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SYNTHESIS OF CALCAREOUS NANNOFOSSIL EVENTS IN TETHYAN LOWER AND MIDDLE JURASSIC SUCCESSIONS

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Abstract. This paper is a synthesis of calcareous nannofossil biostratigraphy for the Lower and Middle Jurassic of the Mediterranean Province based on several sections from Northern and Central Italy. Nannofossil events were calibrated with ammonite biostratigraphy and, when necessary, ammonite-controlled sections in South East France were incorporated. Data derive from previously published biostratigraphies and unpublished data of the authors.

The large data-set allowed estimates of reliability and reproducibility of single events. As a result, in the Hettangian-Bathonian interval we propose 47 main events based on diagenesis-resistant and common taxa, 17 events based on rare but ubiquitous taxa and 12 potential events requiring further investigations due to taxonomic problems and sporadic occurrence. A biostratigraphic scheme, consisting of 11 zones and 15 subzones, is proposed for the Tethyan Lower and Middle Jurassic.

The proposed biostratigraphy is compared to recent schemes compiled for Portugal, Morocco, Switzerland and the Boreal Realm. Only 27 events are reproducible in various regions, but diachroneity of most events seems to derive from different ammonite biostratigraphies applied in different areas. A very high stratigraphic resolution is achieved in Italy/France for the Pliensbachian to Lower Bajocian interval. The Sinemurian and Bathonian are characterized by the lowest resolution, and very few sections with ammonite control and/or favourable lithologies are available for improvement of nannofossil biostratigraphy.

This study confirms the potential of calcareous nannofossil biostratigraphy for dating Lower and Middle Jurassic successions as well as for intra- and inter-regional correlations.

Riassunto. Presentiamo qui la sintesi della biostratigrafia a Nannofossili calcarei per il Giurassico Inferiore e Medio della Provincia Mediterranea basata su numerose sezioni nelle Alpi Meridionali e in Italia Centrale. Gli eventi a Nannofossili sono stati calibrati tramite la biozonazione ad Ammoniti e, quando necessario, sono stati incorporati dati provenienti da sezioni nel Sud Est della Francia datate con Ammoniti. I dati derivano da biostratigrafie precedentemente pubblicate e da dati inediti delle scriventi.

Il controllo degli eventi a Nannofossili su un largo numero di sezioni e di campioni ha permesso di stimare l'attendibilità e riproducibilità dei singoli bio-orizzonti. Di conseguenza nello schema proposto per l'intervallo Hettangiano-Batoniano sono stati distinti 47 eventi principali basati su taxa resistenti alla diagenesi e comuni, 17 eventi basati su taxa rari ma ubiquitari, e 12 eventi potenziali che richiedono ulteriori controlli a causa di problemi tassonomici e distribuzione sporadica. Viene inoltre proposto per l'area tetidea uno schema biostratigrafico consistente in 11 zone e 15 sottozone

La biostratigrafia proposta é stata confrontata con recenti sintesi biostratigrafiche compilate per Portogallo, Marocco, Svizzera e il Regno Boreale e sono stati individuati 27 eventi riproducibili nelle varie regioni. Il diacronismo di molti bio-orizzonti é, a nostro avviso, apparente e dovuto essenzialmente alle diverse zonazioni ad Ammoniti utilizzate in varie aree. In Italia/Francia, é possibile ottenere un' alta risoluzione stratigrafica per l'intervallo Pliensbachiano-Baiociano. Sinemuriano e Batoniano sono caratterizzati dalla risoluzione più bassa, ma sono disponibili solo poche sezioni con controllo di Ammoniti e litologie favorevoli per un miglioramento.

Questo studio conferma l'enorme potenzialità della biostratigrafia a Nannofossili calcarei per datare successioni del Giurassico Inferiore e Medio come pure per correlazioni intra- e inter-regionali.

Introduction.

In the past decade, much attention has been devoted to calcareous nannofossil biostratigraphy of the European Jurassic, for example Crux (1984; 1987), Young et al. (1986), Bown (1987a and b; 1996), Bown & Cooper (1989), Cobianchi (1990; 1992), Baldanza et al. (1990) Erba (1990), Lozar (1992), Reale et al. (1992), de Kaenel & Bergen (1993), Bucefalo Palliani & Mattioli (1994), de Kaenel et al. (1996). However, different biozonations are proposed for various regions (see Bown, 1996 and de Kaenel et al., 1996 for recent syntheses).

The chronostratigraphy of the Jurassic is based on ammonite biostratigraphy, but ammonite recovery is problematic in some lithotypes and in particular areas, due to differential preservation and provincialism. This results in partial correlations between different palaeogeographic realms and hampers the calibration of other

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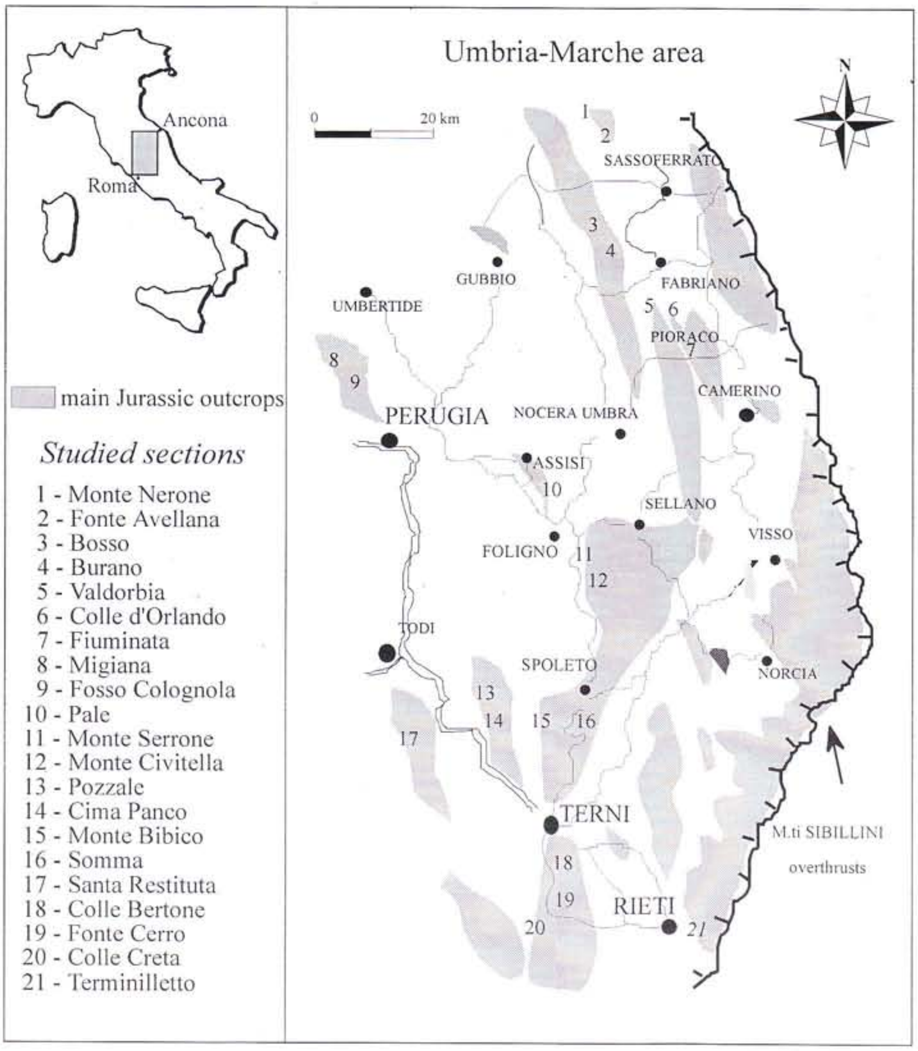


Fig. 1 - Map of the main Jurassic outcrops and location of the studied sections in the Umbria-Marche Basin.

fossil groups. Moreover, cephalopods are rarely abundant and continuously distributed and, therefore, ammonite biostratigraphic dating is often related to discrete horizons rather than continuous intervals.

The biostratigraphic potential of calcareous nannofossils is quite high in the Lower and Middle Jurassic, due to their rapid evolutionary rates, as well as common and continuous occurrence in sediments. Although diagenesis modifies calcareous nannofloras and strong dissolution and/or overgrowth can partially or totally destroy the most delicate taxa (Lozar, 1992, 1995; Mattioli, 1993, 1995, 1997), the common occurrence of diagenesis-resistant forms provides a good stratigraphic resolution.

Two palaeogeographic provinces were recognized in the European Jurassic, namely the Boreal and Tethyan Realms (Arkell, 1956) characterized by differences in faunas and floras. Ammonite assemblages vary both qualitatively and quantitatively (Arkell, 1956; Cariou, 1973). Other benthic and planktonic organisms, such as brachiopods (Vörös, 1977; 1979), foraminifers (Gordon, 1970), dinocysts (Norris, 1965; Dale, 1983; Riding, 1984) and nannoplankton (Bown, 1987b; 1992; Baldanza et al., 1995) show a clear differentiation in the two areas. The boundary between the Boreal Realm and the Tethys Ocean approximates the Alpine fold belt (Hallam, 1969) and is gradual as suggested by ammonite, brachiopod and nannofossil assemblages. In fact, within the Tethys using invertebrate faunas it is possible to distinguish the Submediterranean Province with "European" affinity, and the Mediterranean Province with "African" affinity.

Most Jurassic nannofossil biostratigraphic studies are based on Northern European sections, mainly England, Germany and Northern France (Boreal Realm), or on Portuguese areas (Submediterranean Province), whereas the Mediterranean Province has been studied in less detail. Recently, Bown (1996) and de Kaenel et al. (1996) summarized the nannofossil biozonations available for different areas, but with limited data available for the Mediterranean Province.

