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TAPHONOMIC TOOLS TO EVALUATE SEDIMENTATION RATES AND STRATIGRAPHIC COMPLETENESS IN ROSSO AMMONITICO FACIES (EPIOCEANIC TETHYAN JURASSIC)

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Abstract. A combined multidisciplinary approach has been applied to calculate minimum values of the stratigraphic completeness and, secondarily, sedimentation rates in 9.2 m thick Rosso Ammonitico facies from central Apennines (Italy) and 11 m thick deposits of the same facies in Southern Spain. Middle - Upper Toarcian expanded sedimentation in Valdorbia section (Umbria-Marche Apennines) and extremely condensed Oxfordian – Tithonian sedimentation at Puerto Escaño section (External Subbetic) have been investigated using combined taphonomic, ichnologic and sedimentologic data and analyses. At Valdorbia, infaunal tiering is largely preserved and 27 horizons of infaunal-tiering truncation and casting reveal strong erosional activity forced by tempestite/turbidite events. Therefore, microstratigraphic gaps could be evaluated without biostratigraphic control. In this expanded section, 13 horizons of firm- and hardgrounds have been recorded showing simple or gradational tiering. Conversely, in the condensed Puerto Escaño section, taphonomic analysis reveals 25 horizons of bioclasts truncation (mainly in ammonites), and 56 horizons of firm-hardgrounds intensively bioturbated. In Valdorbia rather than in Puerto Escaño section, the evaluation of flattening in burrows and spherical bioclasts reveal a measurable mechanical compaction and dissolution. In addition, Rosso Ammonitico at Valdorbia section favoured the calculation of decompaction coefficients (nd) for each lithology easier than in Puerto Escaño section. In condensed and essentially hiatal Rosso Ammonitico, mottled deposits due to intense bioturbation dominate and tiering cannot be recognizable. This fact is accentuated by usual overprinting of elementary depositional events, which in turn hampered the accurate calculation of missing deposits. Therefore, in condensed Rosso Ammonitico the latter was only available in terms of minimal missing-record trough the analysis of truncated bioclasts.

Riassunto. Un approccio multidisciplinare è stato applicato alle facies giurassiche nodulari di Rosso Ammonitico in Italia e Spagna, allo scopo di calcolare il valore minimo della completezza stratigrafica e, secondariamente, di misurare il tasso di sedimentazione. L'analisi integrata tafonomica, icnologica e sedimentaria è stata effettuata su 9,2 m di marne, calcari marnosi e intercalazioni calcarenitiche di età Toarciano medio-superiore del Rosso Ammonitico della successione sedimentaria estesa di Valdorbia (bacino Umbro-Marchigiano), e su 11 m di calcari nodulari rossastri di età Oxfordiano-Titonico nella successione condensata di Puerto Escaño (Subbetico esterno). L'indagine a Valdorbia si è basata sulla determinazione del tiering e sul suo grado di erosione e riempimento ad opera di materiale calcarenitico dovuto ad eventi tempestitici/torbiditici. Sono stati determinati almeno 13 orizzonti di firm-hardgrounds, oltre ad un elevato numero di tiers troncati sia di tipo semplice (tot. 13) che gradazionale (tot. 14). In questa successione, inoltre, allo scopo di calcolare il grado di compattazione, sono stati utilizzati i coefficienti di decompattazione (nd) per le singole litologie, riportando indietro burrows e bioclasti attualmente appiattiti alle loro dimensioni originarie. Nella successione condensata e lacunosa di Puerto Escaño sebbene la complicazione dei reticoli biosedimentari abbia reso impossibile l'utilizzo del grado di erosione dei tierings dell'infauna, tuttavia, mediante l'analisi tafonomica di dettaglio si è potuto determinare il minimo grado di erosione dei bioclasti (prevalentemente ammoniti ma non solo). Questa analisi ha condotto all'individuazione di almeno 56 orizzonti di firm- hardground, e di circa 25 orizzonti a bioclasti troncati. Questo tipo di analisi integrata risulta pertanto di notevole utilità nel riconoscere la completezza stratigrafica in facies significative del registro stratigrafico, evidenziando tutte quelle mini-discontinuità che sfuggono alla biostratigrafia, apportando tecniche di indagine di stratigrafia ad alta risoluzione.

Introduction.

To approach changes in sedimentation rates and to identify discontinuities in sedimentation that are difficult to recognise biostratigraphically, the High Resolution Event Stratigraphy (HIRES, *sensu* Kauffman, 1988; Kauffman et al., 1991) has been used to investigate short-term deposition ranging from hours to 100 Ky. The HIRES methodology involves multidisciplinary studies and is employed in basin analysis to recognise well-preserved «isochronous» surfaces and related events (erosion included) in pelagic fine-grained facies. Recently, trace-fossil tiering (the vertical distribution of an endobenthic ichnocoenosis, as proposed by Bottjer & Ausich, 1982), taphonomy, and tractive depositional

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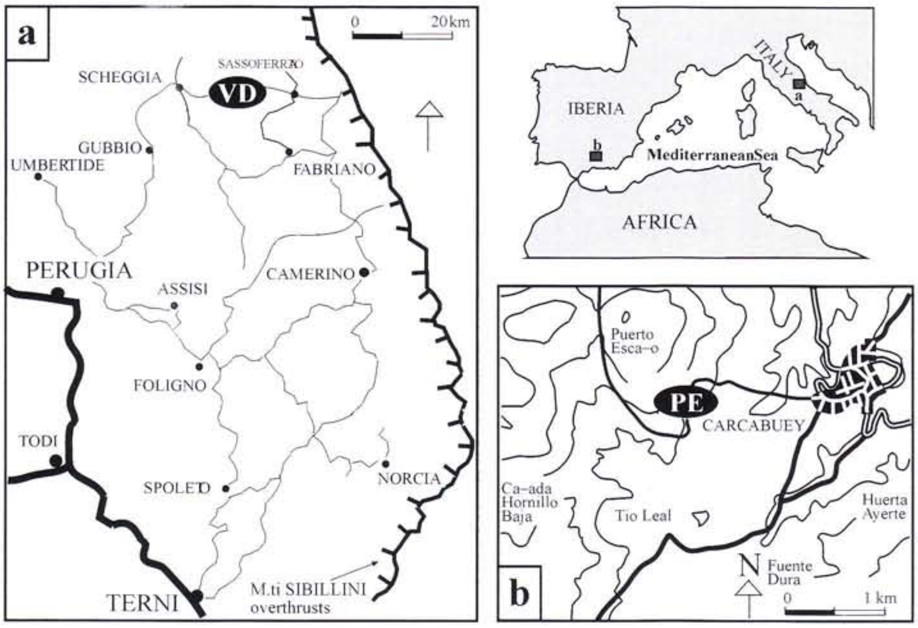

Fig. 1 - Location of the study areas; a) Umbria-Marche Apennines, central Italy (Valdorbia section, VD). b) External Subbetic, southern Spain (Puerto Escaño section, PE).

events have been used both to identify various types of discontinuities and to assist their genetic interpretation (MacEachern et al., 1992; Monaco et al., 1996).

Nodular and cephalopod-rich lime wackestones deposited in submarine swell areas of the Western Tethys (e.g., Rosso Ammonitico and related facies from the Lower to Upper Jurassic) represent an interesting facies for investigating discontinuities and sedimentation rates. In this highly time-averaged bioturbated facies, discontinuous deposition below the level of resolution of ammonite biostratigraphy is not always easy to identify precisely due to intense burrowing, which destroyed significant surfaces, modified previous taphonomic features, and masked centimetre thick depositional events. In addition to biogenic homogenisation, early and late diagenesis was also responsible for altering sedimentary structures and for enhancing nodular features (Caracuel et al., 1996a; Monaco et al., 1996).

The aim of the present paper is to identify and evaluate minor events resulting in discontinuous deposition in two distinct Rosso Ammonitico subfacies: decimetre-scale rhythmic sequences deposited in central Italy during the Middle-Late Toarcian (cf. marly Rosso Ammonitico, sensu Aubouin, 1964), and condensed sequences deposited in southern Spain during the Late Jurassic (cf. calcareous Rosso Ammonitico, sensu Aubouin, 1964). Erosion related to deep storm events is well known in Italy (Monaco, 1992; Monaco et al., 1994; 1996). Similar event deposition has been reported from southern Spain within a calcarenite/siltite context interpreted to be climatically and/or tectonically forced (Checa et al., 1983; Molina, 1987; Molina et al., 1997; Nieto, 1997; Vera & Molina, 1998) and without such a calcarenite/siltite context (Caracuel et al., 1996b). Opposite to the Puerto Escaño section, at Valdorbia, facies homogenisation due to bioturbation is not common, and trace fossil assemblages are typically confined to stratigraphically predictable horizons into a single depositional event (Monaco & Uchman, 1999). In both sections, tapho-sedimentary features (Monaco et al., 1996) enable an accurate evaluation of discontinuities based on: a) trace-fossil development (complete to incomplete tiering); b) invertebrate body-fossil preservation (erosion, corrosion, destructive processes and crushing of cephalopod internal moulds and shells); and c) relationships between substrate hardness and erosional characteristics of tempestite horizons. Restoring back compaction, by estimation of the decompaction number (indicating decompaction degree), and the evaluation of missing deposits permit to approach net sedimentation rate and minor discontinuities.

The stratigraphic framework.

Two settings belonging to West Tethyan epioceanic swell areas, but developing different Rosso Ammonitico subfacies, have been considered: the expanded Lower Jurassic (Middle-Upper Toarcian) section at Valdorbia (Umbria-Marche Apennines, Central Italy; Figs. 1, 2A), and the Upper Jurassic (Oxfordian-Tithonian) condensed section at Puerto Escaño, Betic Cordillera (Southern Spain; Figs. 1, 3A).

