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## The Toarcian marly-calcareous succession in the M. Martani area (Northern Apennines): lithostratigraphy, biostratigraphy, paleoecology and effects of Tethysian events on the depositional environment

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**KEY WORDS** – *Ammonites, Foraminifers, Biostratigraphy, Paleoecology, Toarcian, Umbria (Central Italy).*

**ABSTRACT** – In the M. Martani anticline (between Terni and Perugia) a continuous stratigraphic succession of whitish limestones (Corniola), grey marls (Marne del M. Serrone), reddish nodular marls and limestones (Rosso Ammonitico Umbro-Marchigiano) and bivalve bearing limestones (Calcari a Posidonia) outcrops from the Late Domerian to the Early Aalenian in two sections: Pozzale and Cima Panco. In the Pozzale Section the Marne del M. Serrone Fm. (Early Toarcian) includes black shales indicative of a poor ventilation on the sea-floor related to a global transgressive event. The typical Rosso Ammonitico Umbro-Marchigiano stratigraphic unit (RAUM) follows, which is characterized by red marly-calcareous facies, pervasive bioturbation, a scarcity of detrital intervals, and a nodular structure in layers which are generally rich in ammonites and posidoniids. The RAUM can be subdivided in to three members on the basis of variable autochthonous nodularity and the increase of calcareous content. In the upper part, Aalenian in age, pebbly mudstones occur and the type of nodularity changes due to gravity episodes, recorded in some areas of the Umbro-Marchean Basin. No stratotype as a reference section of the RAUM, exists up to now. The biostratigraphy has been based on ammonites. Research on this group led to the location of the Pliensbachian/Toarcian boundary and the identification of an association of benthic foraminifers, most of them characteristic of the Pliensbachian, in the lower part of the Marne di M. Serrone. It has also revealed a lack of ammonites in the black shales and the occurrence of a new radiation since the H. serpentinus Zone, near to the RAUM base.

Benthic foraminifers are common in the lower part of the Marne del M. Serrone, Early Toarcian in age, showing Pliensbachian affinity, high species diversity and cosmopolitan character. They are abundant but small and oligotypic in the black shales, while they increase in size and in species diversity from the beginning of the reddish marly deposition, which is the oldest member of the RAUM. Both the sedimentological and biological events occurring in the M. Martani area can be related to those of the Mediterranean Thetys, such as marine ingression and deepening in the Early Toarcian, the increase in the clay input, the scarce oxygenation on the sea-bottom and the related extinctions, the improvement in life conditions from the H. serpentinus Zone, and a positive  $\delta^{13}\text{C}$  excursion in the lower part of the H. serpentinus Zone.

A transgressive-regressive cycle was inferred on the basis of the sedimentary record, the foraminiferal assemblages and stable isotopes.

**RIASSUNTO** – [La successione marnoso-calcareo del Toarciano nell'area dei M. Martani (Appennino Settentrionale): litostratigrafia, biostratigrafia, paleoecologia ed effetti degli eventi tetisiani sull'ambiente deposizionale] – Alcune successioni stratigrafiche umbre del Giurassico offrono buone esposizioni delle unità marnoso-calcaree di età Toarciano-Aaleniana rappresentate dal Rosso Ammonitico Umbro-Marchigiano (RAUM) e delle unità litostratigrafiche sottostanti e sovrastanti, con evidenti limiti transizionali. Le due sezioni stratigrafiche qui esaminate, Pozzale (PO) e Cima Panco (CP), appartenenti all'anticlinale dei Monti Martani (tra Terni e Perugia), comprendono l'unità litostratigrafica Corniola (parte alta), la formazione Marne del M. Serrone (MS), le unità Rosso Ammonitico e Calcari a Posidonia, in continuità stratigrafica. Nella sezione di Pozzale le Marne del M. Serrone includono la facies di "black shales" osservata in altre località del Bacino Umbro-Marchigiano, la cui deposizione testimonia una scarsa ossigenazione del fondo marino in corrispondenza del Toarciano inferiore.

Nell'area dei Monti Martani il RAUM presenta caratteristiche litologiche e biostratigrafiche considerate tipiche, consistenti in litotipi marnoso-calcarei di colore rossastro, bioturbazione pervasiva, struttura nodulare degli strati, alto contenuto in ammoniti, assenza o scarsità di episodi detritici e suddivisibilità in tre membri, in base all'incremento del contenuto calcareo e della nodularità ritenuta autoctona.

Si ritiene che sia necessaria la definizione di uno stratotipo e relativa formalizzazione del Rosso-Ammonitico Umbro-Marchigiano in un'area dove questa unità presenti le caratteristiche tipiche riscontrate nelle sezioni dei M. Martani, ma in cui sia possibile seguire arealmente, almeno per qualche centinaio di metri, l'estensione degli affioramenti. Tale definizione potrebbe permettere di distinguere le differenti facies degli affioramenti indicati come rosso ammonitico, al fine di giungere ad una maggiore caratterizzazione di tale unità ed una migliore comprensione della evoluzione paleoambientale del bacino di sedimentazione durante il Toarciano.

Nella parte superiore del RAUM, appartenente all'Aaleniano, la struttura nodulare degli strati calcarei cambia ed è associata essenzialmente alla presenza di "pebbly mudstone". Episodi gravitativi nella sedimentazione calcarea di questo intervallo di tempo sono piuttosto diffusi nel bacino di sedimentazione umbro-marchigiano ed indicano un incremento dell'attività tettonico-eustatica alla fine della deposizione del Rosso Ammonitico.

In base alla successione dei litotipi, all'analisi dei foraminiferi bentonici e delle microfacies e alle recenti analisi isotopiche, si deduce una tendenza al "deepening" del fondo marino al passaggio dal membro inferiore marnoso-calcareo delle MS, ai sedimenti argilloso-marnosi del Toarciano inferiore ed uno "shallowing" in corrispondenza del passaggio ai sedimenti marnoso-calcarei nodulari del Toarciano medio-superiore entro il RAUM.

L'età delle Marne del M. Serrone e del RAUM, in base alla biostratigrafia ad ammoniti, è compresa tra il limite Pliensbachiano-Toarciano e la parte inferiore dell'Aaleniano. L'analisi biostratigrafica ha permesso di suddividere l'intervallo stratigrafico delle due sezioni in biozone. Lo



studio degli ammoniti ha evidenziato che nella parte inferiore della Zona a D. (O.) tenuicostatum sono presenti specie ad affinità domeriana, prevalenti sulle rare forme considerate tipicamente toarciane appartenenti al genere Dactyloceras. Gli ammoniti sono assenti nell'intervallo stratigrafico soprastante, che include le "black shales", mentre una nuova radiazione, con comparsa di taxa tipicamente toarciani è documentabile fin dai primi livelli della Zona a H. serpentinus, in prossimità della base del Rosso Ammonitico.

Per quanto riguarda i foraminiferi bentonici, si è notata, nella Zona a D. (O.) tenuicostatum, alla base delle "black shales", l'estinzione o temporanea scomparsa di generi e specie ereditati dal Pliensbachiano. Nei sedimenti scarsamente ossigenati, la microfauna è sempre presente, ma di piccole dimensioni ed oligotipica. Dalla base delle marne rosse, appartenenti al RAUM, Zona a H. serpentinus, si ha un evidente nuovo aumento della taglia e della diversità sia generica che specifica dei foraminiferi.

Gli ammoniti, i foraminiferi e le faune accompagnanti testimoniano che la scarsa ossigenazione ha provocato una crisi biologica generalizzata ed una ripresa faunistica si è avuta a partire dalla base della Zona a H. serpentinus.

Gli eventi sia sedimentologici che biologici, riconosciuti nelle successioni toarciane dei Monti Martani, si inquadrano nel contesto geologico generale della Tetide Mediterranea: ingressione marina a partire dal limite Pliensbachiano-Toarciano, con incremento della sedimentazione di materiale argilloso; deterioramento delle condizioni di ossigenazione dei fondali e conseguente passaggio da associazioni microfaunistiche k-selected a r-selected; sviluppo discontinuo di facies a "black shales"; estinzione di numerosi taxa nel Toarciano inferiore; successiva ripresa faunistica e radiazione di nuove forme; regressione marina nel Toarciano medio-superiore con ritorno di una sedimentazione principalmente calcarea, di associazioni a foraminiferi k-selected, di abbondanti organismi e dell'aumento dell'energia ambientale.

## INTRODUCTION

In research up to now, the Rosso Ammonitico facies of Central Italy has been considered a marly calcareous sedimentary body, showing nodular structure and abundance of ammonites (Farinacci & Elmi, 1981); it is indicative of open marine (pelagic) conditions and its age is variable in Central Italy. The Rosso Ammonitico facies can be referred to the Sinemurian-Pliensbachian in South-Western Tuscany (Fazzuoli & Pirini-Radrizzani, 1981), to the Domerian, Toarcian, Aalenian and Tortonian in the Umbro-Marchean Apennines (Cecca *et al.*, 1981; Venturi, 1986).

In the Umbro-Marchean Basin the most typical and widespread Rosso Ammonitico facies, named Rosso Ammonitico Umbro-Marchigiano (RAUM, Colacicchi *et al.*, 1988), spans from Early Toarcian to Early Aalenian. It is a well defined lithostratigraphical unit, in the last century quoted as "Marne Rosse Ammonitifere" (Bonarelli, 1893). The main lithotypes of the RAUM consist of red and usually nodular marls and marly limestones, the ratio and vertical distribution of which determine a considerable facies variability in different areas. Moreover, it is generally rich in ammonites within the layers showing an evident nodular appearance; ammonites are almost lacking in non-nodular sediments. This variability is linked to different depositional settings (Colacicchi *et al.*, 1988, Elmi, 1981; Nini *et al.* 1995).

The Rosso Ammonitico Umbro-Marchigiano is clearly distinguishable both from the underlying Marne del M. Serrone Formation (MS) (Pialli, 1969), which consists of varicoloured marls, and from the overlying posidoniid-bearing limestones (Calcari a Posidonia unit, CP). Though Venturi (1973, 1975) and Nicosia & Pallini (1977) outlined the most striking characteristics of the RAUM, outcropping in Monti Martani (Terni), Monte Serano (Foligno),

Monte dell'Eremita (Spoleto) and in the M. La Pelosa area (Polino, Terni) respectively, so far no type section has been established for this well known Lower Jurassic lithostratigraphic unit. Nevertheless a RAUM stratotype could give a useful contribution to a facies heteropy interpretation, sedimentary environment comparison and paleo-physiographical reconstruction.

In this paper two sections of the M. Martani (Pozzale and Cima Panco) were investigated from the lithological and paleontological point of view, with the aim of highlighting the main characteristics of the RAUM and of the units below and above it. This would be useful in order to establish a RAUM stratotype.

The good exposure has allowed interdisciplinary studies to be carried out, mainly concentrated on the Marne del M. Serrone interval and regarding calcareous nannofossil biostratigraphy (Reale *et al.*, 1991), foraminifers and other benthic organisms (Bartolini *et al.*, 1992), organic matter (Bucefalo Palliani & Cirilli, 1993), palinology, calcareous nannofossil and geochemistry (Bucefalo Palliani & Mattioli, 1994), calcareous nannofossils (Mattioli, 1993) and geochemistry (Parisi *et al.*, 1996).

## GEOLOGICAL SETTING AND LOCATION OF THE STUDIED SECTIONS

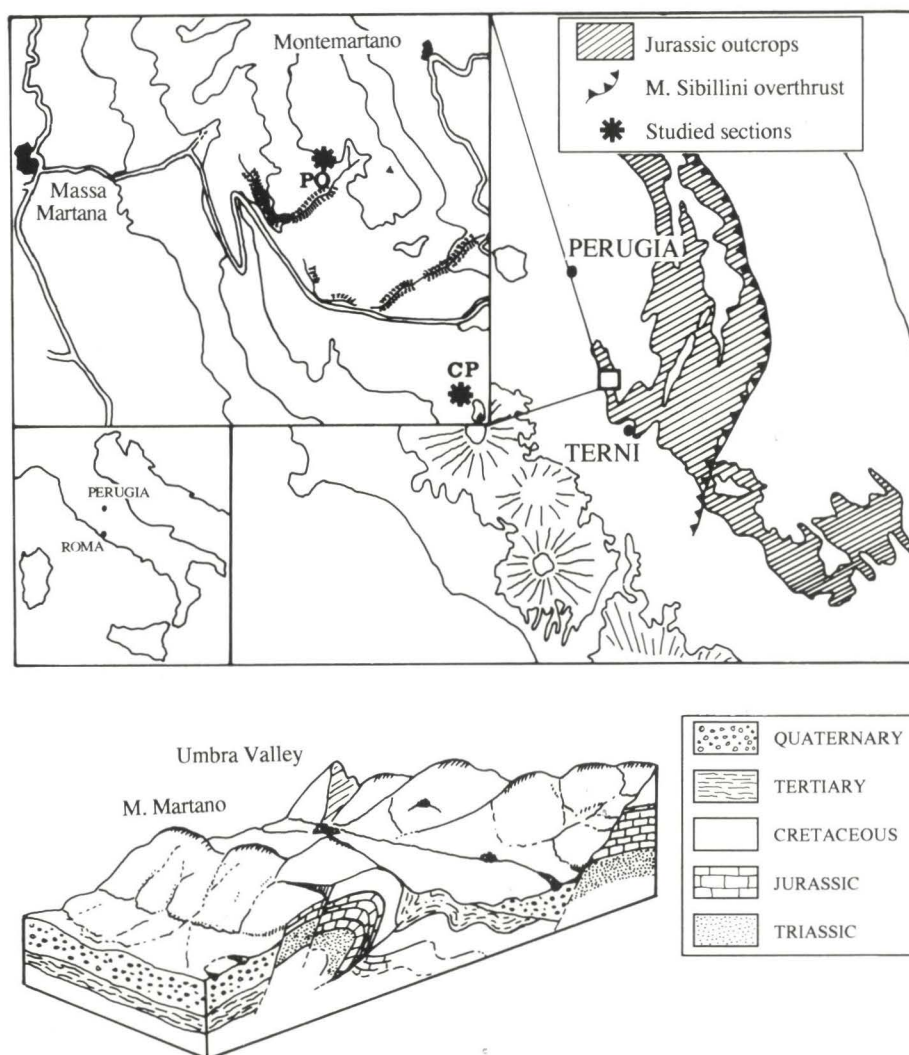
The M. Martani area belongs to the inner belt of the Umbro-Marchean Apennine, between the Tevere River and the main Apennine Range made up of the lineage of M. Nerone, M. Cucco, M. Serano and M. Coscerno. Between the Tiberina Valley and the Umbra Valley, isolated anticlines, North-West - South-East oriented, with a Mesozoic nucleus (e.g. M. Martani and M. Subasio), are surrounded by Tertiary flysch. The M. Martani Range consists of Mesozoic-Tertiary sediments,

folded in an asymmetrical anticline, which is partially overthrust eastward and cut on its western flank by a normal fault (Text-fig. 1).

In the Umbria area the Jurassic open marine succession is made up of the following units: a) Corniola (COR): light grey cherty limestones in decimetric layers, Pliensbachian in age; b) Marne del M. Serrone (MS): varicoloured marls, variable in age from the Early Toarcian to the Middle Toarcian and often including black shales; c) Rosso Ammonitico (RAUM): red marls and marly limestones, generally nodular, mainly Toarcian in age; d) Calcarei a Posidonia (CP): whitish cherty limestones in decimetric layers, very rich in thin bivalves, early Middle Jurassic in age; e) Calcarei Selciferi: varicoloured cherty thin layered limestones, ranging between the Bajocian and the Kimmeridgian; f) Calcarei ad Aptici: grey-whitish limestones without

chert, Kimmeridgian-Titonian in age; g) Maiolica lower portion (Late Titonian): white, lutitic limestones with black cherty nodules.

Colacicchi *et al.* (1988), Cresta *et al.* (1988) and Monaco (1992) divided the Jurassic pelagic successions into three main types: extended, intermediate and condensed. In the extended successions a continuous sedimentation from Corniola to Maiolica, rich in detrital material, occurs and the group of the MS and RAUM units are more than 40 metres thick. Intermediate successions are also referred to as "normal" successions because they are the most common. Detrital supply is scarce or absent and the MS-RAUM group is 10 to 40 metres thick with thin MS (few metres). Finally, successions showing the MS-RAUM group less than 10 metres thick were considered condensed and lacunous. As the authors stipulate, the extended successions are



Text-fig. 1 - Location of the studied sections and geological sketch of the Monti Martani area.



characteristic of depressed areas which acted as depocenters, reached by abundant detrital material; condensed successions are characteristic of morphostructural highs, while normal ones are interpreted as having been deposited on connecting areas between highs and lows.

Farinacci *et al.* (1981) divided the Jurassic formations in the M. Martani area into continuous ones and lacunous ones. The continuous type corresponds to the intermediate one deposited in the relatively depressed areas between the Schignano and Case Canepine structural highs.

The Pozzale and Cima Panco sections belong to normal and apparently continuous successions as the overall thickness of MS and RAUM is below 40 metres, with MS being less than 10 metres and the detrital input very scarce. The two sections are four kilometers apart from each other and belong to the eastern flank of the M. Martani anticline (Text-fig. 1). Antiapenninic strike slip faults separate the two sections, the minimum displacement of which indicates original proximity.

The Pozzale section (sample initials PO) is located in the III N.E. sector, Sheet 131 of the Carta d'Italia, with coordinates from M. Mario: Lat. 42° 42' 40", Long. 0° 07' 50". Cima Panco (sample initials CP) is located in the III S.E. sector, Sheet 131 of the Carta d'Italia, with coordinates from M. Mario: Lat. 42° 44' 50", Long. 0° 08' 80".

The sample number corresponds to the metres indicating the stratigraphic distance from the section base equal to 0.00m.

#### LITHOSTRATIGRAPHY

The stratigraphic interval considered here ranges from the Corniola top to the Calcari a Posidonia base. The boundaries between the units are stratigraphic and usually transitional.

Venturi (1973, 1975) identified the most typical RAUM outcrops in the Monti Martani and in the eastward following range (Monti Serano e di Civitella). The author subdivided this unit into three members from the base to the top: A member with scarcely nodular red marls, B member with nodular red calcareous marls and lastly C member with highly nodular, thicker-layered calcareous marls, and marly limestones.

The Monte Serano and Monte di Civitella Rosso Ammonitico clearly display the above tripartition, with extended and laterally continuous outcrops. Lateral continuity is less evident in the Monti Martani Rosso Ammonitico, being interrupted by condensed successions (Farinacci *et al.*, 1981). The M. Serano and M. di Civitella areas might therefore be

considered more suitable to establish stratotype and type locality.

Text-figs. 2 and 3 show the age and the detailed characteristics of Pozzale and Cima Panco sections. The upper part of the MS, which is not well exposed in the Cima Panco section, was observed in Cima Panco Bis section instead, 20 metres southward. The latter has been represented in Text-fig. 3 because the MS Fm. shows a greater thickness here than in the Cima Panco section, due to the low angle fault at the Corniola-Marne del M. Serrone boundary. In this way some important ammonite bioevents were identified and placed on the log.

The following is a description of the stratigraphical units, from bottom to top.

#### CORNIOLA (COR)

Only the upper part of the unit was examined. It is made up of whitish-grey (10 - 25 cm thick) limestone beds, interbedded with very thin greenish clays. In the last two metres whitish limestone beds alternate with reddish-pink beds.

The upper limit is located at the transition between lutitic limestones and marls, already considered the Marne del M. Serrone Formation. Such a boundary outcrops only in the Pozzale section, since a normal fault cuts out the upper part of the Corniola in the Cima Panco section.