This paper is a synthesis of the nannofossil events recognized in several Lower and Middle Jurassic sections from Northern and Central Italy belonging to the Mediterranean Province. Most sections are ammonite-rich and allow a direct calibration of nannofossil biohorizons. Calcareous nannofossil distribution and events in some sections are previously published (Erba & Cobianchi, 1989; Cobianchi, 1990, 1992; Lozar, 1992; Reale et al., 1992; Mattioli, 1993, 1994, 1995; Bucefalo Palliani & Mattioli, 1994; Sciunnach & Erba, 1994; Bartolini et al., 1995; Nini et al., 1995; Stoico & Baldanza, 1995), others derive from unpublished data of the authors. Nannofossil data from the Belluno Basin (Erba, unpublished data), the Digne area (Erba, 1990) and the Provençal Plateau (Lozar, 1995) are taken into account for calibration of nannofossil versus ammonite events. The proposed biostratigraphic scheme is compared to previously published biozonations and analogies and discrepancies are discussed.

Comments on the relative abundance of single taxa with reference to the assemblage composition and/or to preservation problems are also given in order

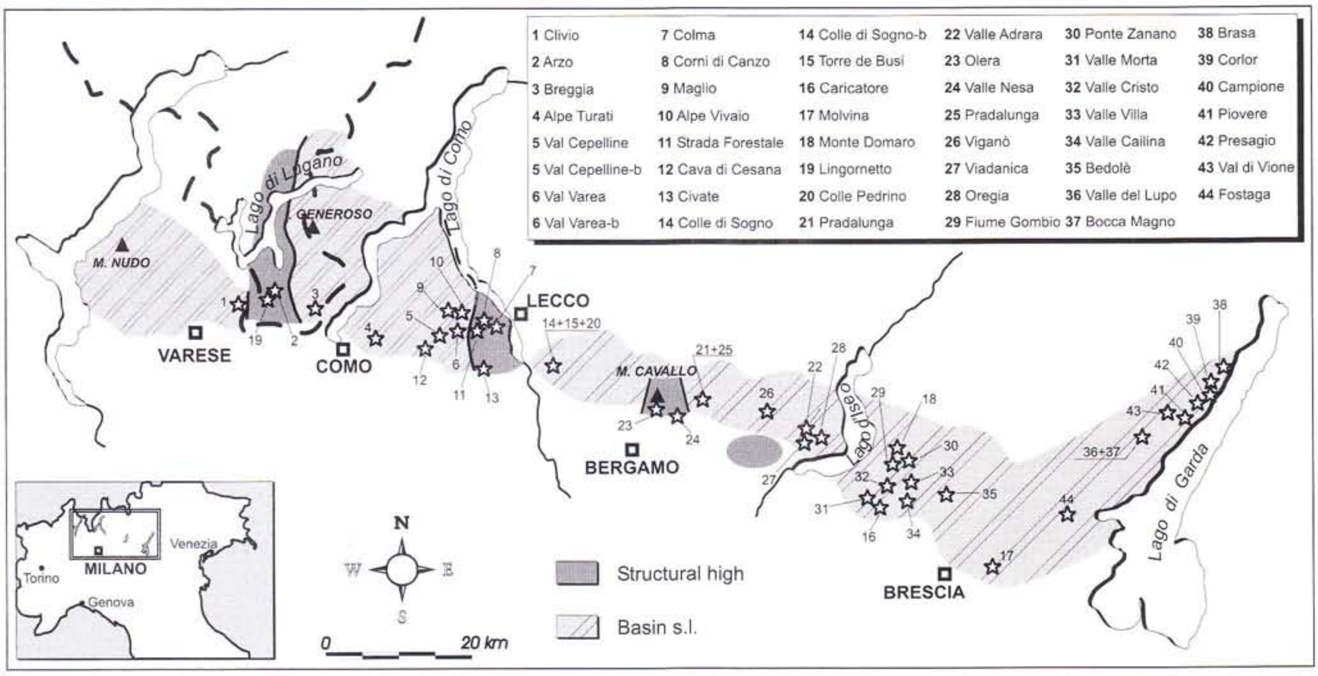


Fig. 2 - Map of the main Jurassic outcrops and location of the studied sections in the Lombardy Basin (modified after Gaetani & Erba, 1990).

to better characterize the Jurassic nannofossil assemblages of the Umbria-Marche and Lombardy Basins.

Geological framework.

Within the Mediterranean Province, the Umbria-Marche (Fig. 1) and Lombardy (Fig. 2) Basins were chosen as reference areas because of the continuity, good exposure and good ammonite control in the Lower and Middle Jurassic successions. Moreover, they represent two key areas for understanding the evolution of the Western Tethys during the Jurassic. The studied sections are located in different settings and constitute ideal transects from basins to platforms. All the information concerning these sections, including their age, geological setting, thickness and number of analyzed samples are summarized in Tables 1 and 2.

Umbria-Marche Basin.

The Umbria-Marche Basin, located between the Sillaro Valley to the North and the Latium-Abruzzi carbonate platform to the South, constitutes the southernmost portion of the Northern Apennines (Fig. 1). The basin originated in the Early Jurassic, when extensional tectonics, related to the opening of the Western Tethys, produced the break up and drowning of the Calcare Massiccio carbonate platform (Farinacci et al., 1981; Colacicchi et al., 1989; Cresta et al., 1989). The rifting and subsequent subsidence phase led to a heterogeneous physiography of the basin with structural highs and troughs connected by variously inclined slopes. This complex paleobathymetry is reflected by condensed and incomplete sequences on the highs, and thick, continuous sequences, with several resedimented levels, in the depressions (Fig. 3). The slopes are characterized by continuous sequences, with intermediate thicknesses and minor resedimented levels.

Subsidence and sea level reached their maximum during the Toarcian, when argillaceous sediments were deposited throughout the basin. The drifting phase occurred in the Middle Jurassic, when siliceous sedimentation became predominant, related to a major increase in abundance of radiolarians. A great lateral facies variability persisted during the Late Jurassic, when eventually the depositional pattern became predominantly calcareous and more uniform as marked by the Maiolica limestones.

Lombardy Basin.

During the Jurassic the Lombardy Basin was part of the African passive continental margin and its structural and sedimentary evolution was directly controlled by extensional tectonics. The Liassic rifting phase caused the break up of a Triassic carbonate platform into structural highs and troughs. These were bounded by synsedimentary faults controlling facies distribution during the Jurassic. As in the Umbria-Marche Basin, sedimentation was highly differentiated: very condensed sequences were deposited on structural highs, while troughs are characterized by thick and continuous sections, with frequent turbidites of peri-platform carbonates.

During the Liassic, a deepening trend began, probably related to the beginning of oceanic spreading. Sedi-

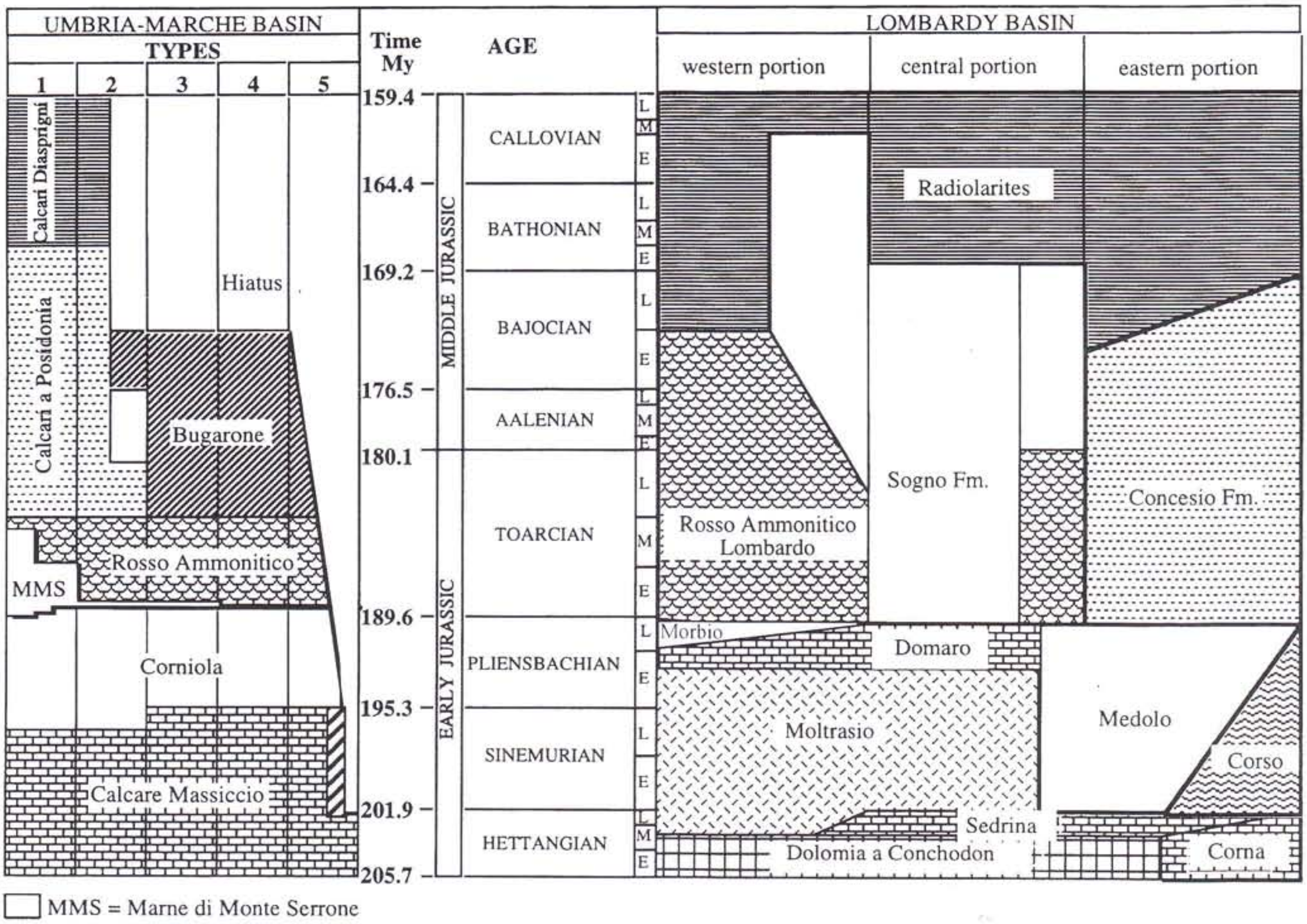


Fig. 3 - Litho- and chronostratigraphy of the studied units in the Umbria-Marche and Lombardy Basins. Different types of sections in the Umbria Marche Basin were distinguished according to Colacicchi et al. (1989). Time scale after Gradstein et al. (1994).

mentation rates decreased and condensed sequences (Rosso Ammonitico facies) were deposited in the western part of the basin. In contrast, in the eastern part, sedimentation rate increased due to calcareous turbidites (Concesio Fm.). The generation of turbidites was probably related to a renewed tectonic activity along the Garda fault escarpement, which separated the Lombardy Basin from the Trento Plateau (Gaetani, 1975). The deposition of thin turbidites continued throughout the Middle Jurassic (Sogno and Concesio Fms) (Gaetani, 1975; Winterer & Bosellini, 1981; Castellarin & Vai, 1982; Bersezio et al., 1996; Picotti & Cobianchi, 1996).

