi (PESSAGNO)	■	■				■			■				■					
Unuma echinatus ICHIKAWA & YAO			■		■								■					
Unuma latusicostatus (AITA)					■													
Unuma michelei CHIARI, MARCUCCI & PRELA		■																

Fig. 5. Occurrence chart of the main radiolarian taxa, with the defined UAZones (UAZ.) of the examined samples.

Sample 4070 (1.8 m upsection). The assemblage corresponds to the UAZ. 5 (latest Bajocian to early Bathonian), for the co-occurrence of *Mirifusus guadalupensis* PESSAGNO with *Hexasaturnalis suboblongus* (YAO) and *Unuma latusicostatus* (AITA).

Sample 4071 (1.7 m upsection). The co-occurrence of *Mirifusus guadalupensis* PESSAGNO, *Palinandromeda podbielensis* (OZVOLDOVA) and *Ristola procera* (PESSAGNO) with *Hexasaturnalis suboblongus* (YAO) shows that this assemblage also corresponds to the UAZ. 5 (latest Bajocian to early Bathonian). In addition, *Bernoullius rectispinus delnortensis* PESSAGNO, BLOME & HULL occurs in this sample. Baumgartner et al. (1995a) indicate the UAZ. 2–7 range (late Aalenian to late Bathonian–early Callovian) for this taxon. After Beccaro et al. (2002) the range could be UAZ. 2–8 (late Aalenian to middle Callovian–early Oxfordian).

Sample 4072 (0.5 m upsection). It was collected in the uppermost part of the section. The co-occurrence of *Theocapsomma cordis* KOCHER with *Hexasaturnalis suboblongus* (YAO) indicates the UAZ. 5 (latest Bajocian to early Bathonian).

To sum up, if we take into consideration the stratigraphical position of the samples (see Fig. 4), the following ages result: UAZ. 4–5 (late Bajocian to latest Bajocian–early Bathonian) for 4065; UAZ. 5 (latest Bajocian to early Bathonian) for 4066, 4067, 4069, 4070, 4071 & 4072.

Giuliana – Contrada Lombardia section

In the Contrada Lombardia section, five samples were collected from the base of the Radiolaritic Unit (Fig. 4). The radiolarian fauna is well preserved in four samples while the sample 4684 yielded poorly preserved radiolarians:

Sample 4680 (about 1 m above the contact with the basalt top). The radiolarian assemblage permits only a broad age assignment. The co-occurrence of *Hexasaturnalis minor* (BAUMGARTNER) with *Transhsuum maxwelli* gr. (PESSAGNO) indicates the UAZ. 5/6–10 (early or middle Bathonian to late Oxfordian–early Kimmeridgian). The range of *H. minor* (BAUMGARTNER) is reported by Baumgartner et al. (1995a). These authors consider the UAZ. 3–11 range (early-middle Bajocian to late Kimmeridgian–early Tithonian) for *H. minor*. After Dumitrica & Dumitrica-Jud (2005), this species has a more restricted age range, from early or middle Bathonian to late Kimmeridgian–early Tithonian (UAZ. 5/6–11).

Sample 4681 (1 m from 4680). In this sample the co-occurrence of *Tetratrabs bulbosa* BAUMGARTNER with *Mirifusus fragilis praeguadalupensis* BAUMGARTNER & BARTOLINI indicates the UAZ. 7–8 (late Bathonian–early Callovian to middle Callovian–early Oxfordian). Baumgartner et al. (1995a) report a very short range for *M. fragilis praeguadalupensis* (UAZ. 3–3). This is probably a material mistake, the range of this taxon being UAZ. 3–8 (early–middle Bajocian to middle Callovian–early Oxfordian) as reported in the database of Bartolini et al. (1995).

Sample 4682 (0.4 m from 4681). Also in this sample the radiolarian assemblage does not give a precise age assignment. In fact the occurrence of *Mirifusus dianae* s.l. (KARRER), *Podobursa chandrika* (KOCHER), *Ristola altissima altissima* (RÜST) with *Spongocapsula perampla* (RÜST) indicates the UAZ. 7–11 (late Bathonian–early Callovian to late Kimmeridgian–early Tithonian).

Sample 4683 (0.3 m from 4682). The occurrence of *Napora lospensis* PESSAGNO, *Podobursa spinosa* (OZVOLDOVA) with *Hexasaturnalis minor* (BAUMGARTNER), *Perispyridium ordinarium* gr. (PESSAGNO), *Spongocapsula perampla* (RÜST), *Tetratrabs bulbosa* BAUMGARTNER, *Triactoma blakei* (PESSAGNO) indicates the UAZ. 8–11 (middle Callovian–early Oxfordian to late Kimmeridgian–early Tithonian).

