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Agglutinated foraminifera from the proposed GSSP stratotype for the Barremian/Aptian boundary (Gorgo a Cerbara, Umbria-Marche basin, Italy)

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ABSTRACT

The Barremian to Aptian formations outcropping in the Gorgo a Cerbara Section, Umbria-Marche basin, Italy, centred around the 'Selli Level' (OAE1a) were studied for their micropalaeontological content, with particular emphasis on the agglutinated foraminifera. Faunal variations are observed that are in phase with the lithological variations. Foraminiferal assemblages display an overall increase in diversity and abundance upsection.

A low-diversity Barremian benthic foraminiferal assemblage is replaced by a more diverse assemblage during a faunal turnover identified -5 m below the base of the black shale corresponding to the OAE1a. From 40 to 20 cm below the base of the anoxic layers, an acme of *Verneuilinoides* cf. *neocomiensis* is closely followed by the LO of this species (the last specimens of which are all pyritised). At 20 cm below the base of the Selli Level the turnover rate peaks, with the first occurrence of a litioloid assemblage that continues above the Selli Level, representing the benthic microfacies characteristic of the greenish-grey cherty member of the Marne a Fucoidi.

Above the calcareous-free, radiolarian-bearing anoxic levels, foraminifera start to appear in the assemblages at ca. +50 cm above the top of the Selli Level. From that point upward, the trend is an overall increase in benthic foraminiferal diversity, particularly accelerated at +3.5 m above the Selli Level where the first red beds occur, peaking in the uppermost samples collected from the section. A local zonal scheme based on agglutinated foraminifera is proposed, with a stratigraphic resolution twice greater than the standard planktonic zonation.

INTRODUCTION

In order to investigate the dramatic changes in the sedimentation recorded across the OAE1a layers in the Umbria-Marche basin, Italy, detailed sampling has been carried out along the Gorgo a Cerbara Section, near Piobbico, Italy. This section has already been proposed as the worldwide reference section for the Barremian/Aptian boundary (Erba, *et al.*, 1996; Gradstein *et al.*, 2004) and has a rich past literature of stratigraphic and palaeontological studies (Coccioni *et al.*, 1992, 2006; Erba *et al.*, 1996, 1999; Channell *et al.*, 1995, 2000; Cecca *et al.*, 1994 among others). However, the agglutinated benthic foraminiferal assemblages in this section have never been investigated in any detail. The aim of this study is to present the first account of the agglutinated benthic foraminiferal faunas recovered from a 33 m thick section centred around the Selli Level of the Gorgo a Cerbara (upper part of the Maiolica Formation and lower part of the Marne a Fucoidi Formation).

Quantitative and qualitative changes in the agglutinated assemblages are also documented, particularly at the levels adjacent to the OAE1a horizon. For detailed discussion on the variations of palaeoenvironmental proxies in the studied section and on the significance of micropalaeontological data to shed new light on the onset and development of the OAE1a anoxia, see Patruno *et al.*, (in press).

The Umbria-Marche basin

The Umbria-Marche basin was an Early Jurassic to Miocene deep sea basin with pelagic and hemipelagic sedimentation developed as a part of the southern passive margin of the Tethys Ocean, and then of the Alpine chain foreland (Cresta *et al.*, 1989). The rocks of the Umbria-Marche basin were deformed during the latest phases of the Alpine-Himalayan orogenesis, and are today exposed as a part of the NE Apennine fold and thrust belt (Umbria-Marche Apennines). These mountains are entirely made of marine

sedimentary rocks of the so-called Umbria-Marche Sequence, which represents a continuous record of the geotectonic evolution of an epeiric sea from the Late Triassic to the Pleistocene (Montanari & Koeberl, 2000).

At the time of the opening of the North Atlantic (Late Triassic – Early Jurassic) within the Tethyan domains the Pennide-Liguride Ocean (ancestral to the present Alpine mountain chains) was also opening through associated rifting. This new ocean was connected with part of the ancient Tethys Ocean to the east, outlining a northward-pointing promontory of African crust, named Adria or the Adriatic Promontory, and described as a large continental passive margin nearly isolated from input of clastic sediments (Dercourt *et al.*, 1993, Channell *et al.*, 1979).

The first marine unit is an Upper Triassic, 1-3 km thick evaporite-dolomite sequence, deposited under lagoonal-tidal conditions in the vicinities of sabkhas, known as the *Burano Anhydrites* (see Martinis & Pieri, 1964). Lying on these evaporites, the oldest extensively exposed formation is the 700 m thick Hettangian-Sinemurian *Calcare Massiccio*, i.e., a poorly stratified, massive, carbonate platform unit, displaying oolitic bars, lagoonal and tidal flat facies (Colacicchi *et al.*, 1970, Cecca *et al.*, 1987a,b).

From the Sinemurian to the Pliensbachian time an acceleration of tectonic subsidence through active syn-sedimentary faulting lead to the division and drowning of the carbonate platform: the entire Umbria-Marche area, subsided to depths where pelagic sedimentation of the Umbria-Marche Basin s.s. began, continuing without interruption into the Cretaceous until the late Miocene. In the southern sectors of the basin, clastic horizons (calcareous turbidites, frequent slumps) derived from the platform margins bordering the basin eastwards are intercalated into the normal succession (Castellarin *et al.*, 1978, Colacicchi *et al.*, 1978). Due to this Early Jurassic active synsedimentary extensional pulse, in the Umbria-Marche area a variety of depositional environments was created and the thickness of the Jurassic of the Umbria-Marche sedimentary cover is not uniform throughout the Umbria-Marche region.

Mid Jurassic – Lower Cretaceous sediments show a clear difference of thickness and facies from place to place, going from extremely reduced, shallow water seamount successions (horsts) to considerably thick basinal facies (grabens). Two main Umbria-Marche pelagic sequences have been recognised: 1. a 400-700 m thick “complete series” (four overlying formations distinguished based on the colours and the ratio limestone/cherts and limestone/clay: *Corniola* Formation – see Colacicchi *et al.*, 1970; Cecca *et al.*, 1987a, b; Cresta *et al.*, 1989; Cecca *et al.*, 1989a;

Bosso Formation – see Cecca *et al.*, 1989a, Cresta *et al.*, 1989, *Posidonia Marls* Formation – see Cresta *et al.*, 1989, Cecca *et al.*, 1989a; *Calcari Diasprigni* Formation – see Cecca *et al.*, 1989a; Cresta *et al.*, 1989, Baumgartner, 1995) and 2. a 10-60 m thick “condensed series” (often identified with the name of *Bugarone* Formation - see Colacicchi *et al.*, 1970, Cresta *et al.*, 1989; Cecca *et al.*, 1989a,b). The Umbria-Marche pelagic sequence consists of “limestones and marly limestones with subordinate marls and radiolarites and rare, but characteristic, discrete black shale layers rich in organic matter” (Coccioni *et al.*, 1992).

The upper Tithonian to lower Aptian Maiolica limestones, deposited on a submarine topography, eventually filled up the deep basins with thicker, continuous sequences and topped the seamounts only with a few meters of condensed or reduced sequences (Micarelli *et al.*, 1977). For instance, at Monte Nerone, 90 m seamount version of the *Maiolica* Formation, is lithologically similar to the basinal 300-500 m thick Maiolica (e.g., sections of Bosso, Gorgo a Cerbara, Fosso Giordano), see: Lowrie & Alvarez, 1984; Cecca *et al.*, 1989a,b; Colacicchi *et al.*, 1970. By the end of the Maiolica deposition (Aptian), the submarine topography was largely levelled out throughout the Umbria-Marche basin, with the depositional surface inferred to have reached a consistent bathyal depth everywhere (Micarelli *et al.*, 1977).

Following the Early Cretaceous Maiolica and *Marne a Fucoidi* Formations, Late Cretaceous to Oligocene homogeneous pelagic limestones, marly limestones and marls with thin, tabular stratifications were deposited. These lithotypes are known as the “Scaglia Group”, and are differentiated from bottom to top into four formations based on their characteristic lithologies and colours (Montanari & Koeberl, 2000).

During the Neogene, the Umbria-Marche sequence underwent an intensive shortening, which originated thrust-sheets in motion from the SW to NE, forming a NE-migrating chain-foredeep-foreland system.

MATERIAL AND METHODS

The investigated outcrop is located along the right bank of the Candigliano brook (a tributary of the river Metauro), near the town of Piobbico (Fig. 1). It is well visible from the bridge situated about 3 km east of Piobbico along Road SP257, which links the towns of Piobbico and Acqualagna. The outcrop is easily accessible by a lateral path, branching from the road just after the bridge and crossing the Candigliano brook. This geographical position corresponds to the northernmost part of the

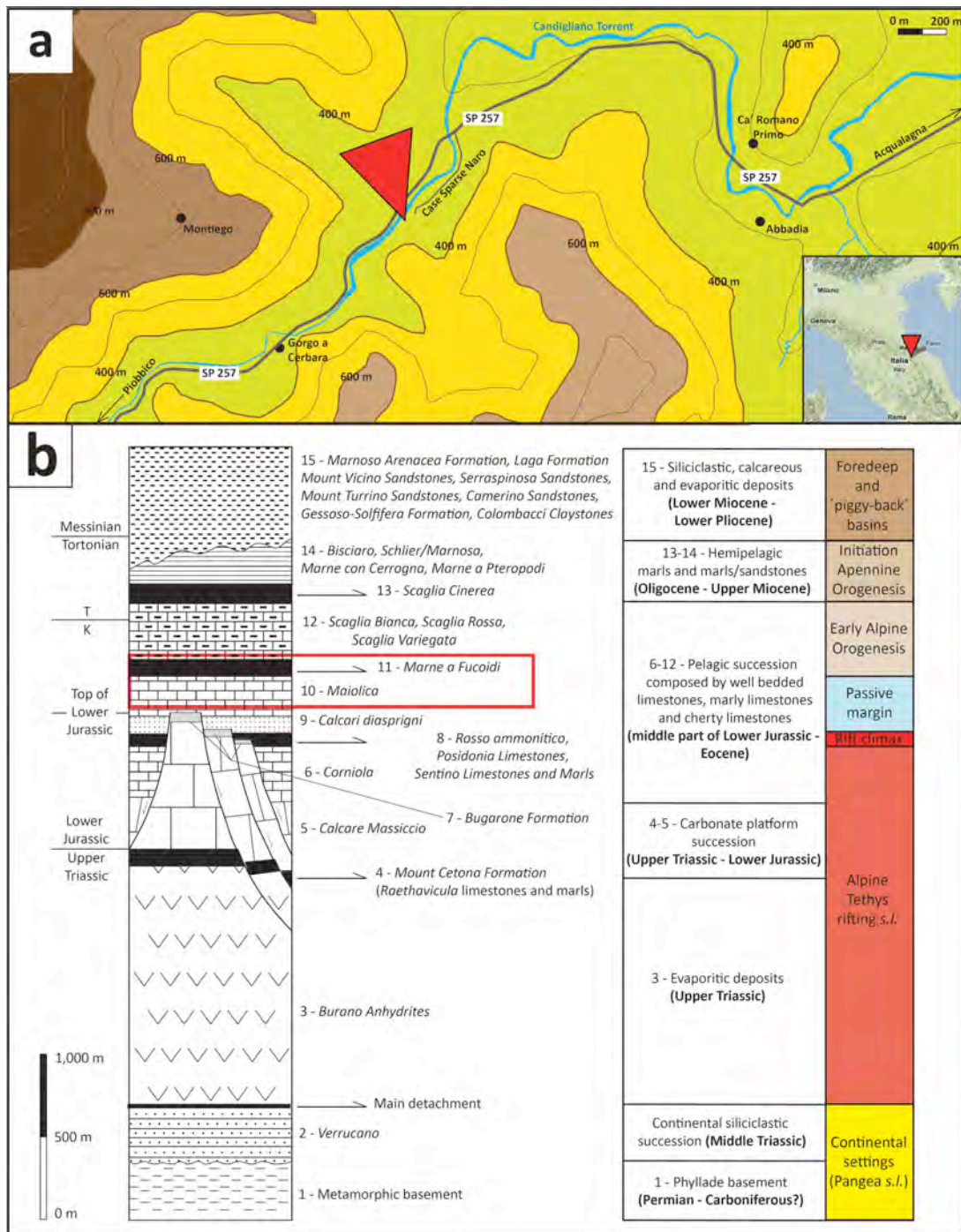


Figure 1. a. Geographical setting of the Gorgo a Cerbara section. Road linking the villages of Piobbico and Acqualagna, near Urbino, Marche District, northeast central Italy, from Googlemaps: <http://maps.google.co.uk/maps?hl=en&tab=wl>. b. Stratigraphic scheme of the Umbria-Marche basin, with indication of the interval studied (transition *Maiolica* Fm. – *Marne a Fucoidi* Formation), modified from Pierantoni (1997).

outcropping Umbria-Marche domain, described as the basin depositional centre, representing the deepest palaeobathymetry.

