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JURASSIC MICROFACIES, ROSSO AMMONITICO LIMESTONE, SUBBETIC CORDILLERA, SPAIN

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Abstract

Two thin condensed sections of Rosso Ammonitico from Southern Spain are compared to similar facies in Northern Italy. The characteristic microfauna is composed of protoglobigerinids, Calcisphaerulidae associated with *Bositra* and abundant young ammonites. The matrix is diagenetically altered and no iron bacterial filaments are observed. The iron has been remobilized in the early stages of the lithification as shown by the microsparitization of the matrix, the strong solution-recrystallization processes inside the shells and the fillings of the complex calcitic veinlets associated with the formation of very irregular hematitic veils that criss-cross the matrix. In such strongly diagenetically altered environments submicronic filaments would have been destroyed.

Key words: Condensed series, Red matrix, Iron bacteria, Hemipelagic sedimentation.

Résumé

Deux minces séries condensées de l'Ammonitico Rosso du Sud de l'Espagne sont comparées avec des faciès similaires du Nord de l'Italie. La microfaune caractéristique est composée de Protoglobigérinidés et Calcisphérulidés associés à des *Bositra* et à d'abondantes petites Ammonites. La diagenèse a fortement altéré la matrice micritique et aucun filament de ferro-bactéries n'a pu être observé. Le fer a été remobilisé dès les premiers stades de la lithification lors de la formation de microspar calcitique dans la matrice micritique, en association avec des processus de dissolution-recristallisation intrabioclastiques et de développement de veines irrégulières de calcite à remplissages complexes. Des voiles hématitiques fort irréguliers recoupent la matrice. Dans de tels environnements fortement affectés par la diagenèse précoce les filaments submicrométriques ont probablement été détruits.

Mots clés: Séries condensées, Matrice rougeâtre, Ferro-bactéries, Sédimentation hemipélagique.

Resumen

En este estudio se realiza un análisis comparativo entre dos secciones finamente condensadas de facies del tipo Ammonitico Rosso, una en el sur de España y la otra en el norte de Italia. La macrofauna característica está formada por protoglobigerínidos, Calcisphaerulidae asociados con *Bositra* y con abundantes ejemplares juveniles de ammonites. La matriz está alterada diagenéticamente y no se observan filamentos bacterianos ferrosos. El hierro ha sido removilizado en los estadios iniciales de la litificación, como lo demuestra la microesparitización de la matriz, los marcados procesos de disolución-recristalización que se producen en el interior de las conchas, y los rellenos calcíticos en forma de nerviación compleja asociados con la forma de velos irregulares de hematites que entrecruzan la matriz. En ambientes tan diagenéticamente alterados se han destruido los filamentos submicrónicos.

Palabras clave: Series condensadas, Matriz roja, Bacterias ferruginosas, Sedimentación hemipelágica.

INTRODUCTION

We have recently studied the sedimentation of the Rosso Ammonitico Veronese (Mamet & Préat, 2003). We initiated that research in Northern Italy, the classical region of that facies and published recently new results for these series (Préat *et al.,* 2006). The unit has been studied for more than one century and some of the stratigraphic aspects are remarkably well-known (Sturani, 1964; 1971). The sedimentary aspect (palaeontology, sedimentology, diagenesis) was the subject of an exhaustive symposium (Farinacci & Elmi, 1981) recently updated by Martire (1996). The only aspect that was neglected up to now was the origin of the pigmentation of the rocks and our research (Mamet & Préat, 2005; 2006; Préat *et al.,* 2006) has shown that the red colour is related to the presence of iron microbes that oxidized the ferrous iron at the sediment (micrite)–water interfaces. The small-sized (< 1 μm *in* Préat *et al.,* 2006) micritic support was colonized by iron-bacterial and fungal hyphae, forming mats within the carbonate matrix. The microbial activity led to the bioprecipitation of submicronic iron/manganese oxy-hydroxide minerals in the facies which became reddish. Since these microbes were probably growing under microaerophilitic conditions, autooxidation of Fe(II) is to be expected to proceed at slow rates (Ghiorse, 1984). Under oxygen-depleted conditions, microbially mediated Fe(II)-oxidation is an important component of the Fe redox cycles and bacteria oxidized passively the ferrous iron (Brierley, 1990). In most cases, the products of biologically oxidized Fe are highly insoluble ferric [Fe(III] (hydro)oxide minerals that have the potential to be preserved in rocks (Haese, 2000; Croal *et al.,* 2004).