Considering for this section the stratigraphical position of the samples, the resulting ages are: UAZ. 5/6–8 (early or middle Bathonian to middle Callovian–early Oxfordian) for 4680; UAZ. 7–8 (late Bathonian–early Callovian to middle Callovian–early Oxfordian) for 4681; UAZ. 7–11 (late Bathonian–early Callovian to late Kimmeridgian–early Tithonian) for 4682; UAZ. 8–11 (middle Callovian–early Oxfordian to late Kimmeridgian–early Tithonian) for 4683.

Campofiorito – Timpe Rosse section

In this section four samples collected at the base of the Radiolaritic Unit were examined (Fig. 4). We found badly preserved radiolarians in sample C15, and more or less well preserved radiolarians in the following samples:

Sample C12 (at the contact with the pillow basalts). The co-occurrence of *Hexasaturnalis suboblongus* (YAO), *Mirifusus proavus* TONIELLI and *Parvicingula schoolhousensis* gr. PESSAGNO & WHALEN indicates the UAZ. 3–5 (early–middle Bajocian to latest Bajocian–early Bathonian).

In this paper we consider for *M. proavus* the range indicated by Bartolini & Larson (2001), as reported in Fig. 6 (UAZ. 2–5; late Aalenian to latest Bajocian–early Bathonian).

Sample C13 (0.2 m upsection). In this sample the co-occurrence of important species as *Ares cylindricus flexuosus* (TAKEMURA) with *Eucyrtidiellum* (?) *quinatum* TAKEMURA gives a precise Unitary Association Zone: UAZ. 4 (late Bajocian). The taxon *Hsumm altile* HORI & OTSUKA is also present. The age range of *H. altile* is referable to the late Early Jurassic to early Middle Jurassic after Yeh & Cheng (1996).

Sample C14 (0.25 m upsection). The last examined sample of this section contains *Hexasaturnalis suboblongus* (YAO) with *Hsuum matsuokai* ISOZAKI & MATSUDA, their co-occurrence indicates the UAZ. 3–5 (early–middle Bajocian to latest Bajocian–early Bathonian).

Considering the stratigraphical position of the three examined samples, the resulting ages are: UAZ. 3–4 (early–middle Bajocian to late Bajocian) for C12; UAZ. 4 (late Bajocian) for C13; UAZ. 4–5 (late Bajocian to latest Bajocian–early Bathonian) for C14.