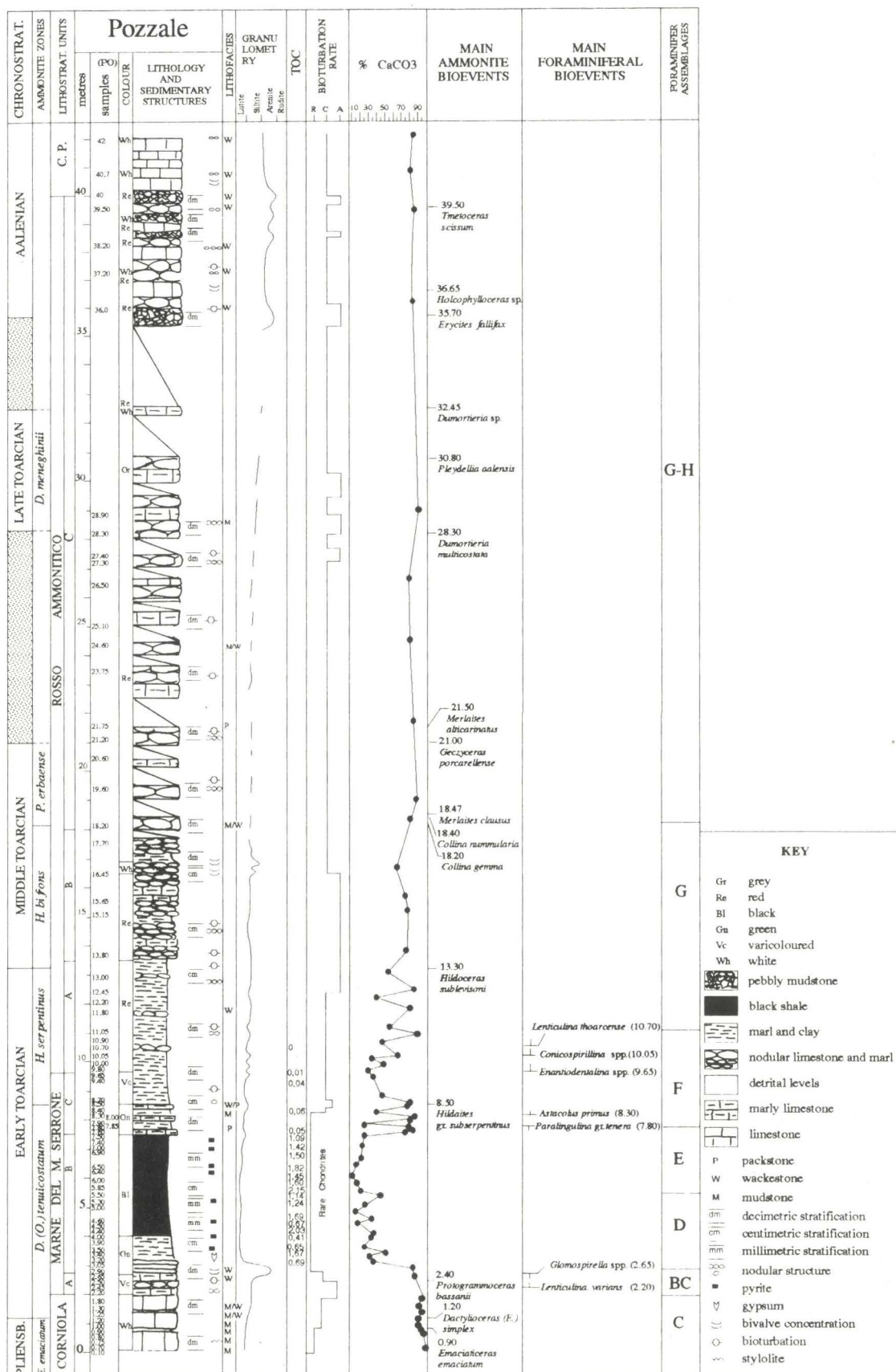
#### MARNE DEL M. SERRONE (MS)

The Marne del M. Serrone Formation has a higher clay content than the underlying and overlying units. The colour is variable from grey to red-violet, the red never prevails. Reddish flames are present in the Pozzale section both at the base and at the top of the formation, the overall thickness is about 7.5 metres. Three members are recognisable from bottom to top.

a) Calcareous marly member (A member). The lower boundary corresponds to the clay increase, which was considered a distinctive feature here. The MS lower member consists of reddish marly calcareous beds, sometimes nodular, interbedded with centimetric reddish and green clay. It was recovered also in several other sections of the Umbro-Marchean Basin (Faraoni *et al.*, 1994; Nini *et al.*, 1995; Nocchi & Bartolini, 1994). This interval shows a pervasive bioturbation and contains ammonites of the *D. (O.) tenuicostatum* Zone. The A member is one metre thick.

A yellowish crust, 3-4 cm thick, was found 2.80 metres above the base of the Pozzale section. It is possible that this lithological feature represents hard





Text-fig. 2 - Pozzale section. In the chronostratigraphical column the grey pattern indicates uncertain age due to the lack of ammonite recoveries.

ground, overlain by a thin bivalve lumachella, but it is considered local and uncertain here because it was not found in other sections of the Umbro-Marchean Basin.

b) Marly-clayey member (B member) with black shales. In the Pozzale section the carbonate content drastically decreases (Text-fig. 2), giving way to dark grey finely laminated marly clays, scarcely bioturbated, which, in this work, are considered a black-shale facies on the base of the field observations. This member is circa 5 metres thick.

c) Marly member (C member). This member consists of varicoloured marls, which are grey-green in the lowest portion and turn grey-red where the first ammonites of the *H. serpentinus* Zone are found. This member has a thickness of 2 metres.

Radiolarian-bearing beds were identified in the upper part of the MS in Pozzale at 7.60m, 7.90m and 8.40 metres. Their occurrence gives the beds a silty grain size. The Total Organic Carbon (TOC) values in the black shale interval range between 1% and 2.15%.

The MS unit is stratigraphically overlain by the Rosso Ammonitico Umbro-Marchigiano unit. The limit is transitional, and is located where red marls become dominant over grey ones. The bioturbation degree increases to give the rock a nodular structure.

In the Cima Panco section a fault running at the contact between COR and MS cuts out both A and B members. Here the MS Fm. is made up of 1 metre of dark grey laminated marls (C members), scarcely bioturbated and chaotic due to tectonics.

#### ROSSO AMMONITICO UMBRO-MARCHIGIANO (RAUM)

The unit thickness, measured in the Pozzale section, is 30.5m. At the Cima Panco section, the upper part of the RAUM is almost completely covered. The specific features of the RAUM in the two studied sections are: the upward increasing nodularity and carbonate content (Text-fig. 2), the intense red colour, the high abundance of ammonites and the occurrence of bivalve lumachellas.

Venturi's (1973, 1975) tripartition of the RAUM is evident, and stratigraphic boundaries between members are transitional.

- Clayey-marly member (A member): basal reddish marls, that turn into dark red ones, are often slightly bioturbated and nodular. Centimetric nodular white beds are interbedded with marls. The thickness of A member is 4 metres in Pozzale, and 5 metres in Cima Panco.

- Nodular marly member (B member): dark red nodular and calcareous marls, well stratified (cen-

timetric beds), intensively bioturbated, the nodularity of which increases upwards. The marls are interbedded with nodular white hard beds. In the upper part of the member, bivalve (posidoniids) lumachellas occur. The thickness of B member is 4.5 metres in Pozzale and 7 metres in Cima Panco.

- Nodular calcareous member (C member). The boundary with the previous member is not easily recognisable everywhere, due to frequent detrital coverings. The most distinctive feature is therefore the increase of calcareous and marly calcareous nodular beds (from 8 to 30 cm in thickness), which substitute the underlying argillaceous nodular red marls dominant in B member. Nodular limestones vary in colour from dark red to grey-pink, with white or red nodules embedded in a pink matrix. The grey limestones are usually less nodular. Bioturbation is evident throughout the upper part of marly-calcareous beds, and it is associated with well developed nodularity. At Cima Panco a limonitic yellow bed was identified in a stratigraphic position similar to other Umbro-Marchean sections (e.g. Valdorbia), at the base of C member of the RAUM.

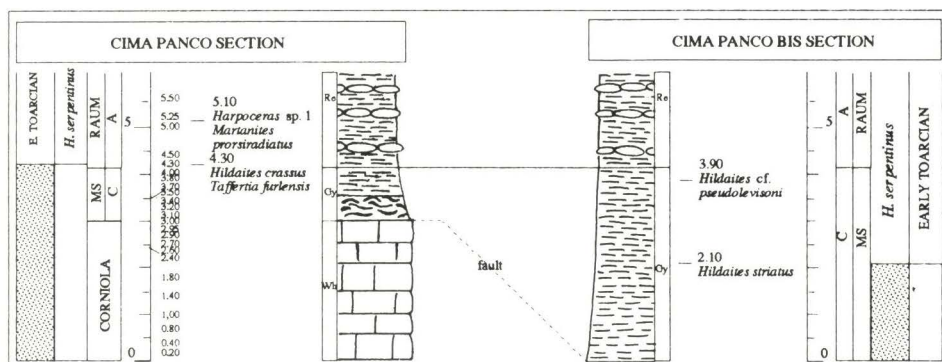
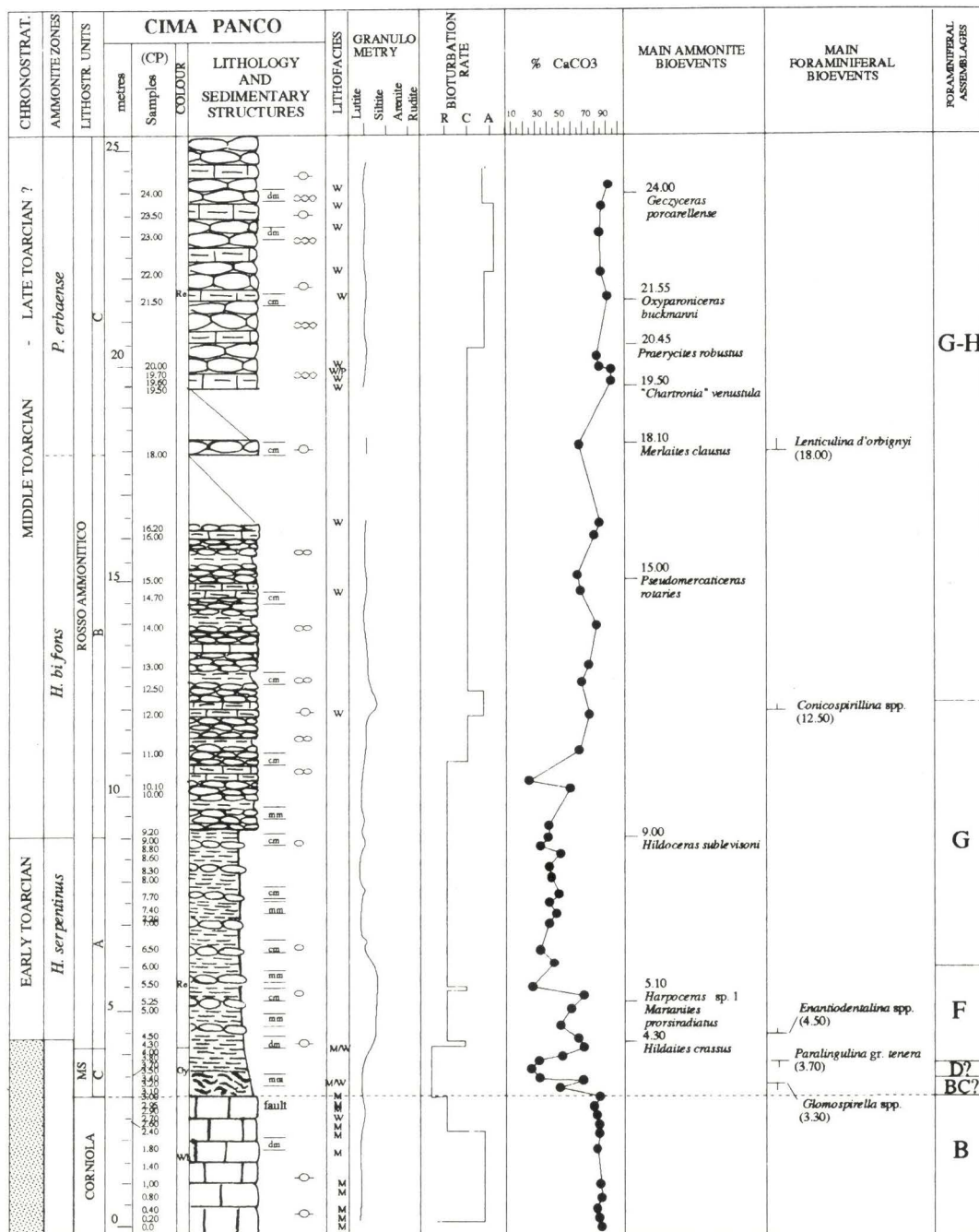
In the Pozzale section (at 35.20m), 17 metres above the B member and C member transition, calcareous beds up to 60 cm in thickness begin. They are formed of red, chaotic, highly bioturbated pebbly mudstones, with white, angular pebbles, alternated with reddish calcareous beds bearing white nodules. Aalenian ammonites are rare, while posidoniids are very abundant. These pebbly mudstones were also identified in the Cima Panco section, outcropping discontinuously under the abundant detrital covering. The overall thickness of C member is of 22 metres in Pozzale, and only of 7 metres in Cima Panco, due to the bad exposure.

The upper limit of the RAUM is identifiable only in Pozzale. It can be placed in different positions, according to the criteria adopted for its field identification. In this work nodularity, red colour and pebbly mudstone occurrence have been considered typical of the RAUM, though white, hard decimetric calcareous beds, typical of the CP unit, appear in the last part of the section. The limit has in fact been located at the point where these white-grey beds become dominant. Aalenian red nodular facies with edged or rounded nodules indicating transported nodular limestones, are indicated by Farinacci *et al.* (1981) in the M. Martani area (Case Canapine) and by Elmi and Ameer (1984) in the Aalenian of M. Serrone (Foligno).

#### CALCARI A POSIDONIA (CP)

The lithologic interval attributed to this informal unit is given by white decimetric limestones,





Text-fig. 3 - Cima Panco section and the complementary Cima Panco Bis section (see Pozzale section key).

bearing abundant thin bivalves and styloliths. As the CP unit is not considered in this work, only its first 2 metres were examined in the Pozzale section.

#### BIOSTRATIGRAPHY

Pending further data in order to define a Toarcian ammonite biozonation, characteristic of the Umbro-Marchean basin, this work utilizes the classic scheme proposed by Donovan (1958) and Gallitelli Wendt (1969), and also by Monaco *et al.* (1994).

The sampling of ammonites in the Pozzale section was extended from the upper part of the COR to the base of the CP unit, leading to the identification of a bioevent succession from the Upper Domerian to the Lower-Middle Aalenian. A good biostratigraphic resolution was achieved only from the upper part of the *E. emaciatum* Zone to the lower part of the *P. erbaense* Zone, due to the paucity of ammonite findings between the upper *P. erbaense* and *D. meneghinii* Zones. At the Cima Panco section ammonite findings allowed the identification of the interval comprised between the *H. serpentinus* and *P. erbaense* Zones. The *D.(O.) tenuicostatum* Zone is partially missing because of a fault that obliterates the COR-MS transition. A tentative correlation of the zonal limits was carried out on the basis of the Standard Mediterranean Zonation proposed by Elmi *et al.* (1994), supported by Guex (1973), Goy *et al.* (1988), Jiménez & Rivas Carrera (1991, 1992).

The first occurrence of the most significant ammonites are indicated in Text-figs. 2 and 3, while Text-figs. 4 and 5 show ammonite vertical distribution.

In the M. Martani area the new genus *Martanites* (Venturi 1997, this volume) was discovered and two new species were established. Moreover seven species, shown in Pl. 1, belonging to *Harpoceras*, *Hildaites*, *Urkutites* and "*Nodiceloceras*" have been left in open nomenclature because not yet formally described.

#### *Emaciatoceras emaciatum* ZONE

Lower boundary: not identified.

Upper boundary: FO of *Dactylioceras (Eodactylites) simplex*.

The presence of *E. emaciatum*, characteristic of the Late Domerian, in the upper part of the COR in the Pozzale section, is indicative of the *E. emaciatum* Zone.

#### *Dactylioceras (Orthodactylites) tenuicostatum* ZONE

Lower boundary: FO of *Dactylioceras (Eodactylites) simplex*.

Upper boundary: FO of *Hildaites subserpentinus*.

The occurrence of *D. (Eodactylites) simplex* 30 cm above *E. emaciatum*, allows the identification of the Pliensbachian-Toarcian boundary, which falls within the upper portion of the COR unit. The same bioevent succession was identified by Faraoni *et al.* (1994) allowing the authors to place the boundary between the *E. emaciatum* and *D. (E.) mirabilis* Zones (*sensu* Guex, 1973). Generally this boundary is characterized in the Mediterranean area by the spread of several species of *Dactylioceras (E.)* with separated ribs, and by a dramatic decrease in Arieticeratinae (Ferretti, 1970). This biological change has already been observed in the M. Catria and M. Nerone areas (Cecca *et al.*, 1990; Faraoni *et al.*, 1994; Ferretti, 1970 and 1972).

In the Pozzale section the base of the *D. (O.) tenuicostatum* Zone occurs 1 metre below the COR/MS boundary. Centimetric and decimetric nodular marly beds (A member of the MS, with overall thickness of 1 metre) contain the following species: *Calaiceras calais*, *Harpophylloceras eximium*, *Protogrammoceras bassani*, *Petrancoceras mariottii*, "*Neolioceratoides*" *laeviornatus*, *Geyeroceras* sp., *Meneghiniceras lariense*. Such an assemblage, also revealed at M. Nerone (F. Bosso), is typical of the *P. bassani* subzone (acme zone), belonging to the *D. (E.) mirabilis* Zone (Faraoni *et al.*, 1994). There is no ammonite recovery in the overlying grey clayey marls and in the black shales interval.

Correlations: Following Goy *et al.* (1988) and Jiménez & Rivas Carrera (1991), *D. (E.) simplex* occurs contemporaneously to *D. (E.) polymorphum* (Fucini). Therefore the lower zonal boundary observed in the Pozzale section might correspond to that of the *D. (E.) polymorphum* Zone of the cited authors, and to that of the Standard Zonation proposed by Elmi *et al.* (1994) for the Mediterranean area. According to Elmi *et al.* (1994), this boundary corresponds to the lower one of the *D. (E.) mirabilis* Zone of Guex (1973).