In the Middle Jurassic biogenic siliceous sedimentation replaced carbonates, and only in the latest Jurassic did calcareous sedimentation resume, as documented by the Maiolica limestones.

Materials and methods.

The stratigraphic framework of the studied lithologic units of the Umbria-Marche and Lombardy Basins is given in Fig. 3. The studied lithologies, in the Umbria-Marche Basin, comprise (Fig. 4):

- nutty to white micritic limestones, with some detritic interbeds and chert in layers or nodules (Corniola Unit), Sinemurian to Domerian in age;
- marlstones and argillaceous marlstones, yellow to dark in colour, with calcarenites in the more expanded sections, usually including black shale levels (Marne di Monte Serrone Fm.), Early Toarcian in age;
- nodular marlstones and limestones, red to greenish, with clay content decreasing upward (Rosso Ammonitico Unit), Middle Toarcian to Late Toarcian in age;
- whitish to red limestones, containing a variable amount of bivalve shells and occasionally chert (Calcari e Marne a Posidonia Unit), Late Toarcian to Early Bajocian in age;
- whitish limestones with abundant chert in layers and ribbons and, in the more expanded sections, turbiditic beds (Calçari Diasprigni Unit), Bajocian to Kimmeridgian in age.

In the Lombardy Basin calcareous nannofossils were investigated from the following lithotypes (Fig. 4):

- grey to dark grey marlstones and marly limestones with chert in layers and nodules (Moltrasio Limestone

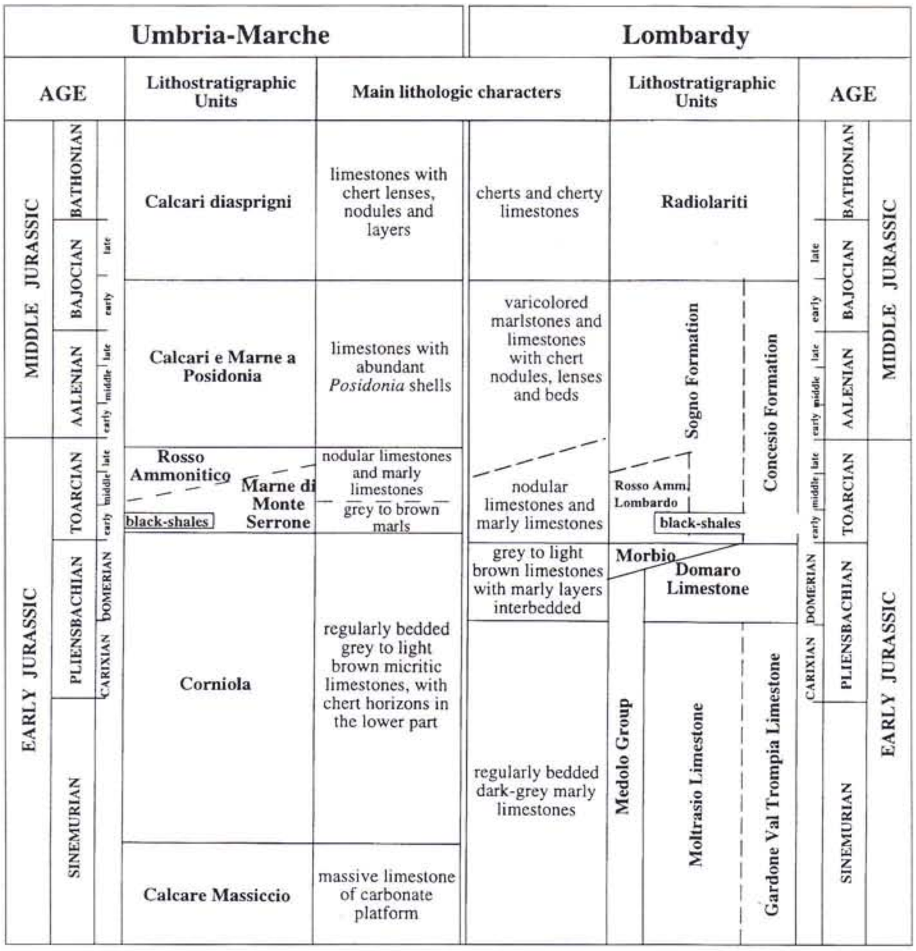


Fig. 4 - Age and main lithologic characters of the units studied in the Umbria-Marche and Lombardy Basins.

and Gardone Val Trompia Limestone), Sinemurian to Carixian in age;

- grey to light brown limestones and marly interbeds (Domaro Limestone), Domerian in age;
- dark grey and green marly claystones and black shales, Early Toarcian in age;
- reddish nodular marlstones and limestones (Rosso Ammonitico), Toarcian to Early Bajocian in age;
- varicolored marlstones and limestones with some chert in lenses, beds and nodules (Sogno and Concesio Formations), Toarcian to Bajocian in age;
- green and red chert with few marly interbeds (Radiolariti), Bathonian in age.

Samples were taken at regular intervals, from micritic limestones and/or from marlstones, trying to avoid the detritic levels. Depending on the accumulation rate, sample spacing varies from a few decimeters to one meter. Only a few sections, on which quantitative analyses were performed (with an asterisk in Table 1), were sampled every 10-20 cm.

Samples were prepared by simple mechanical breakage of a small amount of rock, dilution with distilled water, spreading onto a cover glass and drying in a stove. Cover glasses were attached to slides with Canada Balsam or Norland Optical Adhesive. This simple preparation technique retains the original assemblage and petrographic composition. Observations were performed using a light polarizing microscope, at 1000X to 1200X magnification. The scanning electron microscope was used only for selected samples to document preservation and nannofacies.

Previous works on Jurassic nannofossil biostratigraphy.

After the pioneristic papers on Jurassic nannofossil biostratigraphy (Stradner,1963; Prins, 1969; Amézieux, 1972; Barnard & Hay, 1974), several investigations have been carried out in order to provide biozonations applicable in various areas. Recent syntheses of Jurassic nannofossil schemes (Perch-Nielsen, 1985; Bown, 1987b, 1996; Bown et al., 1988; de Kaenel et al., 1996; Bown & Cooper, 1998) highlight the increasing importance of nannofossil biostratigraphy.

Investigation of calcareous nannofloras in Italian sections was initially sporadic, but in the past decade nannofossil biostratigraphy has been carried out on a large number of successions and samples, especially in Northern and Central Italy, resulting in the proposal of a few schemes (Bralower et al., 1989; Cobianchi, 1990, 1992; Reale et al., 1992; Baldanza & Mattioli, 1992b). More recently, detailed studies of sections in the Umbria-Marche Basin (Bartolini et al., 1995; Mattioli, 1995; Nini et al., 1995; Stoico & Baldanza, 1995) and in the Southern Alps (Erba, unpublished data; Sciunnach & Erba, 1994; Bersezio et al., 1996; Picotti & Cobianchi, 1996) contributed to the establishment of a biostratigraphic scheme for the Lower and Middle Jurassic of the Mediterranean Province.

Proposed biostratigraphy.

Nannofossil events.

The synthesis of nannofossil events recognized in this work is presented in Figure 5, where first occurrences (FOs) and last occurrences (LOs) are calibrated