Lithostratigraphy

We analyzed the lithological features of a 33 m thick section, centered on the Selli layer (the local name for the Early Aptian OAE1a). A total of 41 samples (20 from the beds below and 21 from the upper part of

the Selli level, and above) have been collected to examine their micropalaeontological content (Fig. 2). In addition to the Selli layer, the interval studied contains the magnetostratigraphically defined Barremian/Aptian boundary (about 3 m below the base of the OAE1a according to Channell *et al.*, 2000) and the boundary between the *Maiolica* Formation (upper Tithonian – lower Aptian) and the *Marne a Fucoidi* Formation (lower Aptian – upper

Albian), 80 cm below the base of the Selli Level. The last black chert is the criterion traditionally used in the literature to identify the lithological boundary between the *Maiolica* and *Marne a Fucoidi* Formations (Coccioni *et al.*, 1987, Cresta *et al.*, 1989).

The *Maiolica* Formation is a whitish pelagic limestone intercalated with dark cherts, also known to represent the first occurrence of significant thickness of nannofossil-generated carbonates in Earth History. The upper part of the *Maiolica* Formation is made of cyclical alternations of more massive, hard, whiter pelagic limestones and darker intervals, characterised by layers of black clays, black cherts, and softer, greyish marly limestones. This part displays a lithological cyclicity with a period of 90 cm (Patruno 2008) (Fig. 3).

The *Marne a Fucoidi* Formation is composed by variegated (reddish, greenish and grey-black) alternations of marly limestones, marls and clayey marls. At approximately 3.50 m above the top of the OAE1a the passage between the harder, dysoxic “greenish-grey cherty member” and the softer, well-oxygenated “lower reddish marly member” (*sensu* Coccioni *et al.*, 1987) of the *Marne a Fucoidi* Formation is observed. This passage is marked by the occurrence of the lowermost red marly claystone. This is a softer material with respect to the greenish/grey/whitish marls, with enhanced clay content and with less calcareous and siliceous components. From this point and for the next 15 m, reddish marly claystones are predominant, interrupted by sporadic beds of tougher greenish/grey/whitish marls, which are particularly thick every 4-5 m of succession.

Sample Collection

During April 2008, the section was logged in detail, and a total of 42 samples were gathered in order to examine their micropalaeontological content. Of these, 21 were collected from the beds below the Selli Level (s01-s21), six from the uppermost portion of the Selli Level itself, above the highest black shale layer (s22-s27) and 13 from the overlying strata (s28-s42). In order to have a general overview of the entire section and a detailed analysis of the beds adjacent to the Selli Level, the sampling resolution from the base or top of the Selli Level approximates an exponential function (Table 1, Fig. 1).

Processing and picking

For each sample a total of 400 g of rock was processed: 200 g was treated with hydrochloric acid (HCl), the second half with acetic acid (as suggested by Lirer, 2000), in order to assess the siliceous/agglutinated assemblage and the total assemblage. Only two samples (s26 and s39) were judged soft

enough to be successfully processed by mechanical washing. Sample s08 did not yield any satisfactory results using both methods (it was a largely silicified limestone). Therefore, the original 42 field samples were turned into 80 processed samples to be picked for microfossils.

A minimum of 300-400 microfossils from the $\geq 125 \mu\text{m}$ fraction of 50 out of the 80 processed samples was picked and arranged onto cardboard slides. For several samples, both the HCl and the acetic-samples were picked (Table 1). Two samples (s24 and s29) were barren.

Data analysis

The final factor used to normalise the quantitative abundance data given below, is obtained by the multiplication of two other factors (see Table 2). The first of these is the function of the number of times the samples were split before picking the microfauna; the second is needed for the acetic samples only (for the HCl samples is equal to 1), and is a function of the proportion of the material resulting from the acetic procedure coarser than 0.5 mm. The first factor has the purpose normalizing the data to 200 g of original sediment; the second to remove the implicit underestimation arising, in the samples treated with acetic acid, by the presence of a variable amount of “unbroken” coarse grains for which the procedure was not successful, and are likely to contain other microfossils which were not picked.

Agglutinated foraminiferal abundances are generally very similar between the equivalent HCl and acetic samples, which testifies to the correctness of the double normalization used here. Therefore, the averages between these couples (when available) are used to develop a quantitative biostratigraphy. The only exception is given by the “textulariids”, for which the simple acetic data are plotted due to their complete absence in samples treated with HCl (app. 1). This is a significant indication that this category includes forms that preferentially agglutinated calcareous grains, and that their wall was not diagenetically silicified. Therefore, in our dataset, we define as “textulariids” all those agglutinated foraminiferal species recovered only through acetic acid preparation, and whose serial/elongated morphology is comparable with the modern textulariids. The informal category of “textulariids” is justified on this basis.

We selected some of the better preserved specimens of representative species encountered in this study in order to image them with a scanning electronic microscope (SEM). The SEM photos were made at UCL in July, 2008. These pictures were subsequently edited using Corel Paint Shop Pro Photo X2.

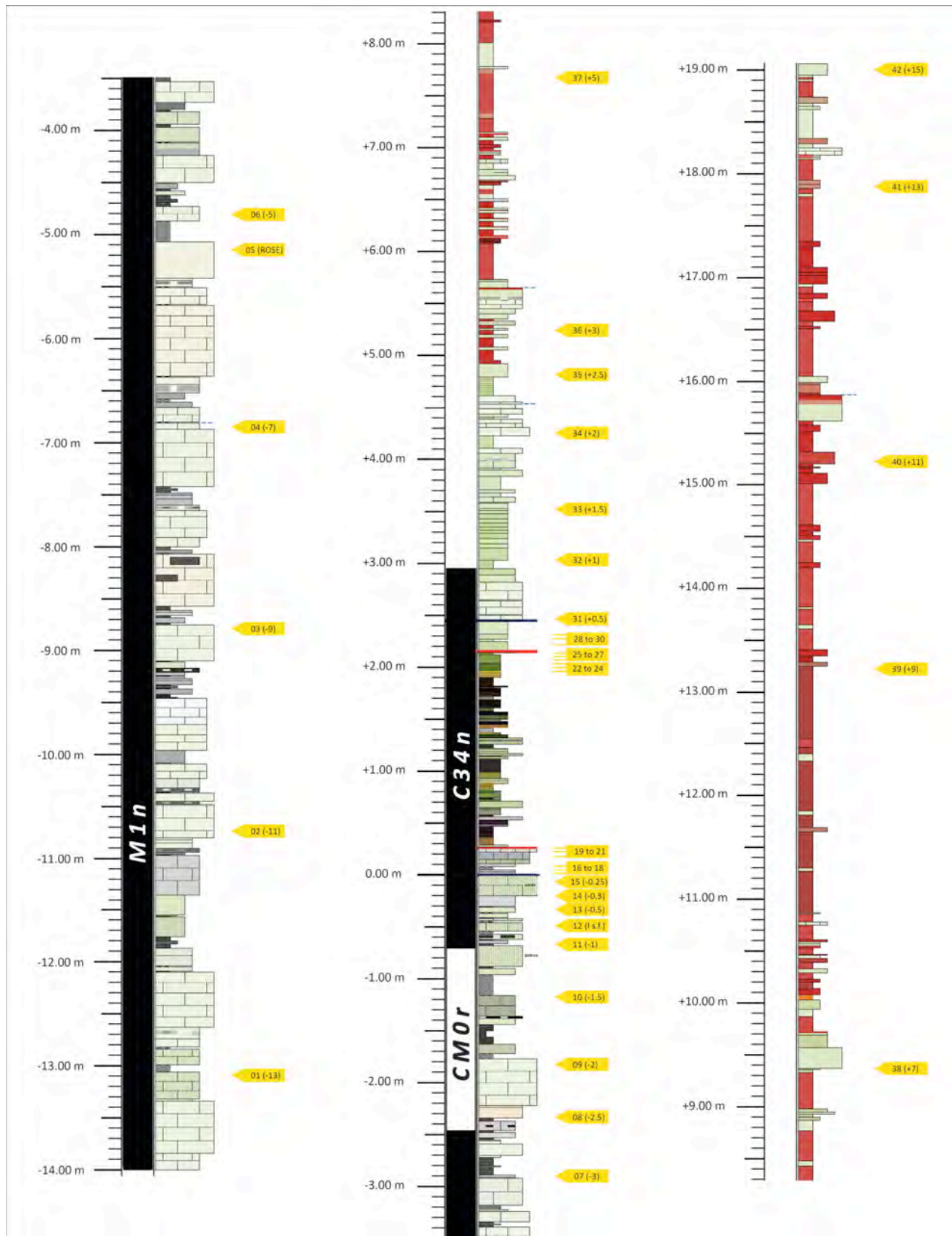


Figure 2. Column showing the lithostratigraphic data collected in the field. The stratigraphical position of the 41 samples gathered and their designations are also marked. These are calculated in terms of distance from the top of the uppermost white, strong, Maiolica-like calcareous bed (Bed A of Patruño *et al.*, in prep.). This level also corresponds with the nannoconid crisis of Coccioni *et al.* (1992) and Erba (1994).

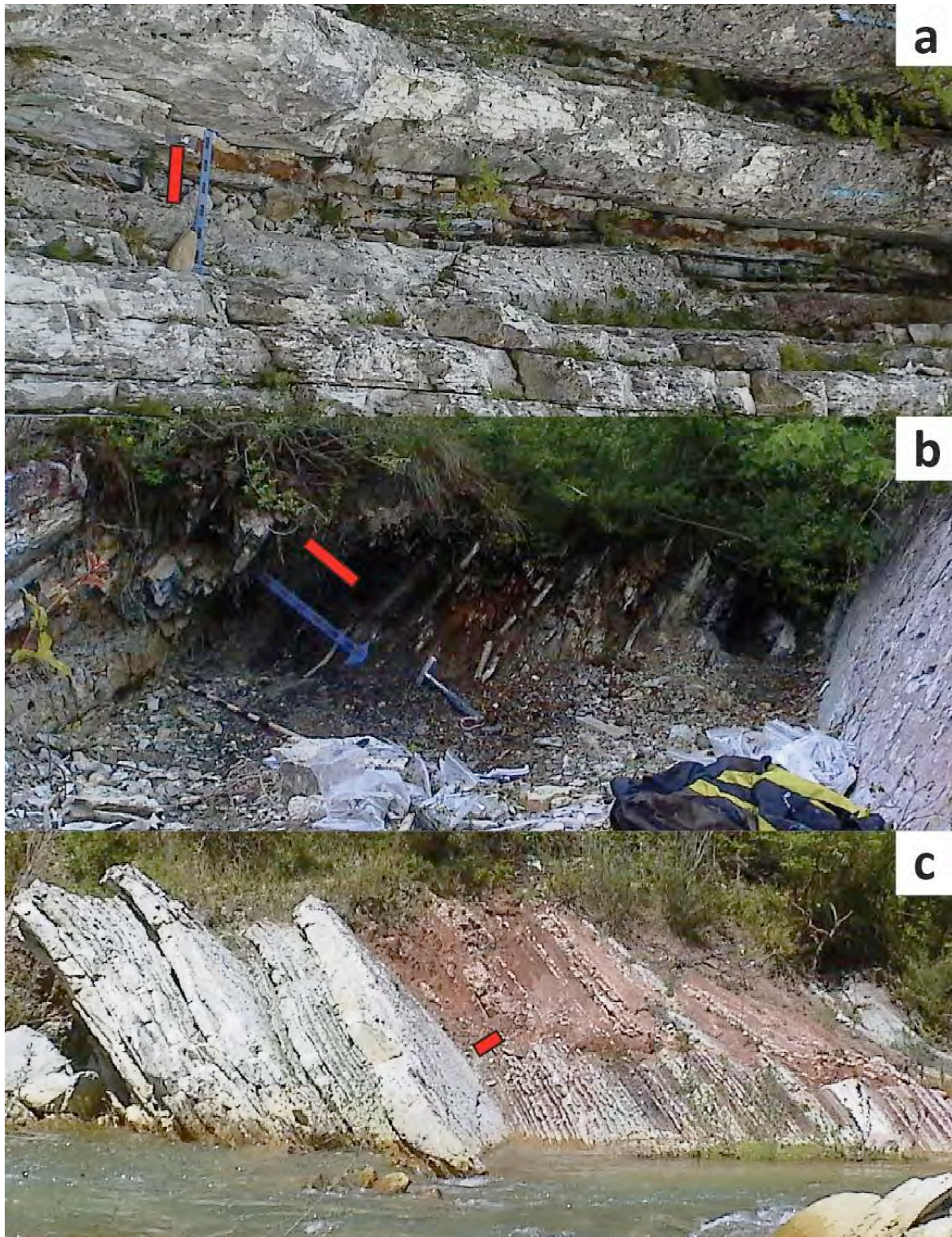


Figure 3. **a.** Cyclical alternations between whitish pelagic limestone and darker intervals, formed by cherts, marls and black clay. These are outcrops of the part of the Maiolica Formation lower than -5 m below the base of the Selli Level (i.e., '*Maiolica s.s.*'). **b.** The Selli layer is composed of 170-190 cm of black shales, variegated clay and radiolarites. On the left, the top of the last tough, Maiolica-like calcareous bed is visible. On the right is the base of the greenish-grey cherty member of the Marne a Fucoidi Formation. **c.** The lower part of the *Marne a Fucoidi* Formation, as outcropping to the left of the brook Scandigliano at Gorgo a Cerbara. The transition between the greenish-grey cherty member (to the left) and the lower reddish marly member (to the right) is clearly visible. The red scale-bars in each photo indicate 20 cm.