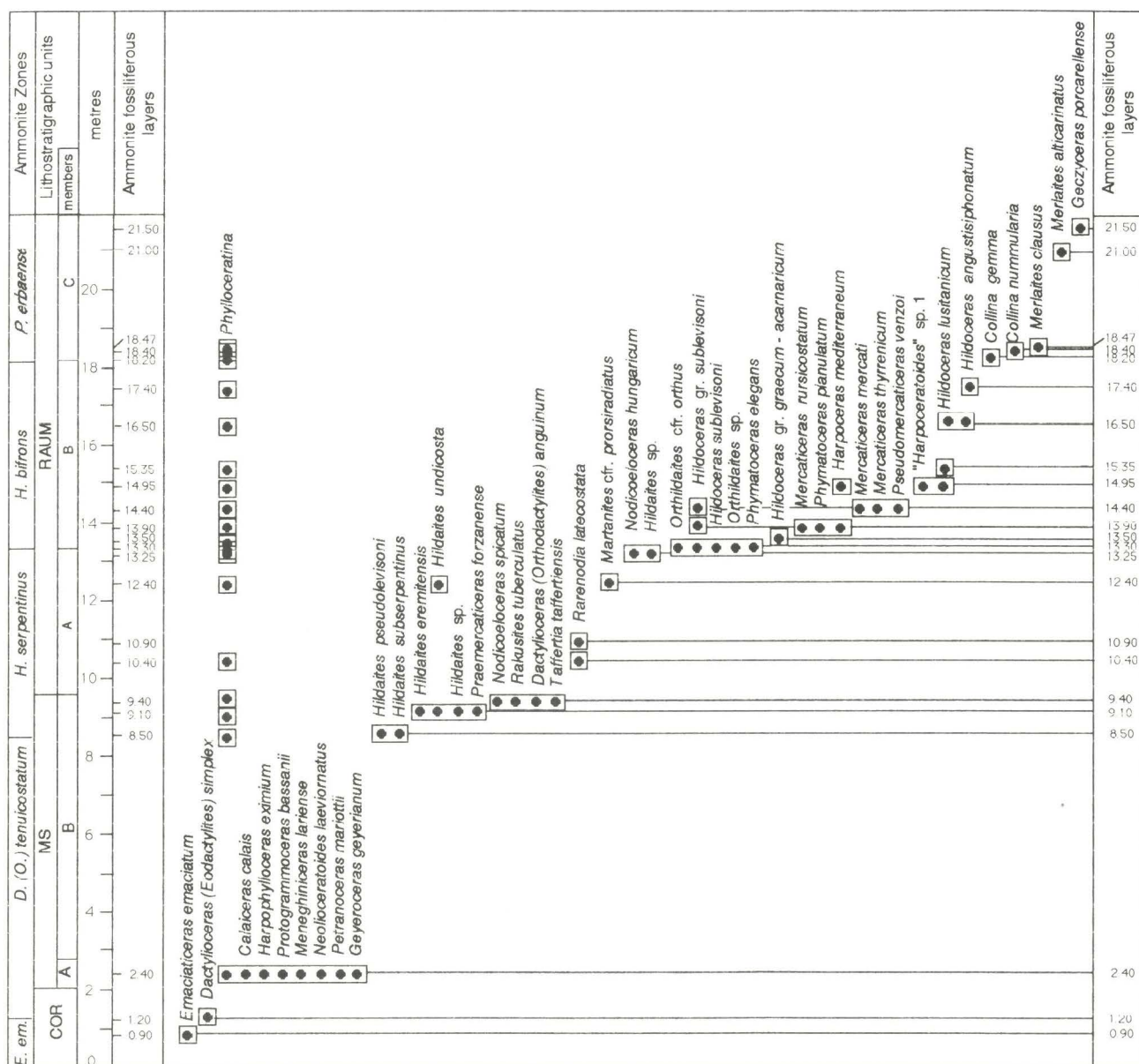
#### *Hildaites serpentinus* ZONE

Lower boundary: FO of *Hildaites subserpentinus*.

Upper boundary: FO of *Hildoceras sublevisoni*.

*H. subserpentinus* and *H. aff. pseudolevisoni* occurrences in the Pozzale section allow the identification of the *H. serpentinus* Zone in the last grey-pink beds of the Marne del M. Serrone C member, as evidenced by Venturi (1975, 1981) in the same section and in the sections of Corciano, Civitella and Pian di Spina. In the Cima Panco Bis section the first fossiliferous horizon is located in the upper part of the MS unit (Text-fig. 3) and can be related to the *H.*





Text-fig. 4 - Ammonite fossiliferous layers, Pozzale section.

*subserpentinus* Zone due to the presence of *Hildaites striatus*.

The genus *Hildaites* is present throughout the zone. In the lower portion involuted, flattened, finely and densely ribbed forms are dominant, while in the upper one prevail evolute, non-flattened, bisulcated ones, bearing strong but scarce ribs. The lower part contains the following taxa: several species of *Taffertia*, *Praepolyplectus forzanensis*, *P. epiroticus*, *Rakusites tuberculatus*, *Dactyloceras (Orthodactylites) anguinum*, *Praemeraticeras forzanense*, *Nodicoeloceras spicatum*, *Martanites prorsiradiatus* and *Martanites evolutus*. The upper part contains

*Polyplectus cf. pluricostatus*, *Rarenodia latecostata*, *Orthidaites douvillei*, *O. cf. orthus* e *Martanites cf. prorsiradiatus* (1). The finding of very rare specimens of *Renziceras* sp., and of *O. douvillei* in the Cima Panco section is worthy of note due to their taxonomic value. In fact *Renziceras* is a typical taxon of the Central Tethys Domain while *O. douvillei* is a significant species which correlates the Apenninic Toarcian with the Toarcian Stratotype in France. On the basis

(1) The new genus *Martanites* was discovered for the first time in the Monti Martani area. In this volume Venturi (1997) gives a description of this new taxon.

of ammonite assemblages the whole A member of RAUM corresponds to *H. serpentinus* Zone.

The assemblage *N. spicatum*, *R. tuberculatus*, *D. (O.) anguinum* and *T. taffertiensis*, at 9.40m above the base of the Pozzale section, allows the correlation with 5.10m above the base of Cima Panco section, where together with the above species, *T. maghreben-sis* and *H. striatus* also occur.

Correlations: The lower boundaries of the *H. serpentinus* Zone, as considered in the Apennines, and of the *H. levisoni* Zone proposed by Elmi et al. (1994) in the Standard Zonation, are not easy to correlate. From the scheme of Elmi et al. (1994), it is in fact not clear which taxon should be used to define the lower boundary of the *H. levisoni* Zone in the Mediterranean area. Moreover, Guex (1973) pointed out that there is little research on Mediterranean ammonite faunas, "subsequent to the *D. (E.) mirabile* Fucini levels, and preceding the

*Hildaites levisoni* (Simpson) and *Hildaites* spp. levels."

The assemblages at the 9.40m level in Pozzale and at the 5.10m level in Cima Panco show a strong affinity with assemblages of the *H. striatus* subzone of Goy et al. (1988), Jiménez & Rivas Carrera (1992), and of the *H. levisoni* subzone of Guex (1973).

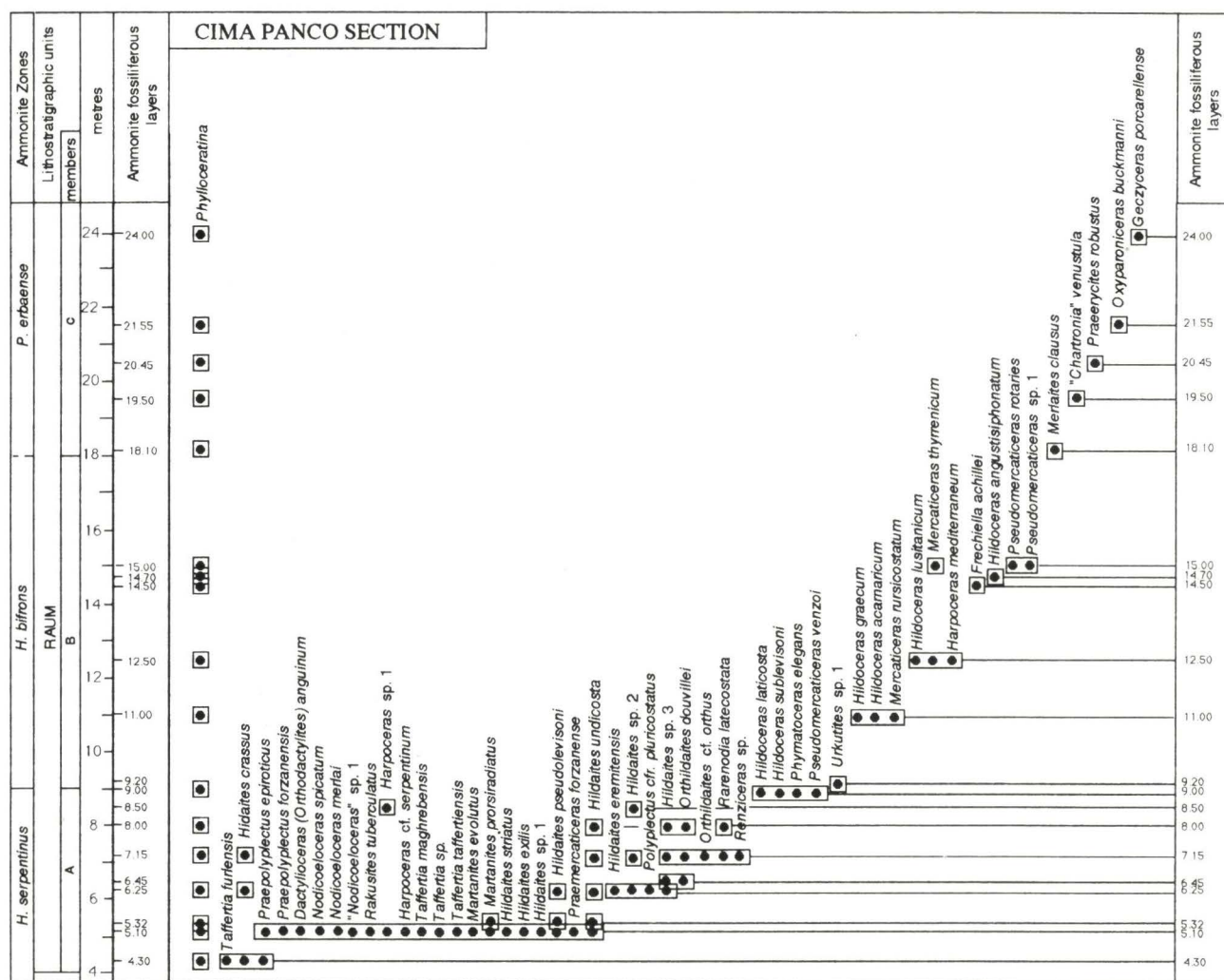
#### *Hildoceras bifrons* ZONE

Lower boundary: FO of *Hildoceras sublevisoni*.

Upper boundary: FO of *Collina gemma*.

The first occurrence of *Hildoceras sublevisoni* is uniformly used to place the lower boundary of the *H. bifrons* Zone. The bioevent succession of *Orthildaites douvillei* and *H. sublevisoni*, allows for the precise location of the boundary.

The *Hildoceras* genus was found (Text-figs. 4 and 5) throughout the whole zone. In both sections this



Text-fig. 5 - Ammonite fossiliferous layers, Cima Panco section.



zone lasts throughout the B member of the RAUM.

In this interval, several *Hildoceras* species, phylogenetically linked, succeed one another (Donovan, 1958; Gallitelli Wendt 1969; Venturi, 1972, 1975 and 1991). The B member is rich in ammonites such as *Harpoceras mediterraneum*, *Mercaticeras*, *Pseudomercaticeras* and *Frechiella achillei*.

Correlations: It seems that the base of the *H. bifrons* Zone can be well correlated in the whole Mediterranean area and in western Europe. Therefore no major problems of correlation exist between the Zonation of Goy *et al.* (1988), Jiménez & Rivas Carrera (1991, 1992) and the Standard Zonation of Elmi *et al.* (1994).

#### *Phymatoceras erbaense* ZONE

Lower boundary: FO of *Collina gemma*.

Upper boundary: not identified.

The FO of *Collina gemma* is traditionally used in the Apennines to locate the lower boundary of the *P. erbaense* Zone, as Gallitelli Wendt (1969) and Monaco *et al.* (1994) did in Valdorbis. The FO of *C. gemma* usually occurs just above the LO of *Hildoceras angustisiphonatum*. In the Pozzale section, where the same succession of events was observed, the boundary can be precisely located. At Cima Panco however, a detrital covering has inhibited the sampling of the upper portion of the *H. bifrons* Zone. Therefore the boundary is approximately placed at the occurrence of *Merlaites clausus*, which testifies the presence of the *P. erbaense* Zone. Other significant ammonites are *Praerycites robustus*, *Oxyparonoceras buckmanni*, and in the upper part *Merlaites alticarinatus* and *Geczyoceras porcarense*. The lower boundary of the Zone approximately corresponds to the transition of the B and C members of the RAUM.

Correlations: No accurate discussion can be carried out because of the scarcity of collected material. The correlation of the lower boundary of the *P. erbaense* Zone with that of the *B. gradata* Zone of Goy *et al.* (1988) and Jiménez & Rivas Carrera (1991) is still unverified. According to their data, the FO of *C. gemma* occurs before the disappearance of *Hildoceras semipolitum* Buckman and *H. angustisiphonatum*. Therefore, it is not easy to establish the correlation with the Standard Zonation of Elmi *et al.* (1994).

#### UPPER TOARCIAN

In the Pozzale section, above the first occurrence of *G. porcarense*, specimens of *Pleydellia aalensis* and of some species of *Dumortieria* were found, in-

dicating the presence of the *D. meneghinii* Zone (Text-fig. 2).

In the C member of the RAUM no other zonal boundaries could be placed. However, sediments comprised between the 35.70m level and the 39.70m level in the Pozzale section can be referred to the Early-Middle Aalenian, as shown by the occurrence of *Erycites fallifax* and *Tmetoceras scissum*.

Some problematic zonal boundaries of the Toarcian of M. Martani underlined in this work are common to other sections, already published, of the Umbro-Marchean Apennine. It would be necessary to establish a biozonation, characteristic of the Umbro-Marchean Apennines emphasizing the taxa, used as biozonal indexes, so as to obtain a straightforward correlation between the Mediterranean area sections, and between these latter and those of central Europe.

#### TAXONOMIC INDEX OF THE AMMONITES FOUND IN POZZALE AND CIMA PANCO SECTIONS

##### PHYLLOCERATINA

##### PHYLLOCERATIDAE

##### CALLIPHYLLOCERATINAE

*Calaiceras calais* (Meneghini, 1881)

*Holcophylloceras* sp.

##### PHYLLOCERATINAE

*Geyeroceras* sp.

##### JURAPHYLLOLITIDAE

*Harpophylloceras eximium* (Hauer, 1854) *Holcophylloceras* sp.

*Meneghiniceras lariense* (Meneghini, 1867)

##### AMMONITINA

##### DACTYLOCERATIDAE

*Collina gemma* Bonarelli, 1893.

*Collina nummularia* Ramaccioni, 1939.

*Dactylioceras* (*Eodactylites*) *simplex* (Fucini, 1935)

*Dactylioceras* (*Orthodactylites*) *anguinum* (Reinecke, 1818)

*Nodicoeloceras hungaricum* Geczy, 1967

*Nodicoeloceras merlai* (Pinna, 1969)

*Nodicoeloceras spicatum* Buckman, 1927

"*Nodicoeloceras*" sp.1

*Rakusites tuberculatus* Guex, 1973

##### HILDOCERATIDAE

##### ARIECERATINAE

*Emaciatoceras emaciatum* (Catullo, 1853)

##### PROTOGRAMMOCERATINAE

"*Neolioceratoides*" *laeviornatus* Pallini, 1994

*Petranoceras mariottii* Venturi, 1994

*Protogrammoceras bassanii* (Fucini, 1900)

##### HARPOCERATINAE

*Harpoceras* cf. *serpentinum* (Schlotheim, 1813)

*Harpoceras mediterraneum* Pinna, 1968

*Harpoceras* sp. 1

"*Harpoceratoides*" sp. 1

*Martanites* cf. *prorsiradiatus* Venturi, 1997

*Martanites evolutus* Venturi, 1997

*Martanites prorsiradiatus* Venturi, 1997  
*Taffertia furlensis* (Venturi, 1981)  
*Taffertia maghrebensis* (Guex, 1973)  
*Taffertia taffertiensis* (Guex, 1973)  
*Taffertia* sp.

## POLYPLECTINAE

*Polyplectus* cf. *pluricostatus* (Haas, 1913).  
*Praepolyplectus epiroticus* (Renz, 1925)  
*Praepolyplectus forzanensis* Venturi, 1981

## HILDOCERATINAE

*Hildaïtes crassus* (Guex, 1973)  
*Hildaïtes eremitensis* Venturi, 1973  
*Hildaïtes exilis* Venturi, 1973  
*Hildaïtes pseudolevisoni* Venturi, 1981  
*Hildaïtes striatus* Guex, 1973  
*Hildaïtes subserpentinus* Buckman, 1921  
*Hildaïtes undicosta* Merla, 1932  
*Hildaïtes* sp.  
*Hildaïtes* sp. 1  
*Hildaïtes* sp. 2  
*Hildaïtes* sp. 3  
*Hildoceras acarnanicum* Mitzopoulos, 1930  
*Hildoceras angustisiphonatum* Prinz, 1904  
*Hildoceras* gr. *sublevisoni* Fucini, 1919  
*Hildoceras graecum* (Renz, 1912)  
*Hildoceras laticosta* Bellini, 1900  
*Hildoceras lusitanicum* Meister, 1914  
*Orthildaïtes* cf. *orthus* Buckman, 1923  
*Orthildaïtes douvillei* (Haug, 1884)  
*Orthildaïtes* sp.  
*Urkutites* sp. 1

## MERCATICERATINAE

*Mercaticeras mercatii* (Hauer, 1856)  
*Mercaticeras rursicostatum* Merla, 1932  
*Mercaticeras thyrenicum* (Fucini, 1905)  
*Merlaïtes alticarinatus* (Merla, 1932).  
*Merlaïtes clausus* (Merla, 1932).  
*Pseudomercaticeras rotaries* Merla, 1932  
*Pseudomercaticeras venzoi* Pinna, 1963.  
*Pseudomercaticeras* sp. 1  
*Praemercaticeras forzanense* Venturi, 1981

## BOULEICERATINAE

*Frechiella achillei* Renz, 1912  
*Oxyparoniceras buckmanni* (Bonarelli, 1895)  
*Renziceras* sp.

## GRAMMOCERATINAE

*Dumortieria multicostata* Geczy, 1967

*Dumortieria* sp.  
*Pleydellia aalensis* (Zieten, 1832)

## PHYMATOCERATIDAE

"*Chartronia venustula*" Merla, 1932  
*Phymatoceras elegans* (Merla, 1932)  
*Phymatoceras planulatum* (Merla, 1932)

## HAMMATOCERATIDAE

*Erycites fallifax* Arkell, 1957  
*Geczyceras porcarense* (Merla, 1933)  
*Praerycites robustus* (Merla, 1933)  
*Rarenodia latecostata* Venturi, 1975

## TMETOCERATIDAE

*Tmetoceras scissum* (Benecke, 1865)

The stratigraphic levels within the two sections and the biozones to which the ammonites belong are indicated in Text-figs 3 and 4.

## MICROFOSSILS AND THEIR PALEOECOLOGICAL SIGNIFICANCE

## METHODS

The microfossil content of 133 samples, coming from the Pozzale and Cima Panco sections, was examined. The sampled material covers a lithostratigraphic range spanning the top of the Corniola to the base of Calcari a Posidonia.

The MS and the first two members of the RAUM were examined through washed residues, while COR, C member of RAUM and CP through thin sections. Therefore the analyses of Lower and Middle Toarcian micropaleontological assemblages lead to a better characterisation of the benthic communities than that obtained through the Upper Toarcian - Aalenian ones. In any case the analysis in thin sections of the microfossils supplied textural features, which contributed to a better understanding of lithofacies genesis and hydrodynamic energy. Microfacies were interpreted through a comparison with those of Valdorbis (Monaco *et al.*, 1994) and Montebibico (Nini *et al.*, 1995) sections.

