

Lower Toarcian (Jurassic) brachiopod-rich carbonate facies of the Gran Sasso range (central Apennines, Italy)

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ABSTRACT - Several stratigraphic studies have proved that Early Toarcian carbonate platforms and basins suffered a sharp sedimentary and palaeoecologic evolution worldwide reflecting the onset of dramatic environmental perturbations in the atmosphere/hydrosphere system.

An upper Liassic slope carbonate succession cropping out in the Gran Sasso range (Abruzzi, central Italy) and pertaining to the transition between the Latium-Abruzzi carbonate platform and the Umbria-Marche basin has been studied in this light.

According to our sedimentologic, biostratigraphic and palaeoecologic analyses on a reworked biotic facies, a prominent brachiopod-rich assemblage with the remarkable occurrence of cyanobacteria, crinoids and echinoids thrived during the early Toarcian (Serpentinum Zone) in open shelf/proximal ramp setting. A microbially-induced sedimentation could develop also in deeper-water settings since automicrite partly infilled brachiopod shells after their basinward reworking. This points out the spreading of deteriorated environmental conditions in the oceanic waters which supported *r*-competitor forms to thrive in connection with the Early Toarcian Oceanic Anoxic Event. The related environmental disruption induced a sharp drop in the sediment productivity of the shallow-water carbonate factory as well as a marked starvation of the basin.

Biostratigraphic study has allowed us to correlate the recovered association to the Lower Toarcian Soaresirhynchia Beds. The type-species *S. bouchardi* has been recovered for the first time in Italy. This species can be considered as a disaster taxon thriving after the Early Toarcian Oceanic Anoxic Event.

RIASSUNTO - [Facies carbonatiche a brachiopodi del Toarciano inferiore (Giurassico) del Massiccio del Gran Sasso] - Numerosi studi hanno dimostrato che le piattaforme carbonatiche ed i bacini tetidei hanno subito durante il Toarciano inferiore una rapida e significativa evoluzione stratigrafica legata ad imponenti perturbazioni ambientali agenti nel dominio oceanico. Con questo studio abbiamo inteso caratterizzare gli aspetti biostratigrafici, paleoecologici e sedimentologici di una successione in facies di scarpata affiorante nel Massiccio del Gran Sasso e deposta tra il Liassico superiore ed il Dogger inferiore lungo la transizione tra la Piattaforma carbonatica laziale-abruzzese ed il contiguo Bacino umbro-marchigiano. La successione stratigrafica analizzata, spessa circa 100 m, mostra, dal basso verso l'alto, la parte alta della Corniola (circa 20 m), il Verde ammonitico (circa 50 m) e la parte inferiore dei Calcari bioclastici inferiori (circa 30 m). I depositi rimaneggiati posti alla base del Verde ammonitico presentano una ricca associazione a brachiopodi dominata dal genere *Soaresirhynchia*, tra cui è stata individuata la specie-tipo *S. bouchardi* che viene documentata in Italia per la prima volta. Considerazioni biostratigrafiche consentono di attribuire al livello a brachiopodi un'età toarciana inferiore corrispondente alla Zona a Serpentinum. Ulteriori considerazioni litostratigrafiche, ne consentono la correlazione ai Soaresirhynchia Beds descritti in letteratura.

I caratteri tafonomici e sedimentari suggeriscono che, prima del loro trasporto post-mortem, i brachiopodi popolassero ambienti di piattaforma esterna/rampa prossimale caratterizzati da coperture sabbiose bioclastiche composte da frammenti di crinoidi, echinidi e, in minor misura, da foraminiferi bentonici. A questi si uniscono peloidi, cortoidi, cyanoidi ed oncoidi micritici la cui origine è da ascrivere all'azione biosedimentaria esercitata da comunità microbiche (cianobatteri). L'insieme di tali depositi veniva poi trasportata verso il bacino ad opera di debris flows concentrati e torbiditi. Anche in tali ambienti più profondi le condizioni generali consentivano la produzione di sedimenti indotti da comunità microbiche. Il significato paleoecologico dell'associazione fossilifera nel suo complesso suggerisce che i sistemi deposizionali carbonatici subirono durante il Toarciano inferiore una marcata variazione dei parametri ambientali oceanici con conseguente diffusione di organismi del tipo *r*-competitore.

L'insieme dei caratteri biostratigrafici e paleoecologici sembra indicare che il livello studiato ricco di brachiopodi possa rappresentare la locale risposta sedimentaria della Piattaforma carbonatica laziale-abruzzese all'evento geologico globale del Toarciano inferiore (evento anossico oceanico) ed alla relativa crisi di produttività carbonatica. In questo senso, la specie-tipo *S. bouchardi* può essere considerata come disaster taxon.

INTRODUCTION

Phanerozoic carbonate successions which deposited during remarkable, generally rapid changes of the sedimentary, palaeoceanographic and palaeoecologic conditions are the subject of recent considerable

scrutiny (e.g. Weissert et al., 1998; Jenkyns et al., 2002). Independent evidences coming from sedimentological, palaeontological and geochemical studies suggest that: a - synchronous black shales and phosphorites horizons; b - relevant bio-events affecting the diversification and diversity reduction of the fossil assemblages; c - major

excursions of the carbon and oxygen isotope curves, represent geological events co-occurring with impressive changes of global palaeoceanographic conditions (e.g. Arthur et al., 1990; Hallam & Wignall, 1999).

Jurassic successions contain some of the most prominent among the geological events above (e.g. Jones & Jenkyns, 2001; Dromart et al., 2003) which appear to cluster in the upper Liassic. During the Early Pliensbachian-Early Toarcian span it is possible to observe sudden, almost coeval stratigraphic evolutions both in shallow- and deep-water carbonate successions of the Tethyan realm (e.g. Jenkyns & Clayton, 1986; Morettini et al., 2002). Widespread middle Carixian and early Toarcian drowning unconformities of various Tethyan peritidal domains (e.g. Santantonio, 1993; Zempolich, 1993) and replacement of carbonate mud with marls and shales through a black shale level within Lower Toarcian basinal successions (e.g.: Jenkyns, 1988; Jiménez et al., 1996) document that carbonate productivity of oceanic waters dramatically decreased during late Liassic. This seemingly reflected meaningful chemical and physical perturbations of the hydrosphere-atmosphere system at a global scale (e.g. Jenkyns et al., 2002).

As regards Toarcian, integrated stratigraphic investigations suggest that such perturbations are associated to: a - huge rates of organic-carbon burial linked to one of the major Oceanic Anoxic Event (OAE); b - significant mass extinction, biotic diversity reduction

or diversification; c - high paleotemperatures leading to a greenhouse episode; e - transgression of relative sea level (Jenkyns, 1988; Little & Benton, 1995; Hallam & Wignall, 1999; Harries & Little, 1999; Hesselbo et al., 2000; Jones & Jenkyns, 2001; Beerling et al., 2002; Hart et al., 2003). Early Toarcian environmental perturbations had to affect brachiopods also since Spiriferinida, Koninckinidina, and Wellerelloidea suffered an extinction event and some families belonging to Hemithiridoidea had a radiative episode (Ager, 1987; Williams et al. 2002; Manceñido & Owen, 2002; Vörös, 2002).

The results of an interdisciplinary study (biostratigraphy, palaeoecology and sedimentology) on a brachiopod-rich, Lower Toarcian slope succession cropping out in the Gran Sasso range (Apennines, central Italy) are presented here. The possibility to link the investigated succession to the Early Toarcian OAE and to highlight the paleoenvironmental meaning of the relative fossil association is discussed. In addition, the occurrence of *Soaresirhynchia bouchardi* (Rhynchonellidae) is documented for the first time in Italy.