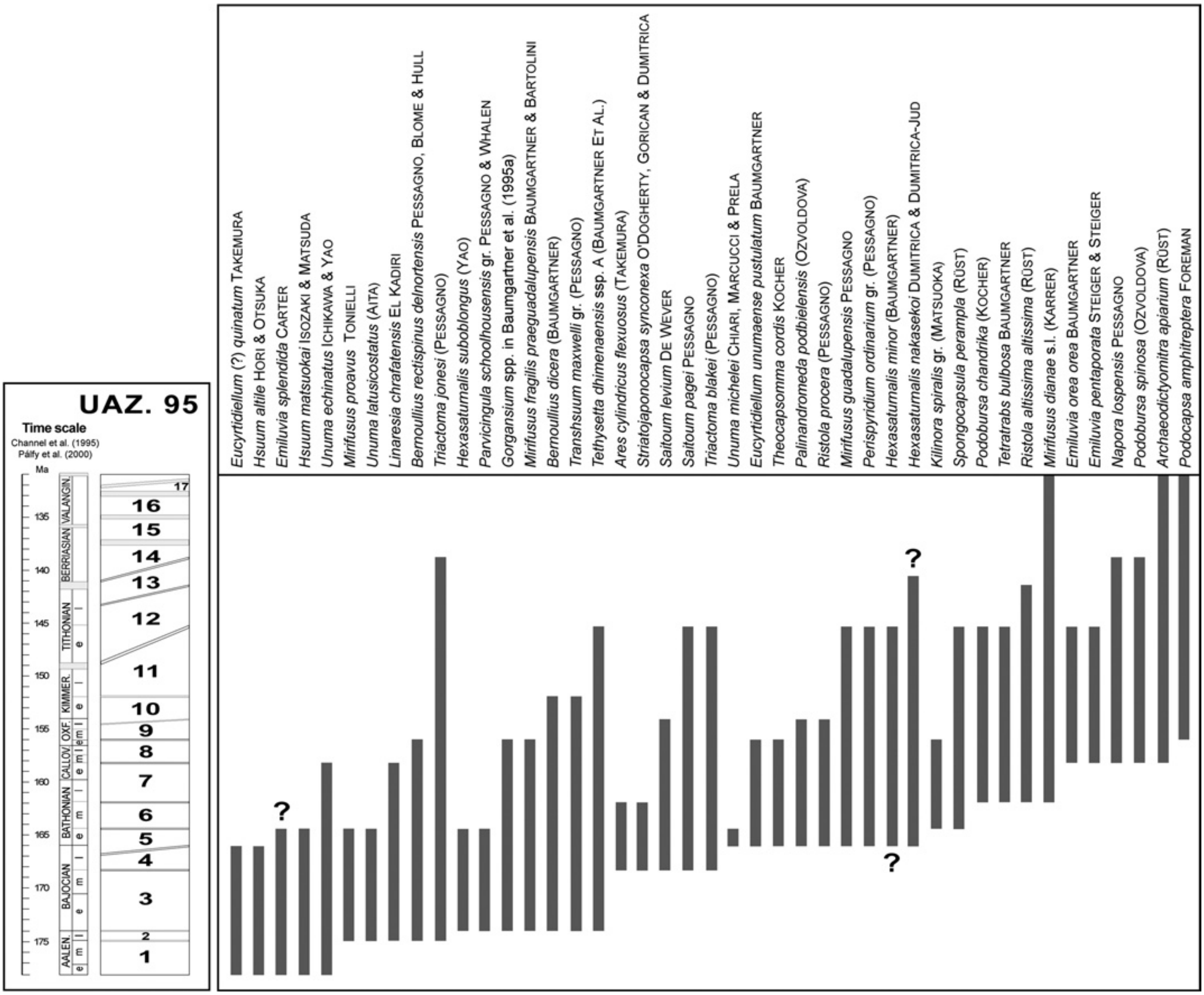

Fig. 6. Middle Jurassic–Early Cretaceous range chart of the radiolarian taxa. Radiolarian UAZones (UAZ.) and range of the taxa according to Baumgartner et al. (1995b). See the text (Radiolarian biostratigraphy section) for the discussion about the range of the species *Bernoullius rectispinus delnortensis* Pessagno, Blome & Hull, *Emiluvia splendida* Carter, *Emiluvia pentaporata* Steiger & Steiger, *Hexasaturnalis minor* (Baumgartner), *Hexasaturnalis nakasekoi* Dumitrica & Dumitrica-Jud, *Hexasaturnalis suboblongus* (Yao), *Hsumm altile* Hori & Otsuka, *Mirifusus fragilis praeguadalupensis* Baumgartner & Bartolini, *Mirifusus proavus* Tonielli, *Parvicingula schoolhousensis* gr. Pessagno & Whalen, *Striatojaponocapsa synconexa* O'Dogherty, Gorican & Dumitrica), (*Striatojaponocapsa plicarum* ssp. A in Baumgartner et al. 1995a) *spiralis* gr. (Matsuoka), *Tethysetta dhimenaensis* ssp. A (Baumgartner, O'Dogherty, Gorican, Dumitrica-Jud, Dumitrica, Pillevuit, Urquhart, Matsuoka, Danelian, Bartolini, Carter, De Wever, Kito, Marcucci & Steiger), *Unuma echinatus* Ichikawa & Yao, *Unuma michelei* Chiari, Marcucci & Prela. Time scale after Pálfy et al. (2000) and Channel et al. (1995).

Monte Barracù – Case Paternostro section

Ten samples were collected for radiolarian analyses in the Radiolaritic Unit (Fig. 4), of which only four contain well preserved radiolarians:

Sample D27. This sample was collected at the base of the Radiolaritic Unit, the co-occurrence of *Ares cylindricus flexuosus* (Takemura) and *Eucyrtidiellum* (?) *quinatum* Takemura gives a precise age: UAZ. 4 (late Bajocian).