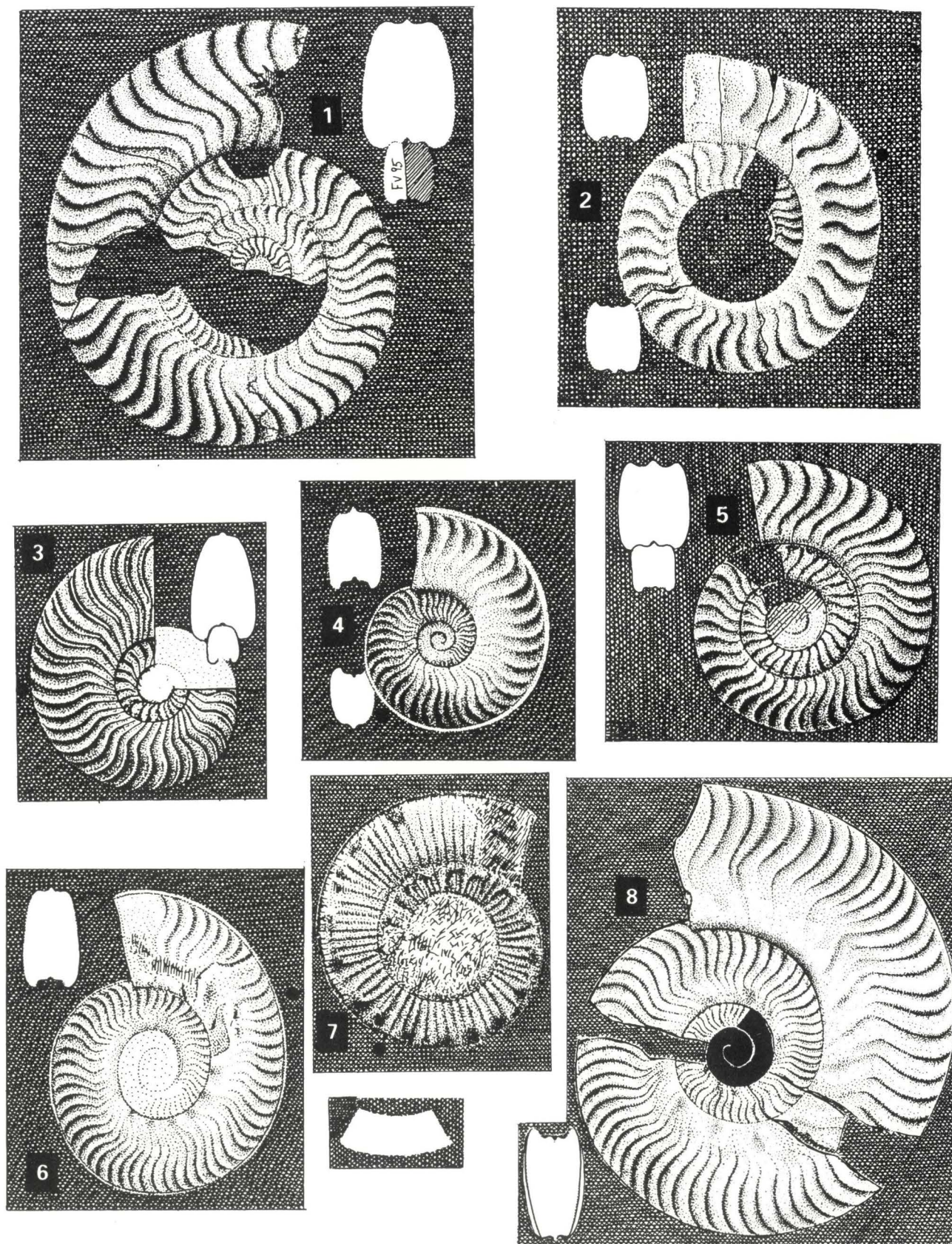
For each washed sample 6 grams of residue were

## EXPLANATION OF PLATE 1

New species of ammonites herein left in open nomenclature. The black dot indicates the beginning of the body chamber. Drawings in natural size unless otherwise indicated.

- Fig. 1 - *Hildaïtes* sp. 3. CP 7.15, *H. serpentinus* Zone.  
 Fig. 2 - *Hildaïtes* sp. 2. CP 8.00, *H. serpentinus* Zone.  
 Fig. 3 - *Harpoceras* sp. 1. CP 8.50, *H. serpentinus* Zone.  
 Fig. 4 - *Pseudomercaticeras* sp. 1. CP 15.00, *H. bifrons* Zone.  
 Fig. 5 - *Hildaïtes* sp. 3. CP 7.15, *H. serpentinus* Zone.  
 Fig. 6 - *Urkutites* sp. 1. CP 9.20, *H. bifrons* Zone.  
 Fig. 7 - "*Nodicoeloceras*" sp. 1. CP 5.10, *H. serpentinus* Zone. 1,5 X  
 Fig. 8 - *Hildaïtes* sp. 1. CP 5.10, *H. serpentinus* Zone.







collected on a 63µm sieve and all the foraminifers were picked to obtain a record of the real assemblage. The abundance of other microfossils (radiolarians, ostracods) and macrofossil remains (crinoids, olothurians, ophiurids, echinids, gastropods, bivalves, brachiopods and ammonites) was evaluated. Every sample contained variably abundant and diversified benthic foraminifers. Simple agglutinated foraminifers and rare *Lagenina* were dominant in the Domerian, while virtually only *Lagenina* were present in the Toarcian - Aalenian interval.

Distribution charts show genera and species relative frequency ( $R < 10\%$ ,  $10\% < C < 30\%$ ,  $A > 30\%$ ) (Text-figs. 6-9). The generic and suprageneric classification was based on Loeblich & Tappan (1987). Picked individuals were measured and clustered in dimensional classes: less than 250 µm, between 250 and 500 µm and over 500 µm.

Recently a strong relationship between benthic foraminiferal test morphology and habitat ecologic factors has been highlighted. Benthic foraminifers

are in fact influenced by chemo-physic bathymetric, substrate, trophic factors.

They were therefore assembled in morphogroups in relation to their adaptive morphology. Morphogroup distributions, together with sedimentological characteristics, provide detailed information about paleoenvironmental features of the sea bottom, following the uniformitarianism concept. In this way morphogroup temporal distribution and variation assume stratigraphic significance known as ecostratigraphy.

This work follows the hyaline benthic foraminiferal morphogroups arrangement of Bernhard (1986) and Bartolini *et al.* (1992), which depends mainly on oxygen and energy rate and on sediment type (Tab.1a). Elongated flattened and elongated tapering morphologies (A and B morphogroups) are indicative of low energy, poor ventilated environment. Cylindrical elongated and flattened planispiral (C and D morphogroups) still represent an adaptation to low energy environment, though with a

| CRONOSTRAT. |  | M. Toarc. |  | Early Toarcian |  | CRONOSTRAT. |  | M. Toarc. |  | Early Toarcian |  | CRONOSTRAT. |  | M. Toarc. |  | Early Toarcian |  | CRONOSTRAT. |  | M. Toarc. |  | Early Toarcian |  | CRONOSTRAT. |  | M. Toarc. |  | Early Toarcian |  | CRONOSTRAT. |  | M. Toarc. |  | Early Toarcian |  | CRONOSTRAT. |  | M. Toarc. |  | Early Toarcian |  | CRONOSTRAT. |  | M. Toarc. |  | Early Toarcian |  | CRONOSTRAT. |  | M. Toarc. |  | Early Toarcian |  | CRONOSTRAT. |  | M. Toarc. |  | Early Toarcian |  | CRONOSTRAT. |  | M. Toarc. |  | Early Toarcian |  | CRONOSTRAT. |  | M. Toarc. |  | Early Toarcian |  | CRONOSTRAT. |  | M. Toarc. |  | Early Toarcian |  | CRONOSTRAT. |  | M. Toarc. |  | Early Toarcian |  | CRONOSTRAT. |  | M. Toarc. |  | Early Toarcian |  | CRONOSTRAT. |  | M. Toarc. |  | Early Toarcian |  | CRONOSTRAT. |  | M. Toarc. |  | Early Toarcian |  | CRONOSTRAT. |  | M. Toarc. |  | Early Toarcian |  | CRONOSTRAT. |  | M. 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Text-fig. 6 - Foraminifer genera distribution chart, Pozzale section. Numbers refer to the counted specimens.



|                                                                                                                                                                          |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| A morphogroup = elongated and flat forms<br>( <i>Paralingulina</i> , <i>Lingulonodosaria</i> and <i>Vaginulina</i> )                                                     |
| B morphogroup = elongated and pointed forms<br>( <i>Eoguttulina</i> and <i>Enantiodentalina</i> )                                                                        |
| C morphogroup = cylindrical and elongated forms<br>( <i>Prodentalina</i> , <i>Marginulina</i> , <i>Pseudolangella</i> ,<br><i>Pseudonodosaria</i> and <i>Nodosaria</i> ) |
| D morphogroup = flattened planispiral forms<br>( <i>Astaculus</i> , <i>Falsopalmula</i> , <i>Vaginulinopsis</i><br>and flattened <i>Lenticulina</i> )                    |
| E morphogroup = planispiral and biconvex strictly coiled forms<br>(biconvex <i>Lenticulina</i> )                                                                         |
| F morphogroup = planoconvex or conical forms<br>( <i>Conicospirillina</i> and <i>Reinholdella</i> )                                                                      |

**a**

|                                                                                                                                                                                                                                                                                                                                                                |                                                |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------|
| <i>Glomospira</i> , <i>Glomospirella</i> , <i>Ammodiscus</i> ,<br><i>Bullopore</i> , biconvex <i>Lenticulina</i> and<br><i>Reinholdella</i>                                                                                                                                                                                                                    | Epifaunal type (E)                             |
| <i>Spirillina</i> and <i>Conicospirillina</i>                                                                                                                                                                                                                                                                                                                  | Primary weed grazing<br>epifaunal type<br>(WE) |
| <i>Bathysiphon</i>                                                                                                                                                                                                                                                                                                                                             | Epifaunal erect type<br>(EE)                   |
| <i>Nodosaria</i> , <i>Astaculus</i> , flattened <i>Lenticulina</i><br>and <i>Haplophragmoides</i>                                                                                                                                                                                                                                                              | Shallow infaunal<br>type (SI)                  |
| <i>Paralingulina</i> , <i>Lingulonodosaria</i> , <i>Vaginulina</i> ,<br><i>Vaginulinopsis</i> , <i>Eoguttulina</i> , <i>Enantiodentalina</i> ,<br><i>Prodentalina</i> , <i>Pseudonodosaria</i> , <i>Pseudolangella</i> ,<br><i>Marginulina</i> , <i>Falsopalmula</i> , <i>Ichtyolaria</i> ,<br><i>Berthelinella</i> , <i>Brizalina</i> and <i>Fronicularia</i> | Infaunal type (I)                              |

**b**

Tab. 1 - a) Calcareo-hyaline foraminiferal morphogroup description. b) Foraminiferal life strategies.

higher level of bottom oxygenation. On the contrary biconvex and conical forms (E and F morphogroups) are indicative of good oxygenation and high energy.

A different morphogroup arrangement including *Textularina* and *Spirillinina* allows for the comparison between test morphology, life strategies and microhabitat preferences such as epifaunal, shallow infaunal, deep infaunal, erect epifaunal and weed epifaunal. This classification also takes into account feeding habits such as passive deposit feeders, active deposit feeders, suspension feeders, bacterial and detrital scavengers (Corliss & Chen, 1988; Jones & Charnock, 1985; Koutsoukos & Hart, 1990; Murray, 1991; Tyszk, 1994). The benthic foraminiferal community was therefore subdivided into five groups of genera (Tab. 1b), the distribution of which is shown in Text-figs. 6 and 8.

Text-figs. 10 and 11 show morphogroup percentages, test size, flattened versus biconvex lenticulinas ratio, species diversity, total abundance, life strategy classes. The temporal evolution of these parameters, shown in graphs, was related to the litho-stratigraphical variations in the two sections.

Benthic foraminiferal assemblages (Nocchi, 1992) typical of the Umbria-Marchean basin were recognised here as well. The parameters above described together with the faunal turnover rate were used to differentiate foraminiferal assemblages (Hallam, 1987). Turnover rate is defined as the sum of the first and last occurrences versus the number of taxa and expresses faunal variability.

Characteristics and vertical order of benthic foraminiferal assemblages stay unaltered in all the studied Toarcian sections even though the temporal extension of each assemblage can vary. It clearly arises from the benthic foraminiferal data set that each assemblage is strongly related to lithofacies. Lithological lateral variation due to morphological dishomogeneity of the sea bottom are noticeable from a concomitant lateral variation of the micropaleontological assemblages. Therefore, unless strong lateral ecologic variations occur, the temporal succession of the benthic foraminiferal assemblage contributes to the identification of stratigraphic unit alternation. Moreover the lateral variability of the assemblages has an important role in the interpretation of the regional paleophysiographic setting.

The same vertical distribution of the benthic assemblages is shown by the ammonite zonation in the Pozzale and Cima Panco sections, although the tectonic displacement in the Cima Panco section has altered the real assemblage succession in the MS.

Benthic foraminiferal assemblages are described below.

## B AND C ASSEMBLAGES (Pl. 2)

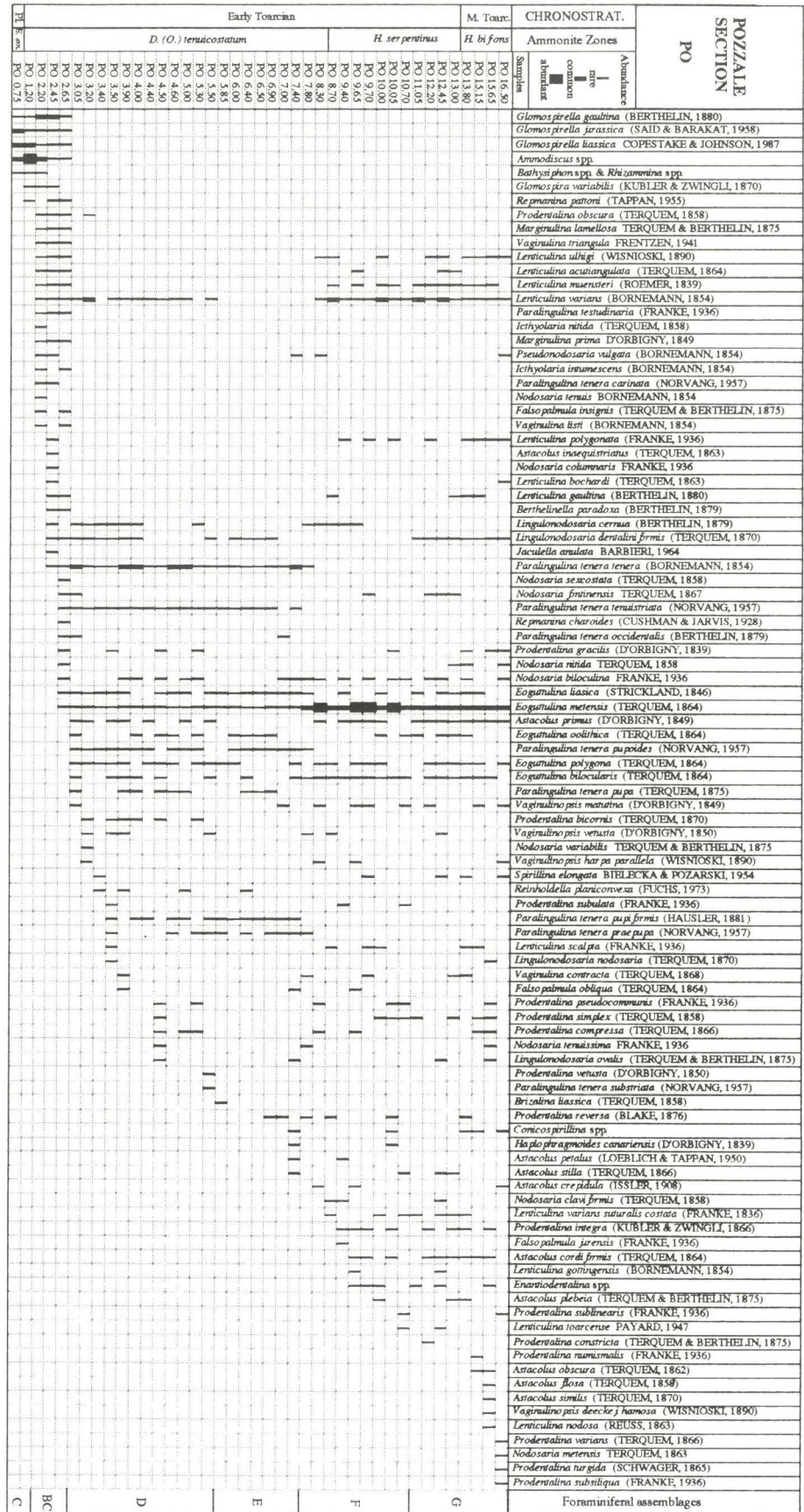
Age: Domerian.

These are characteristic of the upper part of the Corniola unit. Particularly B assemblage was observed in thin sections. It is mainly made up of *Lagenina* and *Textularina* together with radiolarians, echinid fragments, sponge spicules and large ostracods.