GEOLOGICAL SETTING

The Gran Sasso thrust sheet is located at the northern front of the Abruzzi Apennines where the Lower Jurassic-Miocene transition between the Latium-Abruzzi carbonate platform and the bounding Umbria-

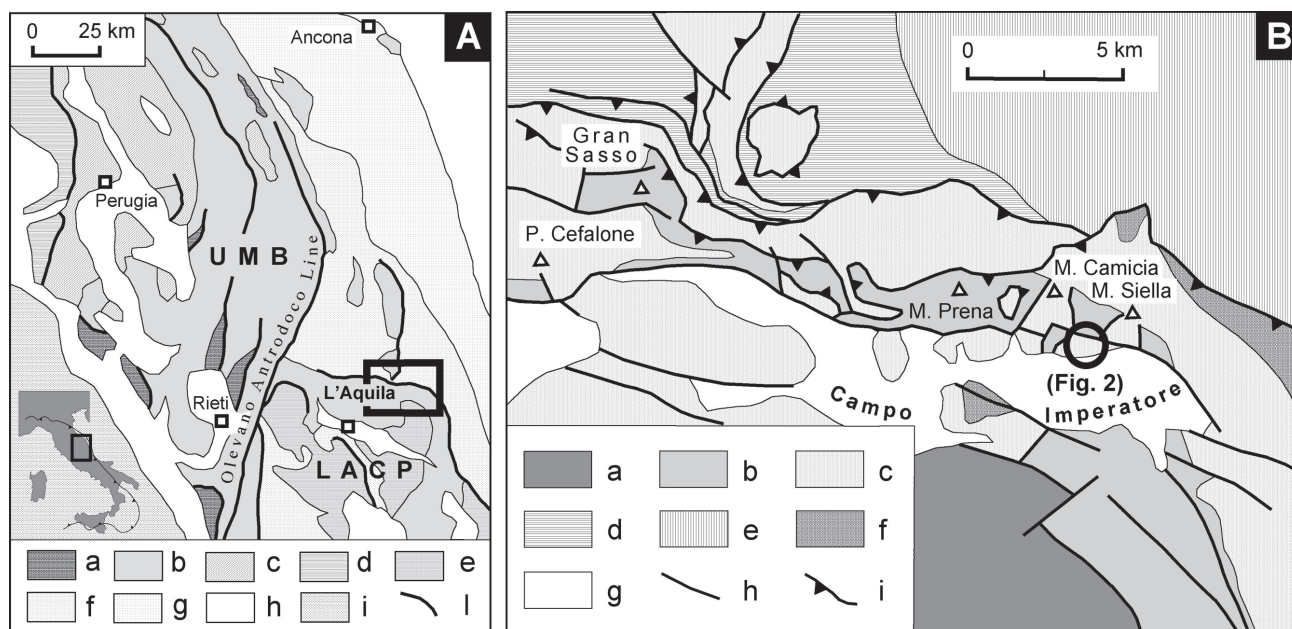


Fig. 1 - Structural sketch of the central Apennine fold and thrust belt (A) and simplified geological map of the study area (B, simplified after Calamita et al., 2004).

A - a) Upper Triassic-Lower Jurassic carbonate platform succession; b) Lower Jurassic-Oligocene basin and slope succession; c) Miocene, mostly foredeep siliciclastics; d) Oligocene-Lower Miocene foredeep siliciclastics of the Tuscan domain; e) Upper Triassic-Miocene carbonate platform succession; f) Upper Miocene-Lower Pliocene foredeep siliciclastics; g) Pliocene-Pleistocene wedge-top deposits; h) Pliocene-Quaternary continental and marine clastics; i) Pliocene-Quaternary volcanics; l) main thrusts; LACP - Latium-Abruzzi Carbonate Platform; UMB - Umbria-Marche Basin.

B - a) Triassic-Cretaceous carbonate platform succession; b) Triassic-lower Liassic carbonate platform; c) upper Liassic-Miocene p.p. slope and basin; d) pre-evaporite foredeep siliciclastics (Messinian p.p.); e) post-evaporite foredeep siliciclastics and carbonates (Messinian p.p.-Lower Pliocene); f) Messinian (?) -Lower Pliocene wedge top basins; g) Quaternary continental deposits; h) normal faults; i) thrusts.

Marche basin (e.g. Parotto & Pratulon, 1975; Bernoulli, 2001) is thrust onto Messinian foredeep siliciclastics (e.g. Calamita et al., 2002, 2004) (Fig. 1). Late Triassic euxinic basins (Adamoli et al., 1990; Bigozzi, 1994) locally record early sinsedimentary tectonics and drowning of some sectors of the Adria carbonate paleoplatfrom (Ciarapica et al., 1987; Barchi & Bigozzi, 1995) at the very onset of the Tethyan rifting (Bernoulli, 2001; Bosellini, 2004). The following termination of large sectors of the early Liassic Adria paleoplatfrom (namely the drowning of the Calcare Massiccio platform) is a regional event (e.g. Passeri & Venturi, 2005) which is well documented in the Gran Sasso area close to the Sinemurian-Pliensbachian boundary (Colacicchi & Bigozzi, 1996) (Fig. 1B). The overlying basinal succession (upper Liassic-Middle Miocene) is made up of largely prevailing carbonate and marly deposits. The mass-flow input of reworked shallow-water sediments documents marked progradations of the slope during Middle-Late Jurassic, Cenomanian, and Late Paleocene-Middle Eocene (e.g. Adamoli et al., 1978; van Konijnenburg et al., 1999). The stratigraphic frame of the Jurassic basinal succession mirrors that of the Umbria-Marche basin (see Morettini et al., 2002, for an updated chronostratigraphic scheme) with only minor variations depending on the close depositional setting of the Gran Sasso successions with respect to the coeval shallow-water carbonate factory.

The local architecture of the Tethyan palaeomargin inherited from the early Mesozoic rifting has greatly influenced the evolution of the Neogene orogenic belt in the studied area (Calamita et al., 2003; Speranza, 2003). Post-thrusting, extensional tectonics cutting into the hanging-wall of the Gran Sasso thrust sheet gave rise to Quaternary subsiding intermontane basins with maximum displacements of about 2,500 m (Calamita et al., 2002). Campo Imperatore is one of the major extensional basins described above. The upper Liassic brachiopods-bearing succession examined here is exposed along the northern slope of Campo Imperatore, between Tremoggia Mt. and Fonte Vetica (Fig. 1B).

Further, slightly older Rhynchonellinae-rich levels have been reported in other sections cropping out not

far away as in the case of Le Carboniere (Ruggiero, 1964) and San Vito Mt. (Taddei Ruggiero, 1997).



Fig. 2 - Panoramic view of the upper Liassic-lower Dogger deep-water succession exposed on the SE slope of Tremoggia Mt. White arrows indicate the studied brachiopod-rich interval at the base of the Verde ammonitico formation.

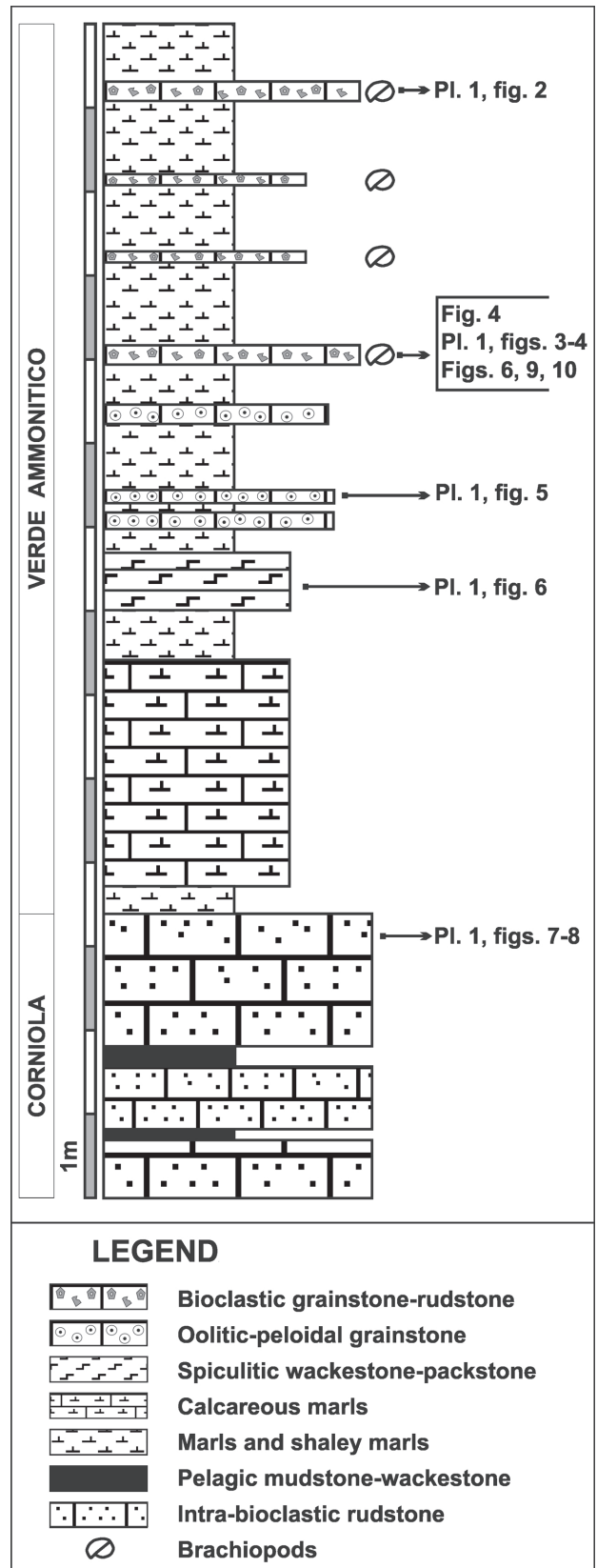


Fig. 3 - Simplified stratigraphic column of the Lower Toarcian p.p. slope succession. Arrows refer to the facies reported in the text.