Sample D35 (about 20 m upsection). The co-occurrence of several important markers such as *Archaeodictyomitra apiarium* (Rüst), *Emiluvia orea orea* Baumgartner with *Eucyrtidiellum unumaense pustulatum* Baumgartner, *Gorgansium* spp. in Baumgartner et al. (1995a) indicates a precise age: UAZ. 8 (middle Callovian–early Oxfordian). *Hexasaturnalis nakasekoi* Dumitrica & Dumitrica-Jud is also present in this assemblage (Fig. 5), its range was reported by Dumitrica & Dumitrica-Jud (2005); these authors indicate the first appearance of *H. nakasekoi* during the lower Bathonian and its last occurrence probably at the end of the Kimmeridgian or lowermost Berriasian. Two other species present in this sample, *Kilinora spiralis* gr. (MATSUOKA) and *Emiluvia pentaporata* STEIGER & STEIGER, it is possible that they have a broader range. *Kilinora spiralis* gr. is referable to UAZ. 6–7 (middle Bathonian to late Bathonian–early Callovian) after Baumgartner et al. (1995a). However, its presence in an assemblage of UAZ. 8 age (middle Callovian–early Oxfordian) suggests a broader range (UAZ. 6–8) for this taxon. For *E. pentaporata* STEIGER & STEIGER (*Emiluvia bisellea* DANELIAN in Baumgartner et al. 1995a), Chiari et al. (2004a) report the UAZ. 9–11 (middle–late Oxfordian to late Kimmeridgian–early Tithonian) age range. Once again, the presence of this taxon in an assemblage of UAZ. 8 (middle Callovian–early Oxfordian) could indicate a larger range (UAZ. 8–11) for *E. pentaporata*.

Sample D36 (about 24 m from D35). The co-occurrence of *Emiluvia pentaporata* STEIGER & STEIGER, *Napora laspensis* PESSAGNO with *Bernoullius dicera* (BAUMGARTNER) indicates the UAZ. 8–10 (middle Callovian–early Oxfordian to late Oxfordian–early Kimmeridgian).

Sample D39 (about 5 m from D36). This sample was collected at the top of the Radiolaritic Unit. The co-occurrence of *Podocapsa amphitreptera* FOREMAN with *Hexasaturnalis minor* (BAUMGARTNER) indicates the UAZ. 9–11 (middle–late Oxfordian to late Kimmeridgian–early Tithonian).

Considering the stratigraphical position of the samples the resulting ages are: UAZ. 4 (late Bajocian) for D27; UAZ. 8 (middle Callovian–early Oxfordian) for D35; UAZ. 8–10 (middle Callovian–early Oxfordian to late Oxfordian–early Kimmeridgian) for D36; UAZ. 9–11 (middle–late Oxfordian to late Kimmeridgian–early Tithonian) for D39.

Discussion and conclusions

At *Casa Gurgo* (Monte Genuardo) the lowermost studied sample (4065) is referable to the late Bajocian to early Bathonian (UAZ. 4–5), while the uppermost sample (4072) indicates a latest Bajocian to early Bathonian age (UAZ. 5) (Fig. 7). Moreover, in this section, a biostratigraphical analysis of the calcareous nannofossil content indicates the presence of *Watznaueria barnesae*, that first occurs at the base of the Bathonian, and of common *Discorhabdus*, whose last common occurrence is recorded in the Bathonian of the Umbria-Marche area (Bucefalo Palliani et al. 2002). The total age range of the sampled section is bracketed between the late Bajocian and Bathonian. However, the age of the basalmost zone of the radiolarites in this section could be older (early Bajocian?) because there is about 5 m of covered radiolarites below the first studied sample. At *Contrada Lombardia* (Giuliana), the sample 4680 collected at the base of the section indicates an early or middle Bathonian to middle Callovian–early Oxfordian age (UAZ. 5/6–8), while the top of this section is referable to middle Callovian–early Oxfordian to late Kimmeridgian–early Tithonian age (UAZ. 8–11; sample 4683) (Fig. 7). In the *Timpe Rosse* (Campofiorito) section the age of the sample C12 collected above the basalt is referable to the Bajocian (UAZ. 3–4) (Fig. 7). The lowermost radiolarian-bearing sample (D27) collected at the *Case Paternostro* section (Monte Barracù) indicates a late Bajocian age (UAZ. 4). However, as at Monte Genuardo, the base of the radiolarites in this area is not exposed. The upper part of the Radiolaritic Unit (D39) is referable to the middle–late Oxfordian to late Kimmeridgian–early Tithonian age (UAZ. 9–11) (Fig. 7). Moreover, the common occurrence of *Saccocoma* in the overlying calcareous beds, without evident discontinuity surfaces, could constrain the age of the topmost beds of this section to the late Kimmeridgian–early Tithonian.