Surprisingly, in spite of the deep red color of the rock, the iron content is remarkably low (average 350 ppm, Préat *et al.,* 2006). Our general conclusions concerning the overall microfacies of the typical Mid Jurassic Rosso Ammonitico Veronese are:

1. a highly condensed open marine, hemipelagic sequence, hence the presence of numerous hardgrounds;
2. dissolved ammonites are in association with protoglobigerinids and thin *Bositra* molluscan shells;
3. some occasional shallow-water fauna are clearly reworked;
4. due to the lack of tectonic stress and very little overburden, a number of fragile bioconstructions are preserved (submicronic filaments, erythrospheres, single and complex biofilms and microstromatolites, various oncolites, hematite infilling of cavities in original voids and perforations).

It was interesting to see if these observations could be extended to an 'apparently' similar Rosso Ammonitico of the Subbetic Cordillera. These Spanish outcrops have been extensively studied and the results are published in the proceedings on the Rosso Ammonitico (Farinacci & Elmi, 1981). We have studied two Mid and Late Jurassic sections: Puente del Zegri and Cortijo de Casa Blanca (Figure 1).

Both sections are described in great details by Braga *et al.* (1981) and Comas *et al.* (1981). We have followed their stratigraphic framework, essentially based on ammonite biozones. Both sections are very well exposed along existing roads. We have collected 41 samples (Figure 2) that have yielded about hundred and thirty thin sections.

PETROGRAPHICAL STUDY

Zegri section (N 37 25 141, W 003 35 490, Figure 2a): 8 m thick, 3 levels of nodular red packstones with hardgrounds. Typical Rosso Ammonitico on the field.

a. Petrography. Highly bioturbated nodular wackestones with abundant *Bositra* (Pl. 2, Fig. 1-2) and

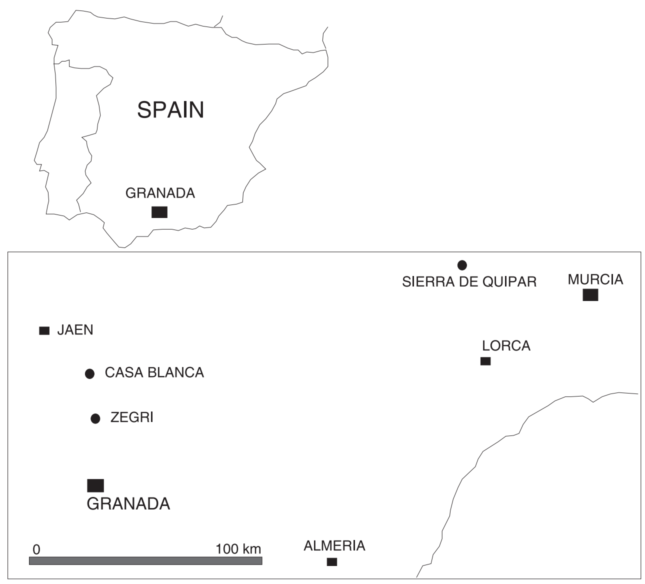


FIGURE 1–Geographical locations of the two studied sections in the Subbetic Cordillera, SE Spain.

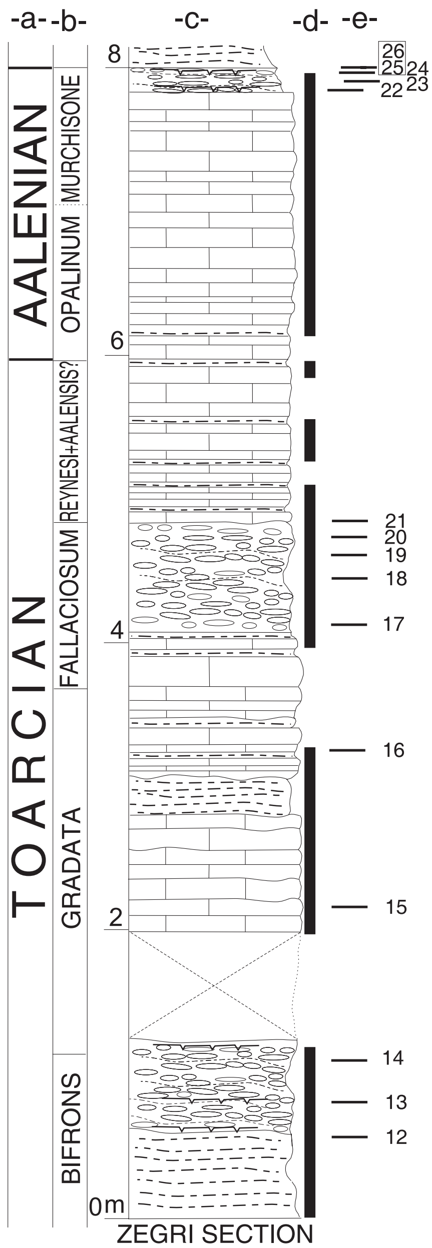


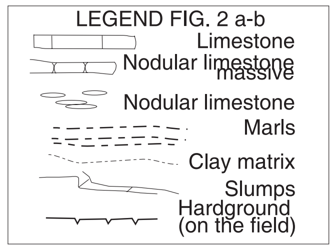
FIGURE 2a–Zegri section with columns -a- Stage; -b- Ammonite zonation; -c- lithology; -d- black bar for red or violet color, other parts are grey or yellowish; -e- samples collected during this study. From Braga *et al.,* 1981 (modified). Legend in figure 2b.