THE STRATIGRAPHIC SUCCESSION

The studied section, about 100 m thick, crops out on the SE slope of Tremoggia Mt., northeastward of Fonte Vetica, on the hanging-wall of a E-W trending, S-dipping normal fault. It consists of: a - about 20 m of the uppermost Corniola, (upper Domerian); b - about 50 m of Verde ammonitico (Lower-Upper p.p. Toarcian); c - about 30 m of the lower Calcari bioclastici inferiori (Upper Toarcian p.p.-Aalenian p.p. ?) (Fig. 2). The attitude of the beds is basically regular whereas the interval corresponding to the marly lithofacies of the Verde ammonitico unit may show local variations because of some ductile deformation. The upper part of the Verde ammonitico and the boundary with the overlying lower Calcari bioclastici inferiori are mostly masked by recent talus deposits.

Corniola Formation

This unit consists of largely prevailing coarse, white-to-greyish grainstones-to-rudstones and subordinate greyish pelagic mudstones-to-wackestones with chert nodules and layers. Rudstone beds are up to 2 m thick whereas pelagic beds usually do not exceed 30 cm. Beds are typically tabular whereas some erosive surfaces may lead to amalgamation. Rudstone beds are mostly massive (faint graded bedding may occur) and clasts are variously sorted and mostly rounded. An abundant matrix made up of bioclastic packstone is present. Grains are composed of echinoid, crinoid, brachiopods and bryozoan debris along with abundant peloids, cyanoids, coated grains and some ooids and benthic foraminifera (Pl. 1, figs. 7-8). Bioclastic grainstones show basically the same composition of the matrix described above. Some pebbly mudstones are also present in a matrix of bioclastic and intraclastic packstones. Pebbles, ranging from 1 to 15 cm in size, are made up of whitish peloidal and oolitic packstones-to-grainstones along with pinkish crinoidal packstones.

As a whole this interval documents a huge feeding of the slope by means of hyper-concentrated debris flow and turbidites.

Verde ammonitico formation

This unit sharply overlies the Corniola Formation (Figs. 2-3). It represents a local counterpart of the well-known, lower-upper p.p. Toarcian Marne del Monte Serrone and Rosso Ammonitico units (e.g. Morettini et al., 2002). The boundary corresponds to the disappearance of coarse gravitative deposits coupled to a drastic decrease of the carbonate content in the pelagic lithofacies; this results in a large diffusion of thin-bedded, whitish-to-greenish marls and shaley marls. Some levels made up of dark grey marly shales a few cm thick occur at the very base of the unit. Several thin-bedded turbidites made up mostly of oolitic and/or peloid-cyanoid grainstones are present (Pl. 1, fig. 5) whereas bioclastic grainstones (crinoids, echinoids and rare benthic foraminifera) are less common. Turbidites seem not to be arranged according to a cyclic pattern. Some marly layers are very rich in siliceous sponge spicules (Pl. 1, fig. 6) which appear not to be reworked. The brachiopod-rich level examined here occurs about 8 m above the boundary with the Corniola Formation (Figs. 2-3) and consists of thin-bedded rudstones-to-floatstones (Pl. 1, figs. 2-4; Figs. 3-4). They show little evidence of erosional surfaces at their base (see below for their description). Apart from the abundant but poorly diversified fossils assemblage (brachiopods, crinoids, echinoids and different kinds of microbially-induced carbonate grains), a remarkable intraclastic fraction occurs (Pl. 1, figs. 3-4).

Calcari bioclastici inferiori formation

This unit sharply replaces the marls of the Verde ammonitico formation. It consists of an intercalation of prevailing fine-to-coarse whitish bioclastic

EXPLANATION OF PLATE 1

Selected microfacies of the upper Pliensbachian-lower Dogger carbonate slope succession of Tremoggia Mt. Scale bars = 2 mm.

- fig. 1 - Lower Calcari bioclastici inferiori, *Mesoendothyra croatica* Zone, early Dogger. Peloidal and bioclastic (echinoids and benthic foraminifera) packstone-grainstone. A detail of *Mesoendothyra croatica* is boxed.
- figs. 2-6 - Lower Verde ammonitico, *Soaresirhynchia bouchardi* Subzone, Early Toarcian.
 2 - Bioclastic floatstone (brachiopods and echinoids) in a matrix of a compositionally similar bioclastic packstone. Note the normal grading and parallel lamination of bioclasts. No compaction-induced flattening occurs.
 3 - Coarse bio-intraclastic packstone (brachiopods, echinoids and crinoids). Most of the grains are micritized. Peloids and fine grained cyanoids also occur. A small intraclastic pebble (ic) is made up of peloidal and oncoidal microbialite containing a brachiopod fragment (arrow).
 4 - Intraclastic floatstone. Large, shallow-water intraclast (ic) made up of peloid- and coated grain-rich packstone-grainstone float in an abundant matrix of unsorted bioclastic (brachiopods-echinoids-crinoids) and microbial (peloids, cyanoids) packstone.
 5 - Coarse grained, fossiliferous cyanoid, ooid and peloid-rich grainstone. Note the isorientation of elongated bioclasts (bivalves).
 6 - Burrowed microbioclastic packstone. Fossils are siliceous sponge spicules and rare radiolaria.
- figs. 7-8 - Uppermost Corniola, Late Pliensbachian. Coarse grained intraclastic rudstones in a matrix of bioclastic (echinoids, crinoids and Bryozoans), peloids and cyanoids packstone. Some bioclasts are silicified (arrow). Note the thrombolitic structure in the intraclast of fig. 7. br: bryozoa; ic: intraclast.