Whereas C assemblage is represented by abundant siliceous agglutinated foraminifers among which *Ammodiscus* and *Glomospirella* prevail. The genera *Bathysiphon*, *Glomospira* and *Repmanina* are also present (Pl. 2, figs. 1-4). This assemblage was recovered in thin clayey layers, which alternate with the limestone beds at the top of COR. These abrupt microfaunal changes could be due to various factors



Text-fig. 7 - Foraminifer species distribution chart, Pozzale section.





| CHRONOSTRAT.    | Ammonite Zones    | CIMA PANCO SECTION |                       | <i>Glomospirella</i> | <i>Glomospira</i> | <i>Biconvex Lenticulina</i> | <i>Bullopore</i> | <i>Spirulina</i> | <i>Conicospirulina</i> | <i>Astacolus</i> | <i>Flattened Lenticulina</i> | <i>Lingulonodosaria</i> | <i>Paralingulina</i> | <i>Eogutulina</i> | <i>Prodenalina</i> | <i>Nodosaria</i> | <i>Pseudonodosaria</i> | <i>Marginulina</i> | <i>Falso palmula</i> | <i>Vaginulino psis</i> |     | Total abundance |     | < 250 m | 250 - 500 m | > 500 m |     |     |
|-----------------|-------------------|--------------------|-----------------------|----------------------|-------------------|-----------------------------|------------------|------------------|------------------------|------------------|------------------------------|-------------------------|----------------------|-------------------|--------------------|------------------|------------------------|--------------------|----------------------|------------------------|-----|-----------------|-----|---------|-------------|---------|-----|-----|
|                 |                   | CP                 |                       |                      |                   |                             |                  |                  |                        |                  |                              |                         |                      |                   |                    |                  |                        |                    |                      |                        |     |                 |     |         |             |         |     |     |
| Middle Toarcian | <i>H. bifrons</i> | Samples            | Epifaunal             |                      |                   | Weed ep.                    |                  |                  | Shallow i.             |                  |                              | Infaunal                |                      |                   |                    |                  |                        |                    |                      |                        |     |                 |     |         |             |         |     |     |
|                 |                   | CP 18.00           |                       |                      | 55                |                             | 6                |                  | 7                      | 10               | 1                            |                         | 24                   | 15                | 3                  |                  |                        |                    |                      |                        |     |                 | 121 |         | 22          | 65      | 34  |     |
|                 |                   | CP 16.00           |                       |                      | 34                | 3                           | 10               | 4                | 10                     | 13               | 2                            |                         | 16                   | 28                | 2                  | 2                |                        |                    |                      | 1                      |     |                 | 122 |         | 20          | 54      | 47  |     |
|                 |                   | CP 15.00           |                       |                      | 16                |                             | 10               |                  | 7                      | 14               | 2                            |                         | 26                   | 30                | 4                  | 2                |                        |                    |                      |                        |     |                 | 110 |         | 19          | 72      | 19  |     |
|                 |                   | CP 14.00           |                       |                      | 19                |                             | 11               |                  | 8                      | 32               | 7                            |                         | 24                   | 20                | 2                  |                  |                        |                    | 1                    | 1                      |     |                 | 107 |         | 21          | 64      | 20  |     |
|                 |                   | CP 13.00           |                       |                      | 11                | 1                           | 13               |                  | 17                     | 8                |                              |                         | 49                   | 47                | 5                  |                  |                        |                    |                      |                        | 2   |                 | 177 |         | 31          | 111     | 32  |     |
|                 |                   | CP 12.50           |                       |                      | 30                |                             | 14               | 6                | 15                     | 10               | 5                            |                         | 31                   | 12                |                    |                  |                        |                    |                      |                        | 2   |                 | 123 |         | 23          | 63      | 38  |     |
|                 |                   | CP 11.00           |                       |                      | 25                | 4                           | 3                |                  | 12                     | 12               | 11                           |                         | 41                   | 49                | 1                  |                  |                        |                    |                      |                        | 4   |                 | 160 |         | 55          | 76      | 31  |     |
|                 |                   | CP 10.10           |                       |                      | 16                |                             | 1                |                  | 6                      | 8                | 2                            |                         | 35                   | 24                |                    |                  |                        |                    |                      | 2                      | 7   |                 | 106 |         | 19          | 57      | 27  |     |
|                 |                   | CP 10.00           |                       |                      | 24                |                             | 2                |                  | 9                      | 8                | 5                            |                         | 39                   | 42                | 3                  |                  |                        |                    |                      |                        |     |                 | 135 |         | 13          | 60      | 60  |     |
|                 |                   | CP 9.20            |                       |                      | 25                | 2                           | 16               |                  | 16                     | 3                | 6                            |                         | 50                   | 57                | 5                  |                  |                        |                    |                      |                        | 8   |                 | 194 |         | 31          | 135     | 27  |     |
|                 |                   | CP 9.00            |                       |                      | 17                |                             | 5                |                  | 17                     | 43               |                              |                         | 54                   | 70                | 3                  | 1                |                        |                    | 1                    |                        |     |                 | 173 |         | 32          | 85      | 56  |     |
|                 |                   | Early Toarcian     | <i>H. serpentinus</i> | CP 8.80              |                   |                             | 33               | 3                | 18                     |                  | 18                           | 44                      | 4                    | 127               | 134                | 13               | 3                      |                    |                      | 1                      | 8   |                 |     | 416     |             | 42      | 243 | 129 |
|                 |                   |                    |                       | CP 8.60              |                   |                             | 12               | 1                | 5                      |                  | 12                           | 13                      | 2                    | 46                | 40                 | 5                |                        |                    |                      |                        |     |                 |     | 167     |             | 39      | 97  | 31  |
|                 |                   |                    |                       | CP 8.30              |                   |                             | 75               | 1                | 37                     |                  | 13                           | 34                      | 1                    | 59                | 140                | 10               | 1                      |                    |                      | 3                      | 2   |                 |     | 374     |             | 68      | 87  | 100 |
| CP 8.00         |                   |                    |                       |                      | 45                |                             | 20               |                  | 32                     | 2                | 5                            | 86                      | 121                  | 5                 | 1                  |                  |                        | 1                  | 2                    |                        |     | 360             |     | 85      | 198         | 75      |     |     |
| CP 7.70         |                   |                    |                       |                      | 28                | 3                           | 6                |                  | 20                     | 15               |                              | 47                      | 96                   | 4                 |                    |                  |                        |                    |                      |                        |     | 209             |     | 34      | 127         | 48      |     |     |
| CP 7.40         |                   |                    |                       |                      | 82                | 2                           | 5                |                  | 29                     | 9                | 2                            | 79                      | 58                   | 4                 |                    |                  |                        |                    |                      | 3                      |     | 288             |     | 53      | 177         | 59      |     |     |
| CP 7.20         |                   |                    |                       |                      | 52                |                             | 17               |                  | 17                     | 34               | 3                            | 51                      | 95                   | 3                 |                    |                  |                        | 2                  | 4                    |                        |     | 272             |     | 56      | 142         | 74      |     |     |
| CP 7.00         |                   |                    |                       |                      | 16                | 2                           | 7                |                  | 14                     | 23               |                              | 61                      | 41                   |                   |                    |                  |                        |                    |                      | 2                      |     | 177             |     | 92      | 74          | 10      |     |     |
| CP 6.50         |                   |                    |                       |                      | 22                |                             | 2                |                  | 9                      | 26               | 5                            | 92                      | 40                   |                   |                    |                  |                        |                    |                      | 4                      |     | 200             |     | 35      | 126         | 39      |     |     |
| CP 6.00         |                   |                    |                       |                      | 64                | 1                           |                  |                  | 17                     | 25               | 1                            | 50                      | 75                   |                   |                    |                  |                        |                    |                      | 3                      |     | 244             |     | 26      | 167         | 49      |     |     |
| CP 5.50         |                   |                    |                       |                      | 5                 |                             | 6                |                  | 17                     | 15               | 5                            | 87                      | 79                   |                   |                    |                  |                        |                    |                      | 5                      |     | 229             |     | 59      | 158         | 12      |     |     |
| CP 5.25         |                   |                    |                       |                      | 1                 |                             | 1                |                  | 16                     | 9                | 1                            | 117                     | 42                   | 2                 |                    |                  |                        |                    |                      | 3                      |     | 198             |     | 63      | 122         | 13      |     |     |
| CP 5.00         |                   |                    |                       |                      | 6                 |                             | 2                |                  | 7                      | 1                |                              | 60                      | 29                   |                   |                    |                  |                        |                    |                      |                        |     | 124             |     | 27      | 83          | 14      |     |     |
| CP 4.50         |                   |                    |                       |                      | 4                 |                             |                  |                  | 10                     | 1                | 2                            | 94                      | 54                   |                   |                    |                  |                        |                    | 1                    | 1                      |     | 185             |     | 25      | 111         | 50      |     |     |
| D. (O.) tenui.  | CP 4.30           |                    |                       |                      |                   |                             |                  |                  | 11                     | 4                |                              |                         | 108                  | 48                |                    |                  |                        |                    |                      |                        |     |                 | 167 |         | 32          | 110     | 25  |     |
|                 | CP 3.80           |                    |                       | 1                    |                   |                             |                  | 13               | 4                      | 2                | 1                            | 97                      | 63                   |                   | 1                  |                  |                        |                    |                      |                        | 182 |                 | 37  | 129     | 16          |         |     |     |
|                 | CP 3.70           |                    |                       | 4                    |                   |                             |                  | 3                | 3                      |                  | 10                           | 62                      | 61                   | 4                 |                    |                  | 1                      |                    |                      |                        | 149 |                 | 55  | 85      | 9           |         |     |     |
|                 | CP 3.50           |                    |                       | 4                    | 2                 |                             |                  | 2                | 11                     |                  | 13                           | 51                      | 62                   |                   |                    |                  |                        |                    | 1                    |                        | 138 |                 | 37  | 91      | 10          |         |     |     |
|                 | CP 3.30           | 27                 | 5                     |                      |                   |                             | 4                | 2                | 1                      |                  | 39                           | 21                      | 1                    | 2                 | 2                  |                  |                        |                    | 1                    | 1                      | 113 |                 | 48  | 60      | 6           |         |     |     |
| CP 3.10         | 8                 | 3                  | 2                     |                      |                   |                             |                  |                  | 1                      | 6                | 43                           | 48                      | 7                    |                   |                    |                  | 1                      |                    |                      | 122                    |     | 41              | 71  | 10      |             |         |     |     |

Text-fig. 8 - Foraminifer genera distribution chart, Cima Panco section. Numbers refer to the counted specimens.

both sinsedimentary and diagenetic, such as silex content variation, calcium carbonate availability, salinity, temperature, pH, calcareous test post-depositional dissolution. This assemblage alternation was found not only locally, but also regionally, since the same phenomenon was recognised in every section in the Umbria-Marchean Basin and in the Jonian Trough (Pettinelli *et al.*, in press).

Since B assemblage was only observed in thin sections, it is not possible to evaluate the real total abundance, size class and morphogroup ratios. C assemblage is characterised by low diversity, with a size mostly comprised between 250 and 500 µm and almost all the taxa belong to the epifaunal and erect epifaunal classes, indicating a good ventilation on the sea-floor (Text-fig. 10f).

#### BC ASSEMBLAGE (Pl. 2)

Age: Early Toarcian - *D. (O.) tenuicostatum* Zone.  
This assemblage was recovered in the MS lower

member. The species diversity is high, with Fisher index values ranging from 10 to 14. Each taxon shows a limited number of specimens but the total abundance is high. Lagenina with Pliensbachian affinity prevail on siliceous agglutinated foraminifers and are represented by forms with thick and sculptured tests (Pl. 2, figs. 5-21). Most of the specimens are larger than 250µm, several of them being over 500µm (Text-fig. 10c). Lenticular planispyral morphotypes, adapted to an epibenthic life habit, prevail over the other morphogroups (Text-fig. 10e). These forms with a low surface/volume ratio show preference for a habitat extending from the sediment surface to 1-2 centimetres within it and are active deposit feeding (Corliss, 1985; Corliss & Chen, 1988). In fact their lenticular shape is suitable for high mobility, hydrodynamic stability, resistance to abrasion and predator activity.

Among biconvex lenticulinas, abraded fusiform shapes are common (Monaco *et al.*, 1994).

The persistence of several Domerian species

(*Marginulina prima*, *Paralingulina* gr. *tenera*, *Vaginulina triangula*, *Paralingulina testudinaria*, *Prodentalina obscura*, *Nodosaria tenuis*, *Falsopalmula insignis* etc.) in the basal Toarcian and their ubiquitous characters was clearly pointed out by Boutakiout (1990) in Northern Morocco.

An assemblage of other organisms, as diversified as the foraminiferal one, was recovered in this short but significant interval. Large ostracods mainly belonging to the Healdidae (Pl. 2, figs. 22 and 23) and all the other invertebrate remains (olothurians, crinoids, ophiurids, echinids, gastropods, bivalves, brachiopods and ammonites) are common. Thin and flat bivalves constitute packstone layers at the top of the MS lower member. The same forms recognised in the washed residues and ammonite nuclei characterise the microfacies from this interval (Pl. 6, fig. 1).

Genera belonging to infaunal and shallow infaunal classes show stout and sculptured walls (Pl. 2; figs. 7-17 and 21). Such morphological adaptation is unsuitable for the mobility within the sediment and suggests a micromigration from infaunal to epifaunal habitats, caused by the peculiar ecological conditions (low sedimentation rate, high oxygenation and low nutrient content). In fact an epifaunal mode of life thrives in a food-limited environment because it allows feeding to take place at the sediment surface, where labile organic matter is most abundant (Corliss & Chen, 1988).

Paleoenvironmental inferences: The BC assemblage features (high genus and species diversity, abundance of stout and sculptured *Lagenina* and of macroinvertebrates remains) are a result, according

to Cubaynes *et al.* (1991), of well oxygenated conditions, with high calcium carbonate availability, high hydrodynamic energy and environmental stability. Stable conditions lead to the establishment of a community characterised by strong interspecific competition (k-selected or equilibrium fauna, Ekdale, 1985).

Calcareous-hyaline taxa prevailing on agglutinated ones are related to a depth of more than 50 - 70 m (Boltovskoy & Wright, 1976). However, the high species diversity and the presence of species which typically live in epicontinental basins indicates that the bathymetry is no deeper than the outer shelf (80 - 200 m) (Cubaynes & Ruget, 1987). Stam (1986) and Cubaynes *et al.* (1989), consider the assemblages, in which biconvex lenticulinas are more abundant than flattened and uncoiling ones, as characteristic of a depth ranging from 80 to 150 m. Moreover Rey *et al.* (1994), demonstrate a correspondence between micropaleontological assemblages and sea level changes and point out that a prevalence of coiled *Nodosariacea* coincides with low sea level.

#### D ASSEMBLAGE (Pl. 3)

Age: Early Toarcian - *D. (O.) tenuicostatum* Zone.

This assemblage was recovered in the lower part of the clayey-marly MS middle member, in the grey marls underlying the black shales. Also the inferior portion of the black shales is characterised by this assemblage.

In the D assemblage the species diversity

#### EXPLANATION OF PLATE 2

Foraminiferal assemblages: C (figs. 1-4) and BC (figs. 5-23), *D. (O.) tenuicostatum* Zone, lower part. SEM photomicrographs. Scale bar = 100  $\mu$ m.

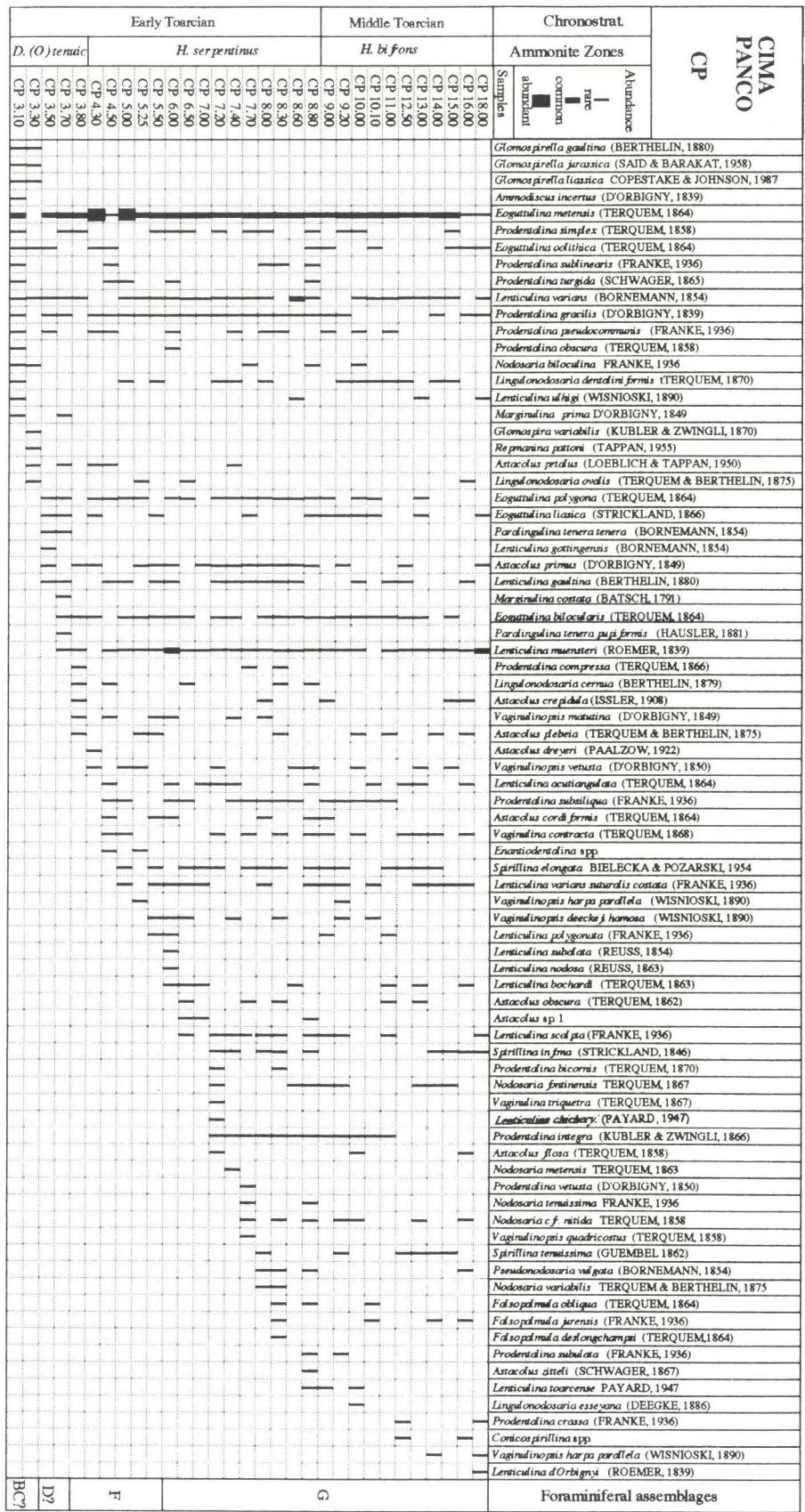
- Fig. 1 - *Repmanina pattoni*. PO 1.20.
- Fig. 2 - *Glomospira variabilis*. PO 1.20.
- Fig. 3 - *Glomospirella gaultina*. PO 1.20.
- Fig. 4 - *Glomospirella* cf. *jurassica*. PO 1.20.
- Fig. 5 - *Glomospirella liassica*. PO 2.20.
- Fig. 6 - *Ammodiscus* sp.. PO 2.20.
- Fig. 7 - *Falsopalmula insignis*. PO 2.45.
- Fig. 8 - *Paralingulina testudinaria*. PO 2.45.
- Fig. 9 - *Astacolus* cf. *inaequistriatus*. PO 2.45.
- Fig. 10 - *Lenticulina bochari*. PO 2.45.
- Figs. 11-12 - *Marginulina prima gibberula*. PO 2.45; 11) lateral view; 12) apertural view;
- Figs. 13-14 - *Marginulina prima prima*. PO 2.65, 13) oblique view; 14) lateral view.
- Figs. 15-16 - *Marginulina lamellosa*. PO 2.65, 15) oblique view; 16) lateral view.
- Fig. 17 - *Marginulina* gr. *prima*. PO 2.65.
- Fig. 18 - *Ichthyolaria intumescens*. PO 2.65.
- Fig. 19 - *Vaginulina listi*. PO 2.65.
- Fig. 20 - *Vaginulina triangula*. PO 2.65.
- Fig. 21 - *Marginulina costata*. CP 3.70.
- Figs. 22-23 - *Hermiella comes* (Malz). PO 2.20, 22) lateral view; 23) ventro-lateral view.







Text-fig. 9 - Foraminifer species distribution chart, Cima Panco section.





decreases abruptly (Text-fig. 7). A large extinction occurs affecting about 50% of species and all the forms with Pliensbachian affinity and siliceous agglutinated foraminifers disappear. The turnover rate of this assemblage in comparison with the previous one is 90%. However some species (*Lenticulina polygonata*, *L. muensteri*, *L. uhligi*, *L. acutiangulata*, *L. gaultina*, *Nodosaria fontinensis* and *Pseudonodosaria vulgata*), the distribution of which is shown in Text-fig. 7, do not become extinct and appear again above the black shales facies. Elongated tapering and flattened morphotypes strongly increase (Text-fig. 10e). In fact flattened lenticulinas prevail over biconvex ones (Text-fig. 10d). *Prodentolina*, *Lingulonodosaria* and small *Eoguttulina* are abundant (Pl. 3, figs. 1-16, 18-20).

In comparison with the BC assemblage most of the taxa are infaunal or shallow infaunal (Text-fig. 10f) and the test size decreases, with peaks of 100% of individuals less than 250  $\mu\text{m}$  (Text-fig. 10c).

Among other organisms radiolarians, smooth ostracods, microgastropods, bivalve fragments and echinid spines are present.

Paleoenvironmental inferences: The huge increase of the infaunal proportion testifies to the development of a poor oxygenated habitat. Their elongate and flattened morphology minimizes the strength to move and feed through the poor oxygenated sediment (Koutsoukos & Hart, 1990) and their high surface/volume ratio allows them to maximise oxygen uptake (Bernhard, 1986). The uncoiled *Nodosariacea* increase is referred by Rey *et al.* (1994) to the occurrence of a transgressive systems tract.