numerous micritized small ammonites (Pl. 1, Fig. 2, 4). Additional fossils are small gastropods, pelecypods, pelagic protoglobigerinids, rare echinoids, sponge spicules, Calcisphaerulidae, benthic foraminifers, ostracods, ophiuroids and probable holothuroids (Pl. 3, Fig. 12-19). Apparent absence of calcareous algae, bryozoans and brachiopods. Aggregates of glauconitic peloids (grey green , Pl. 1, Fig. 2). The micritic matrix is systematically recrystallized and the contacts of fragments and calcite microspar are fuzzy. True stylolites are rare.

b. Habitus of hematite

(1) no obvious bacterial and fungal filaments have been observed. Hematite is erratically dispersed in the microsparitic matrix and diagenetically concentrated between the spar crystals (Pl. 3, Fig. 2, 3, 10). The microspar crystals show a great variety of sizes and shapes from rounded to acicular;

(2) rare sponge perforations observed in the pelecypods and foraminifers (Pl. 3, Fig. 5, 6, 11);



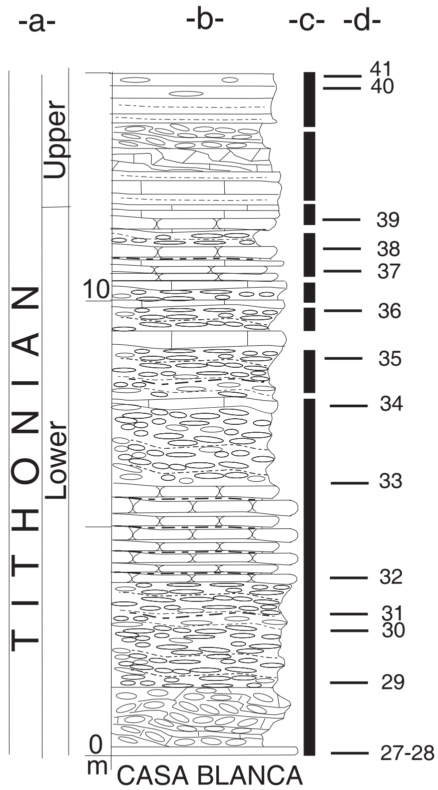


FIGURE 2b–Cortijo de Casa Blanca section with columns -a- Stage; -b- lithology; -c- black bar for red or violet color, other parts are grey or yellowish; -d- samples collected during this study. The Casa Blanca section expands from Lower Jurassic to Lower Cretaceous (Comas *et al.,* 1981). Rosso Ammonitico facies occur in Middle and Upper Jurassic and the part of the studied section concerns only the Tithonian. Legend for figures 2a and b.

(3) infillings of original voids (foraminifers, ammonites) (Pl. 1, Fig. 3);

(4) alteration of crinoidal stereoms (Pl. 3, Fig. 7-8);

(5) incipient blisters;

(6) *Frutexites* tufts (Pl. 1, Fig. 1);

(7) apparent absence of iron stromatolites, oncolites and single or multiple biofilms;

(8) dissolved calcitic penecontemporaneous fissures (Pl. 3, Fig. 9), irregular veils and some hardgrounds (Pl. 3, Fig. 4).

Casa Blanca section (N 37 34 167, W 003 39 889, figure 2b): 13 m of red nodular wackestones with some hardgrounds. Typical Rosso Ammonitico on the field. The red nodular beds vary from limestone nodular facies to more clayey facies with interspersed redeposited layers (Comas *et al.,* 1981).

a. Petrography. Bioturbated red nodular wackestones-packstones with disarticulated ophiuroid and ?holothuroid ossicles. By comparison, ammonites are much less represented. Except the Calpionellidae which could be abundant (Comas *et al.,* 1981), other associated forms consist of Calcisphaerulidae, *Bositra*, pelecypods, gastropods, protoglobigerinids, sponge spicules, echinoids, radiolarians. One reworked fragment of coral has been observed.

b. Habitus of hematite

(1) again no obvious microbial filaments have been detected;

(2) rare sponge perforations preserved in the ophiuroid ossicles and pelecypods. In the former the hematite infillings follow the wall structure (Pl. 1, Fig. 5; Pl. 3, Fig. 11);

(3) infillings of original voids (ammonites and Calpionellidae) (Pl. 2, Fig. 7);

(4) alteration of crinoids and echinoids;

(5) apparent absence of iron stromatolites, oncolites and single or multiple biofilms;

(6) irregular veils (Pl. 1, Fig. 7, 8);

(7) dissolved calcitic penecontemporaneous fissures (Pl. 1, Fig. 6);

(8) early diagenetically stressed calcite fissures that should not be confused with true stylolites;

(9) true stylolites;

(10) some hardgrounds.