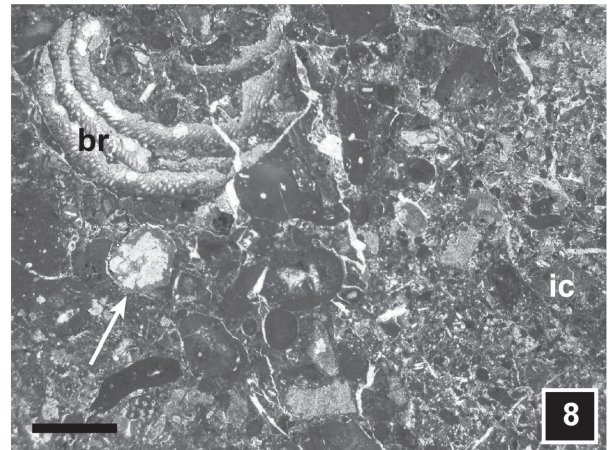
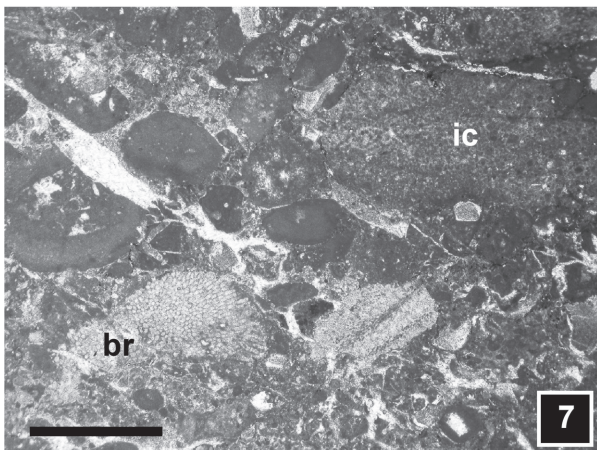
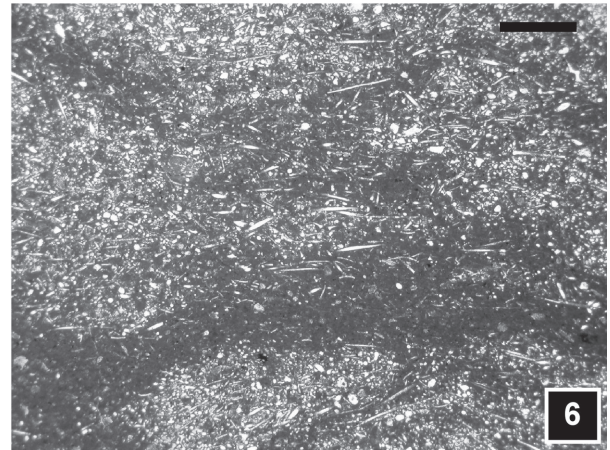
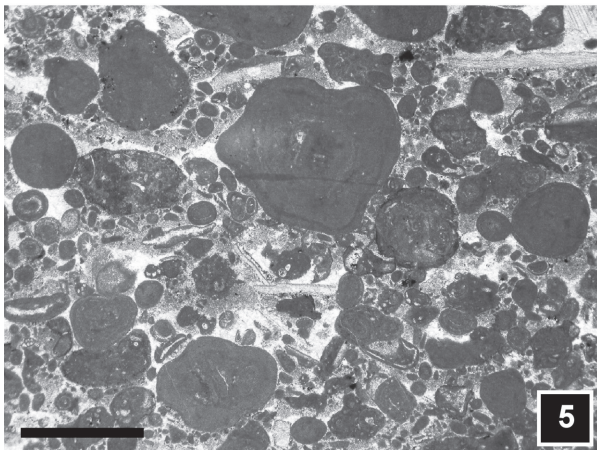
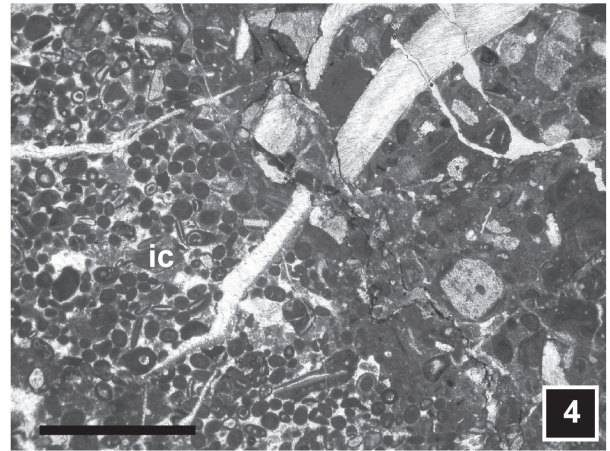
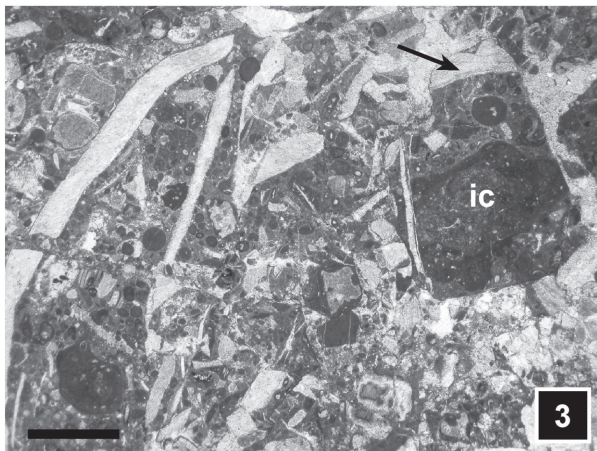
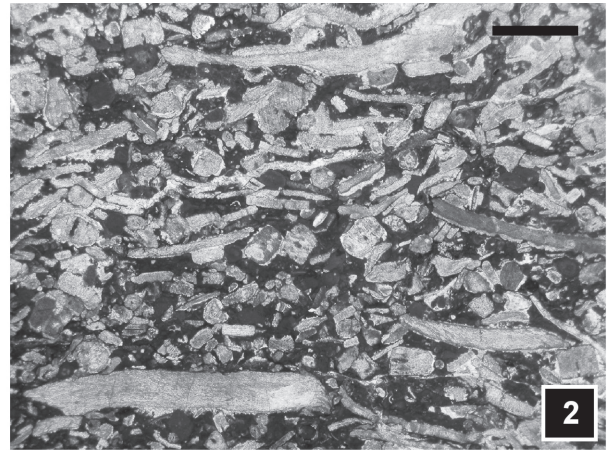
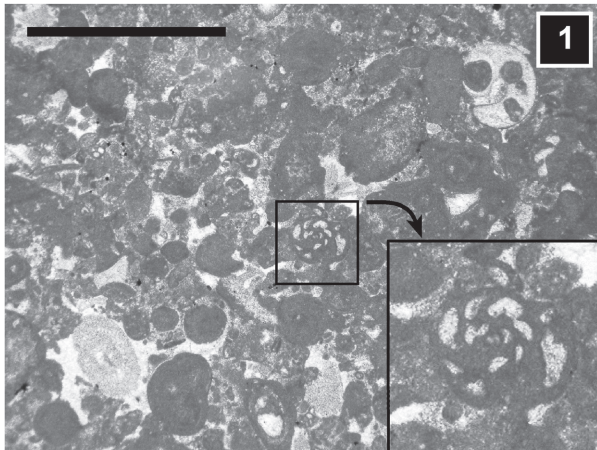




Fig. 4 - Field aspect of the lower brachiopod-rich bed. Note the high sorting of the shells and their chaotic arrangement. Coin is 2.3 cm across.

grainstones and greyish pelagic mudstones-to-wackestones arranged in coarsening and thickening upward cycles which possibly exceed 10 m in thickness. Individual beds are mostly 0.1 to 2 m thick even though frequent amalgamation surfaces may mimic thicker beds. Grainstones are basically composed of echinoid, gastropod and bivalve debris with minor amount of benthic foraminifera among which *Mesoendothyra croatica* (Pl. 1, fig. 1). Such a detectable increase in shallow-water biota diversity parallels a co-occurring shift in the basinal lithofacies which are devoid of any marly interval. Abundant, microbially-induced carbonate grains still characterize the resedimented grainstones occurring in the lower part of this unit (Pl. 1, fig. 1) whereas pelagic deposits are often crowded with densely-packed thin-shelled bivalves ("filaments"). Some bed surfaces in the lowermost portion of this unit present evident iron and manganese mineralizations as both irregular crusts and sparse concretions (Fig. 5).

THE BRACHIOPOD-RICH LEVEL

The brachiopod-rich level consists of four stacked tabular beds, 5 to 25 cm thick, which are regularly distributed within an interval, about 4 m thick, of largely prevailing greenish marls and calcareous marls (Figs. 2-3). The fossiliferous layers show an abundant macrofauna composed of brachiopods with minor amount of regular echinoids; these taxa appear both as well-preserved specimens and fine-to-coarse sized debris. In addition, abundant crinoid fragments and very rare ammonites (Hildoceratidae) have been found. Microfauna is represented by rare benthic foraminifera (*Siphovalvulina* sp., *Glomospira* sp. and encrusting forms) whereas abundant microbially-induced carbonate

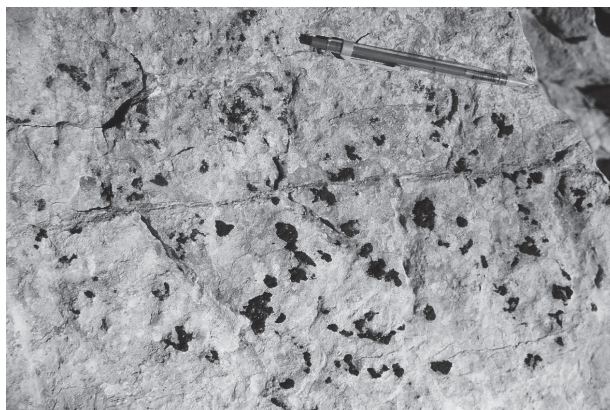


Fig. 5 - Detail of a mineralized bed surface (iron and manganese oxides) pertaining to the lowermost Calcari bioclastici inferiori formation.

grains (ooids, peloids, cortoids, micrite oncoids and cyanoids) occur (Fig. 6).

The brachiopod association is dominated by rhynchonellids whilst Zeilleridae and Terebratulidae are very rare. Rhynchonellids are basically represented by the genus *Soaresirhynchia* with the type-species *S. bouchardi* (see the chapter Systematic description). However it is not to rule out the presence of other species belonging to the same genus. The established chronostratigraphy of the Verde ammonitico unit, the large prevalence of *Soaresirhynchia* and the occurrence of *S. bouchardi* make it possible to consider the studied brachiopod facies as *Soaresirhynchia* Beds *sensu* Gahr (2005). In spite the examined *Soaresirhynchia*-rich levels are not the result of a primary accumulation we propose such a litho- and chronostratigraphic interpretation owing to the relatively rapid "post-mortem" reworking of an outer shelf palaeocommunity (see below).