Rosso Ammonitico deposition at Valdorbia (Umbria-Marche) overlies the Lower Toarcian «Marne di Monte Serrone» Formation (Fig. 2A). Outcrops in the area display the typical characteristics of relatively extended sedimentation (Type 1 Sequence in Colacicchi et al., 1988), in which the Rosso Ammonitico Umbro-Marchigiano (RAUM) ranges from H. bifrons p.p. to L. opalinum p.p. Zones. The thickness of the RAUM in

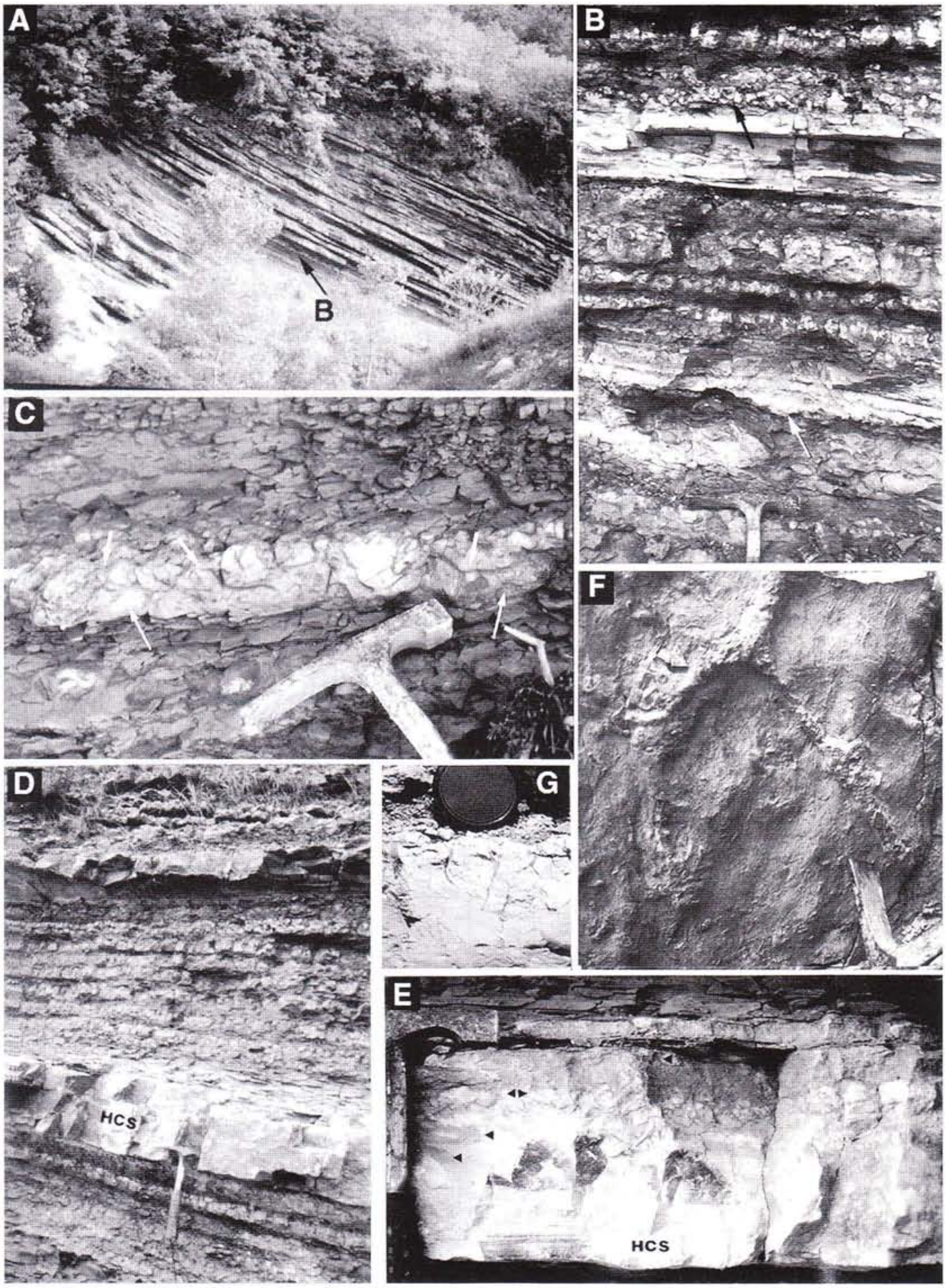

Fig. 2 - Valdorbia section, Umbria-Marche Apennines. A) General view of marly (Lower Toarcian, lower left) and calcareous Rosso Ammonitico (Middle-Upper Toarcian). B) Nodular reddish calcareous and marly Rosso Ammonitico horizons largely bioturbated and showing tempestite beds (arrows). Erosive surfaces facilitate the recognition of truncated tiering of gradational-type in the basal portion of bivalve lags (lower white arrow), while simple (or frozen) tiering developed and was affected by erosion in the upper calcilutitic part of tempestites (upper arrow). C) "Gradational" tiering developed in non-resedimented marls of Rosso Ammonitico of Middle and Upper Toarcian. Deeper tiers are prevalently minute traces of *Chondrites* and *Helminthopsis* (lower arrows), and shallower tiers belong mainly to *Thalassinoides* (upper arrows). D) Hummocky cross-stratified (HCS) calcarenitic tempestites characterize the marly-calcareous and calcareous Rosso Ammonitico in the upper part of Middle Toarcian - lower part of Upper Toarcian. E) "Simple" tiering developed in the upper calcilutitic fraction of hummocky cross-stratified (HCS) beds with sharp base. *Chondrites* and *Helminthopsis* are deepest tiers (13 - 18 cm altogether below surface; lower black-arrow from the bottom), followed upwards by *Planolites* (10 - 12 cm; double black-arrows) and then Thalassinoides in the shallowest tier (up to few centimeters from the surface; upper black-arrow). F) Lower surface of HCS-bed showing a casting of *Thalassinoides*; tier truncation provides information on the amount of erosion and casting at the base of tempestite event (see text for explanation). G) Post-omission hardground showing vertical borings (*Trypanites*?) in calcareous Rosso Ammonitico at Middle-Upper Toarcian transition layers.

this section reaches 25 m, implying a mean sedimentation rate of about 4.5 mm/10^3y (Monaco et al., 1994). The RAUM was deposited in a mid-outer shelf, relatively shallow (100 - 150 m deep), and periodically submitted to seaward-oriented bottom currents (distal tempestites and turbidites) during the late Middle Toarcian. Higher sedimentation was supplied by distal tempestites in combination with unidirectional flows, which are identifiable in marls of the lower stratigraphic levels (Middle Toarcian). Additionally, high accumulation rates recurred during sea level lows of late Middle Toarcian /early Late Toarcian age when tempestites determined oscillating water columns close to major storms wave bases (see Monaco et al., 1994). Thus, the RAUM is an alternation of marly-calcareous lithotypes showing upward decrease in marly content toward the mid-section, while the upper part (uppermost D. meneghinii - L. opalinum Zones) is basically marl-free (Fig. 2A).

According to Monaco et al. (1994), textures range from mudstones to wackestones in marly intervals, and are persistently packstones in more calcareous beds. Dominant bioclasts are thin-shelled bivalves (*Bositra buchi*), smooth as well as sculptured ostracods, radiolaria, echinoid fragments, microgastropods, crinoid remains, and calcareous sponge-spicules. Holothurian sclerites, ophiuroid fragments, brachiopods, fish teeth, Rhyncholites, ammonoid nuclei, and bivalves are secondary.

In southern Spain, the Puerto Escaño section (Fig. 3A) has traditionally been interpreted to belong to the Gaena Unit within the External Subbetic (Rivas et al., 1979; Molina, 1987; Caracuel, 1996). The Upper Jurassic overlies a well-developed multiple-hardground with ferruginous crusts and intensive erosion-corrosion, whose associate hiatuses were interpreted to expand, at the most, from the Middle Bathonian (Sofanus - Costatus Chron) to an unknown interval of presumably Early to Middle Oxfordian age. Variably preserved, thin deposits of Lower and Middle Callovian are intercalated (Sandoval, 1983). The pre-Bimammatum Oxfordian is represented by a clayey interval 1.8 m thick. Ammonites are rare and therefore Oxfordian biostratigraphy is poorly known. The Upper Oxfordian - Tithonian (Bimammatum - Transitorius Zones) section is composed of alternating marly and calcareous nodular limestones. The Rosso Ammonitico facies is 2.5 m thick in the Upper Oxfordian - Kimmeridgian, and 6.8 m thick in the Tithonian mentioned. The mean sedimentation rates of the compacted sediments (0.70 and 0.95 mm/10^3y, respectively) estimated by Caracuel (1996) are equivalent to those calculated by Comas et al. (1981) for the Upper Jurassic calcareous nodular (1 mm/10^3y) and partially nodular (0.75 mm/10^3y) Rosso Ammonitico beds in the close section at Cañada del Hornillo. Thus, we assume that the estimated values could represent, confidently, the mean sedimentation rate of Upper Jurassic deposits in the area.

In Puerto Escaño section, the calcareous Rosso Ammonitico is well stratified (beds 20 - 40 cm thick), and typically includes omission surfaces overlying firmgrounds or incipient hardgrounds. Locally, well-developed hardgrounds with Fe-Mn oxy-hydroxides, ammonite remains, and common trace fossils are concentrated at bed tops. Microfacies are mainly wackestones rich in small-size bioclasts, and locally packstones, within the Tithonian. Dominant bioclasts include thin-shelled bivalves (*Bositra buchi*), *Saccocoma*, *Globochaetae*, *radiolaria*, *Protoglobigerina* and other foraminifera. Bivalves, gastropods, belemnites, aptychi and ammonoid nuclei are secondary. In the Upper Kimmeridgian, *Saccocoma* replaces the noteworthy dominance of filaments in underlying Lower - Middle Kimmeridgian horizons.

Marly Rosso Ammonitico facies are, in general, wackestones poor in bioclasts. Lime mudstones are rare. No significant differences in small-size bioclast distribution have been recognised with respect to the calcareous Rosso Ammonitico facies. In both, calcareous and marly Rosso Ammonitico facies, *Chondrites* (*C. targionii* and *C. intricatus*, Monaco, in press), *Planolites* and *Thalassinoides* are common, the latter particularly so in more calcareous subfacies (Caracuel, 1996).

Microstratigraphic and taphonomic methods.