	SECTIONS	LOCATION	SETTING	Type	Thick.	Sampl	AGE	Reference	Ammonites	Radiol.	Dinoc.	Magnet.
	A (EM)	M. Cetona-S Tuscany, central Italy	basin	.	20	20	Toarcian	Mattioli, unpublished data	no	no	yes	no
	Belvedere (EM)	M. Cetona-S Tuscany, central Italy	basin	.	80	42	Lotharingian-Toarcian	Mattioli, unpublished data	partim	no	yes	no
1	Infernaccio (AB-EM)	M.Nerone-Marche, central Italy	structural high	4	15	19+26	Carixian-Early Bajocian	Baldanza et al., 1990	yes	no	no	no
1	Presale (AB-EM)	M.Nerone-Marche, central Italy	slope	4	25	27+30	Late Domerian-Early Bajocian	Baldanza et al., 1990	yes	no	no	no
1	Ranchi (AB-EM)	M.Nerone-Marche, central Italy	slope	4	9	9+25	Late Aalenian-Early Bajocian	Baldanza et al., 1990	yes	no	no	no
2	Fonte Avellana (EM)	M.Nerone-Marche, central Italy	slope-basin	5.1	55	56	Pliensbachian-Bathonian	Reale et al., 1992	partim	no	no	yes
3	Bosso (EM)	Cagli-Marche, central Italy	basin	1	250	76	Sinemurian-Pliensbachian	Faraoni et al., 1996	yes	no	no	no
4	Burano 1 (EM)	M.Burano-NE Umbria, central Italy	basin	2	13	52	Carixian-Domerian	Mattioli & Morettini, in progress	partim	no	no	no
4	Burano 2 (EM)	M.Burano-NE Umbria, central Italy	basin	2	27	60	Domerian-Toarcian	Mattioli & Morettini, in progress	partim	no	no	no
5	Valdorbia (VR-SM)	Sentino river, NE Umbria, central Italy	basin	1	150	118	Domerian-Early Bajocian	Reale et al., 1992	yes	yes	no	yes
6	Colle d'Orlando* (EM)	M.Cucco-NE Umbria, central Italy	basin	1	23	87	Early Toarcian	Bucefalo Palliani & Mattioli, 1994	yes	no	yes	yes
6	Colle d'Orlando (AB-EM)	M.Cucco-NE Umbria, central Italy	basin	1	123	204	Pliensbachian-Aalenian	Parisi et al., 1998	yes	no	yes	yes
7	Fonte Cocce (EM)	M. Vermenone-Mid-E Umbria, central Italy	basin	2	41	43	Late Domerian-Middle Toarcian	Morettini, 1999	partim	no	no	no
7	Colle Corno (EM)	M. Vermenone-Mid-E Umbria, central Italy	basin	1	49	48	Late Domerian-Late Toarcian	Morettini, 1999	no	no	no	no
7	Fiuminata* (EM)	M. Vermenone-Mid-E Umbria, central Italy	basin	1	30	136	Mid Toarcian-Aalenian	Mattioli, 1994	partim	no	no	yes
8	Migiana (LB)	Massicci Perugini, NW Umbria, central Italy	high	4	133	45	Sinemurian-Domerian	Bombardiere, 1993	no	no	no	no
9	Fosso Colognola (LB)	Massicci Perugini, NW Umbria, central Italy	high	4	60	30	Carixian-Domerian	Bombardiere, 1993	no	no	no	no
10	Pale area (AB-EM)	M. Pale-Central Umbria, central Italy	high	5	30	39	Sinemurian-Early Bajocian	Reale et al., 1992	partim	yes	no	no
11	M. Serrone (AB-EM)	M.Serrone-Central Umbria, central Italy	basin	1	64	36	Late Domerian-Aalenian	Reale et al., 1992	yes	no	yes	no
11	M. Serrone* (EM)	M.Serrone-Central Umbria, central Italy	basin	1	82	229	Late Domerian-Middle Toarcian	Bucefalo Palliani & Mattioli, 1998	yes	no	yes	no
12	M. Civitella (AB-EM)	M.Civitella-Central Umbria, central Italy	basin	2	21	35	Late Domerian-Late Toarcian	Reale et al., 1992	yes	no	no	no
13	Pozzale (AB-EM)	M.Martani-S Umbria, central Italy	basin	2	40	68	Late Domerian-Middle Aalenian	Mattioli, 1995	yes	no	no	no
13	Pozzale * (EM)	M.Martani-S Umbria, central Italy	basin	2	12	84	Late Domerian-Early Toarcian	Mattioli, 1995	yes	no	yes	no
14	Cima Panco (AB-EM)	M.Martani-S Umbria, central Italy	basin	2	20	61	Late Domerian-Toarcian	Reale et al., 1992	yes	no	no	no
15	Monte Bibico (AB)	M.Bibico-S Umbria, central Italy	basin	2	63	52	Late Domerian-Late Toarcian	Nini et al., 1995	no	no	no	no
15	Monte Bibico A (AB)	M.Bibico-S Umbria, central Italy	basin	2	22	42	Late Domerian-Early Toarcian	Nini et al., 1995	no	no	no	no
15	Monte Bibico B (AB)	M.Bibico-S Umbria, central Italy	basin	2	16	17	Toarcian	Nini et al., 1995	no	no	no	no
16	Somma* (EM)	M. della Somma-S Umbria, central Italy	slope	3	5	40	Early Toarcian	Bucefalo Palliani & Mattioli, 1998	no	no	yes	no
16	Torrecola (EM)	M. della Somma-S Umbria, central Italy	basin	1	10	35	Late Domerian-Early Toarcian	Benedetti et al., 1995	no	no	no	no
18	Colle Bertone (EM)	M.la Pelosa-S Umbria, central Italy	basin	1	69	70	Late Toarcian-Early Bajocian(?)	Bartolini et al., 1995	partim	yes	no	yes
19	Fonte Cerro* (EM)	M.Sabini-N Latium, central Italy	basin	1	10	87	Early Toarcian	Bucefalo Palliani & Mattioli, 1994	yes	no	yes	no
19	Fonte Cerro (AB-MS)	M.Sabini-N Latium, central Italy	basin	1	71	41	Late Domerian-Early Bajocian	Stoico & Baldanza, 1995	no	no	no	no
19	Colle Creta (AB-MS)	M.Sabini-N Latium, central Italy	basin	1	32	72	Toarcian-Aalenian	Stoico & Baldanza, 1995	no	no	no	no
21	Terminilletto (EM)	M.Terminillo-N Latium, central Italy	basin	1	70	50	Early Aalenian-Kimmeridgian	Bartolini et al., 1995	partim	yes	no	yes
	Sella dei due Corni (EM)	Gran Sasso-N Abruzzo, central Italy	basin	1	111	65	Domerian-Aalenian	Colacicchi & Bigozzi, 1995	partim	no	no	no
	Filettino (EM)	M.Simbruini-Latium, central Italy	intraplatform basin	1	53	47	Late Domerian-Early Toarcian	Bartolini et al., 1992	partim	no	no	no
	Marettimo (EM)	Sicily, southern Italy	basin	.	20	12	Sinemurian-Pliensbachian	Mattioli, unpublished data	partim	no	yes	no
	Peniche (AB-EM)	W Portugal	basin	.	15	2	Early-Mid Carixian	Baldanza & Mattioli, 1992a	no	no	no	no
	Rabaçal (AB-EM)	W Portugal	basin	.	52	11	Late Domerian-Late Toarcian	Baldanza & Mattioli, 1992a	no	no	yes	no
	Cap Mondego (AB-EM)	W Portugal	basin	.	80	4	Early Bajocian-Callovian	Baldanza & Mattioli, 1992a	no	no	no	no
	Kaballos (AB-EM)	W Greece	basin	.	51	34	Late Domerian-Late Toarcian	Pettinelli et al., 1997	no	no	no	no
	Kalamitsi (AB-EM)	W Greece	basin	.	10	11	Early Toarcian	Pettinelli et al., 1997	no	no	yes	no
	Kalvaria (AB-EM)	Central Hungary	basin	.	40	6	Sinemurian-Toarcian	Baldanza & Mattioli, 1992a	no	no	yes	no
	Kozoskut Ravine (AB-EM)	Central Hungary	basin	.	2.5	6	Pliensbachian-Bajocian	Baldanza & Mattioli, 1992a	partim	no	no	no
	Reka (AB-EM)	Central Hungary	basin	.	15	5	Domerian-Early Toarcian	Baldanza & Mattioli, 1992a	yes	no	yes	no
	Csengohegy (AB-EM)	Central Hungary	basin	.	30	5	Early Bajocian-Callovian	Baldanza & Mattioli, 1992a	partim	no	no	no
	Lokut (AB-EM)	Central Hungary	basin	.	100	14	Carixian-Kimmeridgian	Baldanza & Mattioli, 1992a	partim	no	no	no
	Urkut (EM)	Central Hungary	basin	.	50	25	Toarcian	Vëto, et al. in prep.	no	no	yes	no
	Dotternhausen (EM)	Swabia, SW Germany	epicontinental basin	.	13	8	Early Toarcian	Jäger et al., 1995	yes	no	yes	no
	Opalinum Clay (EM)	Swabia, SW Germany	epicontinental basin	.	20	4	Aalenian	Jäger et al., 1995	yes	no	yes	no
	Wittnau* (EM)	SW Germany	epicontinental basin	.	110	110	Toarcian-Aalenian	Ohmert & Rolf, 1994	yes	no	yes	yes
	Wurmlingen* (EM)	SW Germany	epicontinental basin	.	38	87	Oxfordian	Pittet & Strasser, 1998	yes	no	yes	no
	Balingen* (EM)	SW Germany	epicontinental basin	.	27	105	Oxfordian	Pittet & Strasser, 1998	yes	no	yes	no

Tab. 1 - Summary of location, setting, age, thickness, number of samples, and type of studies carried out in the examined sections in Central Italy. Different types of sections have been distinguished according to Colacicchi et al. (1989). Most of the sections have been already object of publications, the reference is given therein. The different sections were studied by different researchers: AB = A. Baldanza; LB = L. Benedetti; EM = E. Mattioli; SM = S. Monechi; VR = V. Reale.

Tab. 2 - Summary of location, setting, age, thickness and number of samples of the sections studied in Northern Italy and France. For some sections ammonite and calpionellid biostratigraphy is available. The sections in the Lombardy Basin were studied by M. Cobianchi (MC) and E. Erba (EE). In France, E. Erba (EE) and F. Lozar (FL) studied sections in the Digne area and in the Delphinese Basin, respectively.