The same brachiopod association has been sampled also in other transitional successions cropping out along the northern side of the Campo Imperatore basin

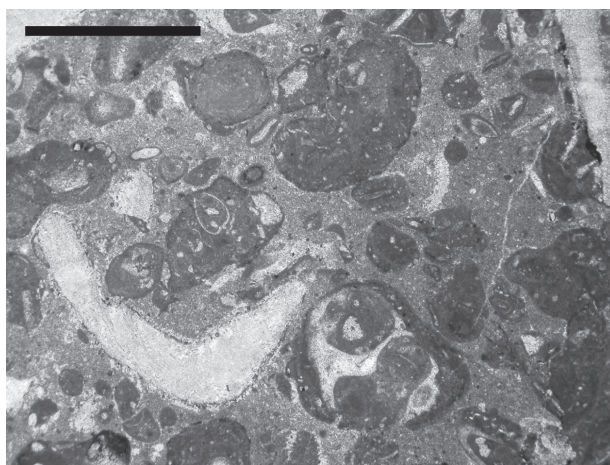


Fig. 6 - Abundant and various microbially-induced carbonate grains (peloids, ooids, micrite oncoids, cyanoids and cortoids) float in a mud-supported matrix. Crinoids, gastropods and encrusting foraminifera also occur. Scale bar = 2 mm.

(Vallone di Vradra, San Vito Mt. and Vado di Sole) suggesting that the examined level may well represent an useful marker for detailed local stratigraphic correlations. A further brachiopod-rich level (*Rhynchonella* cf. *clesiana*) underlying the *Bifrons* ammonite Zone was recognized in the eastern Marsica at the base of Toarcian deep-water marls and shales (Colacicchi, 1967). This points out the possibility of brachiopod-based regional correlations in the upper Liassic transitional successions deposited between the Latium-Abruzzi carbonate platform and the Umbria-Marche basin.

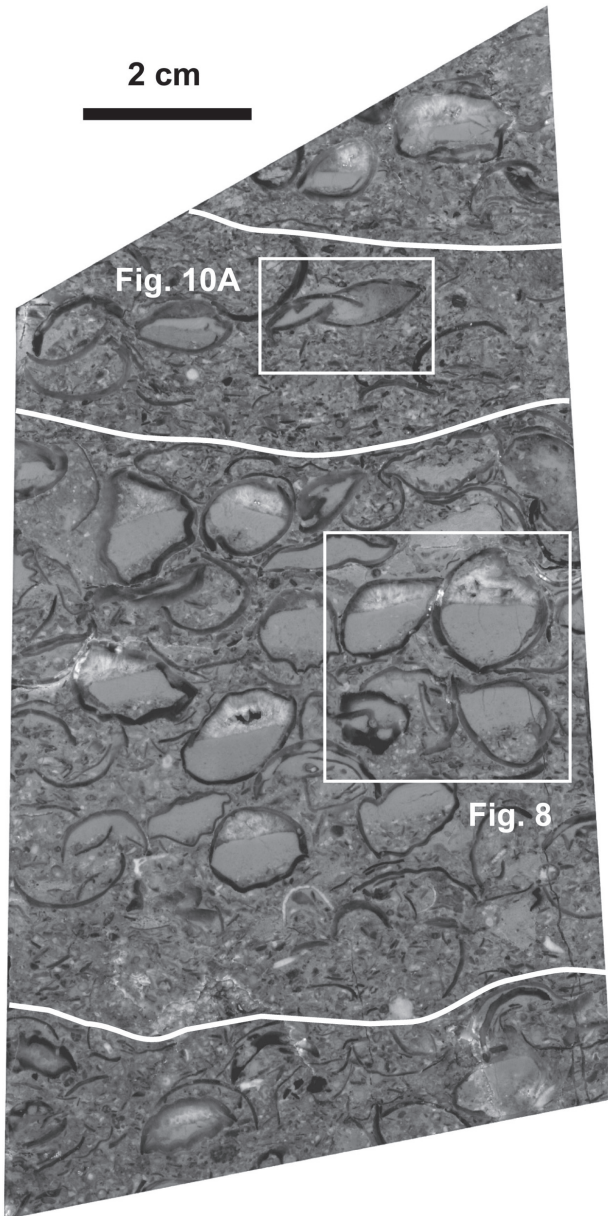


Fig. 7 - Polished slab of the lowermost brachiopod-rich bed. Three amalgamation surfaces separate four debris flow layers. They are made up of coarse bioclastic debris (mostly brachiopods, crinoids, echinoids) along with articulated brachiopod shells floating in a coarse, compositionally similar bioclastic matrix. See text for discussion. Complete shells present an evident multiphase infilling and isoriented geopetal structures (Figs. 8-10). Later compaction resulted in: *a* - deformation/break of several brachiopod shells; *b* - tilting of some geopetal structures; *c* - partial obliteration of the amalgamation surfaces.

Sedimentology

Sedimentological analysis carried out in the field, on polished slabs (Figs. 7-8) and thin sections (Pl. 1; Figs. 6, 9-10) clearly demonstrates that the fossils assemblages of the brachiopod-rich beds are not the result of primary accumulation. Moreover they represent the result of episodic depositions of reworked organisms on the slope by means of concentrated debris flows and high-density turbidites. This assumption is based on the following sedimentologic and taphonomic elements:

a - the almost total lack of juvenile forms implies a sorting of the shells according to their hydrodynamic behaviour (Figs. 4, 7);

b - the platy shell debris is at times normally graded and sub-parallel to bedding (Pl. 1, fig. 2). These features suggest that sediments were transported basinward by debris flow mechanisms in a possibly laminar flux regimen;

c - the multiphase sediment infilling of the articulated shells clearly indicates an early *post-mortem* stage in outer shelf/proximal ramp settings and a later, basically post-reworking stage in deeper water settings by means of microbially-induced micrite (Figs. 8-10);

d - beds show a poor grading, if any, (Figs. 4, 7) and a basal zone of shearing along with slightly irregular tops and large grains projecting. These features clearly reflect a debris flow transport mechanism;

e - articulated shells, hence low-density grains, typically occur at the middle-upper part of the skeletal levels (Fig. 7) suggesting a mechanical partition during downslope transport.

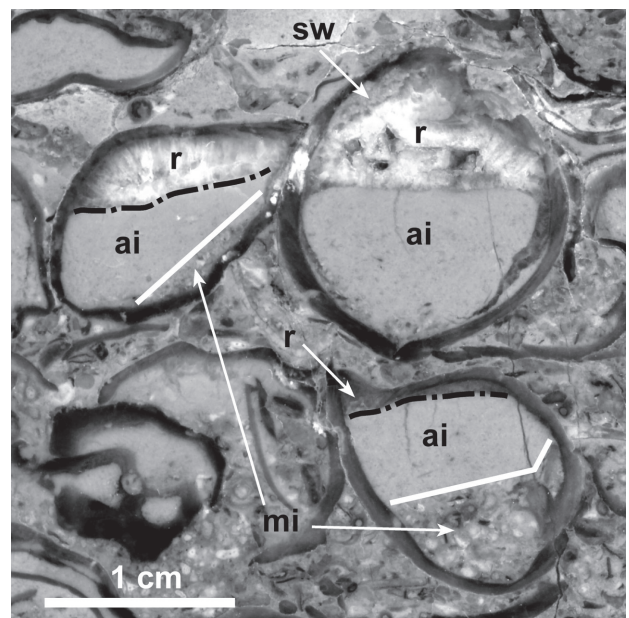


Fig. 8 - Detail of the polished slab of Fig. 7. The differential patterns of mechanical (*mi*) and later automicrite (*ai*) internal sedimentation (upper levels are indicated in white and black respectively) suggest an early post-depositional compaction of the shells following the automicrite formation and prior to the final precipitation of radiacal cements (*r*) (see Fig. 9). Note that the mechanical infilling (*mi*) is the same of the extragranular coarse-grained matrix. Former, early cemented shallow-water internal sediments are also indicated (*sw*) (see Figs. 9-10).