Table 1. List of samples, with indications of their names and their actual stratigraphic position, in terms of distance from both the top of BED A (i.e. the section 0-level) and from the arbitrarily chosen base of the section.

SAMPLE NUMBER (from base to top)	ORIGINAL SAMPLE NAME	HEIGHT (stratigraphic distance from top of BED A) (m)	STRATIGR. DISTANCE FROM THE SECTION BASE (cm)	PROCESSING METHODS (see text)
s01	-13.00	-13.10	91	HCl
s02	-11.00	-10.76	325	HCl
s03	-9.00	-8.81	519	HCl
s04	-7.00	-6.86	714	HCl
s05	ROSE	-5.18	882	HCl
s06	-5.00	-4.83	917	HCl, ACETIC
s07	-3.00	-2.90	1110	HCl
s08	-2.50	-2.31	1169	No results
s09	-2.00	-1.83	1217	HCl
s10	-1.50	-1.17	1282	ACETIC
s11	-1.00	-0.67	1333	HCl
s12	I STR.FUC.	-0.49	1351	HCl, ACETIC
s13	-0.50	-0.33	1367	ACETIC
s14	-0.30	-0.20	1380	ACETIC
s15	-0.25	-0.06	1394	HCl
s16	-0.20	0	1400	HCl, ACETIC
s17	-0.15	+0.04	1404	ACETIC
s18	-0.10	+0.10	1410	HCl, ACETIC
s19	-0.05	+0.18	1418	ACETIC
s20	-0.03	+0.23	1423	HCl, ACETIC
s21	-0.01	+0.25	1425	HCl, ACETIC
s22	+0.01	+1.97	1597	ACETIC
s23	+0.03	+2.00	1600	HCl
s24	+0.05	+2.03	1603	-
s25	+0.10	+2.09	1609	HCl
s26	+0.15	+2.12	1612	Simply washed
s27	+0.20	+2.15	1615	HCl, ACETIC
s28	+0.25	+2.21	1621	HCl
s29	+0.30	+2.28	1628	-
s30	+0.50bis	+2.31	1630	HCl, ACETIC
s31	+0.50	+2.45	1644	HCl, ACETIC
s32	+1.00	+3.04	1704	HCl, ACETIC
s33	+1.50	+3.49	1749	HCl, ACETIC
s34	+2.00	+4.24	1824	ACETIC
s35	+2.50	+4.80	1880	HCl, ACETIC
s36	+3.00	+5.25	1925	HCl, ACETIC
s37	+5.00	+7.67	2167	ACETIC
s38	+7.00	+9.38	2338	HCl, ACETIC
s39	+9.00	+13.21	2721	Simply washed
s40	+11.00	+15.21	2921	ACETIC
s41	+13.00	+17.86	3186	ACETIC
s42	+15.00	+19.02	3302	ACETIC

RESULTS

Agglutinated foraminifera were recovered from all studied samples, except one barren silicified sample below the Selli Level (S08) and three barren samples within the uppermost part of the Selli Level (S22, S27, S28) (Fig. 4). An average of 130 agglutinated specimens were counted per sample, and 26 species were identified and documented using SEM images (plates 1-5). In S37 and S39-S the great predominance of planktonic foraminifera did not allow the picking of a statistically satisfactory number of benthic foraminifera, and therefore the data from these samples could not be used for statistical purposes. Nevertheless, some important benthic FOs were found.

Samples collected from the Maiolica part of the section treated with hydrochloric acid yielded 0.1–0.5 g of insoluble residue from 200 g of original material. This small residue is mainly composed of radiolarians (largely spumellarians) and agglutinated foraminifera. Approximately 300 specimens of agglutinated foraminifera are present in 100 g of original material (mainly fragments of *Rhizammina* spp.).

At -20 cm the top of the last rather massive, mainly calcareous bed occurs. Above this horizon, the non-calcareous clayey and sandy material becomes rapidly more abundant. This is also confirmed by the weight of the insoluble residues of the hydrochloric acid preparation, which increases 20 times compared with the samples at -0.25 m and at -0.20 m, passing from 0.1 g (common result throughout the Maiolica samples) to 2–4 g, values maintained fairly steady throughout the “greenish member” of the *Marne a Fucoidi* Formation.

Despite the theoretical chance of finding fauna within the Selli Level, attempts to treat material with hydrochloric acid failed, confirming that the whole Selli interval is composed of largely noncalcareous materials, namely siliceous and/or radiolarian-bearing deposits.

The sample collected at +3.50 m, in one of the first red beds, reveals a more diversified fauna, and with many benthic specimens larger than 250 micron. Planktonic foraminifera are still subordinate. A sudden monogeneric bloom in planktonics was found in a red marly claystone collected at +9.00 m above the top of the OAE1a, where almost 500 specimens of *Hedbergella* spp. were extracted from 1 g of original material. From that point upwards, planktonic foraminifera outnumber both radiolaria and benthic foraminifera).

Astrorhizids

From the bottom of the studied interval to -5 m below the base of the Selli layer, astrorhizids are almost the only components of the agglutinated assemblage (Fig. 4). Five species of astrorhizids are present:

tubular fragments of *Rhizammina* spp. dominate, but *Bathysiphon* spp. and *Hippocrepina* spp. are minor constituents (comprising up to 10% of the assemblage). In this part of the succession a total of 300 to 500 fragments of *Rhizammina* spp. can be recovered from 200 g of limestone dissolved in HCl. The number of other astrorhizids is usually below 10, but can occasionally approach 30. The average length of the *Rhizammina* fragments is around 700 μ m in the lowermost part, from the base up to -8 m below from the Selli horizon. From -8 to -5 m their length starts to decrease, averaging 550–660 microns.

The sample at -5 m contains the last common occurrence of *Hippocrepina depressa*: only a few specimens were recognised in two samples below the Selli horizon. From -5 to -1 m below the Selli Level an interval consistently poorer in astrorhizids, both in terms of number of specimens and species was observed. Here, only *Rhizammina* is continuously present and, apart from one occurrence of rare *H. depressa*, it is the only astrorhizid. The number of specimens extracted from 200 g is variable, from 400 to 700, whose average length is between 400 and 600 μ m. An interesting exception is sample -3, which holds fewer, but remarkably longer tubular fragments (only 170 specimens, 840 μ m).

At -1.00, in proximity of the Maiolica/Fucoidi formational transition (traditionally placed at the top of the highest dark chert), the four remaining astrorhizids occur together again. The *Rhizammina* fragments here are very variable in number, about 200–700 per 200 g of sediment, also accompanied by up to 50 specimens of *Bathysiphon*. The highest occurrence of *H. depressa* is observed at this point.

Rhizammina spp. and *Bathysiphon* spp. are still present upwards, until the very onset of the OAE1a anoxic layers. The quantities of *Rhizammina* fluctuate highly in the 50 cm below the onset of the anoxic layer (like many other parameters), with minima of 200 and maxima around 1,000; the size, though, remains more stable (430–600 μ m average size).

Rhizammina is still present even in the highest 3 cm below the base of the black shales, but its abundance is reduced to 40–150 specimens per 200 g, with average size at 320–450 μ m. *Rhizammina* spp. is one of the first foraminifera to recolonise the sea floor after the anoxic event, being present in the sample collected at +0.03 cm above the highest black shale layer.

An assemblage of *Rhizammina* together with a growing proportion of *Bathysiphon vitta* and *Bathysiphon brosgiei* characterise the entire “greenish-grey cherty member”, starting from +0.50 m above the top of the Selli layer. From that point upward, a double cycle in the *Rhizammina* abundance is recorded, with two peaks of 780 and 350 specimens.

Table 2: list of the factors used to normalise the quantitative data

Sample No	Sample Name	Processing methods	Normalization Factor 1 (200 g)				NF 2 (for acetic)	Final Normalization Factor			
			BF	Large PF	Small PF	R		BF	Large PF	Small PF	R
s01	-13.00	HCl	1.33	1.33	1.33	1.33	1.00	1.33	1.33	1.33	1.33
s02	-11.00	HCl	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
s03	-9.00	HCl	2.00	2.00	2.00	2.00	1.00	2.00	2.00	2.00	2.00
s04	-7.00	HCl	2.00	2.00	2.00	2.00	1.00	2.00	2.00	2.00	2.00
s05	ROSE	HCl	2.00	2.00	2.00	2.00	1.00	2.00	2.00	2.00	2.00
s06	-5.00	HCl	8.00	8.00	8.00	8.00	1.00	8.00	8.00	8.00	8.00
		Acetic	2.00	2.00	2.00	2.00	5.42	10.84	10.84	10.84	10.84
s07	-3.00	HCl	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
s09	-2.00	HCl	1.33	1.33	1.33	1.33	1.00	1.33	1.33	1.33	1.33
s10	-1.50	Acetic	1.00	1.00	1.00	1.00	20.48	20.48	20.48	20.48	20.48
s11	-1.00	HCl	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
s12	I SF	HCl	2.00	2.00	2.00	2.00	1.00	2.00	2.00	2.00	2.00
		Acetic	1.00	1.00	1.00	1.00	14.08	14.08	14.08	14.08	14.08
s13	-0.50	Acetic	1.00	1.00	1.00	1.00	10.31	10.31	10.31	10.31	10.31
s14	-0.30	Acetic	1.33	1.33	1.33	4.00	12.50	16.63	16.63	16.63	50.00
s15	-0.25	HCl	4.00	4.00	4.00	4.00	1.00	4.00	4.00	4.00	4.00
s16	-0.20	HCl	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
		Acetic	2.67	2.67	2.67	8.00	7.63	20.37	20.37	20.37	61.04
s17	-0.15	Acetic	1.60	1.60	1.60	16.00	1.45	2.32	2.32	2.32	23.20
s18	-0.10	HCl	8.00	8.00	8.00	8.00	1.00	8.00	8.00	8.00	8.00
		Acetic	1.00	1.00	1.00	1.00	1.22	1.22	1.22	1.22	1.22
s19	-0.05	Acetic	1.60	1.60	1.60	5.00	2.80	4.48	4.48	4.48	14.00
s20	-0.03	HCl	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
		Acetic	1.00	1.00	1.00	8.00	10.23	10.23	10.23	10.23	81.84
s21	-0.01	HCl	4.00	4.00	4.00	4.00	1.00	4.00	4.00	4.00	4.00
		Acetic	1.00	1.00	1.00	8.00	2.85	2.85	2.85	2.85	22.80
s22	+0.01	Acetic	365.00	365.00	365.00	365.00	1.13	412.45	412.45	412.45	412.45
s23	+0.03	HCl	10.64	10.64	10.64	10.64	1.00	10.64	10.64	10.64	10.64
s25	+0.10	HCl	21.28	21.28	21.28	21.28	1.00	21.28	21.28	21.28	21.28
s26	+0.15	Washed	200.00	200.00	200.00	200.00	1.00	200.00	200.00	200.00	200.00
s27	+0.20	HCl	4000.0	4000.0	4000.0	4000.0	1.00	4000.0	4000.0	4000.0	4000.0
		Acetic	4000.0	4000.0	4000.0	4000.0	1.00	4000.0	4000.0	4000.0	4000.0
s28	+0.25	HCl	2048.0	2048.0	2048.0	2048.0	1.00	2048.0	2048.0	2048.0	2048.0
s30	+0.50bis	HCl	4.00	4.00	4.00	4.00	1.00	4.00	4.00	4.00	4.00
		Acetic	2.00	2.00	2.00	4.00	2.94	5.88	5.88	5.88	11.76
s31	+0.50	HCl	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
		Acetic	1.00	1.00	1.00	1.00	3.81	3.81	3.81	3.81	3.81
s32	+1.00	HCl	4.00	4.00	4.00	4.00	1.00	4.00	4.00	4.00	4.00
		Acetic	1.00	1.00	1.00	1.00	5.25	5.25	5.25	5.25	5.25
s33	+1.50	HCl	2.00	2.00	2.00	2.00	1.00	2.00	2.00	2.00	2.00
		Acetic	4.00	4.00	4.00	4.00	1.85	7.40	7.40	7.40	7.40
s34	+2.00	Acetic	4.00	4.00	4.00	4.00	4.65	18.60	18.60	18.60	18.60
s35	+2.50	HCl	32.00	32.00	32.00	32.00	1.00	32.00	32.00	32.00	32.00
		Acetic	4.00	4.00	4.00	1024.0	1.13	4.52	4.52	4.52	1157.12
s36	+3.00	HCl	2.00	2.00	2.00	2.00	1.00	2.00	2.00	2.00	2.00
		Acetic	4.00	4.00	4.00	8.00	1.57	6.28	6.28	6.28	12.56
s37	+5.00	Acetic	1.00	1.00	1.00	256.00	1.12	1.12	1.12	1.12	286.72
s38	+7.00	HCl	256.00	256.00	256.00	256.00	1.00	256.00	256.00	256.00	256.00
		Acetic	7.76	7.76	7.76	64.00	3.65	28.32	28.32	28.32	233.60
s39	+9.00	Washed	19.00	128.00	500.00	19.00	1.00	19.00	128.00	500.00	19.00
s40	+11.00	Acetic	8.00	128.00	256.00	5.00	1.85	14.80	236.80	473.60	9.25
s41	+13.00	Acetic	10.00	128.00	512.00	10.00	1.27	12.70	162.56	650.24	12.70
s42	+15.00	Acetic	4.60	512.00	256.00	4.60	2.38	10.95	121.56	609.28	10.95