DISCUSSION AND CONCLUSION

Our discussion consists in a comparison between what is known from the Italian and the Spanish Rosso Ammonitico limestones. We should underline here that our conclusions should be considered with caution as they are only based on a limited number of observations and sections. Indeed the Rosso Ammonitico series have been used in many different situations and interpretations and there has been a controversy in the interpretation of these environ-

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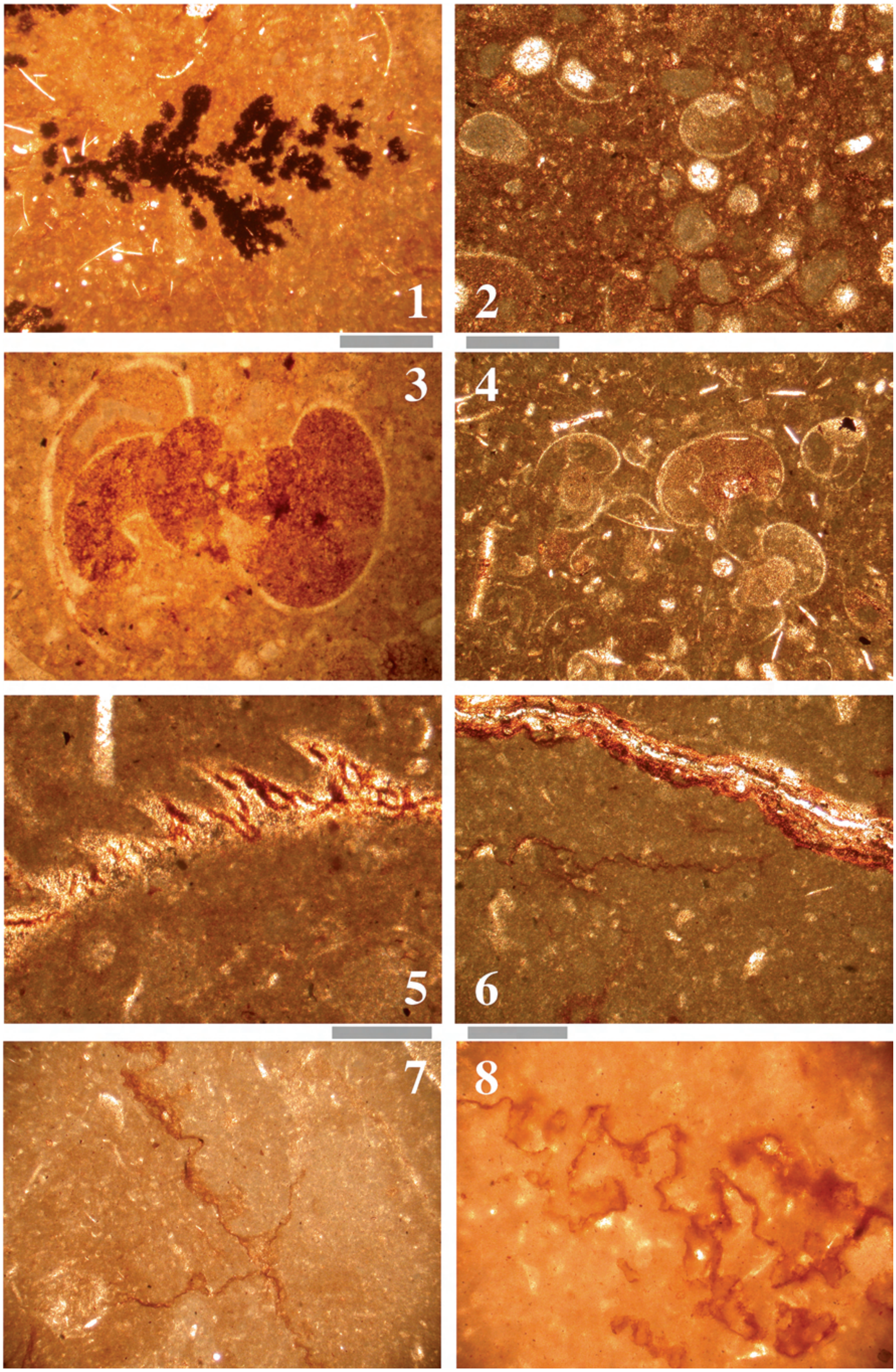
PLATE 1–*1,* Hematite coated *Frutexites* in a red *Bositra* wackestone. Sample ESP 12, ph.ulb.9920, Puente del Zegri, *Bifrons Zone*, muddy red nodular limestone with hardgrounds, Toarcian, scale bar is 950 µm. *2,* Glauconite pellets wackestone. Sample ESP 21, ph.ulb.9976, Puente del Zegri, top of *Fallaciosum* Zone, muddy nodular limestone, Toarcian, scale bar is 155 µm. *3,* Hematite infilling in a partly dissolved ammonoid. Sample ESP 21, ph.ulb. 9966, Puente del Zegri, top of *Fallaciosum* Zone, muddy nodular limestone, Toarcian, scale bar is 100 µm. *4,* A typical Rosso Ammonitico facies with swarms of mud filled young ammonites, Calciphaerulidae, *Bositra* and pelecypod fragments. Sample ESP 14, ph.ulb.9936, Puente del Zegri, top of *Bifrons* Zone, muddy red nodular limestone with hardgrounds, Toarcian, scale bar is 390 µm. *5,* Hematite perforations following the ophiuroid ossicle structure in a red wackestone. Compare the ossicle with Middle Devonian *Pectenura pecten* Boczarowski 2001. Samples ESP 30, ph.ulb.9990, Cortijo de Casa Blanca, nodular red limestone, Lower Tithonian, scale bar is 100 µm. *6,* Hematite/calcite laminar stringers formed during early diagenesis of a microbioclastic wackestone. These should not be confused with hardgrounds. Sample ESP 37, ph.ulb.28, Cortijo de Casa Blanca, nodular red limestone, Lower Tithonian, scale bar is 155 µm. *7-8,* Irregular hematite veils criss-crossing the matrix, formed during early diagenesis as the stringer is interrupted by a bioturbation (Fig. 7, lower left). Again these figures should not be confused with hardgrounds or stylolites. Samples ESP 38 and 41 respectively, ph.ulb.42 and 61 respectively, Cortijo de Casa Blanca, nodular red limestone, respectively Lower and Upper Tithonian, scale bars are 390 and 155 µm respectively.