	SECTIONS	LOCATION	SETTING	Thick.	Samples	AGE	Reference	Ammonites	Calpion.	Magnetos.
1	Clivio (MC)	Lombardy Basin	basin	25	27	Late Domerian-Early Toarcian	Cobianchi, 1992	yes	no	no
2	Arzo (MC)	Lombardy Basin	slope	3	17	Late Carixian-Early Domerian	Cobianchi, 1992	yes	no	no
3	Breggia (MC)	Lombardy Basin	basin	54	57(20)	Late Carixian-Early Bajocian	Cobianchi, 1992	yes	no	yes
4	Alpe Turati (MC-EE)	Lombardy Basin	basin	44	58(20)	Carixian-Late Tithonian	Gaetani & Erba, 1990	yes	no	yes
5	Val Cepelline (MC)	Lombardy Basin	slope	31,7	50(20)	Late Carixian-Late Tithonian	Cobianchi, 1992	yes	yes	no
5	Val Cepelline (EE)	Lombardy Basin	slope	25,3	29	Toarcian-Tithonian	Erba, unpublished data	no	yes	no
6	Val Varea (MC)	Lombardy Basin	slope	31	52	Domerian-Late Tithonian	Cobianchi, 1992	yes	no	no
6	Val Varea (EE)	Lombardy Basin	slope	17	36	Domerian-Aalenian	Erba, unpublished data	no	no	no
7	Colma (EE)	Lombardy Basin	structural high	16,7	46	Late Domerian-Late Tithonian	Gaetani & Erba, 1990	no	yes	no
8	Corni di Canzo (EE)	Lombardy Basin	structural high	10,6	50	Late Domerian-Late Tithonian	Gaetani & Erba, 1990	no	yes	no
9	Maglio (EE)	Lombardy Basin	slope	17	19	Toarcian-Berriasian	Gaetani & Erba, 1990	no	no	no
10	Alpe Vivaio (EE)	Lombardy Basin	slope	16	23	Domerian-Early Bajocian	Erba, unpublished data	no	no	no
11	Strada Forestale (EE)	Lombardy Basin	basin	10	20	Domerian-Toarcian	Erba, unpublished data	no	no	no
12	Cava di Cesana (EE)	Lombardy Basin	basin	14	30	Domerian-Tithonian	Erba, unpublished data	no	no	no
13	Civate (EE)	Lombardy Basin	slope	27,5	40	Domerian-Tithonian	Erba, unpublished data	no	no	no
14	Colle di Sogno (EE)	Lombardy Basin	basin	160	186	Domerian-Bajocian	Gaetani & Erba, 1990	partim	no	yes
14	Colle di Sogno (FL)	Lombardy Basin	basin	390	196	Sinemurian-Pliensbachian	Lozar, 1995	no	no	no
15	Torre de Busi	Lombardy Basin	basin	90	9	Early Bajocian	Baumgartner et al., 1995	no	no	no
16	Caricatore (MC)	Lombardy Basin	basin	39,7	34(20)	Late Domerian-Early Toarcian	Cobianchi, 1992	yes	no	no
17	Molvina (MC)	Lombardy Basin	basin	15	21	Late Domerian-Late Toarcian	Cobianchi, 1992	yes	no	no
18	Monte Domaro	Lombardy Basin	basin	330	80	Late Sinemurian-Early Toarcian	Cobianchi, 1992	yes	no	no
19	Lingornetto (EE)	Lombardy Basin	structural high	10	53	Bajocian-Late Tithonian	Sciunnach & Erba, 1996	no	no	yes
20	Colle Pedrino (FL)	Lombardy Basin	basin	200	130	Sinemurian-Pliensbachian	Lozar, 1995	no	no	no
21	Pradalunga (FL)	Lombardy Basin	basin	256	214	Hettangian-Pliensbachian	Lozar, 1995	no	no	no
22	Valle Adrara (FL)	Lombardy Basin	basin	130	178	Hettangian-Pliensbachian	Lozar, 1995	yes	no	no
23	Olera (FL)	Lombardy Basin	high	70		Domerian-Bathonian	Bersezio et al., 1996	no	no	no
24	Nesa Valley (FL)	Lombardy Basin	high	170		Domerian-Bathonian	Bersezio et al., 1996	no	no	no
25	Pradalunga (FL)	Lombardy Basin	basin margin	170		Domerian-Toarcian (?)	Bersezio et al., 1996	no	no	no
26	Viganò (FL)	Lombardy Basin	basin	300		Domerian-Bathonian	Bersezio et al., 1996	no	no	no
27	Viadanica (FL)	Lombardy Basin	basin	500		Domerian-Bathonian	Bersezio et al., 1996	no	no	no
28	Oregia (FL)	Lombardy Basin	basin	400		Domerian-Bathonian	Bersezio et al., 1996	no	no	no
29	Gombio River (FL)	Lombardy Basin	basin	100	200	Domerian-Early Toarcian	Bersezio et al., 1996	no	no	no
30	Ponte Zanano (FL)	Lombardy Basin	basin	177		Bajocian (?)-Bathonian	Bersezio et al., 1996	no	no	no
31	Morta Valley (FL)	Lombardy Basin	basin	120		Domerian-Aalenian	Bersezio et al., 1996	no	no	no
32	Cristo Valley (FL)	Lombardy Basin	basin	90		Domerian-Aalenian	Bersezio et al., 1996	no	no	no
33	Villa Valley (FL)	Lombardy Basin	basin	400		Domerian-Bathonian	Bersezio et al., 1996	no	no	no
34	Cailina Valley (FL)	Lombardy Basin	basin	116		Domerian-Early Toarcian (?)	Bersezio et al., 1996	no	no	no
35	Bedolé (FL)	Lombardy Basin	basin margin	505		Domerian-Bathonian	Bersezio et al., 1996	no	no	no
36	Valle del Lupo (MC)	Lombardy Basin	slope	77	11	Sinemurian-Domerian	Picotti & Cobianchi, 1996	no	no	no
37	Bocca Magno (MC)	Lombardy Basin	basin	72	13	Sinemurian-Carixian	Picotti & Cobianchi, 1996	partim	no	no
38	Brasa (MC)	Lombardy Basin	high	118	31	Late Sinemurian-Bathonian	Picotti & Cobianchi, 1996	no	no	no
39	Corlor (MC)	Lombardy Basin	basin	61	24	Late Aalenian-Late Aptian	Picotti & Cobianchi, 1996	no	no	no
40	Campione (MC)	Lombardy Basin	basin	300	18	Sinemurian-Valanginian	Picotti & Cobianchi, 1996	no	no	no
41	Piovere (MC)	Lombardy Basin	basin	142	19	Sinemurian-Early Domerian	Picotti & Cobianchi, 1996	no	no	no
42	Pregasio (MC)	Lombardy Basin	basin	53	11	Carixian-Valanginian	Picotti & Cobianchi, 1996	no	no	no
43	Val di Vione (MC)	Lombardy Basin	high	181	11	Sinemurian-Tithonian	Picotti & Cobianchi, 1996	no	no	no
44	Fostaga (MC)	Lombardy Basin	high?	155	25	Carixian-Bathonian	Picotti & Cobianchi, 1996	no	no	no
45	Carpeneda (MC)	Lombardy Basin	high?	85	41	Carixian-Aalenian	Picotti & Cobianchi, 1996	no	no.	no
46	M. Covolo (MC)	Lombardy Basin	high	175	27	Sinemurian-Bathonian	Picotti & Cobianchi, 1996	partim	no	no
47	M. Corona	Lombardy Basin	slope	160	4	Toarcian-Oxfordian	Picotti & Cobianchi, 1996	no	no	no
	Vajont (EE)	Belluno Trough	basin	11	47	Domerian-Early Toarcian	Erba, unpublished data	no	no	no
	Rizapol (EE)	Belluno Trough	basin	10	45	Early Toarcian	Erba, unpublished data	no	no	no
	Termine di Cadore (EE	Belluno Trough	basin	18	40	Domerian-Early Toarcian	Erba, unpublished data	no	no	no
	Longarone (EE)	Belluno Trough	basin	13	75	Early Toarcian	Claps et al., 1995	no	no	no
	Digne (EE)	France	basin	350	114	Late Aalenian-Bathonian	Erba, 1990	yes	no	no
	Gammal (FL)	Dauphinois Basin	slope/basin	15	15	Hettangian (Planorbis)	Lozar, 1995	yes	no	no
	La Rosière (FL)	Dauphinois Basin	basin	160	159	Hettangian-Sinemurian (Lias.-Turn.)	Lozar, 1995	yes	no	no
	Serre des Champs (FL)	Dauphinois Basin	slope/basin	23	21	Hettangian-Pliensbachian (Ang.-Sem.)	Lozar, 1995	yes	no	no
	Le Bosc (FL)	Dauphinois Basin	slope/basin	100	14	Hettangian-Pliensbachian	Lozar, 1995	yes	no	no
	Le Tardieux (FL)	Dauphinois Basin	slope/basin	12	10	Hettangian (Bucklandi)	Lozar, 1995	yes	no	no
	Ravin de Chou (FL)	Dauphinois Basin	slope/basin	56	56	Hettangian (Liasicus-Angulata)	Lozar, 1995	yes	no	no
	La Barrolière (FL)	Lyonese Basin	shelf	16	10	Hettangian-Sinemurian (Ang.-Semic.)	Lozar, 1995	yes	no	no

with ammonite biostratigraphy. The study of several sections from different basins allowed the testing of reproducibility and reliability of every biohorizon. We propose here a sequence of 47 main events (36 FOs and 11 LOs) for the Hettangian-Bathonian interval. These events are based on diagenesis-resistant taxa that are frequent to common in the studied sections and, thus, are easily recognized even in diagenetically altered material.

A further 17 events (11 FOs and 6 LOs) were identified, but are plotted in a separate column because they are based on taxa displaying very low abundance. However, despite their rarity, these biohorizons were recognized in all the studied sections.

Twelve additional events (4 FOs and 8 LOs) require further control before final incorporation in the proposed biostratigraphy. In fact, taxonomic problems must be cleared and some taxa are characterized by rare and sporadic occurrence in the studied sections.

Every event is here discussed in stratigraphic order, from bottom to top. We discuss the taxonomy when needed and compare our findings to stratigraphic ranges reported in the literature for different palaeogeographic realms. All taxa discussed are listed in Appendix 1.