Also the size of the “tubes” shows this rough sinusoidal trend throughout the “greenish-grey cherty member” of the Marne à Fucoidi, with maxima (550 and 650 μm) and minima (430 μm) in the same stratigraphic positions.

The presence of *Bathysiphon* ceases with the onset of the “red marly member”, with which the quantity of *Rhizammina* also greatly reduces. However, this might not be a true phenomenon, and simply due to the lack of observations for the benthics in the finest

fractions (for this part of the section). What is certain is that we found *Rhizammina* in the coarse fraction in almost every sample in the uppermost part of the section, which means that *Rhizammina* is not only present here, but also found a favourable environment to thrive.

Lituolids

Compared with the astrorhizids, the lituolids are almost always subordinate in terms of total abundance, but their diversity is much greater (Fig. 4). The whole lower part of our section, below the Selli level, has lituolid abundances constantly lower than 10% of the total agglutinated foraminifera, particularly for the most calcareous samples. The only exceptions are two samples collected in marly horizons, -5 and -1.50, where the lituolids comprise 10% or more of the total agglutinated assemblage.

In the lowermost part of the section, from the base to -5 m below from the Selli, the only species of lituolid present, with abundances not greater than 15-16 specimens per 200 g of calcareous samples, is *Reophx helveticus* and, more occasionally, *Haplophragmoides kirki*. The size of their longer axis is usually between 200 and 700 microns. Rare small specimens of *Glomospira charoides* are found in some calcareous samples.

The more marly samples -5 and -1.50, located at about -5 and -1.50 m below the Selli base, contain species not observed in the underlying samples, such as *Scherochorella minuta* form B, and *Ammodiscus* spp., in consistent numbers (between 10 and 40 specimens). However, the question is: are these true FOs or are these normal faunal components of marly rocks and unknown in the pure limestones, and since these were by chance the only marly samples collected among the limestone/marls couplets of the upper Maiolica? Further studies will be needed to resolve this question.

Apart from those two marly samples, the interval between -5 m and -1 m is practically lituolid-free (all the other samples were limestone). Not even *R. helveticus* was found here.

Roughly from the base of the Marne a Fucoidi (=1.00 m) to the Selli layer, a few specimens of *Ammodiscus* spp., *Scherochorella minuta* form A, *S. minuta* form B, *Haplophragmoides kirki*, *H. gigas gigas*, *Reophax helveticus* and *Reophax liasicus* are present. This level also represents the last occurrence (LO) of *R. helveticus* and the FO of *R. liasicus*, *S. minuta* form A, and *H. gigas gigas*.

Then, after the end of the anoxia, the lituolids experienced a bloom in terms of diversity (up to 12 species found in sample +3) and abundance (which rises from 0-10% below the Selli to 25%-65% above). The event is represented by sample +0.50 (50

cm above the Selli top, above the radiolarian-rich interval). Here, seven species of lituolids occur, including: *Ammodiscus* spp., *Glomospira charoides*, abundant *Reophax liasicus*, *Scherochorella minuta* form A, *S. minuta* form B, *H. kirki*, and *H. gigas gigas*. We again observe (but more abundant – *R. liasicus* approaching 40 specimens) the same fauna present just before the onset of the OAE1a. Moreover, *R. helveticus* is lacking.

In the upper levels of the greenish-grey cherty member this trend of increasing lituolids continues:

- Well-developed specimens of *Ammodiscus infimus* appear 1 m higher (sample +1.50), together with *G. gordialis*.
- *Ammodiscus infimus* can approach remarkable sizes. In the sample +1.50, one uncoiling specimen is 600 μm across coiled part, and up to 1800 μm including the uncoiled tube (Plate 10, specimen 2).
- *Scherochorella minuta* can approach 100 specimens per sample.

An almost sinusoidal trend is also visible by the percentage of lituolids in this part of the section, this time minima being placed at +1.00.

Several new species appear at +3, with the FOs of *Bimonilina entis*, *Reophax* cf. *parvulus*, and *Haplophragmoides gigas minor*. The “speciation ratio” is high but at the same time, the turnover ratio is low because none of the previous named species are absent. Even a few *Arthrodendron* fragments are present. A new FO is represented by *Glomospirella* sp. (in sample +13).

Textulariids

The first textulariid occurring in the studied section appears in sample -5 (Fig. 4). This is *Verneuilinoides* cf. *neocomiensis* Mjatluk, 1939, which, together with *Dorothia hyperconica* Risch, 1970, forms the textulariid assemblage typical of the section just below OAE1a. In particular, both species experience a sudden bloom around 45 cm below the base of the Selli layer (sample -0.30, with 780 specimens of *V. cf. neocomiensis* and 50 *D. hyperconica*). However, both of the species did not survive the anoxic crisis. In particular, the last occurrence of *V. cf. neocomiensis* is placed about 15-25 cm below the base of the Selli, where numerous pyritised specimens of this infaunal foraminifer occur. Because in these samples this is the only species to be pyritised, we can speculate that the environment must have been characterised by a redox boundary cyclically varying its depth so to allow the life of this infaunal species in great number and then killing the population and pyritising them in an anoxic environment. In other words, the depth of life of this infaunal species would constrain the depth of the palaeo-redox boundary. An alternative explanation would be that pyritisation simply

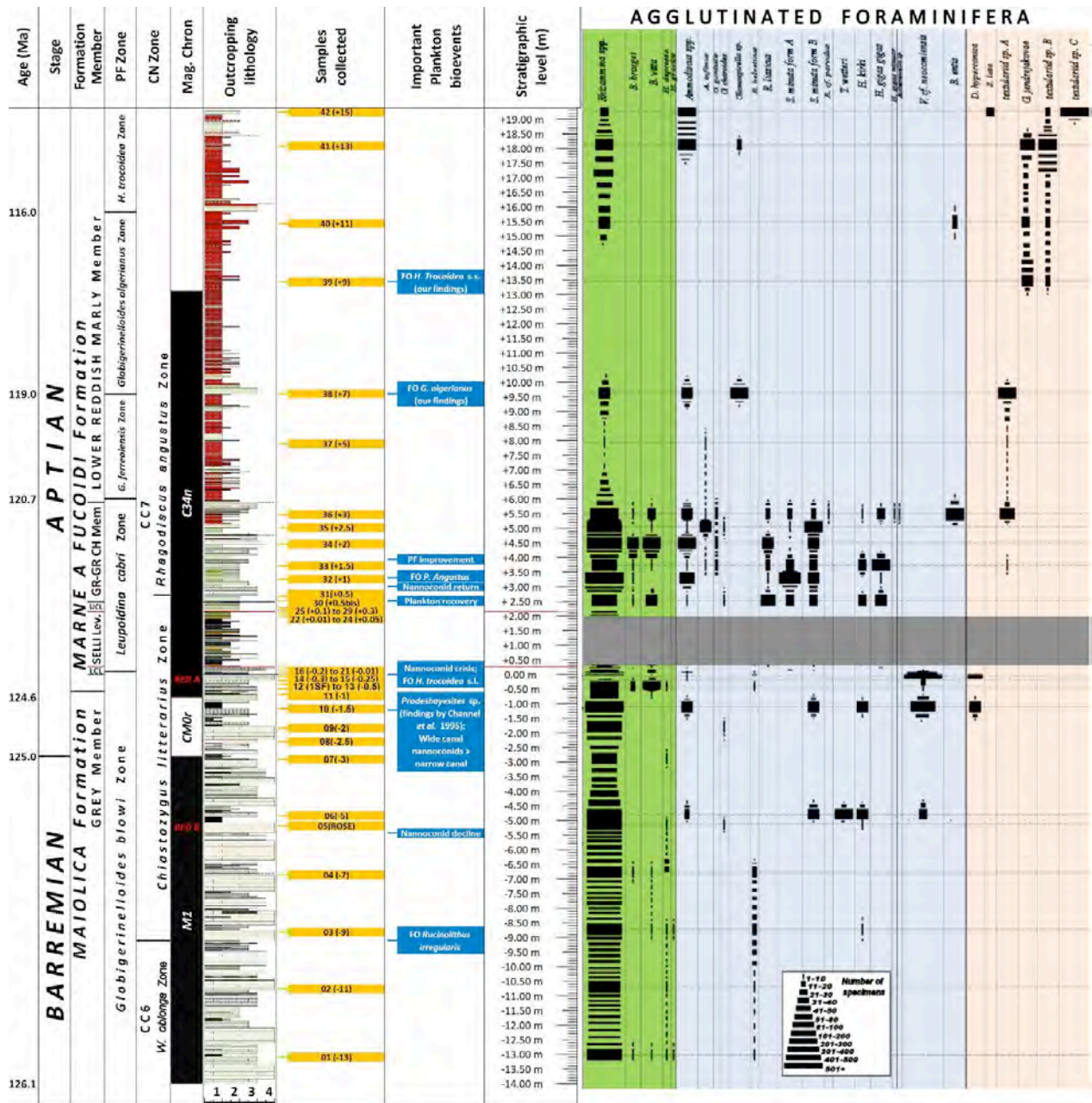


Figure 4. Changes in benthic foraminiferal assemblages plotted against the stratigraphic column. Age, stages, magnetostratigraphy and planktonic foraminifera biozones from Gradstein *et al.*, 2004, Channel *et al.*, 2000, Lowrie & Alvarez (1984) and Coccioni (unpublished). A= *nannoconid crisis*, B=*Deshayesites* findings (after Channel *et al.*, 2000), C= nannoconid decline (Channel *et al.*, 2000), d= *G. algerianus* (our data). Stratigraphic positions calculated in terms of distance from the top of the uppermost white, strong, Maiolica-like calcareous bed (Bed A of Patruno *et al.*, in prep.). This level also corresponds with the nannoconid crisis of Coccioni *et al.* (1992) and Erba (1994).

occurred post-mortem after a short period of burial, when these specimens had been buried down to the level of the redox boundary. This second explanation seems less likely, given the very low sedimentation rate documented at this level.

Above the OAE1a we do not observe any textulariid until the species “textulariid form A” appears (sample +1.50 FO, sample +3 FCO). This species is indicative of the part of the section that we call “transitional between the greenish-grey cherty member

and the red marly member”. This part of the section is mainly composed by red marly clay, but still with abundant intercalations of greenish marly limestones (from +3 to +7). This species is not known above sample +7, its LO is placed at this level.

Samples +9, +11, +13 are characterised by another textulariid assemblage, formed by two species named *Gaudryina jendrekovae* and “textulariid form B”. In the uppermost sample +15 also *Spiroplectinata lata* and “textulariid form C” enter the assemblage. In

summary, three assemblages of textulariids, completely different and unconnected to each other, span the early-mid Aptian time. These assemblages are physically divided by two barriers: the OAE1a and the boundary between the greenish-grey cherty member and lower red marly member.

DISCUSSION

Definition of local agglutinated foraminiferal assemblages.