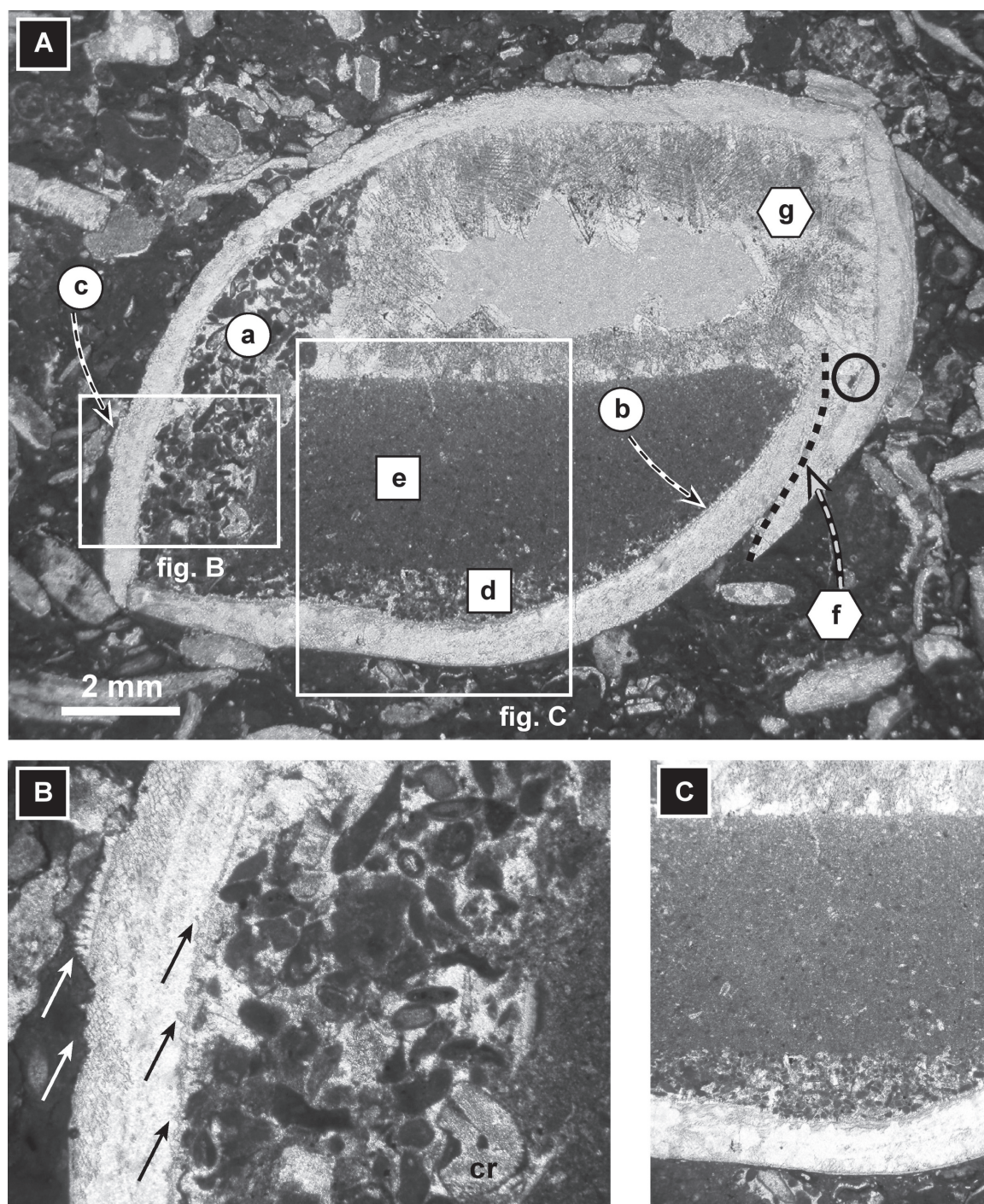


Fig. 9 - Microfacies of the lowermost debris flow-derived brachiopod-rich bed (see text for discussion). Lower Verde ammonitico, *S. bouchardi* Subzone, Early Toarcian.

A - General view of the complete sedimentary and diagenetic history of brachiopods. The shell floats in an abundant matrix composed of poorly sorted and variously rounded coarse brachiopod, crinoid and echinoid packstone. Some intraclasts also occur. *a-c*) Early *post-mortem* stages in outer shelf setting: *a* - mechanical infilling by means of fine, shallow-water peloidal and bioclastic grainstone; *b* - early cementation of both the internal sediments (stage “*a*”) and residual cavity by a thin, isopachous crust of bladed crystals (an early, faint dissolution possibly preceded the stage “*a*”); *c* - cementation of the external surface by a crust of dog-tooth crystals (mostly abraded during subsequent basinward reworking). *d-e*) Syn- (?) and early post-reworking stages: *d* - mechanical deposition of a thin layer of peloidal and bioclastic packstone possibly during downslope movement; *e* - internally precipitated, microbially-induced micrite (automicrite) after downslope movement. *f-g*) Later stages: *f* - mechanical compaction leads to the collapse of the shell by overburden stress. Note the remnant of automicrite (encircled) below the fracture (dotted line); *g* - partial occlusion of the broken shell by a thick, isopachous crust of radial fibrous cements (burial setting?). Remaining pore space results in high intra-skeletal porosity.

B - Detail of the shallow-water, early infilling sediments. A micritized, large crinoid arm element (*cr*) occurs within the fine grained peloids and cortoids which possibly deposited in outer shelf settings. Note abrasion and later stylolitization of the dog-tooth cement crust (white arrows) and the clues of an early dissolution of the shell (black arrows).

C - Detail of the deep-water automicrite formed as microbial precipitation of possibly heterotroph/chemolithotroph organisms. Note the typical thrombolites characterizing the clotted texture of the fine-grained sediments.

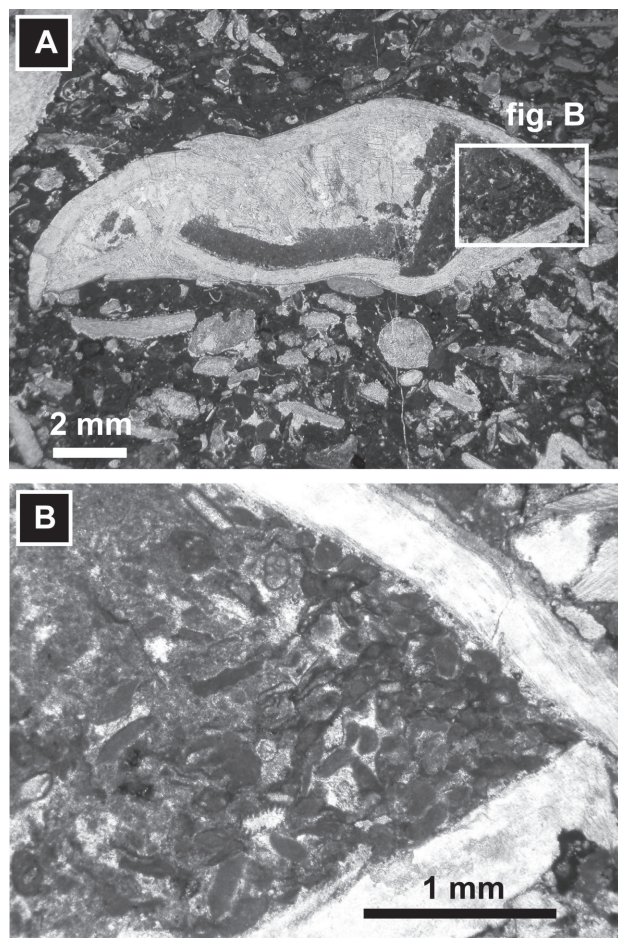


Fig. 10 - Multistage infilling of a brachiopod shell.
A - the sedimentary and diagenetic evolutive path closely resembles that illustrated in Fig. 9. Note the slightly different texture of the early *post-mortem* infilling.
B - detail of the peloid- and cortoid-rich packstone showing a faint graded bedding. Rare bioclasts (benthic foraminifera, *Siphovalvulina* ?) occur.

SYSTEMATIC DESCRIPTION

Order: RHYNCHONELLIDA Khun, 1949
Superfamily: PUGNACOIDEA Rzhonsnitskaia, 1956
Family: BASILIOLIDAE Cooper, 1959
Subfamily: BASILIOLINAE Cooper, 1959
Genus: *Soaresirhynchia* Alm  ras, 1994

Soaresirhynchia bouchardi (Davidson, 1852)
(Fig. 11)

- 1852 *Rhynchonella bouchardi* DAVIDSON p. 82; pl. XV, figs. 3-5.
1962 *Stolmorhynchia bouchardi* (Davidson) - AGER, p.133, pl. XI, figs. 7-9.
1994 *Soaresirhynchia bouchardi* (Davidson) - ALM  RAS, pp. 33-64, pl. 1, figs. 1-17; pl. 2, figs. 1-16 (*cum syn.*).