FO *Crepidolithus timorensis* (Kristan-Tollmann, 1988) Bown in Bown & Cooper, 1998

Small *Crepidolithus* forms have been noticed in the lowermost Jurassic (Hettangian-Sinemurian) in the Tethyan Realm by Cobianchi (1992) and Lozar (1992, 1995). Recently Bown & Cooper (1998) gave a ?Sinemurian distribution for *C. timorensis*, probably the same as the small *Crepidolithus* of Cobianchi (1992).

FO *Crepidolithus crassus* (Deflandre, 1954) Noël, 1965

Crepidolithus crassus is a very solution resistant taxon, although often subject to overgrowth. Lozar (1992, 1995) found *C. crassus* in the Hettangian *liasicus* Zone of the Delphinese basin, which is a very old record with respect to other literature data (Late Sinemurian; Bown & Cooper, 1998). It must be noted that in Central Italy its presence was not observed in sediments older than the Sinemurian/Pliensbachian boundary (Mattioli, personal observation) and in the Lombardy Basin Cobianchi (1992) reported this taxon from the uppermost Sinemurian upward. *C. crassus* is recorded continuously from the Pliensbachian upward but becomes quite abundant only in the Toarcian.

FO *Tubirhabdus patulus* Prins, 1969 ex Rood et al., 1973

Lozar (1992) calibrated this event to the Hettangian *angulata* Zone in the Delphinese area. Although reported throughout the Lower Jurassic, in the studied sections this taxon is rare and discontinuous. Therefore, the reliability of this event is limited.

FO *Parhabdolithus liasicus* Deflandre, 1954

Bown (1987b) considered *P. liasicus* to be represented by two subspecies: *P. liasicus distinctus* and *P. liasicus liasicus*. In the present work the two subspecies are not distinguished due to difficulties in observation of the central process, sometimes as a consequence of diagenetic modifications. Cobianchi (1992) observed *P. liasicus distinctus* from the Sinemurian upward. This taxon is very rare and discontinuous in the studied areas throughout the Lower Jurassic.

FO *Mitrolithus elegans* Deflandre, 1954

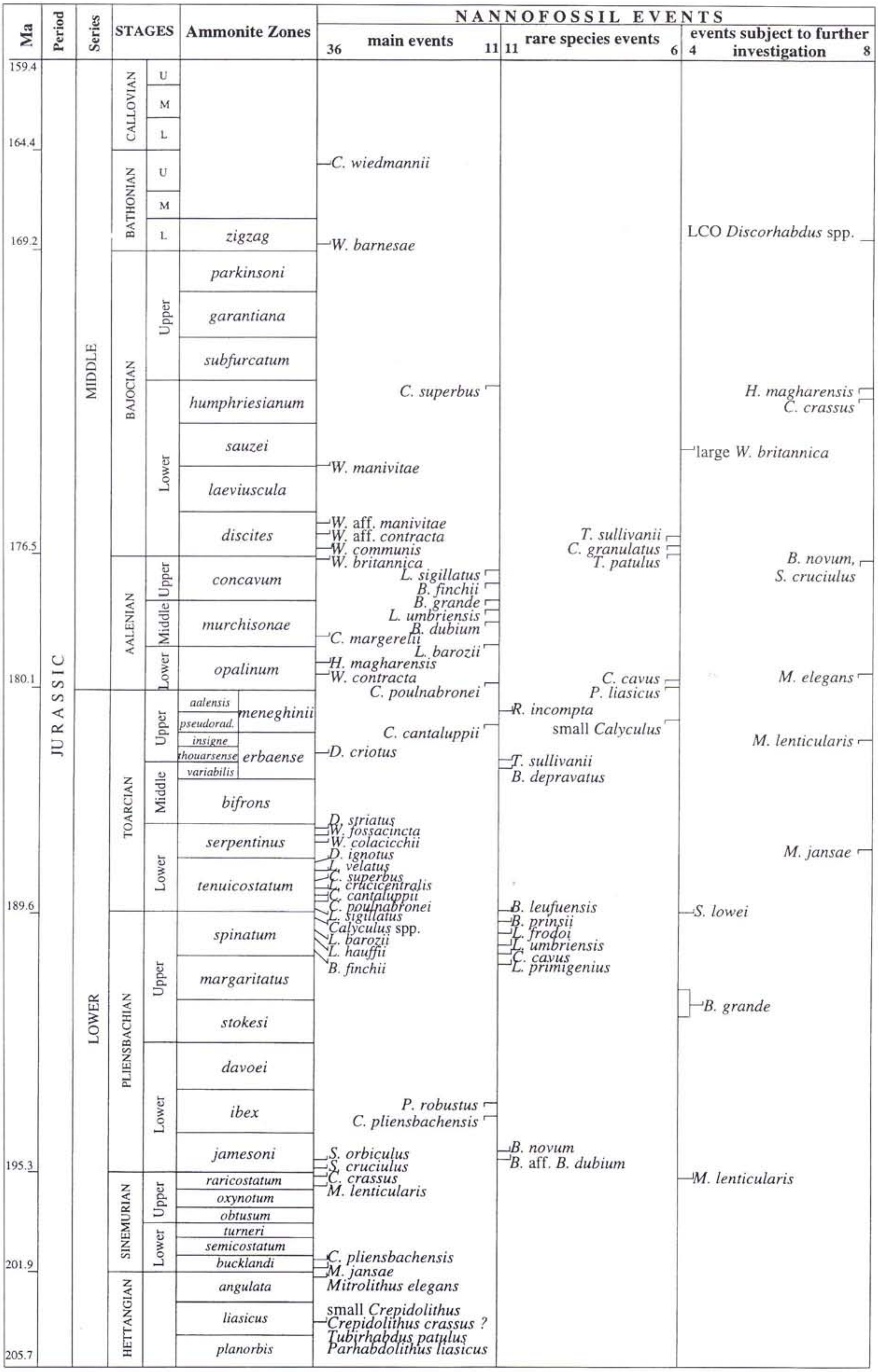
Lozar (1992, 1995) found this event in the Lower Sinemurian of Southern France. Cobianchi (1992) reported the FO of *M. lenticularis* in the Upper Sinemurian of the Lombardy Basin but the photographed specimen (Fig. 20, n) seems referable to *M. elegans*, because of the presence of a spine extending from the basket-shaped distal shield. Also Bown & Cooper (1998) recorded this species as rare and sporadic from the basal Sinemurian. In the studied sections, *M. elegans* is very rare and discontinuous from the base of the Pliensbachian to the base of the Middle Jurassic. The appearance of this protolith coccolith with a tall distal shield corresponds to the entry of the genus *Mitrolithus*. Bown (1987b) interpreted the occurrence of *M. elegans* in sediments younger than Early Toarcian as due to reworking.

FO *Mitrolithus jansae* (Wiegand, 1984) Bown & Young in Young et al., 1986

In the Bosso section (Umbria-Marche Basin) *M. jansae* is present from the *raricostatum* Zone of Late Sinemurian age (Mattioli, personal observation) but older sediments were not studied.

This species is easily recognized, is not solution susceptible and is charaterized by continuous and common occurrence in Pliensbachian through Lower Toarcian, where it is one of the principal components of the assemblage. Some discrepancies exist in the literature

Fig. 5 - Synthesis of the calcareous nannofossil events in the Early and Middle Jurassic of the Umbria-Marche area, Lombardy Basin and Southern France. The events, FOs and LOs, are subdivided into: "main events" commonly and easily found in most of the studied sections; "rare species events", referred to rare but ubiquitous taxa; "events subject to further investigation" referred to taxa requiring further taxonomic studies and/or sparse occurrence. The number on the left hand side in each column corresponds to the number of FOs, on the right hand side to LOs. Time scale after Gradstein et al. (1994).


Ma
Period
Series
STAGES
Ammonite Zones
NANNOFOSSIL EVENTS
main events
36
11
rare species events
11
6
events subject to further investigation
4
8
159.4
164.4
169.2
176.5
180.1
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195.3
201.9
205.7
JURASSIC
MIDDLE
LOWER
CALLOVIAN
U
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BATHONIAN
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BAJOCIAN
Upper
Lower
AALENIAN
Upper
Middle
Lower
TOARCIAN
Upper
Middle
Lower
PLIENSBACHIAN
Upper
Lower
SINEMURIAN
Upper
Lower
HETTANGIAN
zigzag
parkinsoni
garantiana
subfurcatum
humphriesianum
sauzei
laeviuscula
discites
concavum
murchisonae
opalinum
aalensis
pseudorad.
meneghinii
insigne
thouarsense
erbaense
variabilis
bifrons
serpentinus
tenuicostatum
spinatum
margaritatus
stokesi
davoei
ibex
jamesoni
raricostatum
oxynotum
obtusum
turneri
semicostatum
bucklandi
angulata
liasicus
planorbis
C. wiedmannii
W. barnesae
C. superbus
W. manivitae
W. aff. manivitae
W. aff. contracta
W. communis
W. britannica
L. sigillatus
B. finchii
B. grande
L. umbriensis
B. dubium
C. margerelii
L. barozii
H. magharensis
W. contracta
C. poulnabronei
C. cantaluppii
D. criotus
D. striatus
W. fossacincta
W. colacicchii
D. ignotus
L. velatus
C. superbus
C. crucicentralis
C. cantaluppii
C. poulnabronei
L. sigillatus
Calyculus spp.
L. barozii
L. hauffii
B. finchii
P. robustus
C. pliensbachensis
S. orbiculus
S. cruciulus
C. crassus
M. lenticularis
C. pliensbachensis
M. jansae
Mitrolithus elegans
small Crepidolithus
Crepidolithus crassus ?
Tubirhabdus patulus
Parhabdolithus liasicus
T. sullivanii
C. granulatus
T. patulus
C. cavus
P. liasicus
R. incompta
small Calyculus
T. sullivanii
B. depravatus
B. leufuensis
B. prinsii
L. frodoi
L. umbriensis
C. cavus
L. primigenius
B. novum
B. aff. B. dubium
LCO Discorhabdus spp.
H. magharensis
C. crassus
large W. britannica
B. novum,
S. cruciulus
M. elegans
M. lenticularis
M. jansae
S. lowei
B. grande
M. lenticularis

concerning the FO of *M. jansae*. Some of the authors agree that this event is dated as Late Sinemurian (Wiegand, 1984; Young et al., 1986; Bown, 1987b; Bown et al., 1988). Whilst Lozar (1992, 1995) and Bown & Cooper (1998) found this event in the Lower Sinemurian. Different stratigraphic distributions may be related to migrational effects. In fact, Bown (1987b) showed that this taxon is a characteristic component of Tethyan nannofloras, while it is rare in Northern Europe, and probably only lived there sporadically. This event is considered highly reliable and reproducible in the Tethys.