The underlying unit of basaltic pillow lavas and hyaloclastites present at Monte Genuardo, overlies in turn the Calcari di Santa Maria del Bosco. In this location, the topmost beds of this latter unit could be dated as old as early Toarcian on the basis of the nannofossil assemblage (Bucefalo Palliani et al. 2002). Equivalent deposits at Campofiorito (*Timpe Rosse* section) could be assigned to the lower Bajocian on the basis of a belemnite association (N. Mariotti, pers. comm.), while in the Giuliana area no useful biostratigraphical data have been collected until now.

The new biostratigraphical data from the Radiolaritic Unit in the Sicanian Basin, in particular from Campofiorito, indicate the Bajocian (?early Bajocian) as the onset of siliceous sedimentation over large areas of this deep-water palaeogeographical domain, following a widespread magmatic event related to a peak of extensional/transtensional deformations along the Sicilian segment of the Southern Tethyan passive margin. At present, the indications of a possible Bathonian age of the lower part of the Radiolaritic Unit at Giuliana do not allow to confirm a diachronism of the siliceous sedimentation in different areas of the Sicanian basin. In fact in the Giuliana section the radiolarite beds are truncated along the observed shear zone at the contact with the underlying basalts.

Concerning the restoration of the normal carbonate productivity, our data from *Case Paternostro* are in agreement with the previous studies both from the Sicanian Basin (Kito 1989; Kito et al. 1990; Kito & De Wever 1992, 1995) and from the Trapanese domain (Martire et al. 2002; Martire 2002; Beccaro 2004), that indicate a late Kimmeridgian age. The switching from carbonate to siliceous sedimentation in the Jurassic Tethyan basins is still matter of different interpretations: changes in the palaeoceanographical circulation patterns due to the opening of the Ligure-Piemontese Ocean, high CO_2 level in the atmosphere related to the birth of the Pacific Plate, major pulses of magmatism either related to subduction (Bartolini & Larson 2001) or to the Tethyan extension could be concurrent causes. Elsewhere, Muttoni et al. (2005) suggested a possible plate motion toward equatorial upwelling zones, on the basis of palaeolatitudinal data, to explain the genesis of the radiolarites in the Lombardian Basin.

The early Bajocian sees the onset of radiolaritic deposition in the deepest part of the Umbria–Marche Basin, de-

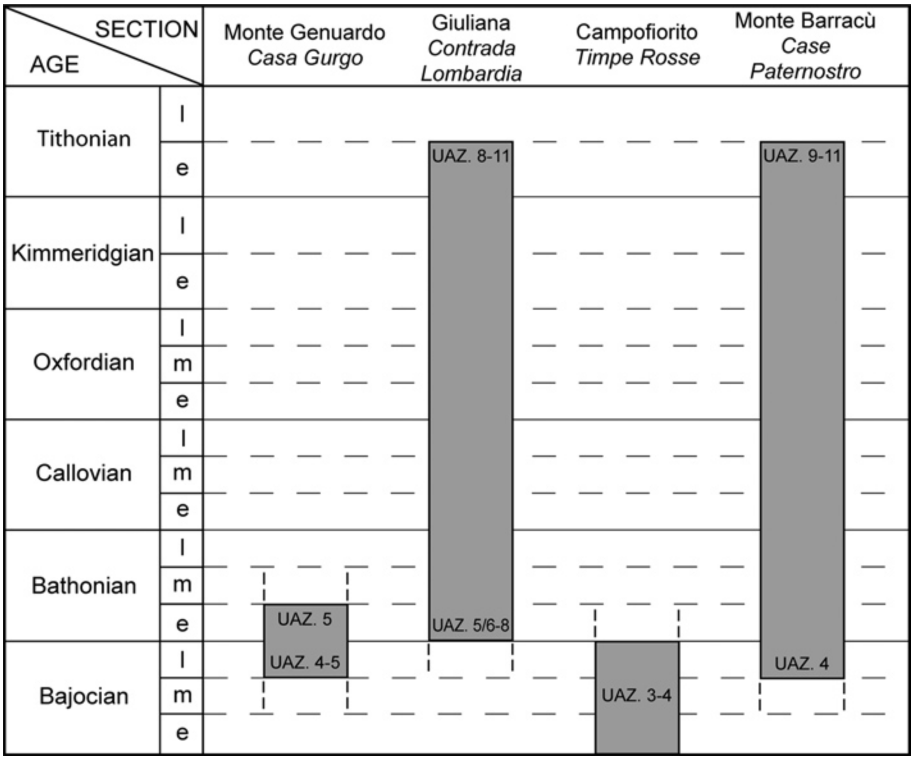

Fig. 7. Chrono-Correlation between the Middle–Late Jurassic examined sections. In each section the Unitary Association Zones (UAZ.) of the lowermost and uppermost samples are reported: section *Casa Gurgo* samples 4065 and 4072; *Contrada Lombardia* samples 4680 and 4683; *Timpe Rosse* sample C12; *Case Paternostro* D27 and D39. Refer to the Figure 6 for the UAZ. ranges.