PLATE 1



ments with hypotheses ranging from oceanic (Aubouin, 1964) to shallow platform (Ameur & Elmi, 1981) with all possible intermediate situations.

We reach similar conclusions on sedimentation in spite the fact that we are dealing with rocks of different ages. The Rosso Ammonitico Veronese has no Tintinnids. But other Italian Rosso Ammonitico contain Calpionellidae that occur from the Tithonian upwards (Colom, 1948; Grün & Blau, 1996). In spite of this, the clear dominance of hemipelagic fauna indicates that both series are at the edge of a continental platform (ammonoids, ophiuroids, holothuroids, Calpionellidae, Calcisphaerulidae, protoglobigerinids). An interesting aspect of our study is the discovery of abundant ophiuroids and probable holothuroids similar to fossil (Middle Devonian *in* Boczarowski, 2001) or Recent forms (the Elasipoda holothurians *in* Hansen, 1977; Gilliland, 1993). These are known to occur at all bathymetric ranges (Barnes, 1980). Holothuroids are important burrowers even at bathyal depth and could explain why the Spanish series are so bioturbated. The Recent smallest species are less than 3 cm in lenght whereas the largest may attain a lenght of 1 m and a diameter of 24 cm (Barnes, 1980). They are chiefly deposit or suspension feeders and the burrowing is accomplished by alternate contraction of longitudinal and circular muscle layers of the body wall in the same manner employed by earthworms. They generally lie on the sea floor or burrow into it with their long axis horizontal (Clarkson, 1986). Many holothuroids burrow or hide and extend their tentacles to obtain food directly from the water (Castro & Hubber, 1997). These animals have extensive internal branching systems (respiratory trees) which arise from the cloaca. Water is pulled into and expelled from the respiratory trees by contractions of the cloaca and gas exchange takes place as this process occurs (Raven & Johnson, 2002). Significant modifications of the sediments have been to be expected as a result of the great sizes of these animals and their important activities (locomotion, nutrition, gas exchange, excretion, burrowing) and this could also explain why some irregular and not well-defined nodules ('pseudo-nodules' with no clear boundaries) could be linked to the presence of these organisms.