FO *Crepidolithus pliensbachensis* (Crux, 1984) Bown, 1987

This species was only recorded in the Bosso section (Central Italy) at the base of the *quadriarmatum* (= *jamesoni*) Zone, basal Pliensbachian (Mattioli, personal observation). An older occurrence is, however, reported in the literature (Early Sinemurian; Bown, 1987b; Bown & Cooper, 1998).

FO *Similiscutum cruciulus* de Kaenel & Bergen, 1993

The entry of *S. cruciulus* was calibrated to the Early Pliensbachian (*quadriarmatum* = *jamesoni* Zone) in the Bosso section (Umbria-Marche Basin, Mattioli, personal observation; Fig. 6).

In the published data, disagreement exists between the genera *Palaeopontosphaera* and *Biscutum*. Recently, de Kaenel & Bergen (1993) revised the Family Biscutaceae, introducing a new genus, *Similiscutum*, represented by various species. The results of this accurate work, are difficult to apply to the studied sections, because: 1) Biscutaceae are represented by very solution susceptible taxa and the preservation of the studied material is often poor; 2) with the light microscope it is impossible to determine the subtle differences among the different species introduced and discussed by de Kaenel & Bergen (1993), with the exception of *S. cruciulus* and *S. orbiculus*.

Although the taxonomic relationships between the genera *Similiscutum*, *Palaeopontosphaera* and *Biscutum* are still under consideration, the FO of radiating placoliths was dated by different authors as Late Sinemurian or Early Pliensbachian (i.e., *Palaeopontosphaera veterna*, Prins, 1969; *Biscutum dubium*, Crux, 1987; *Biscutum novum* (= *S. cruciulus*), Bown, 1987b; *Similiscutum cruciulus*, de Kaenel & Bergen, 1993). This represents therefore a solid event that approximates the Sinemurian/Pliensbachian boundary worldwide.

FO *Similiscutum orbiculus* de Kaenel & Bergen, 1993

The FO of *S. orbiculus* is observed in the Lower Pliensbachian (*quadriarmatum* = *jamesoni* Zone), just above the FO of *S. cruciulus* in the Bosso section (Central Italy, Mattioli, personal observation; Fig. 6). The specimens of *Similiscutum avitum* described and figured by de Kaenel & Bergen (1993) display strong similarities with *S. orbiculus* and, therefore, we consider *S. avitum* a junior synonym of *S. orbiculus*.

S. orbiculus was found in the lowermost Pliensbachian by de Kaenel & Bergen (1993), but in Portuguese sections they reported an older occurrence of *S. cruciulus* with respect to *S. orbiculus* (in agreement with our findings from Central Italy), whilst they observed the opposite sequence of events in Morocco.

FO *Biscutum novum* (Goy, 1979) Bown, 1987

B. novum first appears in the Lower Pliensbachian in Italy (Fig. 6) and is never abundant in the assemblages until the end of the Early Jurassic. It is not excluded that this may result from poor preservation. In the studied areas, this species is an important constituent of Toarcian assemblages characterized by increases both in abundance and diversity of the family Biscutaceae.

The occurrences reported by various authors are generally consistent with the Italian record (Prins, 1969; Barnard & Hay, 1974; Crux, 1984) with the exception of the later record of Bown & Cooper (1998) and de Kaenel & Bergen (1993; Fig. 6).

FO *Biscutum dubium* (Noël, 1965) Grün in Grün et al., 1974

The FO of *B. dubium* was dated as earliest Pliensbachian (*quadriarmatum* = *jamesoni* Zone) in the Bosso section from the Umbria-Marche Basin (Mattioli, personal observation; Fig. 6). This taxon is never abundant in the assemblage, probably due to diagenetic modification of the assemblages and dissolution of delicate species. *B. dubium* differs from *B. novum* in its smaller size, more elliptical shape and wider, subrectangular central area. Due to taxonomic uncertainties and preservation problems, little agreement exists for the FO of *B. dubium* (Fig. 6).

LO *Crepidolithus pliensbachensis* (Crux, 1984) Bown, 1987

In the Bosso River area, this species disappears in the mid Lower Pliensbachian (*gemmellaroi* Zone = *ibex* Zone; Mattioli, personal observation). A similar distribution is given in Bown & Cooper (1998). The relatively short stratigraphic range of this species, restricted to the Sinemurian-Lower Pliensbachian makes *C. pliensbachensis* a very good marker, despite of its rarity.

Cobianchi (1992) reported this species as rare and discontinuous until the Toarcian in some sections of the Lombardy Basin. However, the specimens figured by Cobianchi (1992; Fig. 22, i and l) as *C. pliensbachensis* seem referable to *C. crassus*. Reale et al. (1992) reported this taxon as discontinuous and rare in the Toarcian-Aalenian of some Umbria-Marche Basin sections. However, the specimens attributed to *C. pliensbachensis* should be attributed to *Tubirhabdus patulus*. In addition to the taxonomic discrepancies discussed above, reworking must be taken into account for the discrepancies on the LO of *C. pliensbachensis*.

LO *Parhabdolithus robustus* Noël, 1965

In Central Italy (Bosso section), this event is observed in the Lower Pliensbachian (*gemmellaroi* Zone = *ibex* Zone; Mattioli, personal observation), just above the LO of *C. pliensbachensis*. Because the LO of this taxon has been consistently dated as mid Early Pliensbachian (Bown & Cooper, 1998), this event may be considered highly significant and reproducible.

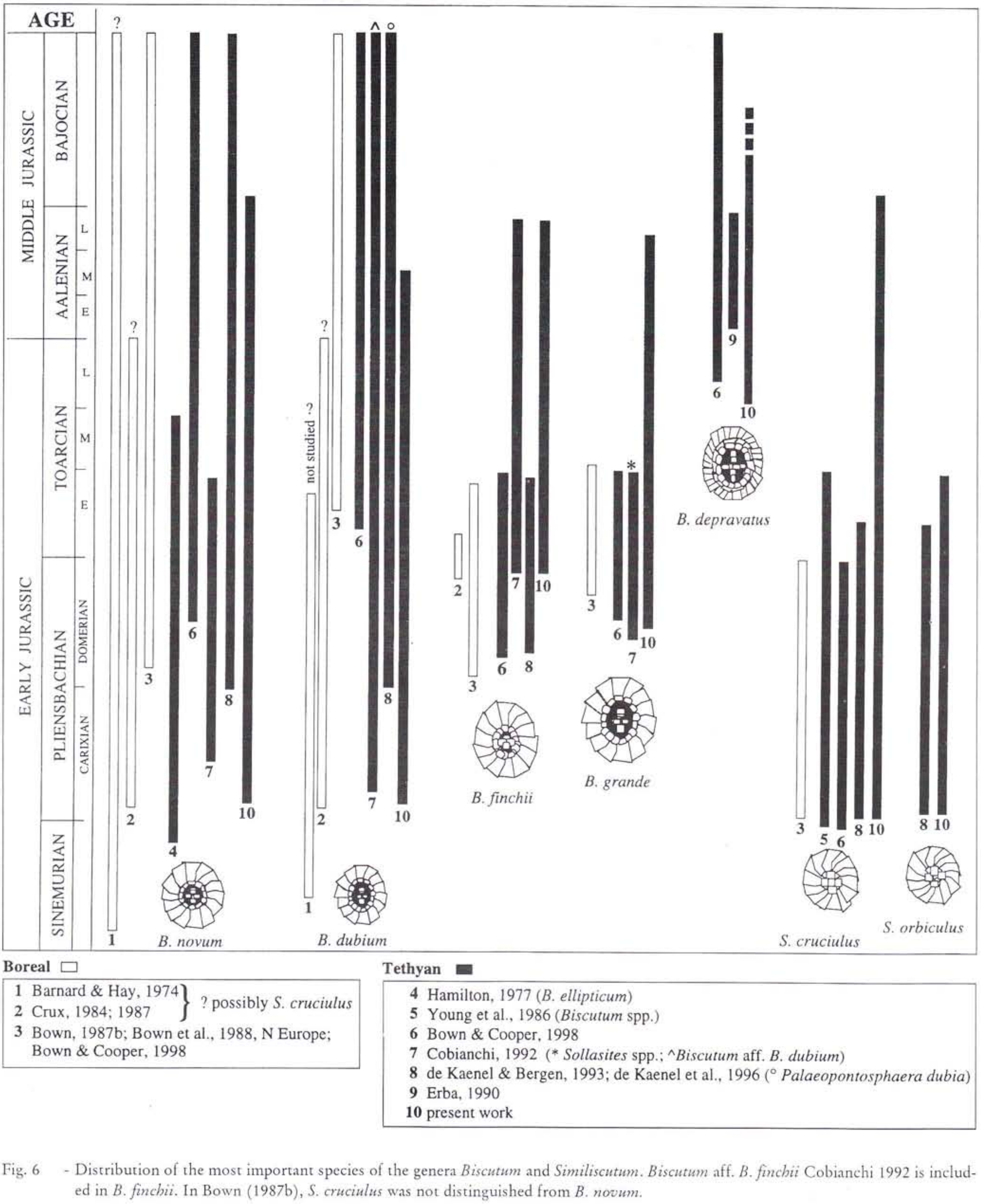


Fig. 6 - Distribution of the most important species of the genera *Biscutum* and *Similiscutum*. *Biscutum* aff. *B. finchii* Cobianchi 1992 is included in *B. finchii*. In Bown (1987b), *S. cruciulus* was not distinguished from *B. novum*.