In the Rosso Ammonitico facies of Umbria-Marche Apennines, Monaco et al. (1996) considered minor discontinuities or erosional gaps clearly below biostratigraphic resolution. These authors applied the quantification of infaunal tiering truncation caused by sea-bottom currents and calcarenitic tempestites/turbidites (e.g. Wetzel & Aigner, 1986). Complementarily, they evaluated the truncation of the upper part of shells and inner casts of invertebrates by erosion after exhumation. This has been a subject that deserved increasing attention in parallel with progressing understanding on ectocochleate cephalopods preservation and stratigraphic interpretation (Seilacher, 1963, 1971, 1973; Ziegler, 1975; Müller, 1979; Fürsich, 1979; Fernández-López, 1984; Caracuel, 1996; Caracuel et al., 1996a).

a) Truncated tierings. Within the substratum, the vertical partitioning of burrows distribution belonging to a community represents the community subdivision forced by ecological factors operating within the sediment (tiering). This fact is known from endobenthic activity in modern and ancient deposits (see Seilacher, 1978; Ausich & Bottjer, 1982; Bottjer & Ausich, 1982; Bromley, 1996). The resulting inner-bed stratification of burrows will depend on the sediment accumulation rate

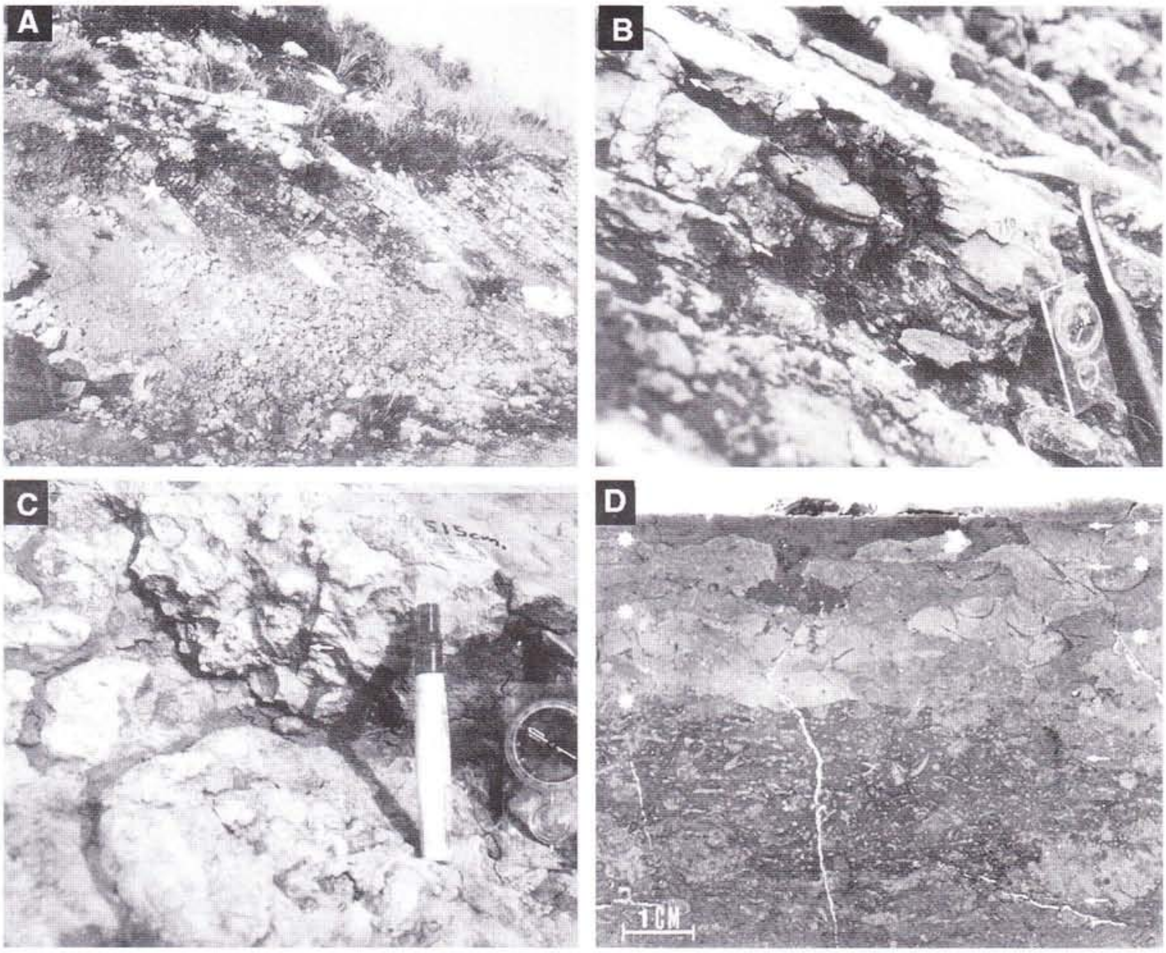

Fig. 3 - Puerto Escaño section. A) General view of marly (Oxfordian) and calcareous Rosso Ammonitico beds (Kimmeridgian-Lower Tithonian p.p.). White asterisk marks the Oxfordian-Kimmeridgian boundary. B) Close-up view of an ammonite-rich level of calcareous Rosso Ammonitico (toward 5.65 m from bottom) shows ammonites (mainly *Hybonoticeras hybonotum*) with variable truncation of the upper side (arrows). C) Close-up view of calcareous Rosso Ammonitico level (towards 5.15 m from bottom) colonised by *Thalassinoides*, showing horizontal net spreading and vertical tubes in overlying horizons (arrow) piped from the upper firm-hardground surface. D) Polished vertical surface of a calcareous Rosso Ammonitico bank showing several levels of colonisation (indicated by arrows) and erosion surfaces (asterisks).

(s. Gómez & Fernández-López, 1994), while the possibility of recognition of infaunal tiering in the geologic record will depend on the rate of sedimentation (s. Gómez & Fernández-López, 1994). Each tier is formed by biogenic activity producing burrows that intersect one another, and could be partially overlapped by the adjacent tier according to particular palaeoecologic parameters (Seilacher, 1978) and/or to the degree of stratigraphic condensation. Simple tiering (frozen tier, sensu Goldring, 1995) indicates the first phase of substrate colonisation by endobenthos just after the tempestite/turbidite events deposited (Fig. 4A). Gradational overlap (term by Goldring, 1995) of tiering/burrowing instead reflects persistent colonisation when gradual changes in ecological and palaeoenvironmental parameters of sea-bottom and substrate occurred. Hence, starvation due to sea-level variations, as well as fluctuations in oxygenation and/or organic matter, among others, are decisive factors rather than changes in the net sedimentation rate (Goldring, 1995; Bromley, 1996; Savdra & Bottjer, 1989; Tunis & Uchman, 1996; Monaco & Uchman, 1999). In cases of abrupt increases in substrate oxygenation and organic matter, co-occurring with decreasing rates of sediment accumulation, packed boxwork burrowing was usual and preserved locally, resulting in masked tiering (mottled deposits; Monaco & Uchman, 1999) (Fig. 4B).

The truncation of simple tiers provides precise information on the amount of erosion and burrow casting below the base of the overlying erosive turbidite or tempestite event (Wetzel & Aigner, 1986). However, the application of this method provides a minimum erosion value that corresponds to the colonisation depth of the shallower trace fossils (*Thalassinoides* in the case studied). In the Valdorbia section, only tiered trace fossil assemblages composed of *Thalassinoides*, *Planolites*, *Helminthopsis* and *Chondrites* (Fig. 4A) should be taken into account since they represent burrowing immediate-

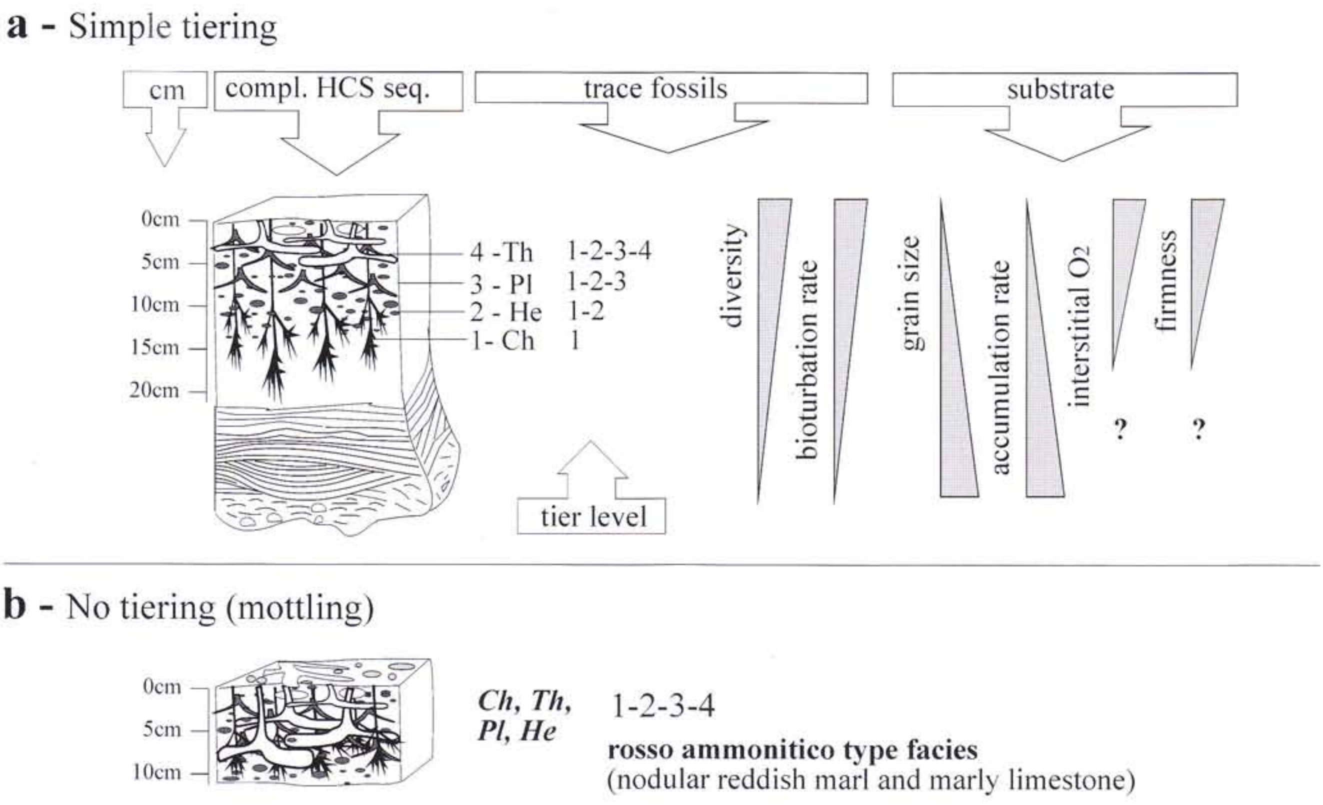

Fig. 4 - a) Idealized complete sequence of simple-tiering, before compaction, developed under high-accumulation rates. Note the colonization of *Thalassinoides* (Th) makers in the upper layer, where trace-fossil diversity and bioturbation density were higher, and that of *Planolites* (Pl), *Helminthopsis* (He) and *Chondrites* (Ch) downward, respectively. b) - Depositional horizon where no trace-fossil tiering occurred and overprinting of burrows (mottled) indicates low accumulation rate.

ly beneath the sea floor in horizons potentially affected by erosional events that eroded softgrounds, and probably not excessively cohesive firmgrounds. Deeper layers were comparatively lithified due to early/advanced cementation and could be exhumed but not easily eroded. Additionally, cannibalistic levels (deposits showing bio- lithoclasts reworking) have not been noted.