Therefore D assemblage indicates the beginning of a consistent ecologic change towards restricted conditions, which can be interpreted as a deepening upward trend during a transgressive phase (Boutakiout, 1990). This environmental change has been considered the main cause of the extinctions affecting the paleontological community. Some benthic foraminifers reappear from the *H. serpentinus* Zone on, after the improvement of sea-floor oxygenation, since they must have found a refugium habitat (Harries *et al.*, 1996) with better conditions during the biological crisis.

#### E ASSEMBLAGE (Pl. 3)

Age: Early Toarcian, *D. (O.) tenuicostatum* Zone.

This assemblage, dominated by *Paralingulina* gr. *tenera*, is characteristic of poorly oxygenated sediments, which are rich in organic matter (Bartolini *et al.*, 1992). The specific diversity is very low ( $\alpha = 2$ ) while the total abundance is even higher

than in the previous assemblages (Text-figs. 10a and 10b). This high abundance is caused by *Paralingulina* bloom, which occurs together with maximum TOC percentages (Parisi *et al.*, 1996). The elongate flattened morphogroup reaches an 85% peak and the elongate tapering group is also abundant, due to the presence of small eoguttulinas. The whole assemblage belongs to the infaunal class and shows an infaunal deposit feeder habit (Text-fig. 10f). The size of most of the individuals are less than 250  $\mu\text{m}$  (Text-fig. 10c).

Other fossils consist of radiolarians and pyritized bivalve prodossoconchs, gastropods and small sculptured ostracods (among which some prociterurids).

Paleoenvironmental inferences: The occurrence of small pyritized fossils, pyrite granules and the values of the TOC testify that a poor oxygenated environment occurred on the sea bottom. Typical E assemblage morphotypes live within the sediment up to 15-20 centimetres below the sediment surface (Corliss, 1985). However according to Kaiho (1994), they can reach the surface and become also epifaunal in low-oxygen conditions, due to a reduction in the interspecific competition. The E assemblage shows the main features of a typical opportunistic assemblage (r-selected, according to Ekdale, 1985) such as low species diversity, highly dominated fauna and reduced size, all of which indicate stressed conditions. In this case the limiting condition is represented by the widespread and low oxygenated bottom waters.

Kaiho (1994) subdivided recent benthic foraminiferal taxa in dysoxic, suboxic and oxic indices. Although the comparison with living genera is difficult, the peculiar morphologies of the E assemblage forms makes for them to be considered dysoxic indicators. *Paralingulina* and *Eoguttulina* are in fact comparable to *Bolivina*, *Bulimina* and *Pleurostomella* in terms of functional morphology. Therefore the sea-bottom paleoenvironment can be considered as dysoxic with oxygen content variable between 0,1 a 0,3 ml/l.

Between the BC and the E assemblages the equilibrium species disappear and are replaced by intermediate and then opportunistic forms. The total abundance increases progressively, apart from an abrupt decrease at the extinction of the taxa with a Pliensbachian affinity (Text-fig. 10a). These observations are in accordance with the Sjoersdama & Van der Zwaan (1992) model about recent restricted environments. In the E assemblage, however, the oxygen content is sufficient to satisfy the ecologic requirements of the opportunistic species and the "bottle-neck frequencies" and "benthic desert" phases are not reached.



## F ASSEMBLAGE (Pl. 4)

Age: Early Toarcian, uppermost *D. (O.) tenuicostatum* - *H. serpentinus* Zones.

A new faunal progressive diversification takes place in the varicoloured marls deposited above the black shales and in the red marls of the RAUM lower member. *Paralingulina* extinction is abrupt, causing a huge decrease in the elongate flattened morphogroup (Text-fig. 10e). The turnover rate in comparison with the E assemblage is equal to 88% (Text-fig. 7). Infaunal forms such as prodentalinas and eoguttulinas (B and C morphogroups) are still dominant, but their dimensions increase notably. Epibenthic forms (D, E and F morphogroups) appear again after the low oxygen crisis. Their abundance is regular and slowly increasing. Some typical forms such as large polymorphinids, belonging to the genus *Enantiodontalina*, in addition to *Lenticulina toarcense*, *Astacolus primus*, etc. appear (Text-figs. 7 and 9).

Also other organisms show a high diversification. Ophiurids reappear and echinids, bivalves and ostracods become common again.

Radiolarian packstones containing rare ammonite nuclei were recovered in the upper part of the MS (Pl. 6, figs. 2 and 3). The ammonite nuclei indicate the reappearance of this group after the biological crisis. One metre above the last radiolarian packstone bed, macroscopic ammonites have been found. They belong to the genus *Hildaites* and mark the beginning of the *H. serpentinus* Zone.

Paleoenvironmental inferences: It is worth pointing out that the radiolarian packstone beds are

widespread not only in the whole Umbria-Marchean Basin but also in the Ionian Trough (Pettinelli et al., in press). The radiolarian bloom is probably related to upwelling currents, which raised, within the water column, nutrients accumulated on the sea-bottom.

The F assemblage testifies the improved bottom conditions following the dysoxic environment. The species vertical distribution shows a progressive and slow biological diversification (Text-figs. 7 and 9). However the dominance of uncoiled flattened forms (*Astacolus*, flattened lenticulinas) over lenticular ones (Text-figs. 10d and 11d) is indicative of low energy. The relative frequencies of the morphogroups allow this interval to be referred to a middle-outer shelf bathymetry.

## ASSEMBLAGE G (Pl. 5)

Age: Early to Middle Toarcian, *H. serpentinus* - *H. bifrons* Zones.

In the upper part of the A and in the B members of the RAUM the species diversity increases continuously. The  $\alpha$  index reaches similar values to those registered in the BC assemblage (Text-figs. 10b and 11b), while the total abundance decreases (Text-fig. 10a). Both these characteristics are peculiar to a k-selected community. The genera *Vaginulinopsis* and *Lenticulina* show a high speciation (Text-figs. 7 and 9), the latter becomes predominant, being represented by *L. muensteri*, *L. gaultina*, *L. ulhigi*, *L. bochari*. Sometimes biconvex *Lenticulina* tests are abraded. New sculptured forms appear showing the same functional morphology as the BC assemblage

## EXPLANATION OF PLATE 3

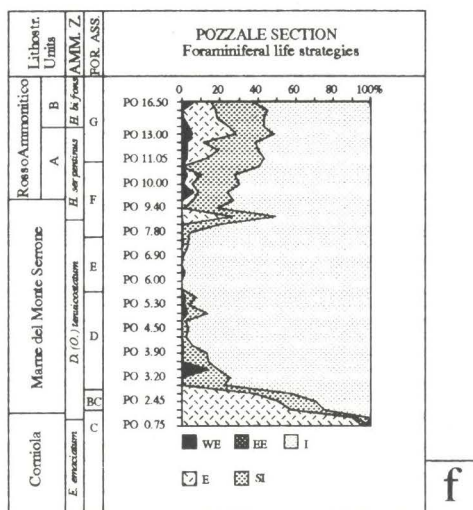
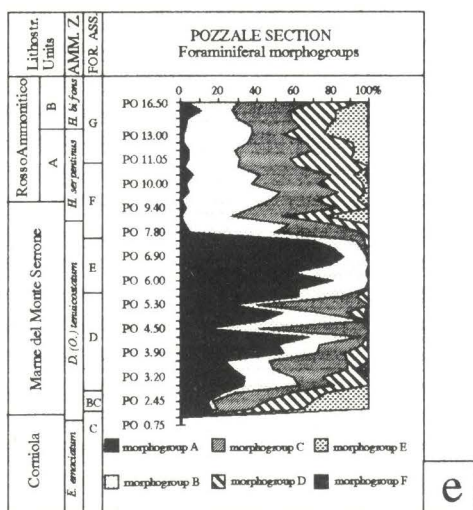
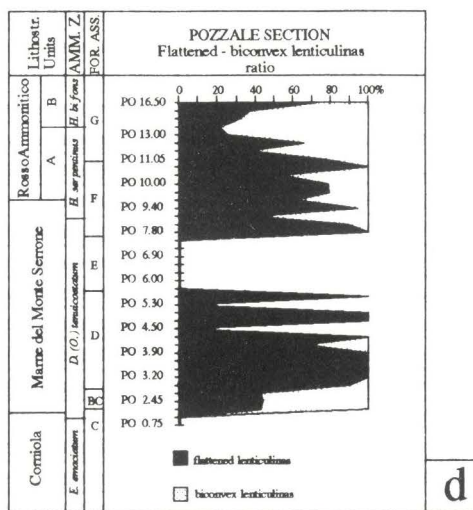
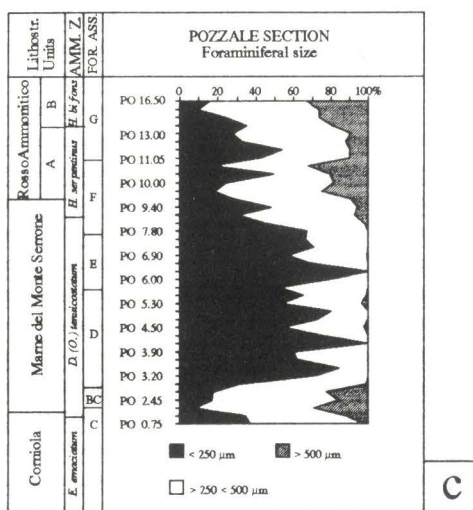
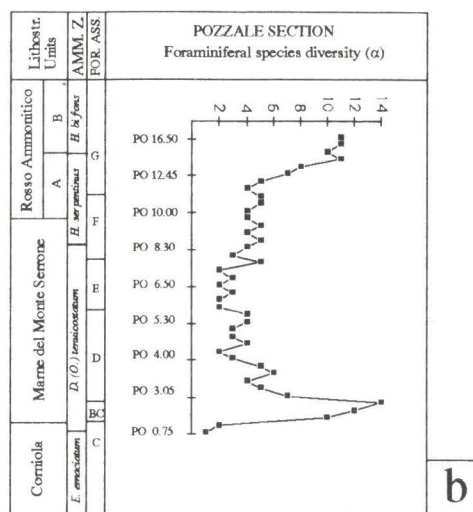
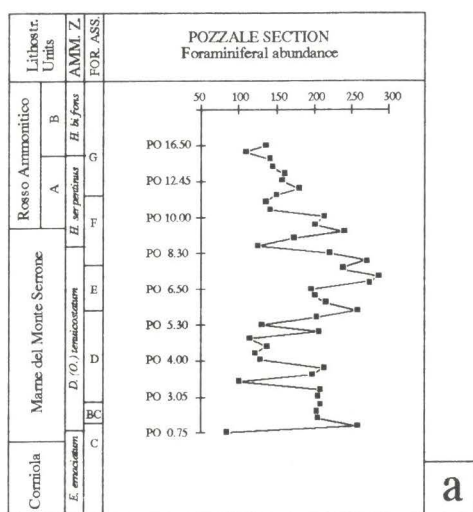
Foraminiferal assemblages D (Figs. 1-16, 18-20) and E (Figs. 17, 21-22), *D. (O.) tenuicostatum* Zone. SEM photomicrographs. Scale bar = 100  $\mu$ m.

- Fig. 1 - *Pseudonodosaria pulchra*. PO 3.20.
- Fig. 2 - *Astacolus primus*. PO 3.20.
- Fig. 3 - *Astacolus cf. vetusta*. PO 3.20.
- Fig. 4 - *Vaginulinopsis harpa parallela*. PO 3.20.
- Fig. 5 - *Astacolus zitteli*. PO 3.90.
- Fig. 6 - *Lingulonodosaria dentaliniformis*. PO 3.20.
- Fig. 7 - *Lingulonodosaria cernua*. PO 3.90.
- Figs. 8-9 - *Lingulonodosaria ovalis*. PO 3.20, 8) lateral view; 9) apertural view.
- Fig. 10 - *Prodentalina gracilis*. PO 3.50.
- Fig. 11 - *Nodosaria claviformis*. PO 3.90.
- Fig. 12 - *Nodosaria tenuissima*. PO 4.50.
- Fig. 13 - *Paralingulina tenera pupa*. PO 3.50.
- Fig. 14 - *Paralingulina tenera tenuistriata*. PO 3.20.
- Figs. 15-16 - *Paralingulina tenera tenera*. PO 3.20, 15) lateral view; 16) apertural view.
- Fig. 17 - *Paralingulina tenera pupoides*. PO 7.40.
- Fig. 18 - *Brizalina liassica*. PO 5.00.
- Fig. 19 - Cytheruridae (*Cytheropteron*?). PO 3.50.
- Fig. 20 - Pyritised bivalve. PO 4.60.
- Figs. 21-22 - Pyritised gastropods. PO 5.85.









Text-fig. 10 - Pozzale section graphs: foraminiferal abundance, foraminiferal species diversity, foraminiferal size, flattened-biconvex lenticulinas ratio, foraminiferal morphogroups, foraminiferal life strategies (symbols are reported in tab. 1b).



components. The benthic foraminiferal size continues to increase and is usually larger than 250µm (Text-figs. 10c and 11c).

In the Cima Panco section *Lenticulina d'orbignyi* appear approximately at the base of the *P. erbaense* Zone, as in other sections in the Umbria-Marchean Basin (Monaco *et al.*, 1994). The E morphogroup, consisting of lenticulinas, increases considerably, due to the decreasing flattened/biconvex lenticulinas ratio. Planoconvex or conical forms, belonging to the F morphogroup, appear and occur discontinuously (Text-figs. 10e and 11e). Epifaunal and shallow infaunal are more representative and some weed epifaunal grazing herbivores (*Spirillina* and *Conicospirillina*) occur (Text-figs. 10f and 11f).

Other organisms are represented by abundant ostracods, bivalve fragments, gastropods, echinids, ophiurids, small brachiopods and radiolarians. Among ostracods it is worth noting the finding of *Monoceratina unguina* Triebel & Bartenstein, which has also been found on the European epicontinental platforms and in Greece (Pettinelli *et al.*, in press).

In the Pozzale section at the 16.45m and 16.55m levels (Pl. 6, figs. 7-9), a thin bivalve grainstone-packstone microfacies is present. Shells are stacked upon each other, densely packed and form undulating laminae, as symmetric ripples or are folded as recumbent foreset structure. They have been interpreted as the response to episodic energy increases, which reelaborate sediment, leading to the deposition of bioclastic sands (winnowed beds *sensu* Monaco, 1992).

Paleoenvironmental inferences: The relative abundance of the E morphogroup epibenthic forms, species diversity, macroinvertebrate remains and the increase and reappearance of ornamented taxa, indicate the recolonisation by a calcareous benthic community living at the sediment surface. Well oxygenated conditions suitable for benthic life, similar to those of the BC assemblage, reappear.

The faunal cosmopolitanism is not so evident as at the base of the Toarcian. In fact in the whole Umbro-Marchean Basin the *Chitarina* bloom typical of the Western Europe epicontinental seas (Arias *et al.*, 1992) was not recorded. However some forms common to those areas, such as *L. toarcense*, *L. chicheryi* and *Lenticulina d'orbignyi* (considered an ubiquitous species by Boutakiout, 1990) were found. Therefore a greater paleogeographical differentiation can be inferred.

Signs of a shallowing trend in this interval are provided by the presence of gastropods, the abundance of *Lenticulina muensteri* and the presence of weed epifaunal taxa, which are linked to the photic zone. According to Rey *et al.* (1994), strictly coiled-

biconvex lenticulinas are more abundant in low stand deposits than in the transgressive and highstand ones. Sedimentary structures, indicating high energy, also testify a shallowing trend in the Middle -Late Toarcian.

#### ASSEMBLAGE G-H

Age: Middle Toarcian (*P. erbaense* Zone) - Early-Middle Aalenian.

This assemblage was found between the base of the C member of the RAUM and the base of the CP. The attribution of this assemblage to the G or to the H ones of Nocchi (1992) is uncertain, because only thin sections from this interval were examined. The observed foraminifers are biconvex lenticulinas. Abundant other fossils have also been recovered, among which bivalves, ammonite nuclei, high-spiralled and low-spiralled ornamented gastropods, microbrachiopods, ostracods, echinid fragments and radiolarians.

In thin sections the microfacies shows grey and red plagues. The grey ones consist of mudstone or wackestone with bioclasts and small tests diluted in a micritic matrix. In the red ones nodules are more evident and are surrounded by arenitic or siltitic dark red matrix, with minutely fragmented and randomly oriented bivalve shells linked to the activity of burrowing organisms (Pl. 6, fig. 10). The bivalve shells are often oriented with their concave side downward (shelter porosity), indicating a high energy regime.

Paleoenvironmental inferences: The abundance of gastropods, biconvex lenticulinas, macroinvertebrate remains and bioturbation, indicate an environment very similar to that of the previous assemblage, but with higher hydrodynamic energy.

#### BIOSTRATIGRAPHIC CORRELATION BETWEEN THE POZZALE AND VALDORBIA SECTIONS

During the Toarcian the Umbro-Marchean Basin recorded significant differences in facies thickness and distribution which caused heteropies between MS and RAUM. The difference between these stratigraphic units is mainly due to sedimentation rates and to detrital input. An example of these differences is shown in the logs of Text-fig. 12, where Pozzale is compared to an extended succession such as Valdorbis section. This section has been examined by several authors (Donovan, 1958; Gallitelli-Wendt, 1969; Centamore *et al.*, 1971; Cresta *et al.*, 1989; Monaco *et al.*, 1994). Among the studied areas within the Umbro-Marchean Basin, the Valdorbis area is the first in which anoxic sediments were recovered



(Elmi & Ameer, 1984) and the anoxic event brought to light (Jenkins & Clayton, 1986).

In order to correlate the Pozzale and Valdorbis sections the work of Monaco *et al.* (1994) was chosen because foraminiferal assemblages of the same time interval are reported in Valdorbis. The two sections are 75 km apart. The main distinctive characteristic is the thickness variability: the interval MS-RAUM measures 38 metres in Pozzale and 80 in Valdorbis. Comparison between the two sections was possible by using the same markers and biozonation.

As shown by Text-fig. 12, the sedimentary shift from COR to MS occurs almost simultaneously, slightly ahead in the extended sections (i.e. Valdorbis). The MS marly-clay interval has a greater extension in Valdorbis than in Pozzale, bearing a considerable amount of resedimented beds (15-37%). Black shales show similar stratigraphic distribution and assemblages in both sections, within the *D. (O.) tenuicostatum* Zone. The MS grey clay-marls of Valdorbis last up to the middle part of the *H. bifrons* Zone, while in Pozzale such marls are already replaced by red nodular marls (A member and part of the B member of the RAUM) from the lower portion of the *H. serpentinus* Zone on.

From the upper part of the *H. bifrons* Zone, uniform sedimentation and similar micropaleontologic assemblages occur in reddish nodular marls and limestones (B and C members of RAUM). From this level onwards, detrital input also decreases in Valdorbis, and the sedimentation rate goes down to a value inferior to that of Pozzale. Within Middle-Late Toarcian average sedimentation rates, estimated without considering sediment compaction, are 4 mm/ka in Pozzale and 3 mm/ka in Valdorbis. Infact Monaco *et al.* (in press) point out the presence of hard grounds and of hyatuses in the upper portion of Valdorbis section. RAUM deposition ends with pebbly mudstone resedimented beds in both sections, indicating an unstable sedimentary phase in the basin.

Benthic foraminiferal assemblages covary with lithological features, but show the same vertical order in the two sections (Text-fig. 12). However the BC assemblage, which is typical of nodular calcareous beds at the base of MS in Pozzale, was not recovered in Valdorbis probably cause of the abundance of the detrital supply. Moreover the G assemblage, typical of the red nodular marly sediments of the RAUM, occurs later in Valdorbis (*H. bifrons* Zone).