Soaresirhynchia might be considered as a later synonym of *Almorhynchia* Ovtsharenko that was instituted only on juvenile specimens (Savage et al., 2002). Further investigations have to be carried out in this light.

Diagnosis

External characters - Shell size medium to small (length 9.1-17.8 mm), longer than wide with the maximum width and thickness in the central area. Oval to subpentagonal in outline, globose, with dorsal valve slightly more convex than the ventral one. Uniplicate, generally symmetrical; shell smooth in the posterior part. The ribs are limited to central-anterior area ranging in number from 3 to 14 in each valve and 2 to 4 in the dorsal fold. Small umbo, suberect. Foramen submesothirid, oval to subcircular, with usually conjuncted deltidial plates.

Internal characters - Dental lamellae are vertical and sub-parallel. Umbonal cavities with secondary fillings; deltidial cavity are square to subtrapezoidal in section. Medium-size teeth are inserted in deep denticular cavities; denticula without accessory cavities are present. Cardinal plates occur; crural bases support long and hamiform crura; median dorsal septum reduced. Mantle canal prints along with saccate morphology occur on the internal mold (see Williams et al., 1997).

Ultrastructure - In spite the diagenetical overprint due to a slight silicification, ultrastructural analysis has been carried out. The secondary layer shows successions of rhomboidal, tabular large fibres which are characteristic of the basiliolidine-type (*sensu* Kamyshan, 1977).

Remarks and comparisons - *Soaresirhynchia* shows a wide morphological variability (Rousselle, 1974; Tchoumatchenco, 1994; Alm  ras, 1994). In our association some flattened specimens show few ribs beginning from the front and correspond to the form-type figured by Davidson (1852).

Other species can be present: *S. flamandi* and *S. rustica* (Dubar, 1931), but the relative study is still in progress.

Biostratigraphy - The genus *Soaresirhynchia* has been documented in Great Britain, Germany, France, Spain, Portugal, Italy, Bosnia, Montenegro, Morocco, Algeria and is limited to the Toarcian (Savage et al., 2002).

The type-species *Soaresirhynchia bouchardi* examined here (Fig. 11) has been diffusely found in sections pertaining to the European palaeobiogeographical province, both in the Celto-Swabian unit (Great Britain, Germany, and NE France; Alm  ras, 1994) and in the Iberian one (south France, Spain, Portugal, Morocco, and Algeria; Comas-Rengifo & Goy, 1975; Tchoumatchenco, 1994). Prior to our finding of *S. bouchardi* in the Apennine range, this species has been reported in the Mediterranean province only in the Bosnia region (Gakovic & Tchoumatchenco, 1994). This type-species has an Early-Middle Toarcian stratigraphic range (*Tenuicostatum* - *Bifrons* Zones; e.g. Alm  ras, 1994).

Soaresirhynchia-rich assemblages, known as *Soaresirhynchia* Beds, have been noted to occur in the

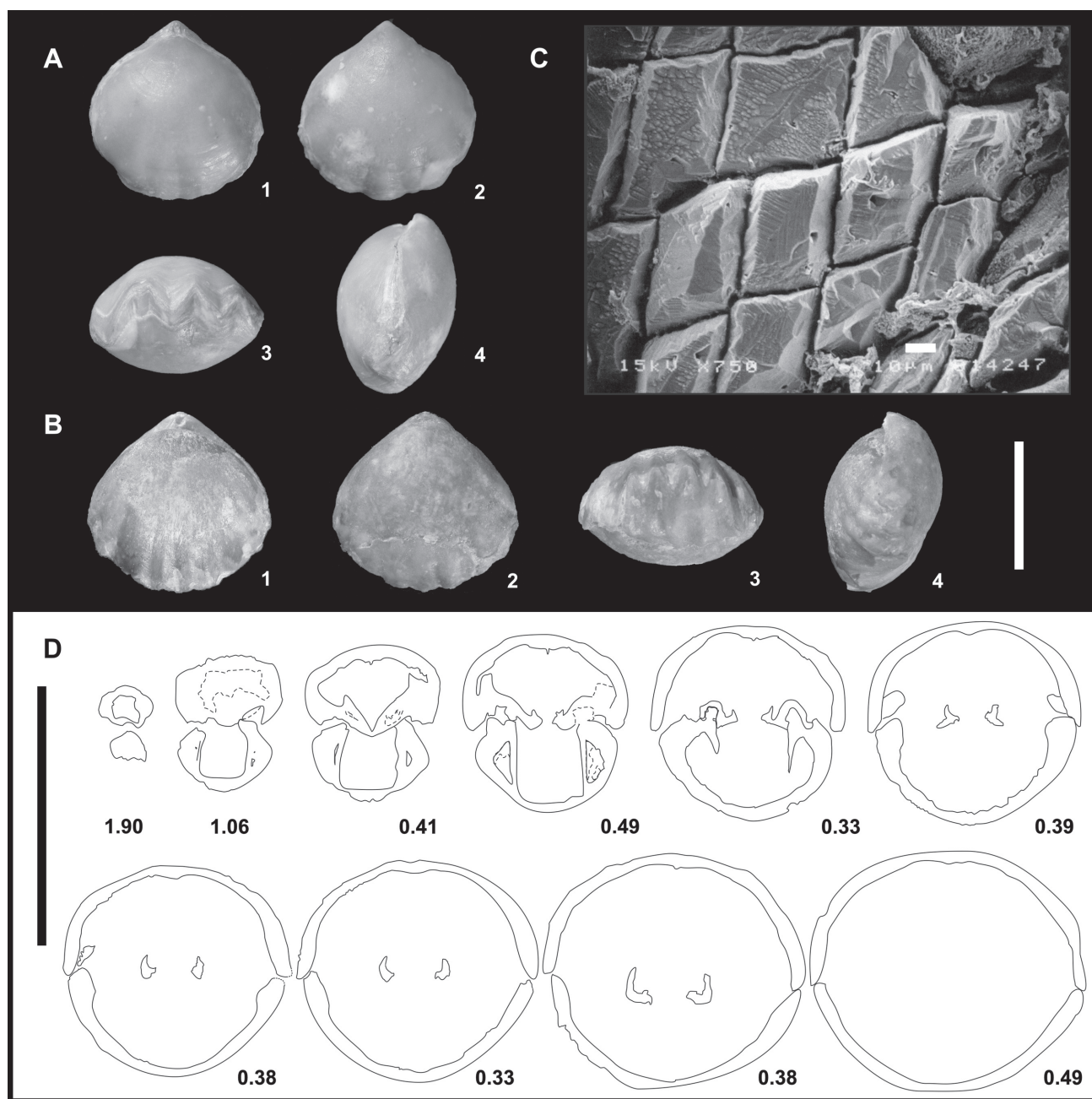


Fig. 11 - *Soaresirhynchia bouchardi* (Davidson), Tremoggia Mt. (Early Toarcian).

A - Specimen V17; 1 - dorsal; 2 - ventral; 3 - anterior; 4 - lateral view.

B - Specimen V4; 1 - dorsal; 2 - ventral; 3 - anterior; 4 - lateral view.

C - SEM micrograph of the transverse section of the shell (secondary layer), specimen S2-B3. Scale bar = 10 µm.

D - Transverse serial sections of specimen V2. Scale bar = 1 cm. Numbers indicate the spacing in mm among serial sections except the first which represents the distance from the umbo.

Celto-Iberian domain only few metres above the *Tenuicostatum-Serpentinum* zonal boundary and represent a key-marker horizon for stratigraphic correlations since they fall within the *Exaratum* subzone (Ghar, 2005). As a consequence, the *Soaresirhynchia* Beds seem to be particularly interesting in terms of paleoecological investigations owing to a rough chronostratigraphic correspondance to the Early Toarcian Oceanic Anoxic Event (Jenkyns, 1988) and to the early Toarcian mass extinction event (Fürsich et

al., 2001).

Due to its widespread occurrence and narrow stratigraphical distribution, *Soaresirhynchia bouchardi* is included in the brachiopod biozonations available for the northern and southern Tethys (Tab. 1).