In the Valdorbia area, Umbria-Marche Apennines, hummocky cross-stratified calcarenitic/ruditic tempestites 30 - 40 cm thick (Fig. 2), were deposited during the Bifrons and Erbaense Chrons, Middle - Late Toarcian (Monaco, 1992; Monaco et al., 1994). Clay mineral abundance (Ortega-Huertas et al., 1993; Monaco et al., 1994), probably contributes to the prevention of diagenetic recrystallization of calcium carbonate, leading to trace fossil preservation. In this section, intensely bioturbated marls show erosive surfaces, which facilitate the recognition of truncated tierings (Figs. 2B-E). Missing tiers due to the erosive potential of tempestites that truncated soft to firm substrate and cast burrows represent a tool to reveal discontinuous deposition in Rosso Ammonitico facies (Fig. 5), opposite to truncated bioclasts in Puerto Escaño (Fig. 6). The data set plotted in Fig. 7 enables the estimation of the minimum value of erosional degree, indicating the relative substrate consistency and the type of tiering identified.

Two types of tiering were affected by erosion causing the incomplete preservation of primary tiering. Monaco et al. (1996) identified simple-tiering truncation and gradational-tiering truncation (for simple and gradational tiering see Goldring, 1995; Einsele & Seilacher, 1991):

I) The simple tiering developed within tempestites ("frozen" tiering sensu Bromley, 1996), and it was generally isolated in the upper calcilutitic part of tempestite events with an overall range of 10 - 20 cm from the bed top (Figs. 2E, 4). *Chondrites* occupy the deeper tier (10 - 20 cm below surface), overlain by *Helminthopsis* (10 - 15 cm), *Planolites* (5 - 15 cm), and then *Thalassinoides* in the shallower tier preserved (up to 5 - 10 cm from the surface). Fig. 4 shows an ideal elementary sequence with complete simple tiering before compaction. We assume that this ideal sequence developed in high accumulation rate conditions as those related to deposits showing hummocky-cross-stratification (HCS). Monaco (1995, 1996) interpreted substrate evolution based on decreasing grain size and accumulation rate, and increasing interstitial oxygenation and substrate firmness (Fig. 4). In accordance, trace fossil diversity and bioturbation rate increase upward in the elementary sequence, and all ichnotaxa recorded show intercrossing near the top.

Thirteen horizons of simple-tiering truncation

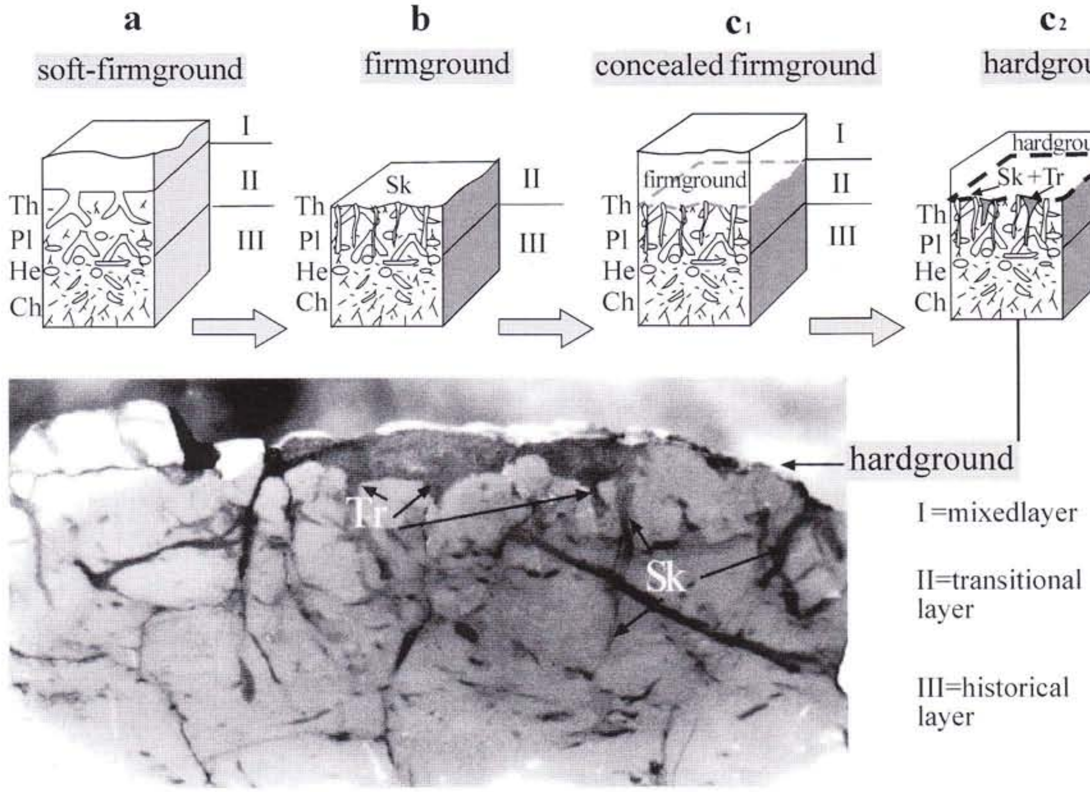

Fig. 5 - Evolving substrate conditions in stratigraphic level colonised by a trace-fossil assemblage showing simple tiering: a) softground; b) firmground (erosion and exhumation of the mixed layer and partially the transitional layer with colonisation by *Skolithos*); c1) concealed firmground (new depositional event); c2) hardground (erosion and exhumation of the new mixed layer with colonization by *Skolithos* and *Trypanites*). Th = *Thalassinoides*; Pl = *Planolites*; He = *Helminthopsis*; Ch = *Chondrites*; Sk = *Skolithos*; Tr = *Trypanites*.

(mean value of 5 cm) were recognised mainly in the Erbaense Zone, where calcilutitic beds were widespread (Fig. 7). The development of simple tiering was probably favoured by the constant accumulation rate of the lutitic fraction on the final stage of a tempestite/turbidite event of deposition. No abrupt changes in bioturbation intensity have been recorded and, therefore, no abrupt variations in oxygenation should be expected following Savrda & Bottjer (1986, 1989). Eight firmground and five hardground horizons were recognised. They developed in the upper surface of the calcilutite member of the elementary sequence, being revealed by erosional features. Firmgrounds were intensely bioturbated (pseudo-bored) with *Skolithos*, while hardgrounds contain pervasive borings, mainly by *Trypanites* makers (post-omission guild) (Fig. 5).

II) Gradational-tiering erosion by gravity flows was found in non-resedimented autochthonous marly Rosso Ammonitico (Figs. 2C, 4), particularly when marls and limestones alternated with clayey levels (Fig. 2B). The distribution of trace fossils is that of the tiering previously described. Low accumulation rates and high oxygenation could favour a gradational tiering in the substrate, with bioturbation density increasing/decreasing upward according to trends of increasing/decreasing oxygenation (Savrda & Bottjer, 1989). The gradational tiering increases/decreases the complexity of trace fossil assemblages forced by gradual changes in ecological parameters and accumulation rates. Since *Thalassinoides* belongs to the shallowest tier in the section studied (Fig. 2C), casts of truncated *Thalassinoides* indicate shallow-erosion events removing vertical tubes belonging to the *Thalassinoides* framework (5 cm; Fig. 2F). Unfortunately, deeper tiers are prevalently minute traces (*Helminthopsis* and *Chondrites*) that rarely show favourable preservation for precise interpretation. Fourteen horizons of gradational tiering have been found (Fig. 7). The major erosive features are present both in the lower and upper part of the section (Middle and Upper Toarcian) showing erosion up to a decimetre of substrate by calcarenites, as revealed by casts of *Thalassinoides* (Fig. 2F) or *Planolites*.

In the Upper Jurassic section studied at Puerto Escaño (Southern Spain), superimposition of trace fossil assemblages, tiered or not, and unclear burrow relationships impede the precise evaluation of discontinuities in extremely condensed Rosso Ammonitico facies. According to Caracuel (1996) and Caracuel et al. (1996b), the most widespread trace fossils are *Chondrites*, *Planolites* and *Thalassinoides*. These authors recognised four trace fossil assemblages, which were interpreted to be commonly successive, but not neces-

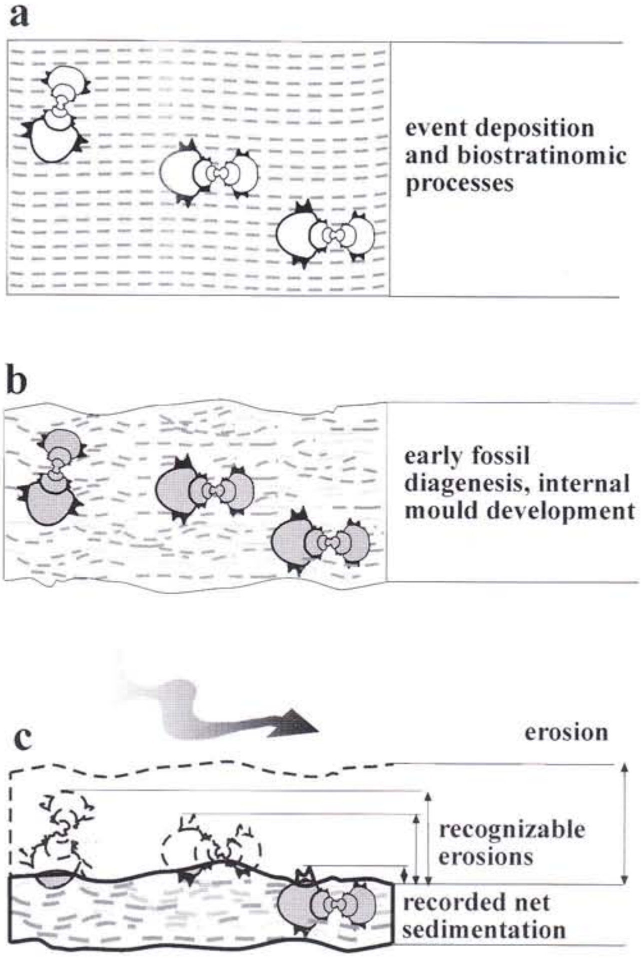

Fig. 6 - Ammonite shells buried by a depositional event (a). After early diagenesis and inner cast development (b), variable erosion (c) permit to measure a minimum thickness of the erosional event.

sarily continuous, reflecting differences in substrate consistency (Figs. 3C-D): I) small *Chondrites* exclusively, II) small *Planolites*+*Chondrites*, III) small *Thalassinoides*+*Chondrites*+*Planolites*, and IV) large *Thalassinoides* exclusively. Thus, changes from assemblage I to IV could be related to changes from soft, firm- to incipient hardgrounds. Nevertheless, distribution of assemblages I and II could also be related to the poorly oxygenated conditions in the lowermost horizons rather than a high substratum consistency, or more likely to their combination.