The Early Toarcian facies heteropy, and the thickness difference between the two sections might be accounted for by non-homogeneous bathymetry due to differentiated subsidence rates. The beginning of the RAUM sedimentation in Valdorbis could be interpreted as the consequence of the partial infilling of morphological depressions, change in the subsidence rate, and of the sea-level fall. The combination of these factors has probably led to a homogenization of the sedimentation beginning from the upper part of the *H. bifrons* Zone, when the conditions, which had caused the Early-Middle Toarcian facies heteropy, no longer existed.

#### THE TOARCIAN MEDITERRANEAN TETHYSIAN EVENTS REGISTERED IN THE M. MARTANI AREA

Some effects of geologic and biologic events, occurring in the Mediterranean area during the Toarcian, has been recognised in the depositional environment of the M. Martani area and of the Umbria-Marchean Basin in general.

#### 1 - Change in the sedimentary regime at the Pliensbachian-Toarcian boundary.

At the Pliensbachian-Toarcian boundary, many areas of Tethys register a change in the sedimentary regime of carbonate platforms, in the open sea or pelagic adjacent basins, and in the continental

#### EXPLANATION OF PLATE 4

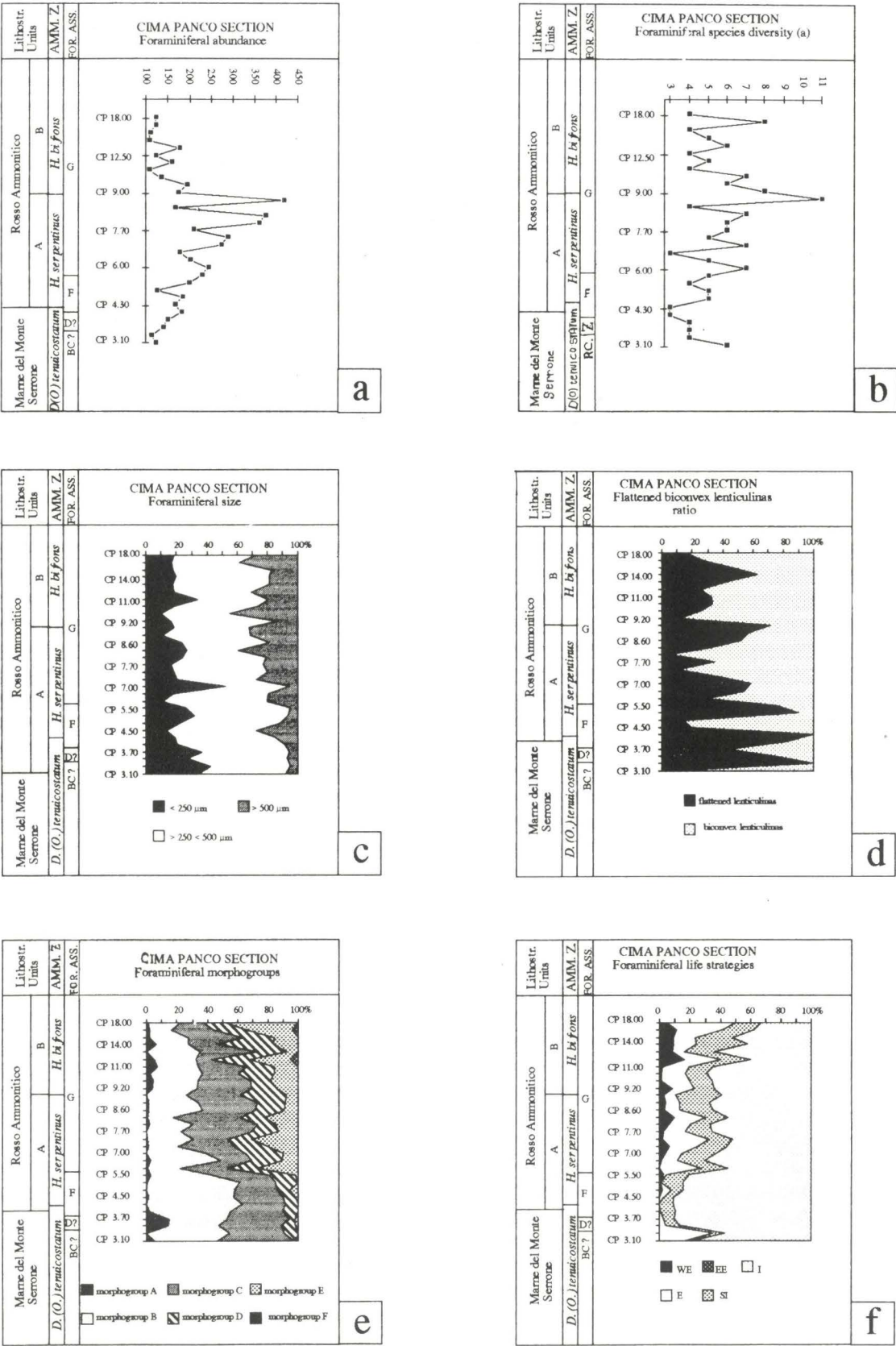
Foraminiferal assemblage F. Fig. 1-3, *D. (O.) tenuicostatum* Zone, upper part; Fig. 4-12, *H. serpentinus* Zone. SEM photomicrographs. Scale bar = 100 µm.

- Fig. 1 - *Eoguttulina metensis*. PO 7.80.
- Fig. 2 - *Eoguttulina bilocularis*. PO 8.40.
- Fig. 3 - *Eoguttulina liassica*. PO 8.40.
- Fig. 4 - *Enantiodontalina* sp.. PO 9.65.
- Fig. 5 - *Prodentalina integra*. PO 9.65.
- Fig. 6 - *Falsopalmula obliqua*. PO 9.65.
- Fig. 7 - *Vaginulina* sp.. PO 9.65.
- Fig. 8 - *Astaculus petalus*. PO 9.40.
- Figs. 9-10 - *Lenticulina* cf. *gaultina*. PO 9.65, 9) edge view; 10) lateral view.
- Figs. 11-12 - *Lenticulina toarcense*. PO 10.00, 11) edge view; 12) lateral view.



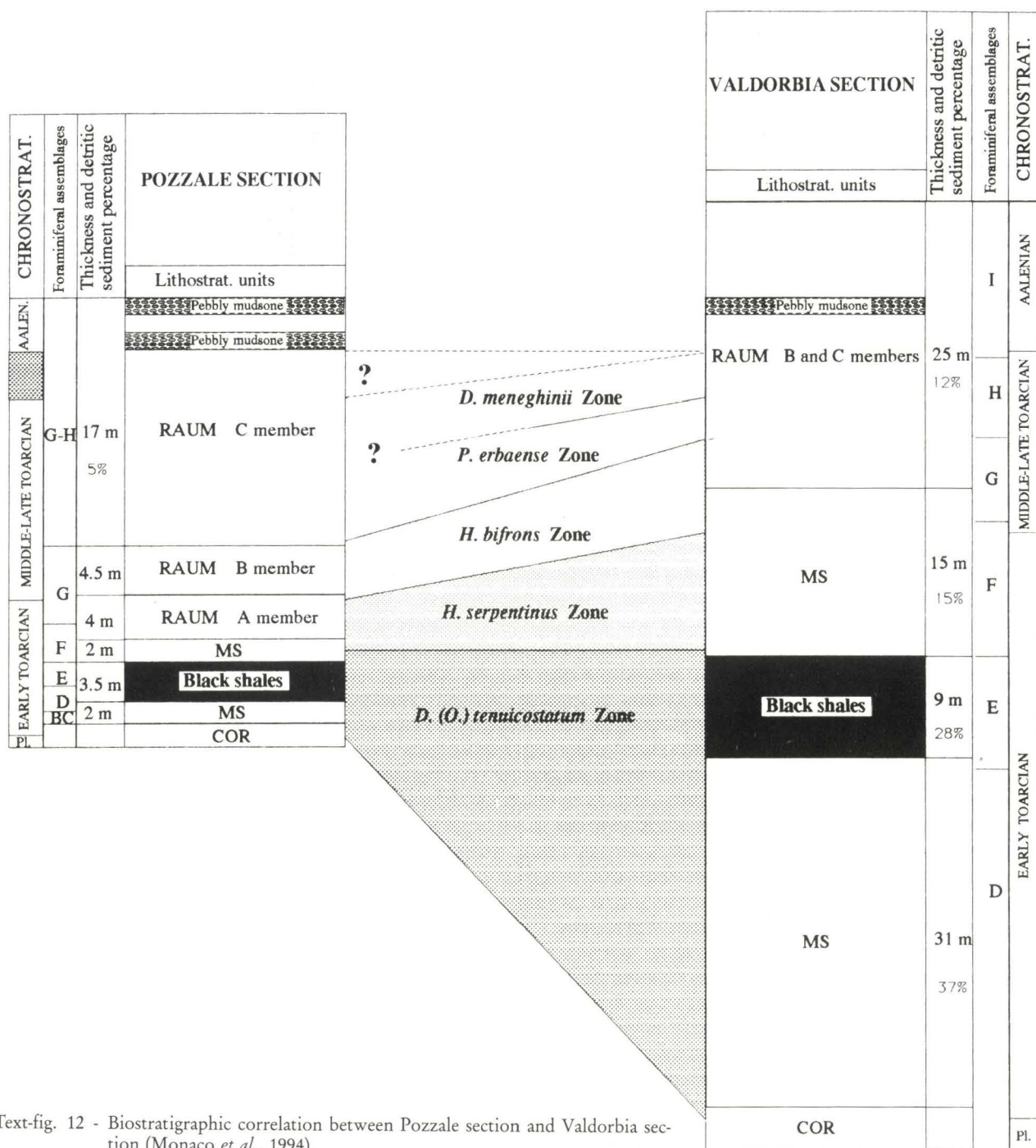






Text-fig. 11 - Cima Panco section graphs: foraminiferal abundance, foraminiferal species diversity, foraminiferal size, flattened-biconvex lenticulinas ratio, foraminiferal morphogroups, foraminiferal life strategies.





terrigenous platforms of western Europe (Bassoulet & Baudin, 1994). In the Mediterranean Tethys carbonate sedimentation turns into a marly and clayey deposition due to an input of clay material both in basins and margins. The overall Toarcian clay increase is probably due to the Early Toarcian transgressive cycle identified by Hallam (1988) and Haq *et al.* (1988). The consequent flooding of the car-

bonate and epicontinental platforms, and of the continental areas caused the run off of clay material and its discharge into the basins (Johnson, 1976; Ortega Huertas *et al.*, 1993).

This sedimentary event is well recognisable through the calcimetric curve decrease in the Pozzale section, at the base of the Marne del M. Serrone (Text-fig. 2). The clay increase does not seem

to be linked to a reduction in organic carbonate production, as both benthic and nektonic organisms are common. Furthermore no condensation or decrease in the sedimentation rate occurs, so as to justify the abrupt compositional change. The interruption of the calcium carbonate input as periplatform ooze (Bombardiere, 1993), does not account for sedimentary variation at the Plieusbachian-Toarcian boundary. In fact the sedimentation rate of MS is 6 mm/Ka, which does not differ from the underlying Corniola unit. It is therefore likely that the change in sedimentation refers to an increase in extrabasinal fine material more than to a drop in calcium carbonate production.

## 2 – Transgression and its effect on biotas.

The enhanced cosmopolitanism of nektonic *Eodactylites* fauna (Ammonitina) considered ubiquitous by Elmi *et al.* (1994) together with benthic faunas (foraminifers and ostracods) (Ruget, 1985; Boutakiout, 1990) indicates the beginning of the transgression.

Data from the M. Martani area testifies that the *Dactylioceras* (*Eodactylites*) bioevent represents a contemporaneous population renewal in the Mediterranean Tethys since there is no documentation of any ancestral faunas of *Dactylioceras* group in the Umbro-Marchean Basin (Faraoni *et al.*, 1994). The benthic foraminifers of BC assemblage show a clear cosmopolitanism as revealed by the several species common to coeval assemblages of western Tethys (Boutakiout, 1990; Nocchi & Bartolini, 1994; Herrero, 1994; Nini *et al.*, 1995; Pettinelli *et al.*, in

press). In the M. Martani area the very early phase of the transgressive event caused an increase of clay input, which created muddy substrates favouring a highly specialized infaunal and epifaunal association. Bioturbation accounts for a good oxygenation of sediments, which are found to be as nodular and reddish as the overlying RAUM.

## 3 – Oxygen deficiency related to the transgressive event.

With the advance of the Early Toarcian transgression the Mediterranean Tethys and the northern European epicontinental platforms were affected by poorly oxygenated environments, as testified by dark laminated marls and clays. The establishment of such environments implies both an increase in argillaceous sedimentation and the preservation of organic matter on restricted sea-floor (Bartolini *et al.*, 1992; Bassoulet & Baudin, 1994; Baudin *et al.*, 1990).

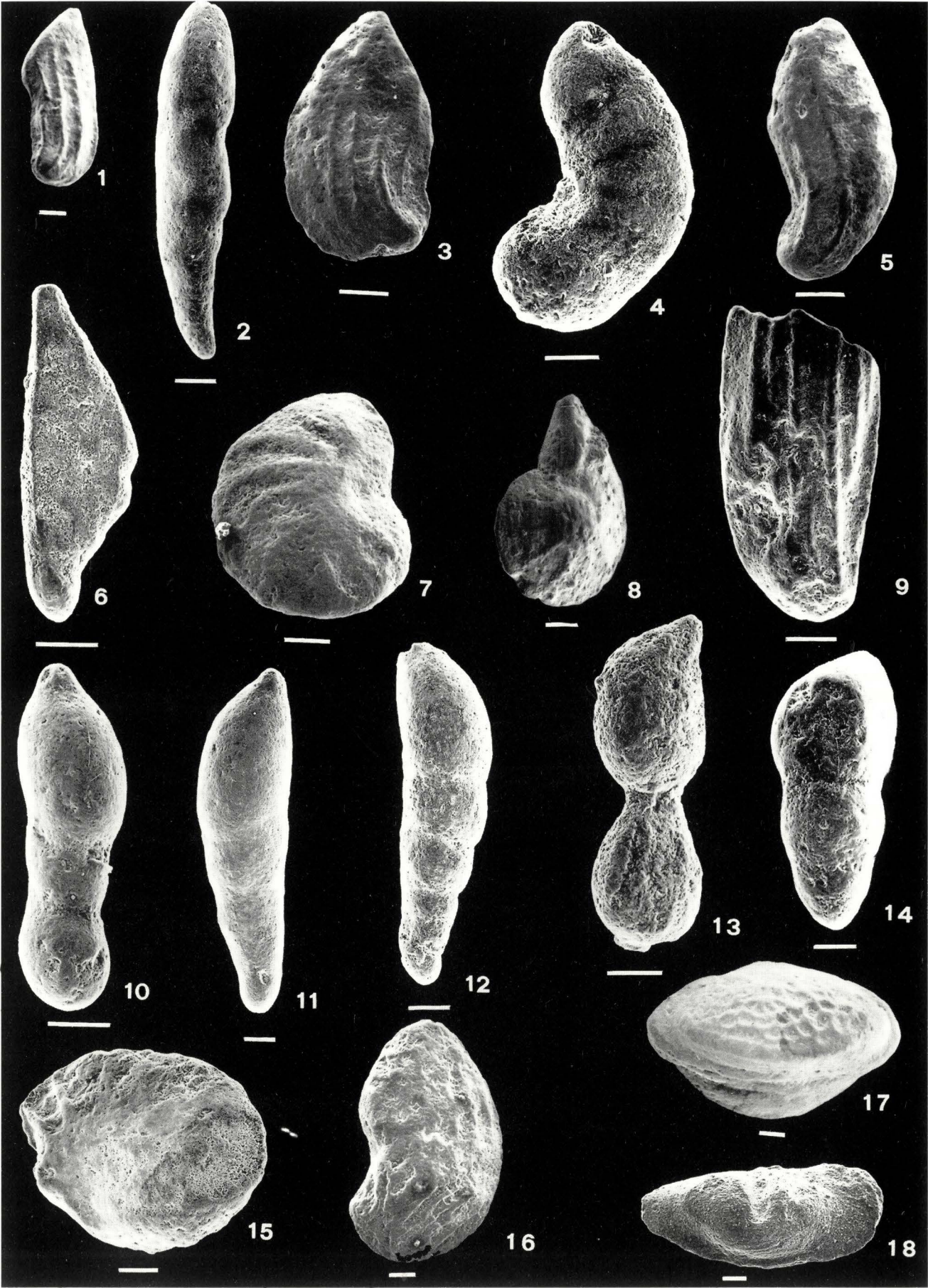
Low oxygenated conditions become active within the *D. (O.) tenuicostatum* Zone (Jenkins *et al.*, 1991), but seem to differ in vertical distribution in the various paleogeographic domains. In several areas of the Mediterranean Tethys such conditions end at the top of the *D. (O.) tenuicostatum* Zone, i.e. Morocco (Boudchiche & Ruget, 1993; Guex, 1973), Greece (Pettinelli *et al.*, in press), Central Italy (Parisi *et al.*, 1996), Subbetic domain (Jiménez *et al.*, in press). Wider vertical distribution of the poorly oxygenated facies up to the lower *H. serpentinus* Zone occurs in the Quercy area, SW France (Cubaynes & Fauré, 1986), up to the top of *H. serpentinus* Zone in Yorkshire (House, 1989), and up to

## EXPLANATION OF PLATE 5

Foraminiferal assemblage G. Figs. 1-10 and 17, *H. serpentinus* Zone; Figs. 11-15 and 18, *H. bifrons* Zone; Fig. 16, *P. erbaense* Zone. SEM photomicrographs. Scale bar = 100 µm

- Fig. 1 - *Vaginulinopsis quadricostata*. CP 7.70.
- Fig. 2 - *Prodentalina constricta*. PO 12.20.
- Fig. 3 - *Astacolus* sp. 1. CP 6.50.
- Fig. 4 - *Astacolus obscurus*. CP 8.30.
- Fig. 5 - *Vaginulinopsis* cf. *radiata*. CP 7.00.
- Fig. 6 - *Vaginulina triquetra*. CP 7.20.
- Fig. 7 - *Lenticulina chichereyi*. CP 7.20.
- Fig. 8 - *Lenticulina bocharii*. CP 8.00.
- Fig. 9 - *Citharina* sp.. CP 7.40.
- Fig. 10 - *Prodentalina numismalis*. PO 15.15.
- Fig. 11 - *Prodentalina pseudocommunis*. CP 11.00.
- Fig. 12 - *Prodentalina subsiliqua*. CP 9.00.
- Fig. 13 - *Prodentalina varians*. PO 16.50.
- Fig. 14 - *Prodentalina crassa*. CP 12.50.
- Fig. 15 - Abraded specimen of *Lenticulina*. PO 15.15.
- Fig. 16 - *Lenticulina d'orbigny*. CP 18.00.
- Fig. 17 - Sculptured ostracod. CP 6.50.
- Fig. 18 - *Monoceratina unguina*. PO 15.15.







the top *H. bifrons* Zone in the epicontinental platforms of south-western Germany (Oschmann, 1995).

The low-oxygenated event occurs in the M. Martani area during the medium-upper part of the MS stratigraphic interval, identified by black-shale laminated sediments within the *D. (O.) tenuicostatum* Zone. Bucefalo Palliani *et al.* (in press), by using palinology, relate the black-shale event to the transgressive system tract, as supported by these present results.