The pattern of local first occurrences (FOs) and last occurrences (LOs) of agglutinated foraminiferal taxa has been used to subdivide the studied stratigraphic section into nine different assemblages, each characterised by distinct agglutinated taxa. These assemblages have been progressively named from GC-A (the oldest) to GC-I (the youngest). Furthermore, the names of species that characterise each of these assemblages have been used to create longer assemblage intervals, using the traditional biostratigraphic concepts of “taxon range zone” (TRZ), “concurrent range zone” (CRZ), “interval zone” (IZ) and “acme zone” (AZ). These are considered to be completely informal and local “zones”. Because the correlation potential of these biostratigraphic boundaries need to be tested, it is more correct to refer to them as “assemblages” rather than “zones”. These agglutinated assemblages and the clustering of bioevents at their bases are generally compatible with calcareous benthic foraminiferal trends (Patruno *et al.*, in press).

Assemblage GC-A (*Reophax helveticus* – *Hippocrepina depressa* “CRZ”).

Interval: from base of the sampled section to ca. -5.00 m below the base of the Selli Level (samples S01 to S05). This interval comprises the upper Maiolica Formation, in the upper part of the *Globigerinelloides blowi* planktonic foraminiferal biozone (Coccioni *et al.*, 1992) and the M1 chron. As a consequence, this assemblage is older than 125 Ma (upper Barremian). Assemblage GC-A is composed of well-developed *Rhizammina* spp., with subordinate *Reophax helveticus*, *Hippocrepina depressa*, *Hippocrepina gracilis*, *Bathysiphon vitta*, *Bathysiphon brosgiei*. Small-sized *Glomospira charoides* may also be occasionally present.

Assemblage GC-B (*Trochammina wetteri* “TRZ”)

Interval: from ca. -5.00 m below the base of the Selli Level to the base of the Marne a Fucoidi Formation (samples S06 to S11). This interval falls within the uppermost Maiolica Formation, in the uppermost part of the *Globigerinelloides blowi* planktonic foraminiferal biozone (Coccioni *et al.*, 1992). Within this sedimentary unit, both the boundary between M1 and

CM0r chrons (i.e., the Barremian/Aptian boundary) and between CM0r and the overlying long Cretaceous normal magnetic interval (CM0r) are found. The age of this assemblage is approximately 124.5–125.5 Ma. The boundary between assemblages GC-A and GC-B is marked by a major benthic foraminiferal turnover and a striking diversity increase. A clustering of bioevents is observed: last consistent occurrence (LCO) of *R. helveticus* and *H. depressa*; the first occurrence (FO) of *Ammodiscus* spp., *Scherocorella minuta* forma B, *Trochammina wetteri*, *Verneuilinoides* cf. *neocomiensis*; the first consistent occurrence (FCO) of *Haplophragmoides kirki*. The base of GC-B also coincides with a sudden change in lithostratigraphic and biostratigraphic features of the succession (top of BED B of Patruno *et al.*, in press). Assemblage GC-B comprises mainly smaller fragments of *Rhizammina* spp. than those found in GC-A; occasionally (only in the marly layers?) these are accompanied by few specimens of *Ammodiscus* spp., *Bathysiphon* spp., *H. depressa*, *H. charoides*, *H. kirki*, *S. minuta* forma B, *T. wetteri*, and *V.* cf. *neocomiensis*.

Assemblage GC-C (*Verneuilinoides* cf. *neocomiensis* “AZ”)

Interval: from -0.45 m below the base of the Selli Level to -0.20 m below the base of the Selli Level (samples S12 to S17). This short but very characteristic interval falls within the basal greenish-grey cherty member of the Marne a Fucoidi Formation, in the uppermost part of the *Globigerinelloides blowi* planktonic foraminiferal biozone (Coccioni *et al.*, 1992), and it coincides with the uppermost mainly calcareous, hard, ‘Maiolica-like’ bed of the studied succession (BED A of Patruno *et al.*, in press). This assemblage is tentatively dated to 124.6–124.0 Ma (lowermost Aptian). The passage from assemblage GC-B to GC-C is marked by distinct changes in the relative and absolute abundance of agglutinated foraminifera, and in particular by the beginning of the acme of *Verneuilinoides* cf. *neocomiensis* and *Dorothia hyperconica*. Assemblage GC-C is composed of dominant *V.* cf. *neocomiensis* and *D. hyperconica* (both of which showing a significant abundance acme). Subordinate components include *Ammodiscus* spp., *Bathysiphon* spp., *Rhizammina* spp. and *R. helveticus*.

Assemblage GC-D (*Haplophragmoides gigas gigas* “TRZ”)

Interval: from -0.20 m below the base of the Selli Level to ca. +1.70 m above the top of the Selli Level (samples S18 to S21 and S30–S32). This interval falls within the lower part of the greenish-grey cherty member of the Marne a Fucoidi Formation, and

contains the Lower and Upper Critical Intervals (*sensu* Coccioni *et al.*, 1992) and the Selli Level itself. The GC-D assemblage coincides with the lower part of the *Leupoldina cabri* planktonic foraminiferal biozone (Coccioni *et al.*, 2006; Tejada *et al.*, 2009), and therefore an age range between 124.6 and 120.7 Ma is assigned to this assemblage (lower Aptian).

The base of assemblage GC-D corresponds to an agglutinated foraminiferal turnover in which species characteristics of the Maiolica Formation (assemblage GC-A) disappear or reduce their abundance, and new lituolid species appear. The new FOs outnumber the LOs, resulting in an overall diversity increase. In spite of the anoxic event, the latter species are also found above the Selli Level, and are therefore regarded to be typical components of the microfossil assemblages within the greenish-grey cherty member of the Marne a Fucoidi Formation. In particular, the transition between assemblages GC-C and GC-D is recognised by the FOs of *Haplophragmoides gigas gigas*, *Reophax liasicus* and *Schero-corella minuta* forma A, and by the LO of *V. cf. neocomiensis* (which disappears shortly after displaying a high-magnitude peak in abundance, in GC-C). The last bioevent is typically highlighted by the recovery of pyritised last specimens of *V. cf. neocomiensis* at the base of assemblage GC-D. Assemblage GC-D is characteristically comprised of *Rhizammina* spp., *Ammodiscus* spp., *B. brosgiei*, *B. vitta*, *H. gigas*, *R. liasicus*, and *S. minuta* (forma A and B).

Assemblage GC-E (*Ammodiscus infimus* “IZ”)

Interval: from ca. +1.70 m above the base of the Selli Level to the lowermost reddish marly layer (samples S33 to S35). This interval coincides with the upper part of the greenish-grey cherty member of the Marne a Fucoidi Formation, and with the upper part of the *Leupoldina cabri* planktonic foraminiferal biozone. Therefore, an age older than 120.7 Ma is inferred for this assemblage (lower Aptian).

The transition from assemblage GC-D to GC-E is marked by the occurrences of new lituolid and textulariid species, resulting in another rise in diversity. In particular, the FOs of *Ammodiscus infimus*, “textulariid sp. A” and *Glomospira gordialis* cluster around the base of GC-E. Assemblage GC-E comprises the following agglutinated species: *Rhizammina* spp., *B. brosgiei*, *B. vita*, *Ammodiscus* spp., *A. infimus*, *G. charoides*, *H. gigas gigas*, *H. kirki*, *R. liasicus*, and *S. minuta*.

Assemblage GC-F (“textulariid sp. A” “TRZ”)

Interval: approximately from +3.00 m to +7.00 m above the base of the Selli Level (samples S36-s37).

This interval falls within the lower part of the lower reddish marly member of the Marne a Fucoidi Formation, and roughly coincides with the *Globigerinelloides ferreolensis* planktonic foraminiferal biozone. Therefore, an age between 120.7 and 119.0 Ma is inferred for assemblage GC-F (middle Aptian).

A new increase in diversity has been documented at the passage from the greenish-grey cherty member to the lower reddish marly member of the Maiolica Formation (occurrence of the lowermost reddish marly layers). In particular, we note the FOs of *Bimonilina* sp., *H. gigas minor*, *Reophax cf. parvulus* and the FCO of “textulariid sp. A”. Typical components of the GC-F assemblage are *Ammodiscus infimus*, “textulariid sp. A” and abundant *Rhizammina* spp.

Assemblage GC-G (*Glomospirella* spp. “IZ”)

Interval: approximately from +7.00 m to +11.00 m above the base of the Selli Level (sample S38). This interval falls within the lower-middle part of the lower reddish marly member of the Marne a Fucoidi Formation and the lower part of the *Globigerinelloides algerianus* planktonic foraminiferal biozone. An age between 119.0 and 116.0 Ma is inferred for assemblage GC-F (middle Aptian). Within this interval, at about +10 m above the Selli layer, the earliest macroperforate planktonic foraminifera (*Hedbergella trocoidea*) appear in the assemblages, rapidly and greatly outnumbering both benthic and microperforate planktonics. These hedbergellids markedly increase their abundance and overall size throughout the rest of the section.

This interval is relatively unsampled and a precise definition of the benthic assemblage components cannot be given. However, *Glomospirella* spp. was first recovered in sample S38; furthermore, “textulariid sp. A” was not found in levels higher than +3 m above the Selli Level, and its last occurrence might be tentatively interpreted at the base of this assemblage.

Assemblage GC-H (*Gaudryina jendrekovae* – “textulariid sp. B” “CRZ”)

Interval: approximately from +11.00 m to +16.50 m above the base of the Selli Level (samples S39 to S41). This interval falls within the middle-upper part of the lower reddish marly member of the Marne a Fucoidi Formation. The transition from *Globigerinelloides algerianus* and *Hedbergella trocoidea* planktonic foraminiferal biozones occurs in the lower-middle portion of this interval, and an age of approximately 117.0-115.0 Ma (middle Aptian) is assigned to assemblage GC-H.

We differentiate assemblage GC-H from the underlying GC-G based upon the first occurrences of

new textulariid species, such as *Gaudryina jendrekovae* and “textulariid sp. B”. Typical agglutinated components of assemblage GC-H include *G. jendrekovae*, “textulariid sp. B”, abundant *Rhizammina* and occasional *Bimonilina* spp.

Assemblage GC-I (*Spiroplectinata lata* “IZ”)

Interval: approximately from +16.50 m above the base of the Selli Level to the top of the sampled section (sample S42). This interval falls within the upper part of the lower reddish marly member of the Marne a Fucoidi Formation and in the *Hedbergella trocoidea* planktonic foraminiferal biozone. An age younger than 116.0 Ma is assumed for assemblage GC-I (upper Aptian).

The base of GC-I is defined by the first occurrences of new agglutinated species, such as *Spiroplectinata lata* and “textulariid sp. C”. The overall trend of increasing diversity here reaches maxima values. Typical agglutinated components of the GC-I assemblage comprise *Rhizammina* spp., *Spiroplectinata lata*, *Gaudryina jendrekovae*, “textulariid sp. C” and “textulariid sp. D”.

Correlation between agglutinated assemblages and lithological changes

The three points with the highest taxonomic turnover in the studied section (at -5 m, -0.20 m and +3 m) are evident on the physical section in the field, because all three points are highlighted by notable morphology and/or colour breaks. Additionally, all the other assemblage boundaries are marked by minor changes of colours or morphology breaks (see Patruno, 2008).

The level at -5 m below the Selli Level base is highlighted by an evident morphological break (the water fall coincident with the top of the last white, massive calcareous bed) and a change of the bed rhythms below and above. This level represents the transition between zone A and zone B, with the first remarkable turnover in the agglutinated faunas (LCOs of some astrorhizids – *R. helveticus*, *H. depressa* – and FOs of some litoiids – *T. wetteri*, *S. minuta*, *V. cf. neocomiensis*). Perhaps by coincidence, here there is also the first record of calcareous faunas (first sample soft enough to be successfully processed by acetic acid). There is also a good correlation with the *nannoconid decline* (Channell *et al.*, 2000).

All these data seem to point out that the “true” Maiolica-type sedimentation terminates already -5 m under the Selli level (-4 m below its formally-defined boundary), and that all the material between this point and the next remarkable point (the Selli base) might be considered as the “transition to the Fucoidi”.

At ca. -20 cm below the OAE1a base, the top of the last rather massive, tough, calcareous bed is

observed, and above this level the sediment is much more terrigenous. This passage is described by the very first peak in the percentage of non-calcareous sandy materials, the amount of which increases abruptly 20-fold on the top of the calcareous bed (compared with the steady values recorded below that point).

The first peak in diversity and abundance of benthic foraminifera coincides exactly with the last calcareous bed and our assemblage C (acme of *V. cf. neocomiensis*, *D. hyperconica* and *L. muenstri*). A second relative peak is placed just ca. 1 to 12 cm below the OAE1a base (*Lower critical interval* sensu Coccioni, the base of our assemblage D), where the highest calcareous layers are found. This last part coincides with the highest turnover rate in the entire section (almost all the new benthic forms we commonly found above the Selli already appeared in this horizon, i.e., at the base of assemblage D), which corresponds with the transition between the *G. blowi* and *L. cabri* planktonic foraminifera zones (Coccioni *et al.*, 2006).