Opposite to the expanded Rosso Ammonitico of Valdorbia, in the extremely condensed Puerto Escaño section gradational overlap of burrows/tiering becomes unrecognisable through the masking forced by usual extreme overprinting, including that of thin depositional horizons. Hence, tiering is rarely preserved and interpretable, while mottled deposits dominate. However, trace-fossil assemblages are superimposed over omission surfaces, recording a trend toward increasing substrate consistency. Achieving firm- and locally hardground conditions during the development of omission surfaces, would exist the possibility for a potential estimation of the significance of the stratigraphic gaps involved, but the precise volume of missing sediments remains unknown. Moreover, a complete absence of cannibalistic reworking is difficult to ensure for some stratigraphic horizons, particularly within the Tithonian (soft pebbles, pebbly-mudstones). In accordance, the application of trace- fossils truncation analysis is largely limited.

b) Truncated bioclasts. In the Rosso Ammonitico facies, the extreme corrosion of the upper part of the deposited bioclasts is related to the fact that they are high time-averaged deposits (s. Staff et al., 1986; Fürsich & Aberhan, 1990). Thus, according to Caracuel (1996) and Caracuel et al. (1996a), corrosion of the upper part of the bioclasts prior to burial, or erosion/corrosion of buried and subsequently exhumed bioclasts, are key factors to determine missing sedimentary record. In extremely condensed Rosso Ammonitico facies, where tiers are typically superimposed, the most effective criteria for evaluating the erosion of the substrate, and therefore to reveal discontinuous sedimentation, is the evaluation of bioclasts truncation.

Ammonite shells can be corroded/abraded at the top prior to the first burial, and during a long-lasting residence-time on the substrate, probably resulting from a complex history of incomplete burial and partial exhumations. Thus, the preservation of complete ammonite shells should indicate depositional events \forcing the complete burial of ammonites even within the context of the essentially discontinuous sedimentation of Rosso Ammonitico facies (Olóriz et al., 1993; Caracuel, 1996). This interpretation has been also applied to ammonite preservation in epicontinental carbonate settings (Fernández-López, 1997). Whatever the case, and assuming variable preservational histories (Henderson & McNamara, 1985), the proposed dynamics is the complete burial of ammonite shells during depositional events. A common history derives from the possibility for later complete/incomplete exhumations of ammonite remains as internal moulds, which experienced variable erosion (korrosion determining kappung sensu Seilacher, 1963; and/or erosional capping sensu Seilacher, 1971 = abrasion determining facetting in English literature). According to Caracuel (1996) and Caracuel et al. (1996a), the record of corroded bioclasts (mainly ammonites), pre- and/or post-burial (exhumed bioclasts and/or inner casts), are key features to determine omission or erosion, respectively, in the condensed Rosso Ammonitico facies. Bioclasts truncated during exhumation-exposition (Fig. 3B) provide an effective criterion to recognise and estimate discontinuous deposition and missing deposits (Fig. 6; minimum recognisable erosion equal to the thickness of the missing part of eroded bioclasts). Unfortunately, ammonites are generally preserved in a subhorizontal orientation, and thus the potential to record exhumation is reduced to carcasse/inner-cast thickness (2 - 4 cm in the case studied). Nevertheless, in a favourable situation, most of a vertically embedded ammonite may be missing, evidencing cm-dm range exhumation and erosion (Fig. 6). In addition, above of the truncated bioclasts preserved could be a variable stratigraphic interval of missing information, which could embraces several horizons of completely destroyed bioclasts (no record). Since the thickness of the depositional event preserved after erosion is independent of the original thickness (although finally related to it through the relation between erosive energy and sediment/water inter-phase cohesion and thickness), in practice, only a recognisable minimum erosion can be estimated (Fig. 6). Moreover, according to Fernández-López & Meléndez (1993) and Caracuel (1996), poor preservation does not permit always the clear differentiation of pre-burial (biostratinomic) and post-burial (fossildiagenetic) abrasion/corrosion.

Upper Jurassic deposits at Puerto Escaño are wackestones, occasionally packstones, with *Bositra buchi*, *Saccocoma*, *Globochaetae*, *radiolaria* and *Protoglobigerina* as main components. No grain supported bioclastic laminae were recognised. Corrosion of microbioclasts is not common, meanwhile originally calcitic components as large bivalves, echinoids, gastropods belemnites and aptychi usually show bio-erosion. Ammonites are dominant and commonly preserved as internal moulds (incomplete but epigenized shells are occasionally preserved in slightly nodular and calcareous facies). Generally, phragmocones are more frequent than body-chambers and peristomes are extremely rare. As usual in Rosso Ammonitico, ammonites lie parallel to bedding planes and show sharp facetting on the upper side. More or less oblique/vertical orientation was only identified for small size ammonites, and interpreted as resulting from intense burrowing, mainly. No preferential orientation was identified in macroinvertebrates other than ammonites.

The analysis of exhumed truncated-bioclasts in the Upper Jurassic section at Puerto Escaño enables the recognition of 56 levels of missing record. As shown in Fig. 8, most horizons showed relatively thin corrosion, although more intense exhumation-erosion was registered at the top of calcareous Rosso Ammonitico beds, locally. In addition, firmgrounds and particularly hardgrounds involved variable omissions (even erosion) making difficult the evaluation of missing record, even assuming the averaged sedimentation rate in the section. Hence, only those cases associated with bioclast truncation were measured (25 horizons). Moreover, it is noteworthy that erosion surfaces were recognised under microscope at the top of elementary depositional events. The high frequency of dissolution seams, but not pressure solution fitted-fabrics, within elemental depositional events in condensed calcareous Rosso Ammonitico levels evidence that pre-diagenetic processes forced the identified missing record.

In the Valdorbia section faunal content (particularly ammonites) have been largely investigated since this section is easily accessible and offers good exposure of the Lower Jurassic (e.g. Donovan, 1958; Gallitelli-Wendt, 1969; Centamore et al., 1969, 1971; Elmi, 1981a, 1981b; Venturi, 1981; Monaco et al., 1994). In the RAUM facies, disarticulated echinoid fragments, broken crinoid plates, and thin-shelled bivalves are abundant. Densely packed concentrations of thin-shelled bivalves (e.g., *Bositra buchi* or *Lentilla humilis*) determine 5 - 15 cm thick lags parallel to the bedding, which show convex-up lying of shells, generally, and erosional bed contacts. Abrasion marks are present, both in bivalves and benthic foraminifera, as well as abraded specimens of stout biconvex cigar-shaped foraminifer *Lenticulina münsteri*. These taphonomic features were found in fossils embedded in fine-grained sediments without sedimentary structures linked to high-energy sources. All of this suggests oscillating flow affecting sea bottoms for a long time (likely during maximum sea-level falls) and forcing mechanical stress that caused the foraminifera tests to roll perpendicular to their axis (Monaco et al., 1994). Distal tempestites bringing reworked fossils with a variable taphonomic history are the most probable scenario for these Upper Toarcian deposits at Valdorbia section. As usual, ammonite shells lie parallel to bedding planes and do not show sharp truncation-facets or other features related to exhumation as in the Puerto Escaño section, although some cases of abraded ammonites have been observed in the Bifrons and Erbaense Zones. Relative changes from higher (in marly Rosso Ammonitico levels) to lower (calcarenite/siltites) time-averaging are recognised, and interpreted to be forced by variable lasting exposure of shells prior to burial. As previously noted, no evidence of erosion related to bioclast truncation after exhumation was identified.

c) Decompaction. Decompaction is approached by the evaluation of deformed ellipsoids from original spheres by diagenetic compaction (see Fig. 7, top). Two methods have been followed:

a) Decompaction of actively backfilled trace fossils (e.g. Chondrites) that originally had a circular cross section has been approached according to the formula: $nd = ro/r1$; where nd = decompaction number, ro = original radius, $r1$ = radius of compacted burrow perpendicular to bedding (Wetzel & Aigner, 1986). Eller (1981) applied this methodology to the Rosso Ammonitico-like Red Chalk sequence at Speeton in eastern England.