pending on the palaeotopography and palaeogeographical position with respect to the platform. The correlation of the early Bajocian positive $\delta^{13}C$ shift with the onset of radiolaritic sedimentation may be evidence of meso-eutrophic conditions that could have determined the carbonate productivity crisis and the subsequent decrease of the periplatorm ooze supply into the basins (Bartolini et al. 1999). At the same time, meso-eutrophic sea water conditions boosted the radiolarian productivity. Moreover, the rearrangement of currents in Western Tethys allowed an easy circulation of nutrients and silica. Global and local causes seem to have triggered therefore the switching from carbonates to radiolarites (Bartolini et al. 1996, 1999; Bartolini & Baumgartner 1999; Bartolini & Cecca 1999; Beaumont et al. 2005). Since middle–late Oxfordian, the biosiliceous deep-water sediments became gradually diluted by carbonate, which was mainly supplied by planctonic nannofossils.

Our data on the onset of biosiliceous sedimentation in the Sicanian basin correspond to the same time interval recorded in the Umbria–Marche Basin and corroborate the hypotheses of an early Bajocian carbonate productivity crisis of regional extent in Western Tethys.

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Plate I

Middle–Late Jurassic Radiolarians from the studied sections. Photos taken with the scanning electron microscope (SEM). Scale bars: 50 µm.

1) *Archaeodictyomitra apiarium* (Rüst), D35. 2) *Ares cylindricus flexuosus* (Takemura), C13. 3) *Bernoullius dicera* (Baumgartner), D36. 4) *Bernoullius rectispinus delnortensis* Pessagno, Blome & Hull, 4071. 5) *Emiluvia orea orea* Baumgartner, D35. 6) *Emiluvia* sp. cf. *E. orea ultima* Baumgartner & Dumitrica, 4681. 7) *Emiluvia pentaporata* Steiger & Steiger, D35. 8) *Emiluvia splendida* Carter, 4065. 9) *Eucyrtidiellum* (?) *quinatum* Takemura, C13. 10) *Eucyrtidiellum unumaense pustulatum* Baumgartner, D35. 11) *Gorgansium* spp. in Baumgartner et al. (1995a), D35. 12) *Hexasaturnalis minor* (Baumgartner), 4683. 13) *Hexasaturnalis nakasekoi* Dumitrica & Dumitrica-Jud, D35. 14) *Hexasaturnalis suboblongus* (Yao), 4070. 15) *Hexastylus* (?) sp. cf. *H.* (?) *tetradactylus* Conti & Marcucci, 4067. 16) *Hsuum altile* Hori & Otsuka, C13. 17) *Hsuum matsuokai* Isozaki & Matsuda, C 14. 18) *Kilonora spiralis* gr. (Matsuoka), D35. 19) *Linaresia chrafatensis* El Kadiri, C13. 20) *Mirifusus dianae* s.l. (Karrer), 4682. 21) *Mirifusus fragilis praeguadalupensis* Baumgartner & Bartolini, 4681. 22) *Mirifusus guadalupensis* Pessagno, 4681. 23) *Mirifusus proavus* Tonielli, C12. 24) *Napora lospensis* Pessagno, 4683.