All the foraminiferal assemblage boundaries are also mirrored by changes of physical features of the outcrop, such as morphology breaks, sediment colour, and bed attributes. The level at +3 m above the OAE1a base corresponds to the interval with the most important changes in the physical features of the succession above the Selli level (i.e., passage from the greenish grey cherty member and the lower reddish marly member, with the occurrence of the first red marls). Samples collected from this horizon are also the ones with the highest diversity values.

CONCLUSIONS

The faunal variations observed in the Gorgo a Cerbara Section are constantly in phase with the lithological variation. The first important turnover is placed at ca. -5 m below the base of OAE1a, with a Barremian agglutinated assemblage characteristic of the “true Maiolica” replaced by a transitional “Maiolica passing to Marne a Fucoidi” assemblage. One question still to solve is whether this change is real, or dependent upon the lithology of material sampled in this study (only from calcareous beds below this level).

A second faunal turnover is placed at -40 cm below the base of the OAE1a to the Selli level itself. Here the highest turnover rate of the whole section was observed, together with high-magnitude and high-frequency cycles in all the studied parameters. A bloom of *V. neocomiensis* is typical of this interval, which corresponds to the transition from the last rather massive, Maiolica-like calcareous bed to a mainly terrigenous succession (an abrupt 20-fold

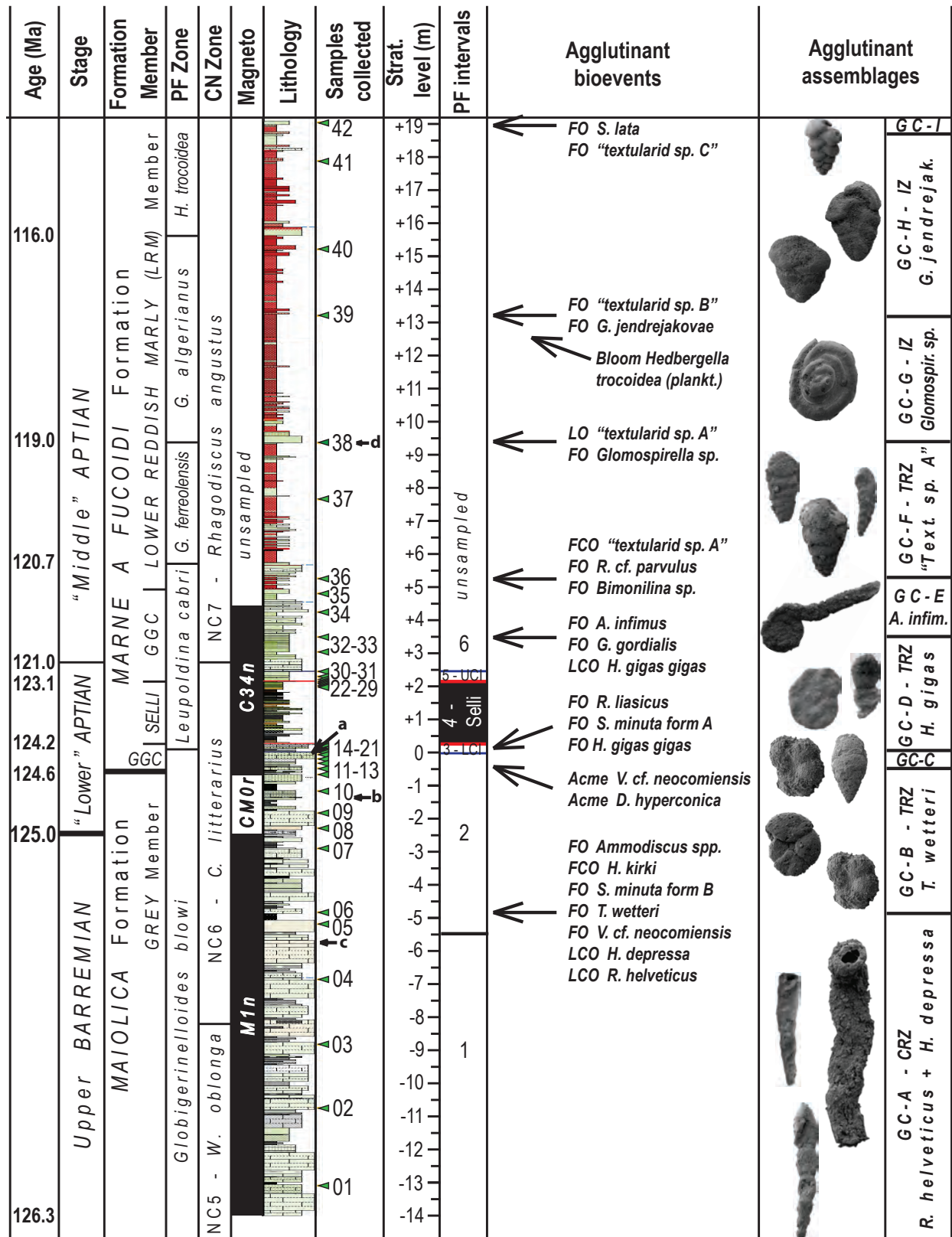


Figure 5. Changes in benthic foraminiferal assemblages throughout the section, principle bioevents, and assemblage zones. Age, stages, magnetostratigraphy from Gradstein et al., 2004, Channel et al., 2000, Lowrie & Alvarez (1984). biozones from Coccioni (unpublished). Planktonic foraminiferal (PF) and calcareous nannofossil (CN) biozones constrained with bioevents from Coccioni (unpublished), Coccioni et al. (1992) and Erba (1994). Planktonic palaeoecological intervals are from Coccioni et al. (1992). A= nannoconid crisis, B= Deshayesites findings (after Channel et al., 2000), C= nannoconid decline (Channel et al., 2000), d= G. algerianus (our data). The details of the calcareous benthic foraminiferal bioevents are described by Patruno et al. (in prep.).

increase in the amount of noncalcareous sandy materials). The top of this last calcareous bed perfectly coincides with the *nannoconid crisis* (Coccioni *et al.*, 1992; Erba, 1994). Immediately above the highest calcareous bed, the true Selli level begins.

Benthic foraminifera re-appear at ca. 50 cm, and from that point an overall trend of increasing diversity upsection has been observed, accelerating at +3.50 cm above the top of the Selli Level (at the lowermost red sediment), where we note a diversity maximum.

At ca. +10 m above the top of the Selli Level there is a remarkable bloom of *H. trocoidea*, which rapidly outnumbers the benthic and the older microperforate forms. Hedbergellids increase abundance and size throughout the rest of the section.

A biostratigraphic scheme based on agglutinated benthic foraminiferal assemblage changes has been proposed. This is viewed as a first step toward a benthic foraminiferal biozonation that is consistent with the major variations of the major lithological changes, recognisable at an outcrop scale in the Umbria-Marche Basin.

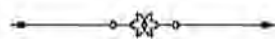
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SPECIES LIST

In this paper we have used English vernacular endings for the higher-rank taxonomic categories, rather than Latin endings because the debate over the exact hierarchy of the supergeneric categories for foraminifera. An alphabetic list of the fully referenced species and genera encountered in this study follows.

Astrorhizids***Bathysiphon brosgiei* Tappan, 1957**

Plate 1, fig. 16

Bathysiphon brosgiei Tappan, 1957. –Holbourn & Kaminski, 1997, p. 31; pl. 1, figs 1-2.

***Bathysiphon vitta* Nauss, 1947**

Plate 1, fig. 15

Bathysiphon vitta Nauss, 1947. –Weidich, 1990, p. 80; pl. 12, fig. 22; pl. 33, figs 15-18.

***Hippocrepina depressa* Vašíček, 1947**

Plate 2, figs 1-3

Hippocrepina depressa Vašíček, 1947. –Holbourn & Kaminski, 1997, p. 34; pl. 15, figs 1-5. –Weidich, 1990, p. 80; pl. 33, fig. 19.

***Hippocrepina gracilis* Holbourn & Kaminski, 1995**

Hippocrepina gracilis Holbourn & Kaminski, 1997, p. 34; pl. 4, figs 3-5.

***Rhizammina* spp.**

Plate 1, figs 1-13

Lituolids***Ammodiscus* spp.**

Plate 2, fig. 19

***Ammodiscus infimus* Franke, 1936**

Plate 3, figs 1-7

Ammodiscus infimus Franke, 1936. –Weidich, 1990, p. 82; pl. 34, figs 1-3. –Holbourn & Kaminski, 1997, p. 35; pl. 4, fig. 9-11.

***Bimonilina entis* Mjatliuk, 1988**

Plate 4, figs 9-11

Bimonilina entis Mjatliuk, 1988, p. 62; pl. 24, figs 6-8.

***Glomospira gordialis* (Jones & Parker, 1860)**

Plate 9, figs 4-5

Glomospira gordialis (Jones & Parker, 1860). –Holbourn & Kaminski, 1997, p. 36; pl. 5, fig. 5.

***Glomospira charoides* (Jones & Parker, 1860)**

Plate 2, fig. 17

Glomospira charoides (Jones & Parker, 1860). –Holbourn & Kaminski, 1997, p. 36; Plate 5, figs 7-11.

***Glomospirella* spp.**

Plate 2, fig. 18

***Haplophragmoides kirki* Wickenden, 1932**

Plate 4, figs 1-3

Haplophragmoides kirki Wickenden, 1932. –Weidich, 1990, p. 87; pl. 3, fig. 17; pl. 7, figs 5-7; pl. 36, figs 4, 9-10.

***Haplophragmoides gigas gigas* Cushman, 1927**

Plate 4, figs 6-8

Haplophragmoides gigas gigas Cushman, 1927. –Weidich, 1990, p. 87; pl. 1, fig. 12; pl. 7, fig. 16; pl. 36, figs 13-14.

***Haplophragmoides gigas minor* Nauss, 1947 *sensu* Weidich**

Plate 4, fig. 5

Haplophragmoides gigas minor Nauss, 1947. –Weidich, 1990, p. 87; pl. 7, fig. 4; pl. 36, fig. 11-12.

***Reophax helveticus* (Haeusler, 1881)**

Plate 2, figs 4-7

Reophax helveticus (Haeusler, 1881). –Holbourn & Kaminski, 1997, p. 39; Plate 8, figs 1-2.

***Reophax liasicus* Franke, 1936**

Plate 2, figs 8-9

Reophax liasicus Franke, 1936. –Weidich, 1990, p. 85; pl. 34, fig. 17.

Reophax cf. parvulus

Plate 2, fig. 16

***Scherochorella minuta* (Tappan, 1940)**

Plate 2, figs 14-15

Reophax minutus Tappan, 1940. –Weidich, 1990, p. 85; pl. 34, figs 19, 21-23.

Remarks. *Scherochorella minuta* forma A and form B have been distinguished based on the relative chamber size. *S. minuta* forma A includes the specimens displaying a remarkable size difference between the first and the last chambers, i.e., faster growing chambers; *S. minuta* forma B comprises the specimens displaying a very low size difference between the first and the last chambers, i.e. slower growing chambers.

***Trochammina wetteri* Stelck & Wall**

Plate 4, fig. 4

Trochammina wetteri Stelck & Wall. –Weidich, 1990, p. 100; pl. 9, figs 1, 5, 8; pl. 9, figs 1, 5, 8, pl. 36, figs 1-3.

***Verneuilinoides cf. neocomiensis* (Mjatliuk, 1939)**

Plate 5, figs 1-9

Verneuilinoides neocomiensis (Mjatliuk, 1939). –Weidich, 1990: p. 108; pl. 12, figs 11-12.

Textulariids (6 genera, 6 species)

***Dorothia hyperconica* Risch, 1970**

Plate 5, fig. 10

Dorothia hyperconica Risch, 1970. –Weidich, 1990: p. 109; pl. 16, figs 4-13.

***Gaudryina jendrekovae* Weidich, 1990**

Plate 5, figs 15-16

Gaudryina inflata Jendrekova, 1968,

Gaudryina jendrekovae Weidich, 1990: p. 102; pl. 14, figs 1-11, 17-18; pl. 38, figs 10-14.

***Spiroplectinata lata* Grabert, 1959**

Plate 5, fig. 19

Spiroplectinata lata Grabert, 1959. –Weidich, 1990: p. 105; pl. 11, figs 5-8, 11; pl. 50, figs 16-19.

“Textulariid sp. A.”

Plate 5, figs 11-14.

“Textulariid sp. B “

Plate 5, figs 17-18.