A negative conclusion concerns the absence of proven bacterial filaments. Most observed hematite concentrations in Spain are similar to those observed in the Italian Rosso Ammonitico, but this does not prove a microbial mediation. The iron has been remobilized in the early stages of the lithification as shown by the microsparitization of the matrix, the strong solution-recrystallization processes inside the shells (Pl. 3, Fig. 1-3, 10) and the fillings of the complex calcitic veinlets associated with the formation of very irregular hematitic veils that criss-cross the matrix (Pl. 1, Fig. 7-8). Such veils have been observed in iron oncolites and stromatolites of the French Sainte-Honorine-des-Pertes Bajocian stratotype (Préat *et al*., 2000). They should not be confused with stylolites or hardgrounds. Therefore it is probable that some hardgrounds mentioned in the Spanish litterature are due to diagenetic processes. In such strongly diagenetically altered environments submicronic filaments would have been destroyed.

Better preservation of microbes is mentionned in the Late Jurassic of the Subbetic Zone of Southern

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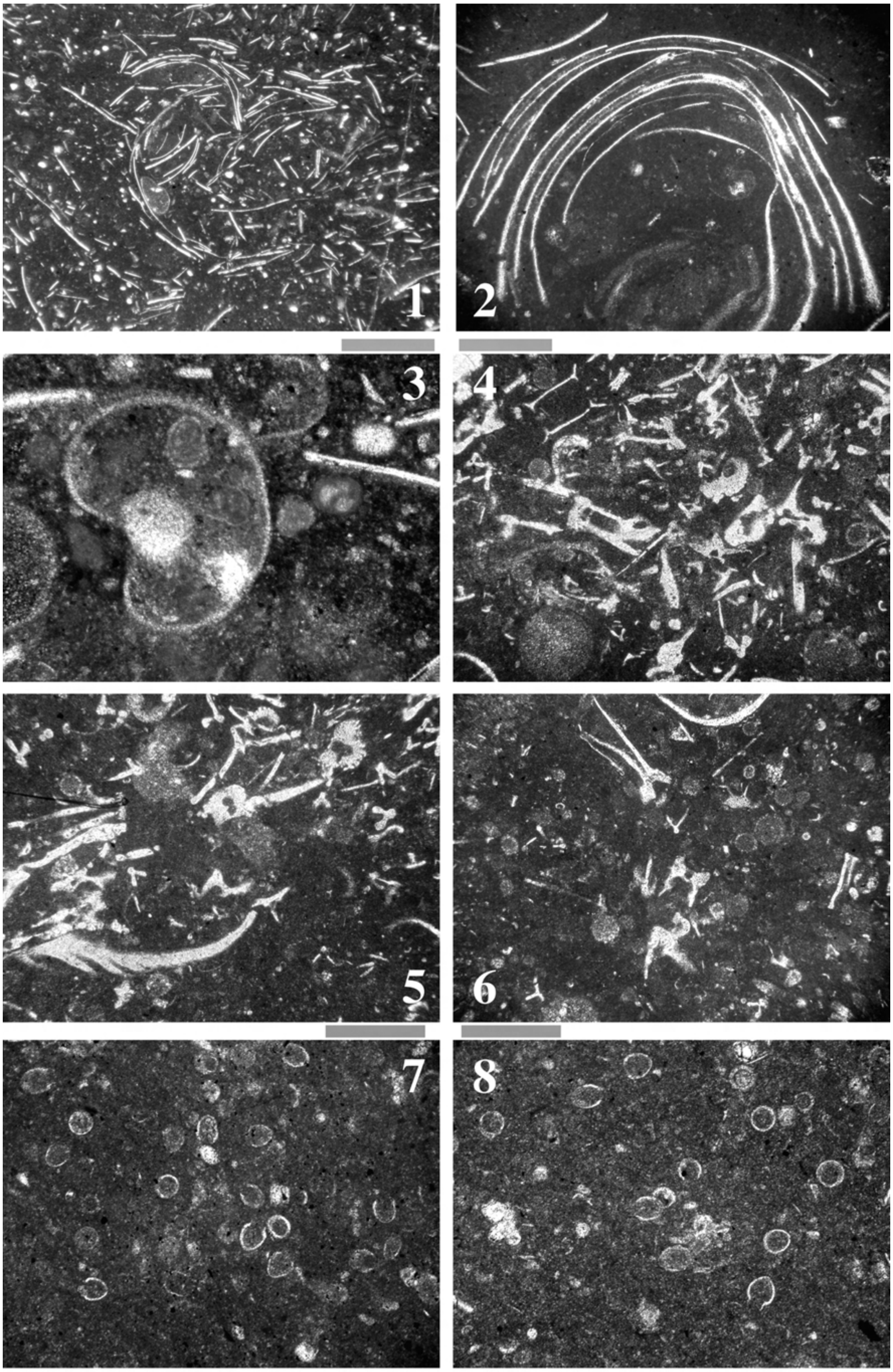
PLATE 2–*1,* Densely packed, bioturbated *Bositra* red packstone. Sample ESP 12, ph.ulb.9923, Puente del Zegri, *Bifrons* Zone, muddy nodular facies with hardgrounds,Toarcian, scale bar is 155 µm. *2,* Imbricated *Bositra* shells indicating gentle water lapping. Sample ESP 25, ph.ulb.32, Puente del Zegri, top of section, muddy nodular facies, *Muchisone* Zone, Aalenian, scale bar is 390 µm. *3,* Mud-filled dissolved ammonoid red packstone, glauconite pellets, *Bositra* fragments, and scattered hematite. Sample ESP 20, ph.ulb.9973, Puente del Zegri, top of *Fallaciosum* Zone, muddy nodular facies,Toarcian, scale bar is 155 µm. *4-5,* Disarticulated holothuroid(?) and ophiuroid ossicles red packstone. Glauconite grains, Calcisphaerulidae and mud filled Calpionellidae. Sample ESP 31, ph.ulb.9993 and ph.ulb.9994 respectively, Cortijo de Casa Blanca, nodular facies, Lower Tithonian, scale bar is 390 µm. *6,* Glauconite-filled Calcisphaerulidae, protoglobigerinids, calcified radiolarians and fragments of holothuroid and ophiuroid ossicles in a red packstone. Sample ESP 35, ph.ulb.48, Cortijo de Casa Blanca, nodular facies, Lower Tithonian, scale bar is 390 µm. *7-8,* Well-sorted mud-filled red calpionellid wackestone *(Calpionella).* Samples ESP 39, ph.ulb.29 and 31 respectively, Cortijo de Casa Blanca, nodular facies, Lower Tithonian, scale bar is 155 µm.