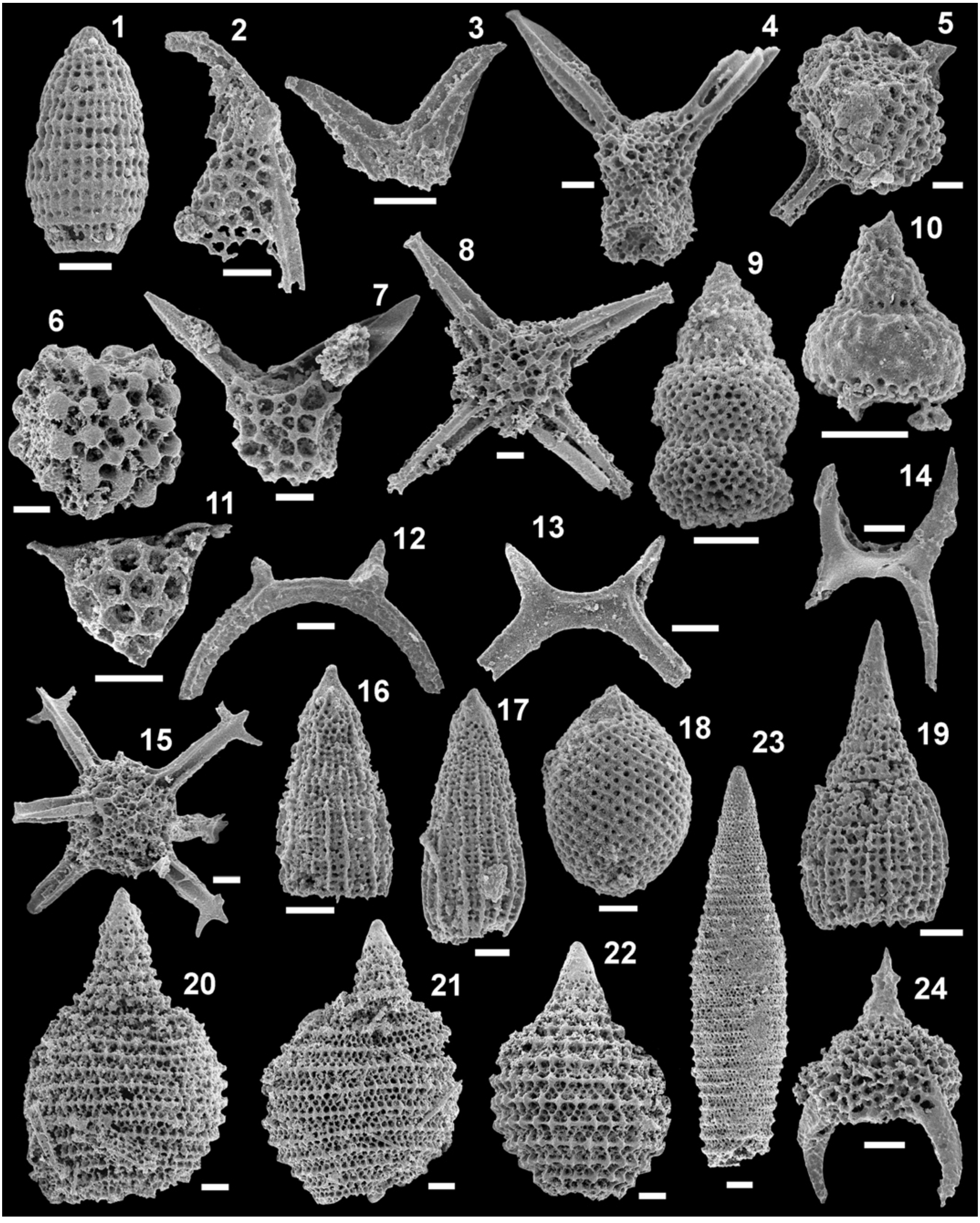
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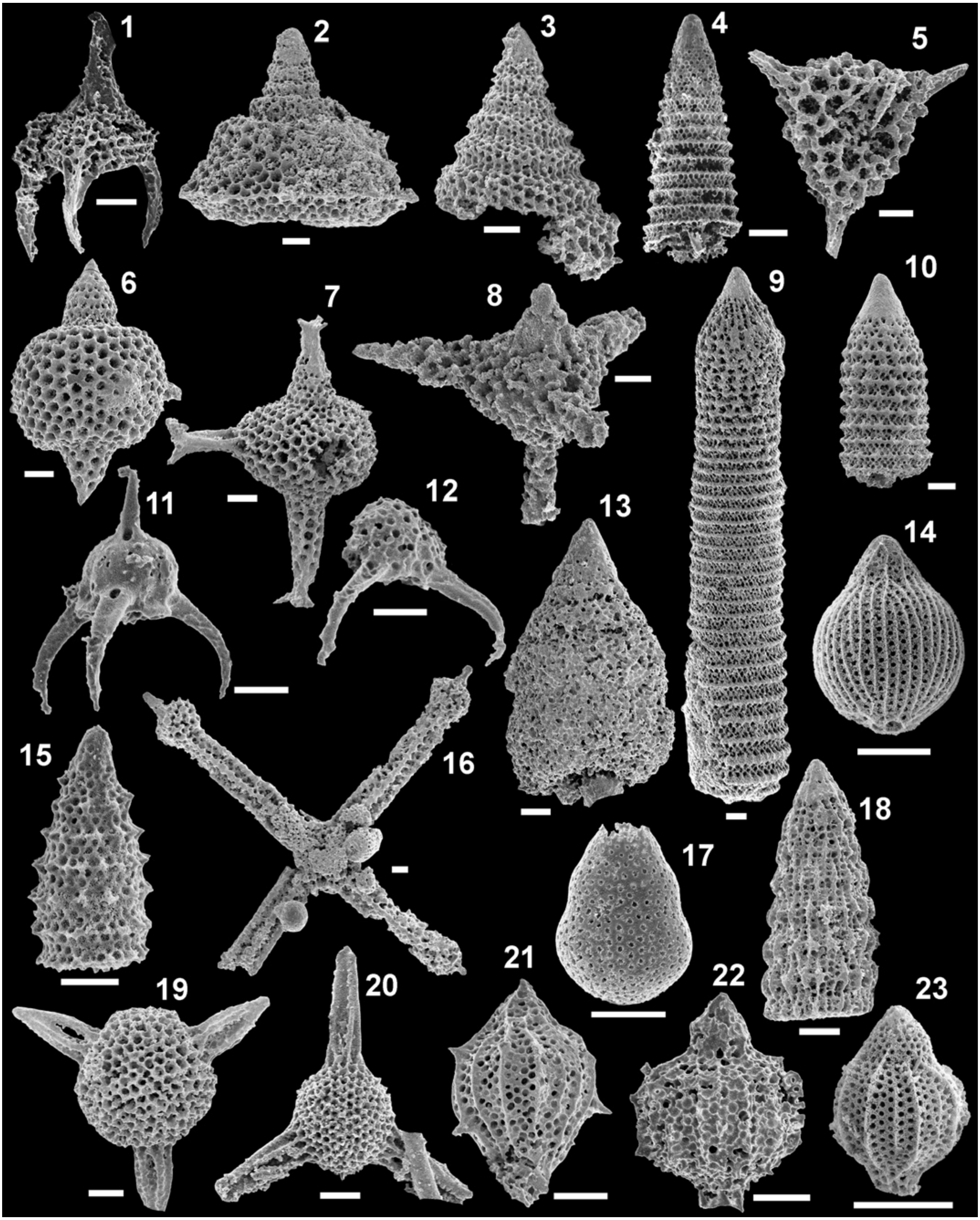
Plate II