“Textulariid sp. C”

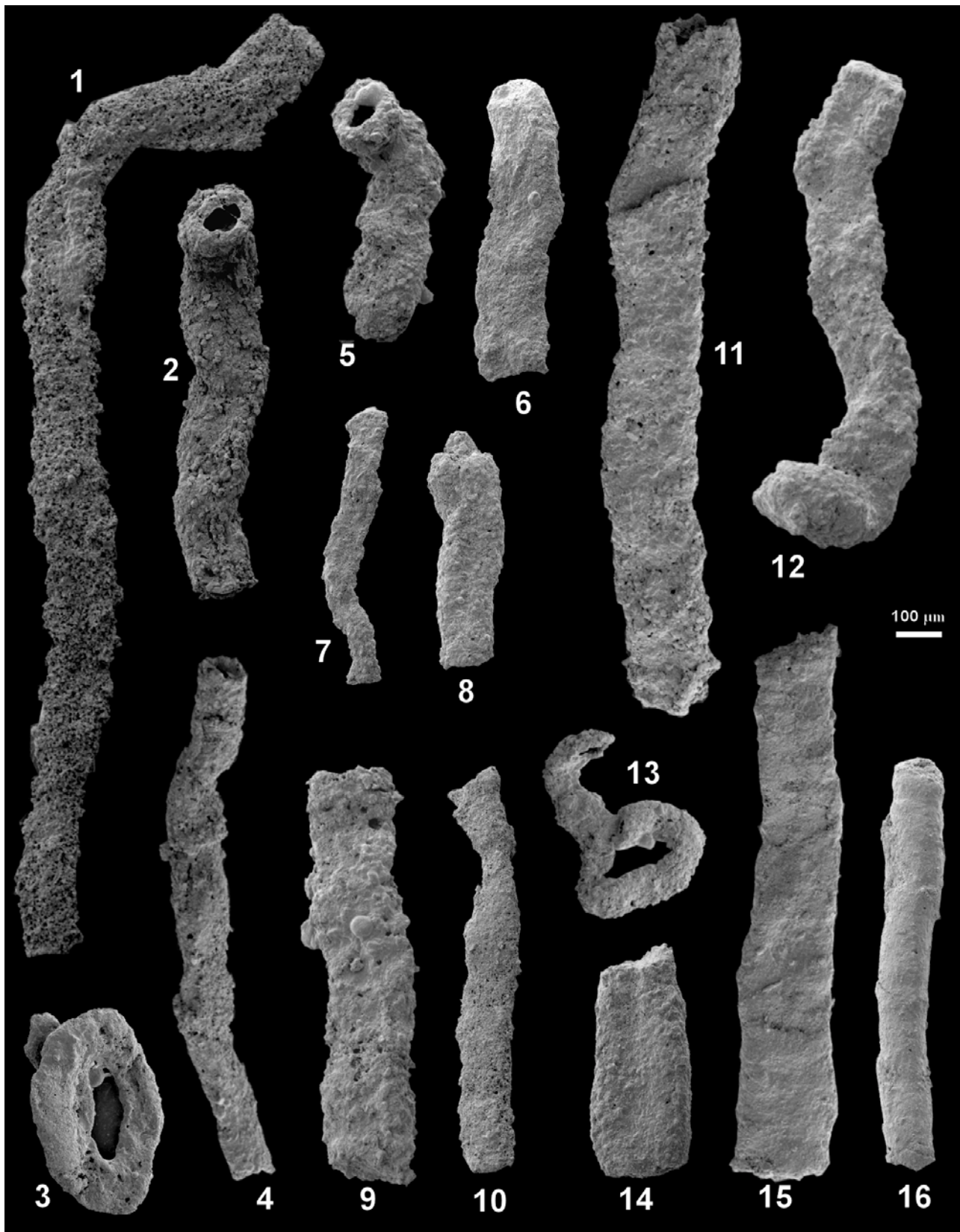


PLATE 1. 1-13. *Rhizammina* spp. Length: 2.18 mm. 1. Sample -3 (HCl). 2. Sample -13 (HCl). Length: 0.94 mm. 3. Sample -9 (HCl). Length: 0.46 mm. 4. Sample -1 (HCl). Length: 1.17 mm. 5. Sample -5 (HCl). Length: 0.60 mm. 6. Sample -0.03 (HCl). Length: 0.68 mm. 7. Sample -0.01 (Acetic). Length: 0.62 mm. 8. Sample +0.50bis (HCl). Length: 0.54 mm. 9. Sample +2.50 (HCl). Length: 0.94 mm. 10. Sample -0.20 (HCl). Length: 0.91 mm. 11. Sample -9 (HCl). Length: 1.57 mm. 12. Sample +1.50 (Acetic). Length: 1.09 mm. 13. Sample -9 (HCl). Length: 0.41 mm. **14-15.** *Bathysiphon vita* Nauss, 1947. Sample +3 (HCl). Length: 0.50 mm. 15. Sample -0.25 (HCl). Length: 1.25 mm. **16.** *Bathysiphon brosgiei* Tappan, 1957. Sample +1 (HCl). Length: 0.92 mm. All specimens x80.

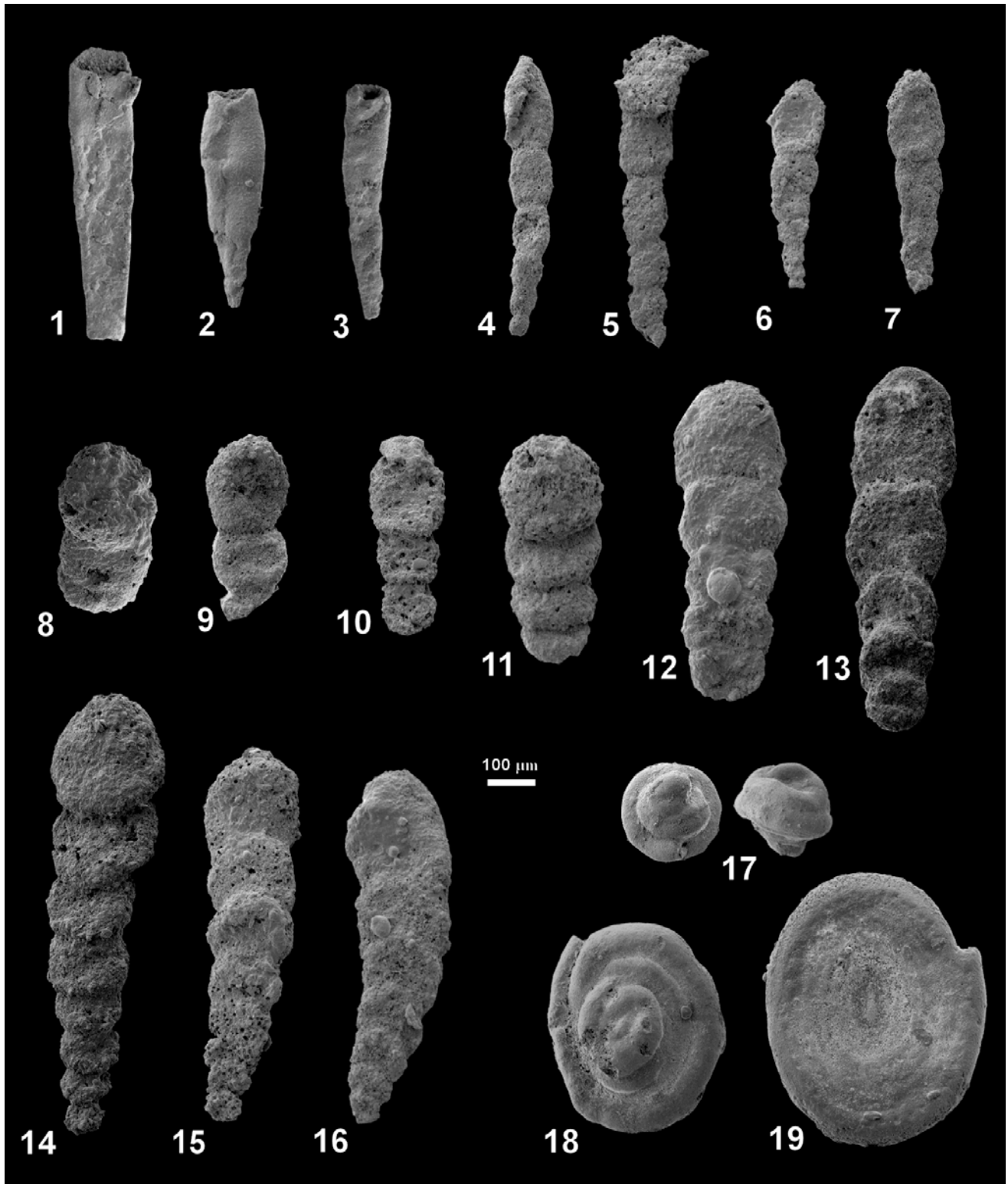


PLATE 2. 1-3. *Hippocrepina depressa* Vašíček, 1947. 1. Sample -13 (HCl). Length: 0.64 mm. 2. Sample -11 (HCl). Length: 0.47 mm. 3. Sample -ROSE (HCl). Length: 0.50 mm. 4-7. *Reophax helveticus* (Haeusler, 1881). Sample -11 (HCl). Length: 0.60 mm. 5. Sample -9 (HCl). Length: 0.66 mm. 6. Sample -9 (HCl). Length: 0.45 mm. 7. Sample -0.25 (HCl). Length: 0.48 mm. 8-9. *Reophax liasicus* Franke, 1936. Sample +0.50bis (HCl). Length: 0.36 mm. 9. Sample +1.50 (HCl). Length: 0.36 mm. 10-13. *Scherochorella minuta* (Tappan, 1940), form B. Sample -0.01 (HCl). Length: 0.43 mm. 11. Sample +0.50bis (Acetic). Length: 0.50 mm. 12. Sample +2.50 (HCl). Length: 0.68 mm. 13. *Scherochorella minuta* (Tappan, 1940), form B. Sample +1.00 (HCl). Length: 0.78 mm. 14-15. *Scherochorella minuta* (Tappan, 1940), form A. Sample +1.00 (HCl). Length: 0.95 mm. 15. Sample +1.50 (HCl). Length: 0.80 mm. 16. *Reophax* cf. *parvulus*. Sample +3 (HCl). Length: 0.75 mm. 17. *Glomospira charoides* (Jones & Parker, 1860). Sample -ROSE (HCl). Length: 0.22 mm. 18. *Glomospirella* sp. Sample +13 (Acetic). Length: 0.45 mm. 19. *Ammodiscus* sp. Sample +15 (Acetic). Length: 0.58 mm. All specimens x80.