PLATE 2



Spain (Braga *et al.,* 1981; Olóriz *et al.* 2003) but no Rosso Ammonitico is present in that tectonic zone. Better preservation of the Rosso Ammonitico is also to be expected in the nearby Murcia Region (Sierra de Quipar). Delgado *et al.* (1981) have actually published an illustration (their Fig. 5D) that clearly shows well preserved iron stromatolites covering an ammonite shell coated by hematite biofilms. It is in such associations that filamentous iron bacteria are normally preserved. Thus more research should be undertaken in that region to track down the elusive bacteria.

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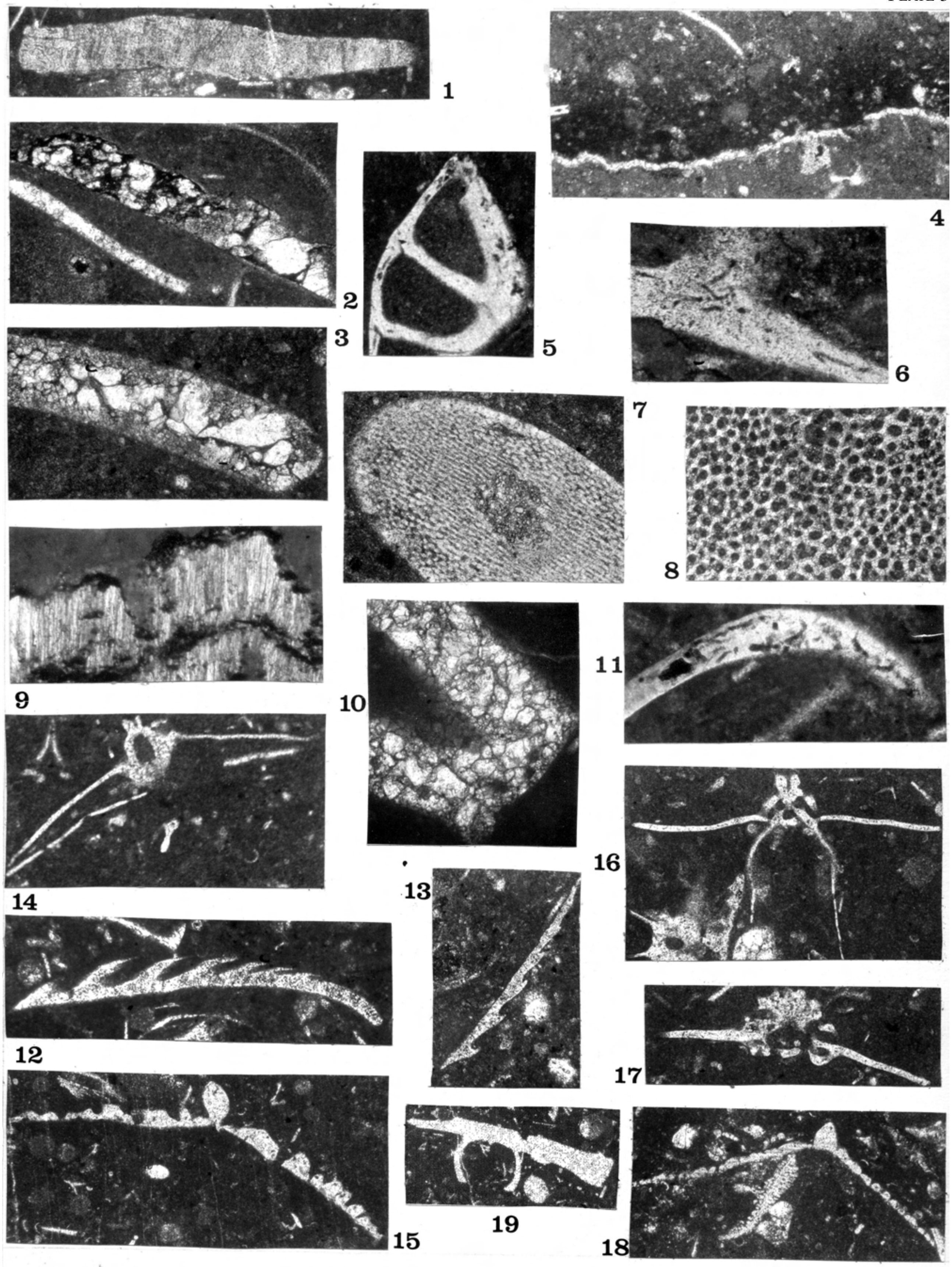
PLATE 3–*1-3,* Progressive alteration of a mollusk fragment. *1,* is unaltered, with faint hematite infilling along the prismatic structure. *2,* is diagenetically altered with some hematite coating on the microspar crystals. *3,* is even more altered with fine residual hematite coating on the microspar and spar. Sample ESP 13, ph.ulb.9926, Puente del Zegri, *Bifrons* Zone, Toarcian, *1-2,* x45; Sample ESP 17, ph.ulb.9957 and 9961 respectively, Puente del Zegri, *Fallaciosum* Zone, Toarcian, *3,* x60. *4,* Dense hematite hardground on a thin regular stressed calcite veinlet (for detail of stress, see Fig. 9). Sample ESP 13, ph.ulb.9929, Puente del Zegri, *Bifrons* Zone, Toarcian, x60. *5-6,* Hematite filled sponge perforations in a foraminifer and a mollusk. Fig. 5, Sample ESP 17, as *2-3,* x60; *6,* Sample ESP 21, ph.ulb.9956 and 9975 respectively Puente del Zegri, respectively base and top of *Fallaciosum* Zone, Toarcian, x100. *7-8,* Hematite-filled crinoid dissolved stereom. *7,* Sample ESP 15, Puente del