Middle–Late Jurassic Radiolarians from the studied sections. Photos taken with the scanning electron microscope (SEM). Scale bars: 50 µm.

1) *Napora* sp. cf. *N. nipponica* Takemura, 4067. 2) *Palinandromeda podbielensis* (Ozvoldova), 4681. 3) *Palinandromeda* sp. cf. *P. sognoensis* Baumgartner, C14. 4) *Parvicingula schoolhousensis* gr. Pessagno & Whalen, 4067. 5) *Perispyridium ordinarium* gr. (Pessagno), 4683. 6) *Podobursa chandrika* (Kocher), 4682. 7) *Podobursa spinosa* (Ozvoldova), 4683. 8) *Podocapsa amphitreptera* Foreman, D39. 9) *Ristola altissima altissima* (Rüst), 4682. 10) *Ristola procera* (Pessagno), 4681. 11) *Saitoum levium* De Wever, 4065. 12) *Saitoum pagei* Pessagno, 4065. 13) *Spongocapsula perampla* (Rüst), 4682. 14) *Striatojaponicapsa synconexa* (O'Dogherty, Gorican & Dumitrica), 4066. 15) *Tethysetta dhimenaensis* ssp. A (Baumgartner, O'Dogherty, Gorican, Dumitrica-Jud, Dumitrica, Pillevuit, Urquhart, Matsuoka, Danelian, Bartolini, Carter, De Wever, Kito, Marcucci & Steiger), 4069. 16) *Tetratrabs bulbosa* Baumgartner, 4683. 17) *Theocapsomma cordis* Kocher, 4072. 18) *Transhsuum maxwelli* gr. (Pessagno), 4681. 19) *Triactoma blakei* (Pessagno), 4683. 20) *Triactoma jonesi* (Pessagno), C13. 21) *Unuma echinatus* Ichikawa & Yao, 4067. 22) *Unuma latusicostatus* (Aita), 4070. 23) *Unuma michelei* Chiari, Marcucci & Prela, 4066.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