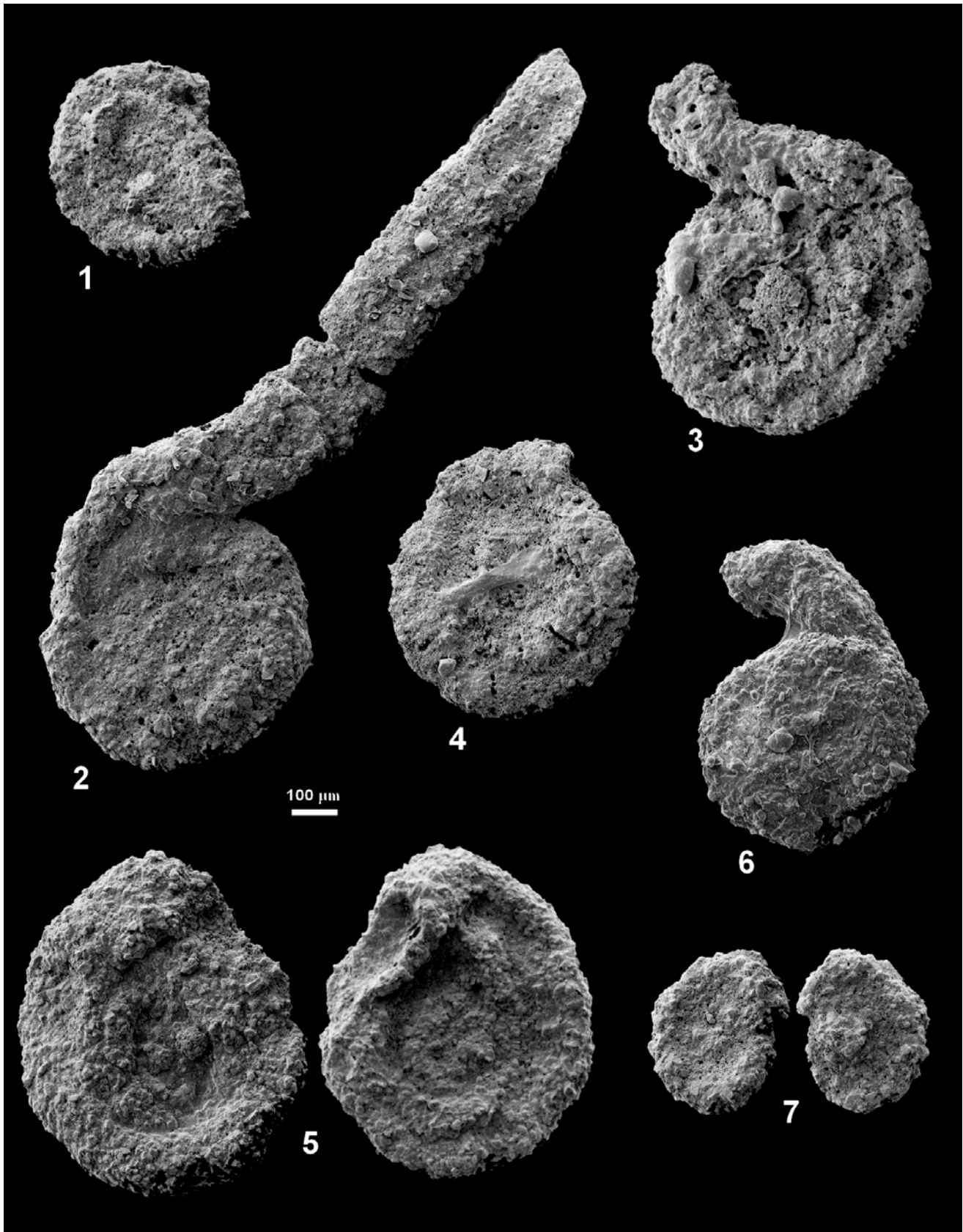


PLATE 3. 1-7. *Ammodiscus infimus* Franke, 1936. 1. Sample +1.50 (HCl). Length: 0.48 mm. 2. Sample +1.50 (HCl). Length: 0.76 mm (central part), 1.87 mm (maximum). 3. Sample +2.50 (HCl). Length: 0.70 mm (central part), 0.87 mm (maximum). 4. Sample +2.50 (HCl). Length: 0.63 mm. 5. Sample +2.50 (Acetic). Length: 0.78 mm. 6. Length: 0.53 mm (central part), 0.71 mm (maximum). Sample +5 (Acetic). 7. Sample +3 (Acetic). Length: 0.38 mm. All specimens x80.

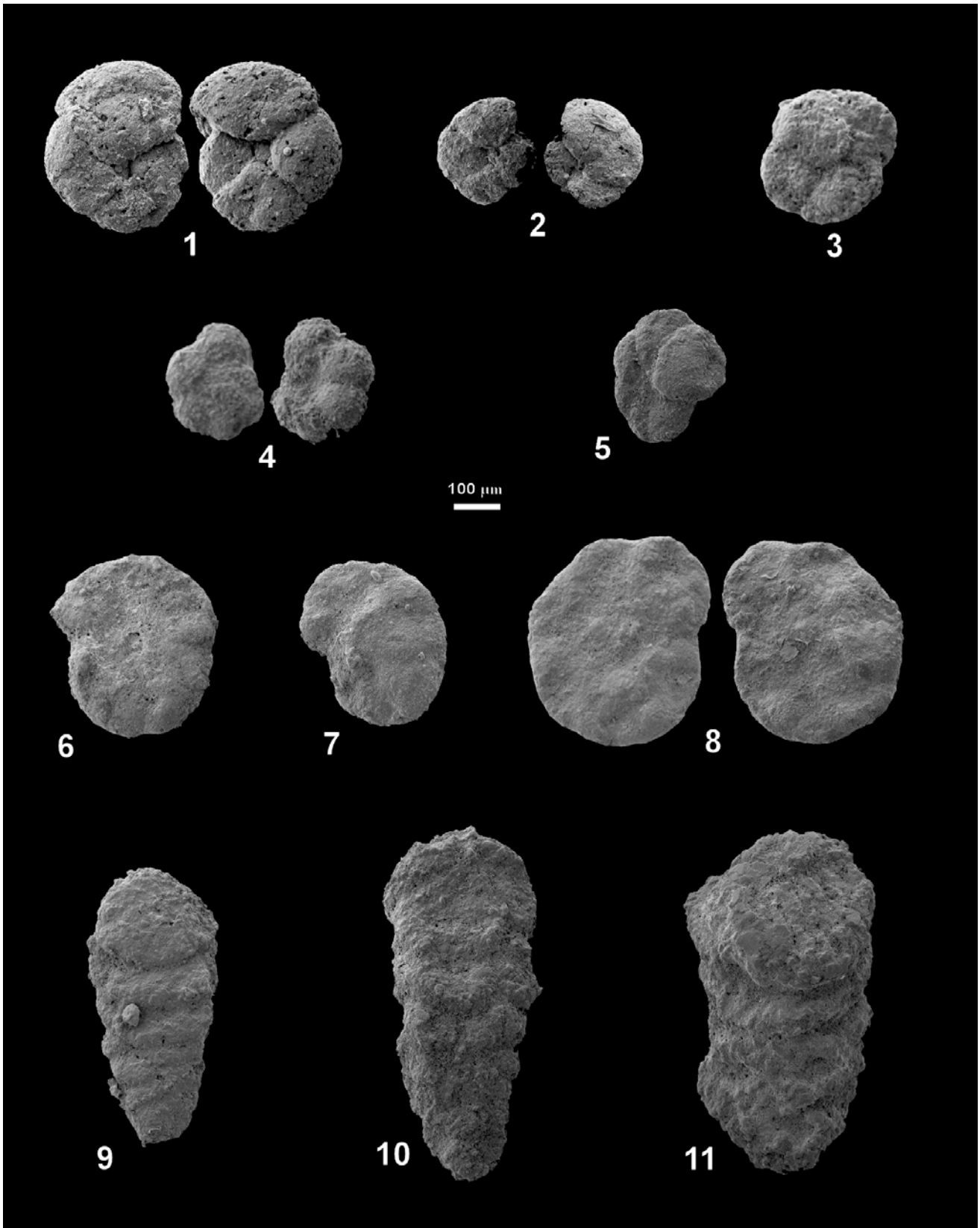


PLATE 4. 1-3. *Haplophragmoides kirki* Wickenden, 1932. 1. Sample -9 (HCl). Length: 0.38 mm. 2. Sample -9 (HCl). Length: 0.25 mm. 3. Sample +0.50bis (HCl). Length: 0.32 mm. 4. *Trochammina wetteri* Stelck & Wall, 1947. Sample -5 (HCl). Length: 0.26 mm. 5. *Haplophragmoides gigas minor* Naus, 1947 *sensu* Weidich. Sample +3 (HCl). Length: 0.30 mm. 6-8. *Haplophragmoides gigas gigas* Cushman, 1927. 6. Sample +1.50 (HCl). Length: 0.41 mm. 7. Sample +1.50 (Acetic). Length: 0.39 mm. 8. Sample +7 (Acetic). Length: 0.48 mm. 9-11. *Bimonilina entis* Mjatluk, 1988. 9. Sample +3 (HCl). Length: 0.61 mm. 10. Sample +3 (Acetic). Length: 0.79 mm. 11. Sample +11 (Acetic). Length: 0.76 mm. All specimens x80.

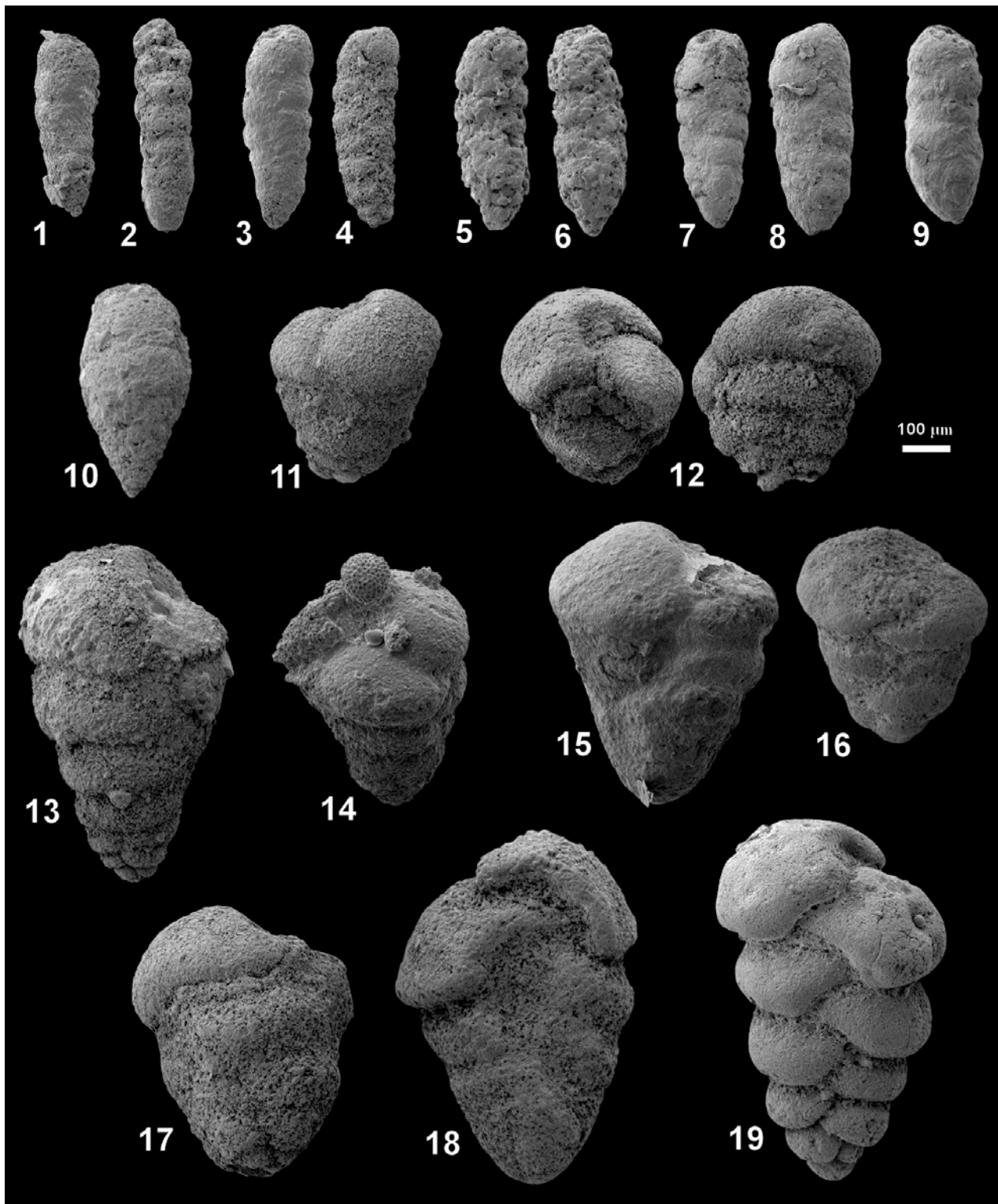


PLATE 5. 1-9. *Verneuilinoides* cf. *neocomiensis* (Mjatliuk, 1939). 1. Sample -5 (Acetic). Length: 0.40 mm. 2. Sample -1.50 (Acetic). Length: 0.46 mm. 3. Sample -0.50 (Acetic). Length: 0.44 mm. 4. Sample -0.30 (Acetic). Length: 0.43 mm. 5. Sample -0.20 (Acetic). Pyritised specimen. Length: 0.44 mm. 6. Sample -0.20 (Acetic). Pyritised specimen. Length: 0.45 mm. 7. Sample -0.15 (Acetic). Pyritised specimen (colour red). Length: 0.43 mm. 8. Sample -0.15 (Acetic). Pyritised specimen (colour red). Length: 0.45 mm. 9. Sample -0.10 (Acetic). Pyritised specimen (colour red). Length: 0.43 mm. **10.** *Dorothia hyperconica* Risch, 1970. Sample -0.30 (Acetic). Length: 0.46 mm. **11-14.** “Textulariid sp. A”. Length: 0.42 mm (x80). 11. Sample +3 (Acetic). 12. “Textulariid sp. A”. Length: 0.45 mm. Sample +3 (Acetic). 13. “Textulariid sp. A”. Length: 0.73 mm. Sample +3 (Acetic). 14. “Textulariid sp. A”. Length: 0.51 mm. Sample +5 (Acetic). **15-16.** *Gaudryina jendrejakovae* Weidich, 1990. Sample +9 (Acetic). Length: 0.61 mm. 16. Sample +11 (Acetic). Length: 0.46 mm. **17-18.** “Textulariid sp. B”. Sample +15 (Acetic). Length: 0.60 mm. 18. Sample +15 (Acetic). Length: 0.76 mm. **19.** *Spiroplectinata lata* Grabert, 1959. Sample +13 (Acetic). Length: 0.78 mm (x80).