#### 4 – Faunal turnover linked to the poorly ventilated environment.

Associated with the poorly oxygenated episode, originally indicated as Oceanic Anoxic Event (Jenkins, 1988), there is a biological crisis that leads to a large extinction among the faunas with Pliensbachian affinity (ammonites, foraminifers and ostracods) (Bassoulet & Baudin, 1994; Hallam, 1987 and 1996; Jiménez *et al.*, in press). This biological event has been indicated by Hallam (1987 and 1996) as early Toarcian mass extinction. According to Jiménez *et al.*, (in press) Mediterranean ammonites replace taxa in the northern European platforms at the beginning of the *D. (E.) polymorphum* Zone. The authors also consider that almost all ammonites disappear in the middle-upper part of the *D. (E.) polymorphum* (considered equivalent to *D. (O.) tenuicostatum* Zone), both in Northern Europe and in Mediterranean Tethys; only Harpoceratinae and *Neolioceratoides*, probable ancestor of *Hildaites*, survive.

In the M. Martani area, within the lower part of the *D. (O.) tenuicostatum* Zone, the maximum extinction rate of ammonite and benthic foraminifer taxa occurs at the top of A member of the MS at 2.50 m in the Pozzale section, as pointed out in the distribution charts (Text-fig. 4 and Text-fig. 7).

Most of the ammonite fauna occurring before the anoxic event, disappear when oxygenated conditions become critical, and no specimen has been found within the black shale facies. An absence of ammonites cannot be caused only by test dissolution in CO<sub>2</sub> rich environments. In fact the almost total faunistic turnover of the *H. serpentinus* Zone leads to the supposition of a real extinction and only *Phylloceras*, *Calliphyllloceras* and *Lytoceras* survive as a consequence of this crisis. Among Hildoceratinae major changes occur, e.g. Harpoceratinae replace Protogrammoceratinae, while Hildoceratinae and Mercaticeratinae replace Arieticeratinae.

Several foraminifers and ostracods (Healdiidae) disappear at the base of the anoxic event together with ammonites. The maximum turnover rate has been recorded at the top of the lower member of the MS. Out of 43 species, 25 species, showing a Pliensbachian character, become extinct in the lower part of *D. (O.) tenuicostatum* Zone and 5 species at the end of this Zone. During black shale deposition, a dwarf oligotypic benthic fauna (E assemblage) and the lack of trace fossils testify to poor benthic life.

#### 5 – Faunal renewal at the beginning of the *H. serpentinus* Zone.

A faunal recovery is evident both for ammonites (Hallam, 1987; Jiménez *et al.*, in press), and for foraminifers (Bassoulet & Baudin, 1994; Nicollin & Ruget, 1988; Pettinelli *et al.*, in press; Ruget, 1985) when, at the beginning of *H. serpentinus* Zone, oxygenated conditions are reestablished.

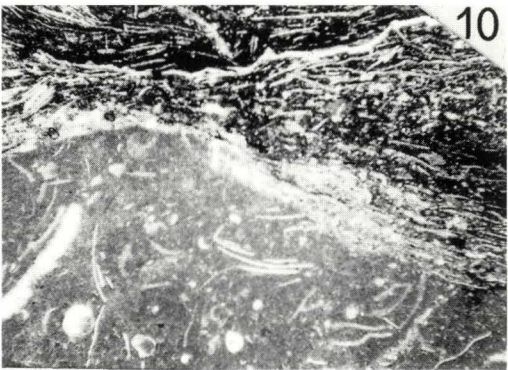
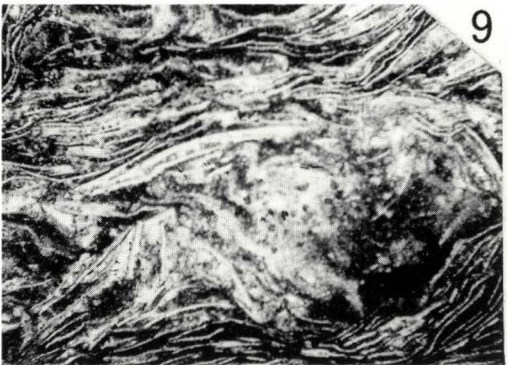
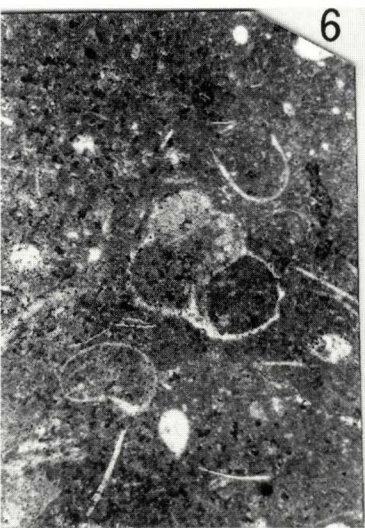
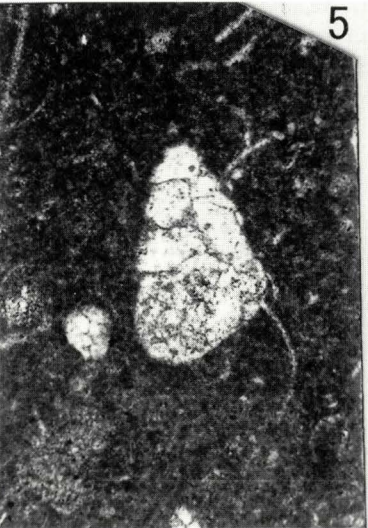
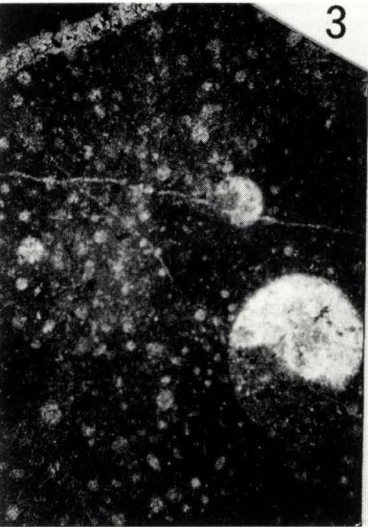
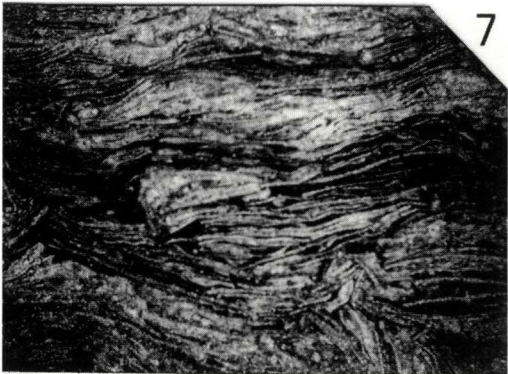
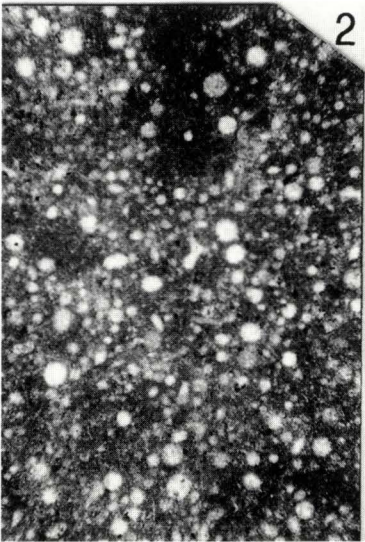
In the M. Martani areas, as in several other areas (Monte Serano, Furlo, Burano, Valdorbia, etc.) of the Umbro-Marchean Basin, Venturi has observed that ammonites show adaptive radiation with the appearance of Hildoceratinae, Mercaticeratinae, Harpoceratinae s.s. and later of cadicone Dactylioceratinae, Leukadiellinae, rarenodine Ham-

### EXPLANATION OF PLATE 6

#### Microfacies.

- Fig. 1 - Bivalve, echinoderm and ammonite nucleus wackestone. PO 2.90, *D. (O.) tenuicostatum* Zone, 17X.
- Fig. 2 - Radiolarian packstone. PO 7.60, *D. (O.) tenuicostatum* Zone, 14X.
- Fig. 3 - Radiolarian wackestone; ammonite nuclei in the upper part. PO 7.85, *D. (O.) tenuicostatum* Zone, 15X.
- Fig. 4 - Bivalves, low spiral gastropods, small brachiopod and ammonite nucleus wackestone. CP 14.70, *H. bifrons* Zone, 19X.
- Figs. 5-6 - Different taxa of gastropods: respectively CP 14.70, 55X and CP 12.00, 35X, *H. bifrons* Zone.
- Fig. 7 - Thin shelled bivalve packstone, organised in undulated laminae. PO 16.45, *H. bifrons* Zone, 17X.
- Fig. 8 - Circular section of bioturbation, which breaks the bivalve orientation. PO 16.45, *H. bifrons* Zone, 19X.
- Fig. 9 - Thin shelled bivalve packstone; the undulated laminae, showed in Fig. 7, are disrupted in a nodular shape by a probable higher hydrodynamic energy. PO 16.55, *H. bifrons* Zone, 17X.
- Fig. 10 - Detail of nodular structure; nodules are limited by bioturbated areas, in which fossils are finely fragmented. PO 21.20, *P. erbaense* Zone, 20X.







matoceratinae (Venturi, 1994) and *Phymatoceras*. The faunistic renewal (well illustrated in Faraoni *et al.*, 1994), which took place at the end of the anoxic event is unique, since no similar turnover had ever occurred before. Almost all the new species figured in Pl. 1, occur within the *H. serpentinus* Zone.

The migration of several Mediterranean taxa towards northern European areas within the Early Toarcian might be related to the fact that normal oxygenated conditions were established earlier in the Mediterranean Tethys than in northern Europe.

The benthic foraminifers of the F assemblage show an abrupt taxonomic renewal, and the new biotas are characterised mainly by large infaunal forms testifying the improved conditions in bottom ventilation; some species already present below the black shales occur again.

#### 6 – Relationship between eustatic curve and $\delta^{13}\text{C}$ curve.

Many authors (Jenkins, in press; Jiménez *et al.*, in press; Renard, 1985) point out the correspondence between the sea-level variation curve and the carbon isotopic (bulk rock) one. Jiménez *et al.* (in press) correlate the positive  $\delta^{13}\text{C}$  excursion with the positive maximum eustatic variation within the *H. serpentinus* Zone, while the  $\delta^{13}\text{C}$  decrease seems to indicate the subsequent regression. The  $\delta^{13}\text{C}$  positive excursion is related to excess burial of organic matter during the anoxic crisis (Jenkyns & Clayton, 1986), coinciding with the transgressive event as identified in Valdorbia (Umbro-Marchean Basin), in the Southern Alps, etc.

In the M. Martani area, Morettini *et al.* (1996) have identified a positive isotopic shift in Pozzale section within the *H. serpentinus* Zone, that can be correlated to the one identified by Jenkyns and Clayton (1986).

#### 7 – An attempt to relate foraminiferal assemblages and sea-level changes.

The vertical distribution of benthic foraminiferal assemblages together with the lithofacies succession seems to reflect the sea level eustatic curve (Hallam, 1988; Haq *et al.*, 1988). Such a correlation could be highlighted by using the “procédure inverse” *sensu* Vail *et al.* (1987) and Olòriz *et al.* (1993), consisting in the use of the global eustatic curve to recognise, through the biostratigraphic markers, the position of the eustatic cycles. At this point of the research the following can be inferred.

At the base of the Toarcian (*D. (O.) tenuicostatum* Zone), the cosmopolitan characteristic of the BC assemblage, associated to the beginning of clay in-

crease, might be interpreted as the evidence of an initial phase of the Early Toarcian transgression. Both sedimentological and microfaunistic data indicate relatively shallow conditions. The sea-level rise begins to show a relevant effect on the benthic community with the occurrence of several extinctions, which determine the replacement of BC assemblage by D and E, the latter ones developing in scarcely oxygenated conditions (*D. (O.) tenuicostatum* Zone). Sediments change from reddish bioturbated marls to laminated dark clays. In fact an evolving Transgressive System Tract determines decreasing energy, leading also to scarce oxygenation in the bottom-waters. This is supported by the recovery of the D and E assemblages typical of poor ventilated conditions.

The F assemblage (*H. serpentinus* Zone p.p.), characteristic of the red bioturbated marls of the RAUM lower member, can be referred to the initial stage of the high stand systems tract.

The G assemblage occurrence, which coincides with a new recovering of calcium carbonate production, refers to a shallowing, which indicates the terminal phase of the highstand systems tract and the successive lowstand in the Middle-Late Toarcian (G-H assemblage). Vertical evolution of micropaleontological assemblages might therefore correspond to a 3rd order transgressive-regressive cycle developing within the Late Pliensbachian - Middle Toarcian interval (UAB4.3 third order cycle of Haq *et al.*, 1988).

#### 8 – Rosso Ammonitico sedimentation and eustatic 3rd order cyclicity.

Several Spanish authors have dealt with extensive studies of the different environments associated to Upper Jurassic Rosso Ammonitico facies, similar to the Toarcian Umbro-Marchean one. They infer that depositional environments of the Rosso Ammonitico are pelagic (open sea), distal (both from continents and carbonate platforms), and correspond to plateaux which are not deeper than 200 metres. Such areas (swells) emerged from time to time, affected by eustatic variations, and differed from epicontinental areas mainly because of faunistic differentiation (Olòriz *et al.*, 1991, 1993 and 1995).

In the Mediterranean area the Rosso Ammonitico nodularity is referred by several authors to different causes, i.e. low sedimentation rate, pervasive bioturbation, winnowing and early diagenetic processes (Elmi, 1981; Eller, 1981; Elmi & Ameer, 1984; Martire, 1989, 1992; Olòriz *et al.*, 1995; Seyfried, 1981). The Toarcian Rosso Ammonitico facies is characterized by hard-grounds and firm-



grounds. It consists of red clayey-marly sediments that become nodular and calcareous in Greece (Lefkas Island) and of gray-pink marls bearing calcarenites that evolve into nodular marly limestones in the Subbetic Zone. Such sediments represent the transition from a transgressive to a regressive phase (Braga *et al.*, 1981; Jimenez *et al.*, in press; Oloriz *et al.*, 1991; Pettinelli *et al.*, in press; Rey, 1993; Seyfried, 1981).

In the RAUM of M. Martani, a transgressive-regressive 3rd order cycle can be inferred on the basis of a change from argillaceous to calcareous sedimentation, thickening and coarsening upwards trend, microfaunistic assemblages variation and  $\delta^{13}\text{C}$  isotopic curve. A transgressive trend is recognisable in the *D. (O.) Tenuicostatum* Zone. The high stand phase can correspond to the lower RAUM member, within the *H. serpentinus* Zone. A shallowing trend (towards a low stand phase) within the *H. bifrons* Zone, is underlined by the characteristics of the microfacies, which are similar to the one occurring on the structural highs of Middle and Upper Umbro-Marchean Jurassic. During such an interval of time these microfacies cannot be found in the depressed areas because of the dissolution of calcareous organisms (Marcucci *et al.*, 1995). On the contrary during the Early Jurassic, phenomena of chemical corrosion do not occur even in the depressed area, indicating a minor differentiation in the sea-floor morphology than during the Middle and Late Jurassic.

The M. Martani area is one of the most suitable for recording eustatic sea-level variations in the Umbro-Marchean area. In fact the basin depth is probably of the same order as that of the sea-level fluctuation. Moreover, neither resedimentation events, nor strong condensation, have disturbed the sedimentary record and the vertical succession of the assemblages.

The M. Martani area might have corresponded to what the Spanish authors have interpreted as swells, where the deposition of sediments without detrital material input occurred. Bioturbants are considered mainly responsible for the calcareous nodularity of the RAUM, in a low sedimentation rate regime, at different energy rates (Monaco, 1994; Monaco *et al.*, 1994). Such a type of nodularity is probably characteristic of steady sedimentary areas that linked depressed and structurally elevated settings (Colacicchi *et al.*, 1988; Santantonio, 1993, 1994). The pebbly mudstone nodularity, typical of the Aalenian of the M. Martani and of several other areas of the Umbro-Marchean Basin, can be referred to an unstable sedimentation phase of the final RAUM deposition.

## CONCLUSIONS

In the Pozzale and Cima Panco sections the outcropping RAUM shows the most typical characteristics of this facies: lithologic tripartition in three members on the basis of carbonate content, scarcity of detrital events, dark red colour, intense nodularity, pervasive bioturbation and ammonite abundance in the *H. serpentinus* and *H. bifrons* Zones. The institutionalisation of this unit and the identification of the section type would be necessary in order to obtain better parameters of comparison between the variable facies of the Toarcian Umbro-Marchean areas, as well as a detailed paleoenvironmental reconstruction.

In the Early-Middle Toarcian the abundant recovery of ammonites has allowed for a good biostratigraphic resolution. On the contrary, the presence of wide covered portions, which interrupt the outcrop continuity, inhibits the definition of the zones in the Late Toarcian. The Pliensbachian/Toarcian boundary is well documented in the area. In fact the stratigraphic distance between the most recent Domerian ammonite *Emaciatoceras emaciatum* and the first Toarcian specimen, *Dactyloceras (E.) simplex*, is about 30 cm. This boundary falls within the last COR beds.

The age of the Marne di Monte Serrone formation is almost totally referable to Early Toarcian, *D. (O.) tenuicostatum* Zone, though the beginning of the *H. serpentinus* Zone falls in the upper part of MS (C member).

The age of the RAUM formation ranges from Early Toarcian (lower part of *H. serpentinus* Zone) to Early-Middle Aalenian. The A member in the M. Martani area, belongs totally to the Early Toarcian (*H. serpentinus* Zone), the B member to the Middle Toarcian (*H. bifrons* Zone) and the C member begins in the upper part of the Middle Toarcian at the boundary between *H. bifrons* and *P. erbaense* Zones, and extends up to Aalenian.

The boundary between Middle and Late Toarcian in the Apennines is still under debate since no widespread bioevents sufficiently significant in terms of faunistic renewal, has been yet recognised. The existence of the Upper Toarcian is, however, documented by the presence of *Dumortieria* and *P. aalensis*.

The Toarcian-Aalenian boundary can not be plotted in the Pozzale section, but the Aalenian is documented in the upper part of the section by the presence of *Erycites fallifax* and *Tmetoceras scissum*. This stratigraphic interval is characterised by pebbly mudstone with typical Aalenian ammonites, which is indicative of a nodular sedimentary event due to gravity slide.



The succession of benthic foraminifer assemblages has led to a paleoenvironmental interpretation also based on a comparison with the established eustatic curve.

The data set obtained reveals that Tethysian geological and paleobiologic events affected the depositional setting of the Umbro-Marchean Basin during the Toarcian, as in the following:

1 - Transgressive event, beginning at the base of the Toarcian.

2 - Cosmopolitanism of benthos and necton in the lower part of the *D. (O.) tenuicostatum* Zone.

3 - Occurrence of a scarcely oxygenated environment in the upper part of the *D. (O.) tenuicostatum* Zone of the Early Toarcian.

4 - Biological crisis linked to worsened ventilated conditions of the sea-bottom, causing the extinction of several taxa with Pliensbachian affinity.

5 - Faunistic turnover and adaptive radiation of benthic and nectonic organisms from the *H. serpentinus* Zone on.

6 -  $\delta^{13}\text{C}$  trend common to other Mediterranean areas, and parallel to the Toarcian sea-level fluctuations.

7 - Vertical succession of benthic foraminiferal assemblages covariant with the eustatic curve.

8 - Shallowing at the Middle-Late Toarcian transition, corresponding to nodular red marly-limestone facies in some Tethysian areas.

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