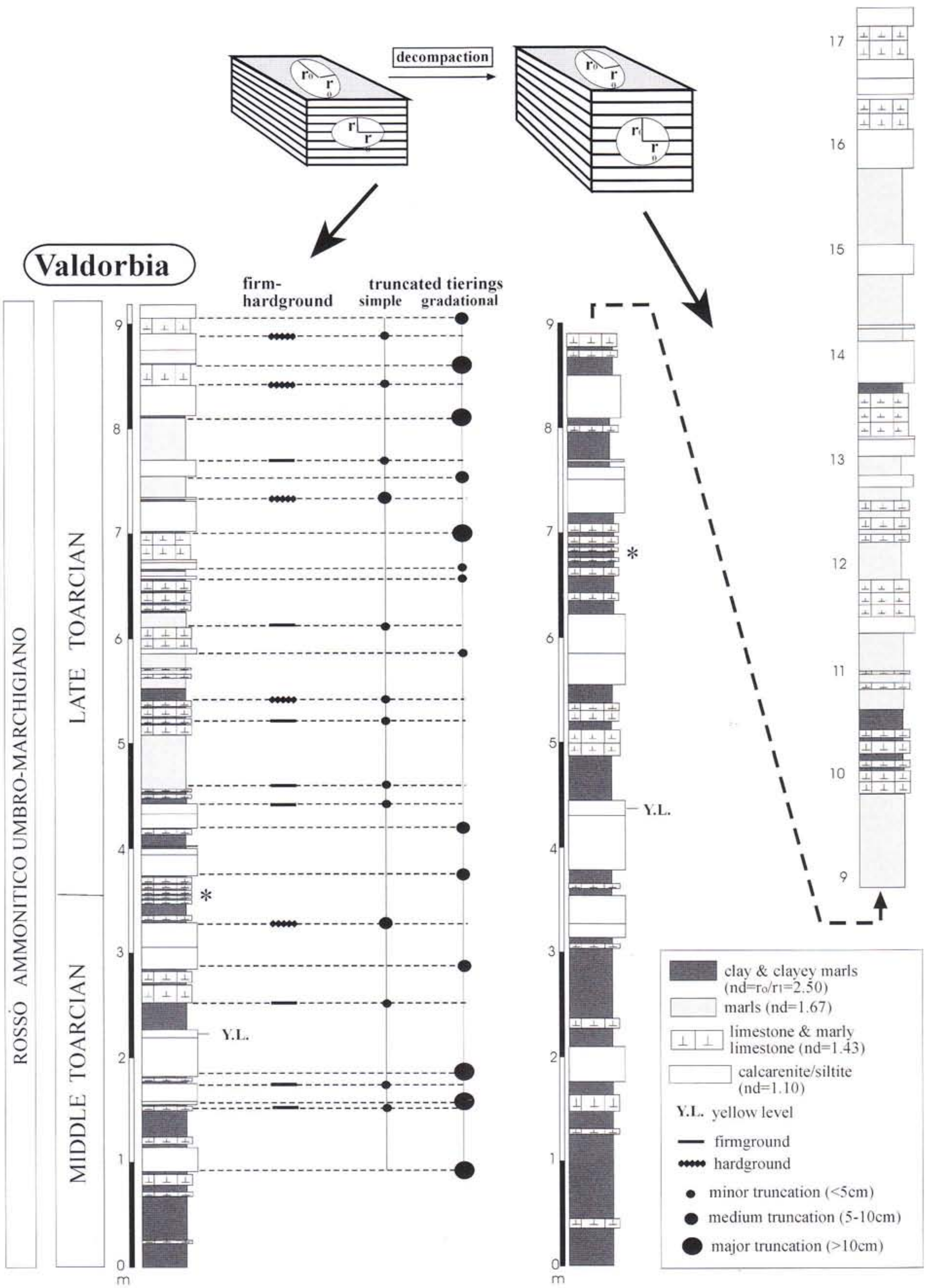

Fig. 7 - Middle-Upper Toarcian stratigraphic section at Valdorbia with indication of firm-and hardground horizons, and several orders of truncated tiering. Missing deposits by truncated tiering (simple at the top of calcarenite levels, and gradational at the top of the marly-clayey intervals) are estimated semi-quantitatively as <5 cm, 5 - 10 cm, and >10 cm. On the right, decompacted Valdorbia section according to decompaction numbers obtained for each lithology (see text for explanation). Y.L. = Yellow Level (calcisiltite level rich in oxy-hydroxides of Fe-Mn); asterisk (*) for correlation of the Middle - Upper Toarcian boundary. Inset explaining decompaction procedure from Wetzel & Aigner (1986).

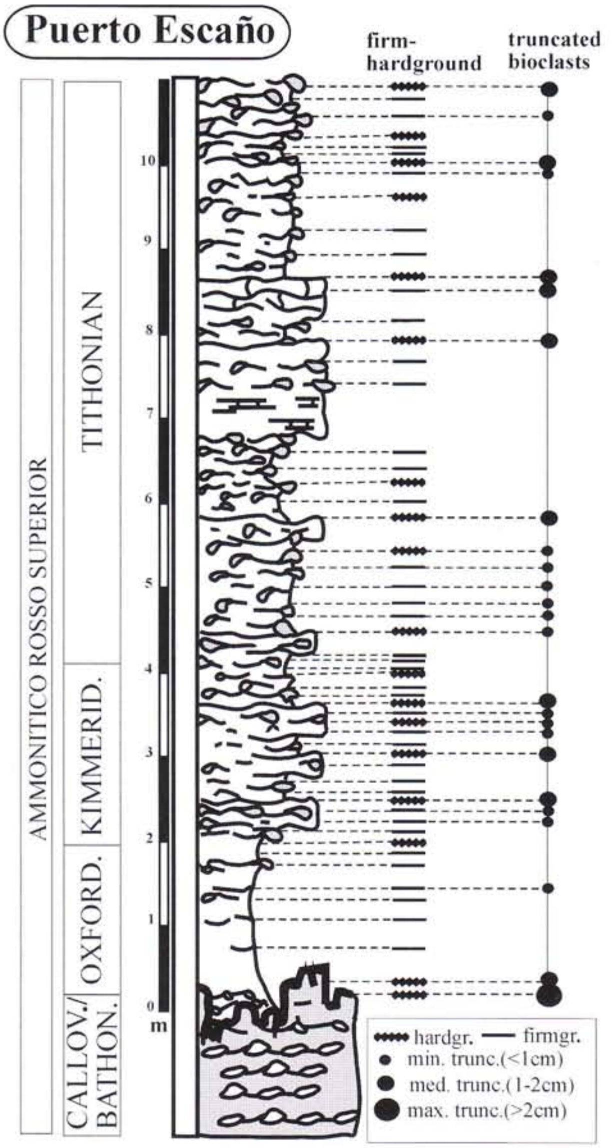

Fig. 8 - Upper Jurassic section at Puerto Escaño with indication of firm- and hardground horizons, and truncated bioclasts. Recognised omission/erosion by truncated bioclasts is reported semiquantitatively (minor truncation = <1 cm, medium truncation = 1 - 2 cm, maximum truncation = >2 cm). See text for explanation.

b) Decompaction of a deformed ellipsoid from original sphere (such as radiolaria or other spherical microfossils) under microscope applying the formula: $K = 100\ (1\text{-}b/a)$; where K is the compaction index, a and b are the major and minor axis of the ellipsoid, respectively. Extended treatment of this method can be found in Martire & Clari (1994) for cases studied in the Lower Cretaceous Biancone from the Venetian Pre-Alps. A complementary quantitative approach for determining a compaction law in non-porous grain-supported carbonate rocks, based on Ricken (1992), can be found in Clari & Martire (1996). Fitted fabric and pressure dissolution due to mechanical and chemical compaction during burial, and wavy "bunching" of clay seams (dissolution seams) were largely considered (post-burial phenomena; Bathurst, 1987), even in Rosso Ammonitico facies (Martire, 1989; Clari & Martire, 1996). In the case-study at Valdorbia section, neither fitted fabric nor pressure-dissolution seams were relevant.

The number of decompaction (nd) was calculated for the Valdorbia section in each Rosso Ammonitico bed, using several burrow sections, both in simple and in gradational tiers. *Chondrites* was selected since their cross sections are primarily circular, and they are actively back-filled traces with no cemented walls. Thus, ellipsoidal cross-sections caused by compaction were traced back into the original circle, in order to calculate the decompaction number. The greatest compaction was found in clays and clayey-marly levels (nd = 2.5), medium compaction degree in marls (nd = 1.67), and the least compaction in the limestones and marly-limestones (nd = 1.43) and calcarenites/calcisiltites (nd = 1.10). Applying these numerical values to the lithologic types identified, we were able to estimate the section thickness confidently (Fig. 7, right).

The application of decompaction numbers to the summation of thicknesses recorded in Figure 7 (total thickness = 10.62 m; clays = 2.58 m, marls = 2.29 m, calcareous-marls and limestones = 2.40 m, calcarenites and calcisiltites = 3.35 m) gave a pre-compaction thickness of 17.38 m (clays = 6.45 m, marls = 3.82 m, calcareous-marls and limestones = 3.43 m, calcarenites and calcisiltites = 3.68 m) for the Lower Jurassic Rosso Ammonitico facies at Valdorbia.

In the comparatively condensed Rosso Ammonitico facies at Puerto Escaño, extreme stratigraphic condensation, facies, and then highly heterogeneous distribution of carbonate nodules and marly internodules matrix, made difficult to calculate decompaction numbers, as approached by spheres deformed into ellipsoids. In fact, no significant features indicating differential dissolution or compaction of bioclasts were identified in dissolution seams within the marly internodules. Therefore, we assumed that dissolution seams resulted, mainly, from highly unstable carbonates (missing bioclasts and sediments) quickly dissolved during early diagenesis. As relatively marly (matrix inter-nodules) and calcareous (nodules) sediments within a given stratigraphic horizon were intricately distributed, showing minor lateral changes at the outcrop level that lead to relatively important variations in calculations and results, neither the Wetzel & Aigner (1986) nor the Martire & Clari (1994) methods have proven sufficiently accurate. Moreover, intense colonisation by *Chondrites+Planolites* and *Thalassinoides*, when developing firm- and hardground conditions, lead to the record of variably flattened trace fossils, even at the same level and some of them being completely crushed. In such a situation, several phases of substrate colonisation and filling were assumed, but no confidence was admitted to deformation values because of probable early diagenetic sliding and readjustment of thin sedimentary horizons. In accordance, we assumed that only incompletely compacted trace fossils (complete crushing absent) could be useful for approaching decompaction values.

This intimate and irregular mixing of comparatively soft (marly inter-nodules) and firm (calcareous nodules) substrates, which prevents the accurate decompaction approach in the Puerto Escaño section, agrees with interpretations by Olóriz et al. (1995) on the relationships identified between micro- and macro-features in Rosso Ammonitico facies. Based on a combined quantitative and qualitative analysis, these authors demonstrated that an overall homogeneity is combined with high heterogeneity in detail, due to complex biological, taphonomic and sedimentary processes that characterise the sedimentological history in this facies.

Discussion and conclusions.

The taphonomic methods applied to evaluate the stratigraphic completeness in Rosso Ammonitico subfacies have been shown variably efficient. For the extended section studied at Valdorbia, the presumably higher rate of accumulation combined with the higher net rate of sedimentation favoured the development and preservation of infaunal tiering. Therefore, the evaluation of the infaunal-tiering erosion enables an accurate estimation of discontinuous deposition and missing record. On the contrary, taphonomic truncation of bioclasts is scarcely documented. Moreover, erosional events (tractive tempestites/turbidites) usually could only eroded soupy-softground substrata. Then, neither bioclasts (relatively lithified) nor deeper and more cohesive layers should be eroded after exhumation, commonly. In such a comparatively low hiatal context, recorded infaunal-tiering erosion offers an accurate approach to quantify missing deposits by erosion.