Soaresirhynchia bouchardi represents the early subzone both of *Homeorhynchia meridionalis* & *Telothyris jauberti* zone (northern Tethys) and *Homeorhynchia batalleri* & *Telothyris jauberti* (southern Tethys) zone which are referable to the

		AMMONITE ZONATION				BRACHIOPOD ZONATION			
		Euro-Boreal Province		Mediterranean Province		French North-Tethyan Realm		Moroccan Middle Atlas	
		Zone	Sub-zone	Zone	Sub-zone	Zone	Sub-zone	Zone	Sub-zone
TOARCIAN p.p.	MIDDLE p.p.	Bifrons	Lusitanicum	Lusitanicum	Bifrons	Sphaeroidothyris vari & S. decipiens	S. vari & S. decipiens	Sphaeroidothyris vari & S. decipiens	
			Laticosta	Laticosta			S. perfida		
		Serpentinum	Falciferum	Latifalcatum	Serpentinum	Homeorhynchia meridionalis & Telothyris jauberti	H. meridionalis & T. jauberti	Homeorhynchia meridionalis & Telothyris jauberti	Soaresirhynchia bouchardi
			Exaratum	Elegantulum			Soaresirhynchia bouchardi		
	EARLY	Tenuicostatum	Semicelatum	Semicelatum	Polymorphum	Liospiriferina falloti & Aulacothyris iberica	N. pygmoea & K. bouchardi		
			Paltum	Mirabile					
		?							

Tab. 1 - Correlation between the ammonite and brachiopod biozones (according to Macchioni & Cecca, 2002, and Alm  ras, 1993, respectively) in the Early and Middle p.p. Toarcian of the northern and southern Tethys.

Serpentinum and lower *Bifrons* ammonite biozones (Alm  ras, 1993).

PALAEOENVIRONMENTAL AND PALAEOECOLOGICAL ANALYSIS

Composition of marine biotic sediments is thought to reflect specific environmental conditions of sea-waters (e.g. Lees & Buller, 1972; Hallock & Schlager, 1986; Carannante et al., 1988; Brasier, 1995).

In spite the shallow-water macrofauna association of the lower Toarcian Tremoggia Mt. section has been clearly reworked downslope, the general features of the original habitat are inferable by means of the ecological characteristics of the taxa and the environmental meaning of the associated carbonate grains.

We have recovered a poorly diversified fossil assemblage which is basically composed of brachiopods, crinoids and echinoids whereas siliceous sponges occur in the prevailing pelagic deposits. These taxa are suspension feeder or grazer organisms and match the classic features of r-strategy, competitor forms. In addition, they are mostly sciaphilous organisms and may be related to mesotrophic up to eutrophic environments (e.g. Hallock & Schlager, 1986; Brasier, 1995).

As a whole, we believe that the reworked macrofauna association is indicative of open marine conditions in upper ramp/outer shelf settings. It is noteworthy that the species of the genus *Soaresirhynchia* become very abundant and polymorphic in the environmental setting above (Elmi et al., 1989). A different setting, represented by deep-water cold seeps, has been hypothesized for slightly older brachiopods (Rhynchonellinae) facies cropping out in the Upper Corniola Formation nearby (Taddei Ruggiero, 1997).

Soaresirhynchia had a working pedicle and a slight

secondary thickening at the posterior part of the shell. Hence the umbo was presumably lying on the sea floor and was adapted to a seminafaunal life mode at very shallow depth (Taddei Ruggiero & Ungaro, 1983, fig. 9, concerning the juvenile stage). Sea floors dwelled by *Soaresirhynchia* had to be blanketed by loose, fine to coarse bioclastic sands where pedicle could easily adhere. This seems to be in agreement with the sedimentological nature of the early *post-mortem* infilling of the umbo which is basically made up of shallow-water peloidal and bioclastic sediments (Figs. 9-10).

More particularly, both the early infilling of the brachiopod shells and a relevant part of the allochems in the debris flows matrix are made up of shallow-water carbonate grains that are basically derived or induced by the activity of microbial consortia (bacteria-cyanobacteria) (Figs. 6, 9-10). In spite not all the cyanobacteria are typical light-independent organisms they may represent relevant carbonate producers in peculiar environmental settings (e.g. Riding, 2000).

Microbial consortia, in fact, may thrive in polluted and/or eutrophicated present-day sea waters (e.g. Golubic, 1994; Paerl, 1999) and a similar assumption has been made for the geologic record also (Whalen et al., 2002; Graziano, 2003; Immenhauser et al., 2005) especially where and when alkaline oceanic waters could develop (e.g. Kazmierczak et al., 1996) during major greenhouse intervals and/or oceanic anoxic events.

Pancost et al. (2004) have carried out microbiogeological studies on the Jurassic-mid Cretaceous of the Umbria-Marche basin as well as other regions worldwide using green sulphur bacteria biomarkers. Their results have demonstrated that photic-zone euxinic conditions occurred in the oceanic waters during the major oceanic anoxic events including the Early Toarcian OAE thus providing a powerful clue to infer that unhealthy ecological conditions for K-strategist organisms occurred during early Toarcian both in the pelagic and neritic shallow-water carbonate

factories.

The Lazio-Abruzzi carbonate platform suffered a significant environmental change during the early Toarcian leading to the widespread diffusion of high-energy oolitic-crinoid-echinoid sedimentation and to a dramatic drop of carbonate productivity within a sharp backstepping trend coupled to a mean transgression (Colacicchi & Bigozzi, 1996). Recent sedimentological analyses carried out in Spain and Portugal have evidenced that autochthonous *Soaresirhynchia* Beds (dominated by *S. bouchardi*) deposited both in highstand (Ghar, 2005) and transgressive system tracts (Duarte et al., 2004).

The scenario above in shallow-water environments is clearly mirrored by several evidences observed in the deeper water section of Tremoggia Mt.

First of all, the deposition of carbonate mud as well as the supply of shallow-water sediments suddenly drop coincident to the Corniola-Verde ammonitico boundary. As a consequence the previously prograding slope suffers a marked starvation during the Toarcian (Figs. 2-3).

Second, the pronounced flourishing of siliceous sponges (Pl. 1, fig. 6), confirms that meso-eutrophic conditions (cf. Hallock, 1988) had to occur throughout the water column also in proximal basin settings. Additional informations in this light come from the environmental meaning of brachiopods since: a - their widespread colonization (Terebratulidae) is reported in circalittoral settings of modern shelves facing the upwelling of cold and nutrient-rich waters (e.g. Kowalewski et al., 2002); b - they have been reported as a disaster taxon during biotic recovery after a major mass extinction (e.g. Rodland & Bottjer, 2001). This seems to be particularly true for *S. bouchardi* (Ghar, 2005).

Looking at the early Toarcian event in a regional perspective we observe that similar facies changes occurred in other Tethyan settings (e.g. Blomeier & Reijmer, 1999; Zempolich, 1993) thus implying a large scale control on the environmental conditions of the oceanic waters (Graziano, 2000) linked to a dramatic evolution of the carbon pump (see discussion in Hesselbo et al., 2000; Jones & Jenkyns, 2001; Beerling et al., 2002, among others). The fact that this event is coeval with the basalts emplacement of the Karoo-Ferrar igneous province (Pálffy & Smith, 2000) is a particularly relevant point in term of palaeoceanographic and palaeoenvironmental implications (e.g. Hesselbo et al., 2000; Jones & Jenkyns, 2001).

Biostratigraphic, sedimentologic, paleoecologic and taphonomic data presented here indicate that the *Soaresirhynchia* Beds found in the examined section coherently reflect the scenario above and may be possibly considered as a key marker which sharply overlies the sediments of the Early Toarcian OAE.

CONCLUSIONS

The present study has allowed to report a new finding of a brachiopod species and to describe its biostratigraphic and palaeoecologic meaning in the frame

of the Toarcian evolving stratigraphy of the Gran Sasso range (central Apennines, Italy). The studied succession ranges from the uppermost Corniola (uppermost Pliensbachian) to the lowermost Calcari bioclastic inferiori (Upper Toarcian) and deposited along the transition between the Latium-Abruzzi carbonate platform and the proximal Umbria-Marche basin.

We have recovered for the first time in the Apennines the *Soaresirhynchia* Beds along with the type-species *S. bouchardi* (Davidson). This key marker occurs within the lower Verde ammonitico, a local unit which correlates with the regionally known Lower-lower Upper Toarcian Marne del Monte Serrone. *S. bouchardi* is the index-species of the *S. bouchardi* Subzone which correlates to the *Serpentinum* Zone.

Our study allowed to recognize that the studied benthic association (brachiopods, cyanobacteria, echinoids and crinoids) inhabited an outer shelf/proximal ramp and was transported basinward by concentrated mass flows. Furthermore we suggest that the r-competitor biota of the examined *Soaresirhynchia* Beds may be considered as disaster taxa which thrived following the environmental perturbation linked to the Early Toarcian Oceanic Anoxic Event.

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