Zegri, *Gradata* Zone, Toarcian, x60; *8,* Sample ESP 19, ph.ulb.9949 and 9963 respectively Puente del Zegri, top of *Fallaciosum* Zone, Toarcian, x60. *9,* Penecontemporaneous stressed calcite veinlet filled with an overlying red mudstone. Some sponge perforations. Sample ESP 24, ph.ulb.9982, Puente del Zegri, *Murchisone* Zone, Aalenian, x60. *10,* Diagenetically altered, dissolved, mollusk fragment with some remnants of perforations. Most of the hematite now coating the microspar and spar crystals. Sample ESP 39, ph.ulb.9946, Cortijo de Casa Blanca, Lower Tithonian, x60. *11,* Hematite-filled sponge perforations in a clam shell. Sample ESP 14, ph.ulb.9934 Puente del Zegri, *Bifrons* Zone, Toarcian, x100. *12-13,* Holothuroid ? (Fig. 12) and ophiuroid (Fig. 13) ossicles. *12,* Sample ESP 19, ph.ulb.19, Puente del Zegri, top of *Fallaciosum* Zone, Toarcian, x60. *13,* Sample ESP 36, ph.ulb.9964, Cortijo de Casa Blanca, Lower Tithonian, x25. Compare with Middle Devonian *Pectenura pecten* Boczarowski 2001 (Pl. 12, Fig. 13). *14-18,* Ophiuroid ? and holothuroid ? ossicles. All samples from Cortijo de Casa Blanca, ph.ulb.3, 18, 2, 9997, 15 respectively, Lower Tithonian. Compare with modern *Ophiothrix* and *Ophiomaza* illustrated in Barnes (1980) (Fig. 19-28A and Fig. 19-30). *14,* Sample ESP 31, x25. The figure shows a typical ophiuroid ossicle. Compare with Middle Devonian *Pectenura pecten* Boczarowski 2001 (Pl. 12, Fig. 13); *15,* Sample ESP 36, x45; *16,* Sample ESP 31, x60; *17,* Sample ESP 31, x25; *18,* Sample ESP 31, x60. *19,* Holothuroid ossicle?, Sample ESP 31, ph.ulb.9995, Cortijo de Casa Blanca Lower Tithonian, x35.

PLATE 3



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