In the highly condensed section with discontinuous sedimentation studied at Puerto Escaño, the only way for recognition of horizons with discontinuous deposition macroscopically identifiable is through the estimation of truncated bioclasts, since tiering analysis cannot apply.

Although the record of erosion deduced from truncated bioclasts has been proved accurate, limitations to precise calculations exist. These are due to the combined fact of the small recognisable thickness (ammonite shells width) and the unrecoverable information from potential primary horizons (ammonite carcasses and/or inner casts completely destroyed) deposited before truncation phases. Therefore, the application of truncated-bioclasts analysis should be complemented in other way to improve the evaluation of stratigraphic completeness.

Along with the quantitatively evaluation of truncated tiering and macro-bioclasts, other features have been taken into account qualitatively: a) recurrence of micro-erosion under microscope, mainly at the top of elemental depositional events (within composite banks); b) existence of pressure dissolution seams; and c) minor stratigraphic gaps involved in firm- and hardgrounds. Although, the evaluation of these features could be highly speculative, they are significant to recognise missing deposits.

In Valdorbia section, maximum erosional events (>10 cm) recognised by truncated gradational tiering are located at the base and the top of the section. They were related to the tractive energy of calcarenite/siltite (tempestitic/turbiditic) depositional events (Fig. 7). In Puerto Escaño section, depositional events recognisable by truncated bioclasts are randomly distributed in the section. Main erosions are linked to sedimentation resulting in calcareous Rosso Ammonitico and followed by paucity in deposition, generally related to variably developing firm-hardground conditions.

It is expected that, depending on the rate of stratigraphic condensation, the evaluation of truncated tierings or bioclasts alternatively at the most cases, may reveal microstratigraphic gaps with magnitude shorter than the biostratigraphic resolution. Thus, evaluation of truncated tierings due to the record of tractive energy of calcilutite/siltite events can be applied only in relatively extended Rosso Ammonitico, where simple infaunal-tiering can be identifiable.

In extremely condensed and hiatal Rosso Ammonitico, the evaluation of truncated bioclasts is the only available way to approach stratigraphic completeness, missing record being caused by common erosion (corrosion included) during long-lasting residence-time of fossils on the taphonomically active zone.

Taking into account 1) the similar paleogeographic context in epioceanic plateaux with differentiated physiography (structural highs and lows) and deposition of calcareous and marly (sensu Aubouin, 1964) Rosso Ammonitico subfacies, respectively; 2) the usual complete burial of carcasses by depositional events; and 3) the reliability of the information gathered from tiered trace fossils, the quantification of minimum-missing-deposits in extended and condensed successions permits to establish how distinct are the rates of sedimentation in the cases studied and to refine the understanding on depositional dynamics.

High frequency of erosional events in condensed Rosso Ammonitico determined a rate of sedimentation 5-fold lower than in the expanded Rosso Ammonitico (0.8 mm/10^3y vs. 4.5 mm/10^3y).

In addition to the quantification of biostratigraphically identifiable stratigraphic gaps, the analysis of truncated tiering and bioclasts (or their equivalent inner casts) open the possibility of analysing the distribution of minor stratigraphic gaps (below biostratigraphic resolution) in terms of magnitude (and hence their potential hierarchy), abundance, and frequency throughout sections. The application of our analyses is of particular relevance in sections showing stratigraphic and sedimentary condensations (sensu Gómez & Fernández-López 1994), as is the case of the highly condensed and hiatal Rosso Ammonitico, a condensed facies even for its relatively expanded subfacies (marly lithotypes in Farinacci & Elmi, 1981).

As a complement of the recognition of erosional events, and therefore of the stratigraphic completeness, decompaction numbers (nd) favours calculations of minimum pre-compactional thickness. Nevertheless, this only was possible on relatively expanded Rosso Ammonitico, where Wetzel & Aigner (1986) methodology was applied. According to the restored thickness in Valdorbia section based on decompaction numbers, a sedimentation rate of 4.5 mm/10^3y is converted to 8.5 mm/10^3y pre-compaction. This is in accordance to recent data from the Venetian Alps (Martire & Clari, 1994), in which a notably higher original thickness was interpreted for the Rosso Ammonitico.

The high frequency of minor stratigraphic gaps (forced by erosion and/or non-deposition) should be considered a significant factor determining condensation in the cases studied, in addition to the averaged low productivity usually assumed for Tethyan epioceanic plateaux during the Jurassic.

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REFERENCES

Aubouin J. (1964) - Réflexions sur la facies «ammonitico rosso». *Bull. Soc. géol. France*, 7, VI, pp. 475-501.

Ausich W.I. & Bottjer D.J. (1982) - Tiering in suspension-feeding communities on soft substrata throughout the Phanerozoic. *Science*, v. 216, pp. 173-174, Tulsa.

Bathurst R.G.C. (1987) - Diagenetically enhanced bedding in argillaceous platform limestones: stratified cementation and selective compaction. *Sedimentology*, v. 34, pp. 749-778, Oxford, London.

Bottjer D.J. & Ausich W.I. (1982) - Tiering and sampling requirements in paleocommunity reconstruction. In: *Proc. Third. Amer. Paleont. Conv.* v. 1, pp. 57-59, Tulsa.

Bromley R.G. (1996) - *Trace fossils. Biology, taphonomy and application*. Chapman & Hall, 280 pp., London.

Caracuel J.E. (1996) - Asociaciones de Megainvertebrados, Evolución Ecosedimentaria e Interpretaciones Ecoestratigráficas en Umbrales Epioceánicos del Tethys Occidental (Jurásico Superior). *Unpubl. Thesis* Univ. Granada. 475 pp.

Caracuel J., Monaco P. & Olóriz F. (1996a) - Conservacion diferencial de ammonites en facies ammonitico rosso. Ejemplos del Kimmeridgiense (Subbetico, S España) y del Toarciense (Umbria-Marche, Italia Central). *Comun. II Reunión de Tafonomía y fosilización*, pp. 79-82, Zaragoza.

Caracuel J., Monaco P. & Olóriz F. (1996b) - Eventos de depósito y colonización del substrato en facies ammonitico rosso (Subbético Externo, Kimmeridgiense). *Geogaceta*, v. 21, pp. 123-125, Madrid.

Centamore E., Chiocchini M., Deiana G., Micarelli A. & Pieruccini U. (1969) - Considerazioni preliminari su alcune serie mesozoiche dell'Appennino umbro-marchigiano. *Mem. Soc. Geol. It.*, v. 8, pp. 237-263, Roma.

Centamore E., Chiocchini M., Deiana G., Micarelli A. & Pieruccini U. (1971) - Contributo alla conoscenza del Giurassico dell'Appennino umbro-marchigiano. *Studi geol. Camerti*, v. 1, pp. 7-89, Camerino.

Checa A., Molina J.M. & Olóriz F. (1983) - Intercalaciones calcareníticas en las facies «Ammonitico rosso» del Jurásico Superior de la Sierra del Ahillo (Subbético Externo, Cordilleras Béticas). In: A.Obrador (Ed.) - *X° Congreso Nacional de Sedimentología*, Comunicaciones, v. 3, pp. 17-21.

Clari P.A. & Martire L. (1996) - Interplay of cementation, mechanical compaction, and chemical compaction in nodular limestones of the Rosso Ammonitico veronese (Middle-Upper Jurassic, Northeastern Italy). *Journ. Sed. Res.* SEPM, v. 66 (3A), pp. 447-458, Tulsa.

Colacicchi R., Nocchi M., Monaco P., Parisi G., Baldanza A., Cresta S. & Pallini G. (1988) - Palaeoenvironmental analysis from Lias to Malm (Corniola to Maiolica Formations) in the Umbria-Marche basin, Central Italy (preliminary report). In: 2nd International Symposium on Jurassic Stratigraphy, Lisbon, v. 2, pp. 717-728, Lisbona.

Comas M.C., Olóriz F. & Tavera J.M. (1981) - The red nodular limestones (Ammonitico rosso) and associated facies: a key for settling slopes or swell areas in the Subbetic Upper Jurassic submarine topography (southern Spain). In: A. Farinacci & S. Elmi (Eds.) *Rosso Ammonitico Symposium Proceedings*, Ed. Tecnoscienza, pp. 113-136, Roma.

Donovan D.T. (1958) - The Ammonite Zones of the Toarcian (ammonitico rosso facies) of Southern Switzerland and Italy. *Eclogae geol. Helv.*, v. 51, pp. 33-60, Basel.

Einsele G. & Seilacher A. (1991) - Distinction of tempestites and turbidites. In: G. Einsele, W. Ricken & A. Seilacher (Eds.), *Cycles and Events in Stratigraphy*, Springer-Verlag, pp. 377-382, Berlin.

Eller M.G. (1981) - The Red Chalk of eastern England: a Cretaceous analogue of Rosso Ammonitico. In: A. Farinacci & S. Elmi (Eds.) *Rosso Ammonitico Symposium Proceedings*, Ed. Tecnoscienza, pp. 207-231, Roma.

Elmi S. (1981a) - Classification typologique et génétique des Ammonitico-Rosso et des faciès noduleux ou grumuleux: essai de synthèse. In: A. Farinacci & S. Elmi (Eds.) *Rosso Ammonitico Symposium Proceedings*, Ed. Tecnoscienza, pp. 233-249, Roma.

Elmi S. (1981b) - Sédimentation rythmique et organisation séquentielle dans les Ammonitico-Rosso et les faciès associés du Jurassique de la Méditerranée occidentale. Interprétation des grumeaux et des nodules. In: A. Farinacci & S. Elmi (Eds.) *Rosso Ammonitico Symposium Proceedings*, Ed. Tecnoscienza, pp. 251-300, Roma.

Farinacci A. & Elmi S. (Eds.) (1981) - *Rosso Ammonitico Symposium Proceedings*. Ed. Tecnoscienza, pp. 602, Roma.

Fernández-López S. (1984) - Criterios elementales de reelaboración tafonómica en ammonites de la Cordillera Ibérica. *Acta Geol. Hisp.*, v. 19, pp. 105 -116, Madrid.

Fernández-López S. (1997) - Ammonites, taphonomic cycles and stratigraphic cycles in carbonate epicontinental platforms. *Cuad. Geol. Ibérica*, v. 23, pp. 95-136, Madrid.

Fernández-López S. & Meléndez G. (1993) - Abrasion surfaces on internal moulds of ammonites as paleobathymetric indicators. *Palaeogeogr., Palaeoclimat. Palaeoecol.*, v. 110, pp. 29-42, Amsterdam.

Fürsich F.T. (1979) - Genesis, environments and ecology of Jurassic hardgrounds. *N. Jb. Geol. Palaont. Abh.*, v. 158, pp. 1-63, Stuttgart.

Fürsich F.T. & Aberhan M. (1990) - Significance of time-averaging for palaeocommunity analysis. *Lethaia*, v. 23, pp. 143-152, Oslo.

Gallitelli-Wendt M.F. (1969) - Ammoniti e stratigrafia del Toarciano Umbro-Marchigiano (Appennino Centrale). *Boll. Soc. Paleont. Ital.*, v. 8, pp. 11-62, Modena.

Gómez J.J. & Fernández-López S. (1994) - Condensation processes in shallow platforms. *Sedimentary Geology*, v. 92, pp. 147-159, Amsterdam.

Goldring R. (1995) - Organisms and the substrate: response and effect. In: D.W.J. Bosence & P.A. Allison (Eds.), Marine Paleoenvironmental Analysis from Fossils, *Geol. Soc., Spec. Publ.*, v. 83, pp. 151-180, London.

Henderson R.A. & McNamara K.J. (1985) - Taphonomy and ichnology of cephalopod shells in a Maastrichtian chalk from Western Australia. *Lethaia*, v. 18, pp. 305-322, Oslo.

Kauffman E.G. (1988) - Concepts and methods in high resolution event stratigraphy. Ann. *Rev. Earth Planet. Sci. Letters*, v. 16, pp. 605 - 654, Tulsa.

Kauffman E.G., Elder W.P. & Sageman B.B. (1991) - High resolution correlation. A new tool in chronostratigraphy. In: G. Einsele, W. Ricken & A. Seilacher (Eds.), *Cycles and Events in Stratigraphy*, pp. 795-819, Springer-Verlag, Berlin.

MacEachern J.A., Raychaudhuri I. & Pemberton S.G. (1992) - Stratigraphic applications of the *Glossifungites* ichnofacies: Delineating discontinuities in the rock record. In: S.G. Pemberton (Ed.), Application of ichnology to petroleum exploration, *Soc. Econ. Paleont. Mineral.* Core Workshop n°17, pp. 169-198, Calgary.

Martire L. (1989) - Analisi biostratigrafica e sedimentologica del Rosso Ammonitico Veronese dell`Altopiano di Asiago (VI). *Unpubl. Thesis Univ. Torino*, 166 pp.

Martire L. & Clari P. (1994) - Evaluation of sedimentation rates in Jurassic-Cretaceous pelagic facies of the Trento Plateau: relevance of discontinuities and compaction. *Giorn. Geologia*, v. 56, pp. 193-209, Bologna.

Molina J.M. (1987) - Análisis de las Facies del Mesozoico en el Subbético Externo (Provincias de Córdoba y Sur de Jaén). *Thesis Univ. Granada*. 512 pp.

Molina J.M., Ruíz-Ortíz P.A. & Vera J.A. (1997) – Calcareous tempestites in pelagic facies (Jurassic, Betic Cordilleras, Southern Spain). *Sedimentary Geology*, v. 109, pp. 95-109, Amsterdam.

Monaco P. (1992) - Hummocky cross-stratified deposits and turbidites in some sequences of the Umbria-Marche area (Central Italy) during the Toarcian. *Sedimentary Geology*, v. 77, pp. 123-142, Amsterdam.

Monaco P. (1995) - Relationships between trace-fossil communities and substrate characteristics in some Jurassic pelagic deposits in the Umbria-Marche basin, Central Italy. *Geobios* M.S., v. 18, pp. 299-311, Lyon.

Monaco P. (1996) - Oxygenation history and substrate characteristics by means of trace fossil tiering in the central Apennines during the Toarcian. *Soc. geol. It, 78th Geologia delle Dolomiti*, Estended Abstracts, San Cassiano, p. 121, S.Cassiano.

Monaco P. (in press) - Tiered ichnoassemblages in Jurassic tempestites from Apennines and southern Alps. *Boll. Soc. Geol. It.*, Spec. Vol. mem. G.P. Pialli (2000).

Monaco P., Nocchi M., Ortega-Huertas M., Palomo I., Martínez F. & Chiavini G. (1994) - Depositional trends in the Valdorbia Section (Central Italy) during the Early Jurassic, as revealed by micropaleontology, sedimentology and geochemistry. *Eclogae geol. Helv.*, v. 87, pp. 157-223, Basel.

Monaco P., Caracuel J.E. & Castellani L. (1996) - Infaunal tiering, bioclast erosion and decompaction as new tools to quantify discontinuities in ammonitico rosso: examples from the Middle Toarcian and the Kimmeridgian. *Paleopelagos*, v. 6, pp. 201-210, Roma.

Monaco P. & Uchman A. (1999) - Deep-sea ichnoassemblages and ichnofabrics of the Eocene Scisti Varicolori beds in the Trasimeno area, Western Umbria, Italy. In: A. Farinacci & A.R. Lord (Eds.), *Depositional episodes and Bioevents, Paleopelagos Spec.* Publ. n°2 (1999), pp. 39-52, Roma.

Müller A.H. (1979) - Fossilization (Taphonomy). In: R.A. Robinson & C. Teichert (Eds.), Treatise on Invertebrate Paleontology, Part A, Introduction, Fossilization (Taphonomy), Biogeography and Biostratigraphy, *Geo-*

logical Society of America and University of Kansas, Colorado, pp. A2-A78, Boulder.

Nieto L.M. (1997) - La Cuenca Subbética Mesozoica en el Sector Oriental de las Cordilleras Béticas. *Thesis Doctoral*, Univ. Murcia, Univ. Jaén. 562 pp.

Olóriz F., Sarti C. & Tavera J.M. (1993) - *Simospiticeras* (Ammonitina) una forma rara ma tipica nel Titoniano superiore della Tetide Mediterranea. *Boll. Soc. Paleont. Ital.*, v. 32 (2), pp. 265-275, Modena.

Olóriz F., Caracuel J.E. & Ruiz-Heras J.J. (1995) - Numerical analysis of sedimentary components: A key for interpretation of macroscopic and microscopic features in ammonitico rosso facies (uppermost Jurassic-lowermost Cretaceous). *Journ. Sed. Res.*, A65, v. 1, pp. 234-243, Tulsa.

Ortega-Huertas M., Monaco P. & Palomo I. (1993) - First data on clay mineral assemblages and geochemical characteristics of Toarcian sedimentation in the Umbria-Marche basin (central Italy). *Clay Minerals*, v. 28, pp. 297-310, London.

Ricken W. (1992) - A volume and mass approach to carbonate diagenesis: the role of compaction and cementation. In: K.H. Wolf & G.D. Chilingarian (Eds.), Diagenesis III, Developments in Sedimentology, v. 47, pp. 291-315, Elsevier, Amsterdam.

Rivas P., Sanz de Galdeano C. & Vera J.A. (1979) - Itinerarios Geológicos a las Zonas Externas de las Cordilleras Béticas. *Serv. Pub. Univ. Granada.* 86 pp.

Sandoval J. (1983) - Bioestratigrafía y Paleontología (*Stephanocerataceae* y *Perisphinctaceae*) del Bajocense y Bathonense en las Cordillearas Béticas. Tesis Doctoral Universidad de Granada. 613 pp.

Savrda C.E. & Bottjer D.J. (1986) - Trace-fossil model for reconstruction of paleo-oxygenation in bottom waters. *Geology*, v. 14, pp. 3-6, New York.

Savrda C.E. & Bottjer D.J. (1989) - Trace-fossil model for reconstructing oxygenation histories of ancient marine bottom waters: application to upper Cretaceous Niobrara Formation, Colorado. *Palaeogeogr., Palaeoclimat., Palaeoecol.*, v. 74, pp. 49-74, Amsterdam.

Seilacher A. (1963) - Umlagerung und Rolltransport von Cephalopoden-Gehäusen. *N. Jb. Geol. Paläont. Mh.*, v. 11, pp. 593-615, Stuttgart.

Seilacher A. (1971) - Preservational history of ceratite shells. *Palaeontology*, v. 14, pp. 16 - 21. London.

Seilacher A. (1973) - Biostratinomy: the sedimentology of biologically standardized particles. In: R. Ginsburg (Ed.), Evolving Concepts in Sedimentology, *Johns Hopkins University Studies in Geology*, v. 21, pp. 159 - 177.

Seilacher A. (1978) - Use of trace fossil assemblages for recognizing depositional environments. In: P.B. Basan (Ed.), Trace Fossil Concepts, *Soc. Econ. Paleont. Mineral.* Short Course Notes, v. 5, pp. 167 - 181, Tulsa.

Staff G.M., Stanton R.J.Jr., Powell E.N. & Cummings H. (1986) - Time-averaging, taphonomy, and their impact on paleocommunity reconstruction: Death assemblages in Texas bays. *Geol. Soc. Amer. Bull.*, v. 79, pp. 428 - 443, Tulsa.

Tunis G. & Uchman A. (1996) - Trace fossils and facies changes in Cretaceous-Eocene flysch deposits of the Julian Prealps (Italy and Slovenia): consequences of regional and world-wide changes. *Ichnos*, v. 4, pp. 169 - 190, Amsterdam.

Venturi F. (1981) - Le "Rosso Ammonitico" du Toarcien infèrieur dans quelques localités de l'Apennin de Marche-Ombrie. Conséquences sur la stratigraphie et la taxonomie des Ammonitina. In: A. Farinacci & S. Elmi (Eds.) *Rosso Ammonitico Symposium Proceedings*, Ed. Tecnoscienza, pp. 581 - 602, Roma.

Vera J.A. & Molina J.M. (1998) – Shallowing-upward cycles in pelagic troughs (Upper Jurassic, Subbetic, Southern Spain). *Sedimentary Geology*, v. 119, pp. 103 - 121, Amsterdam.

Wetzel A. & Aigner T. (1986) - Stratigraphic completeness: Tiered trace fossils provide a measuring stick. *Geology*, v. 14, pp. 234 - 237, New York.

Ziegler B. (1975) - Einführung in die Paläobiologie. Teil 1. Allgemeine Paläontologie. E. Scweizerbart'sche Verlagsbuchhandlung, Stuttgart.