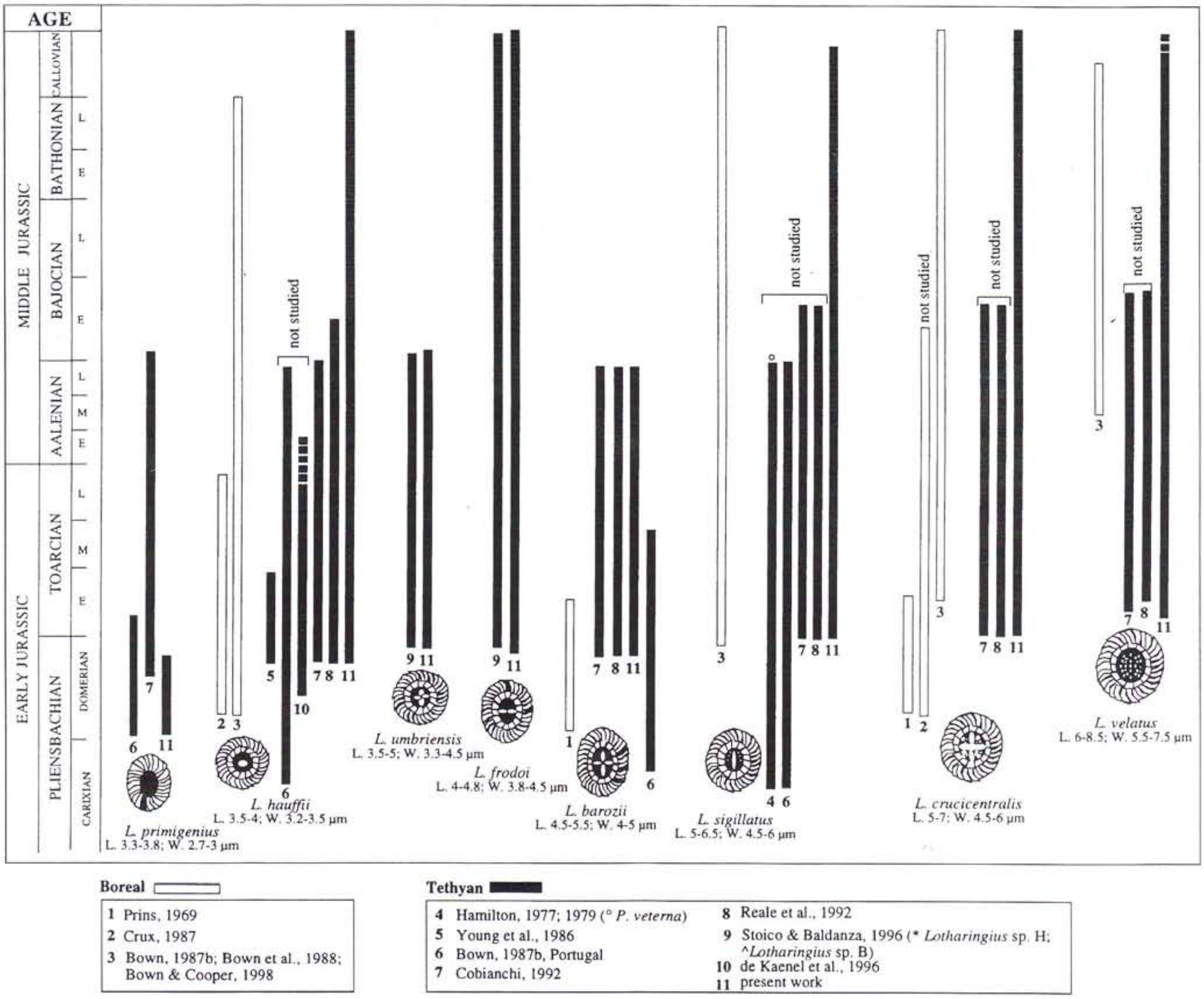


Fig. 7 - Distribution of the most important Jurassic species of the genus *Lotharingius*.

FO *Biscutum grande* Bown, 1987

B. grande first appears in the Upper Pliensbachian (*lavinianum* = *algovianum* Zone) in Central Italy (Bosso section; Mattioli, personal observation) (Fig. 6). This event is usually dated as Late Pliensbachian, although its first common occurrence seems to approximate the Pliensbachian/Toarcian boundary. This species is never abundant in the Upper Pliensbachian. *B. grande* can be considered a characteristic constituent of Toarcian assemblages of the Tethyan Realm and, according to Bown (1987b), occurs only rarely or not at all in some Northern European areas.

FO *Biscutum finchii* (Crux, 1984) Bown, 1987

This event occurs in the Upper Pliensbachian (*lavinianum* Zone) in the studied sections (Fig. 6). *B. finchii* is never abundant in the assemblage, but the relative ease of identification, because of the peculiar shape and size of the central area, makes it a good stratigraphic marker. Bown (1987b) reconstructed a distribution essentially restricted to the Tethyan Realm. The quite consistent occurrences in the literature (Fig. 6) make of *B. finchii* a good marker.

FO *Lotharingius primigenius* Bown, 1987

In Central Italy, this species first occurs in the *lavinianum* Zone (= *algovianum* Zone) of middle Late Pliensbachian age (Mattioli, personal observation). This entry corresponds to the first appearance of the genus *Lotharingius* (Fig. 7). However, *L. primigenius* is not easily distinguished from *L. hauffii* in poorly preserved material, and according to Bown (1987b) it is not possible to exclude that *L. primigenius* represents poorly preserved specimens of *L. hauffii*, in which the inner cycle of the distal shield was dissolved.

FO *Sollasites lowei* (Bukry, 1969) Rood et al., 1971

The entry of the genus *Sollasites* in Central and

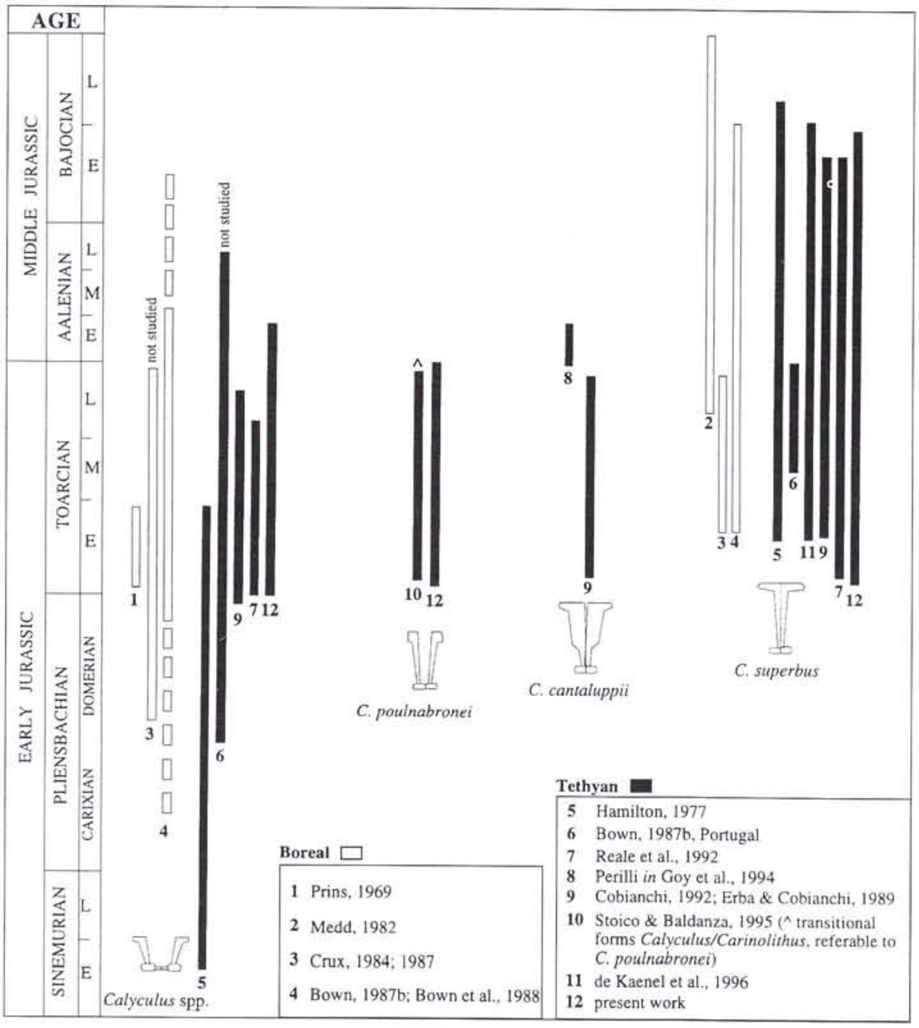


Fig. 8 - Distribution of the most important species of the genera *Calyculus* and *Carinolithus*.

Northern Italy approximates the Pliensbachian/Toarcian boundary. This taxon is usually rare and mainly occurs in Lower Toarcian sediments. As it is very solution susceptible, the central area structures are often dissolved and specific determination is hampered. Its presence, according also to Bown (1987b), is an index of good preservation of the study material, as the central structures of *Sollasites* species are only retained in well preserved material. This could account for the discrepancies existing in the literature about this event (Crux, 1984; Bown, 1987b; Bown et al., 1988; Cobianchi, 1990; Bartolini et al., 1992; Reale et al., 1992; Mattioli, 1993).

FO *Lotharingius hauffii* Grün & Zweili in Grün et al., 1974

This very distinctive event occurs in the uppermost Pliensbachian (*emaciatum* Zone) in the studied areas (Fig. 7) and is considered a main event, because *L. hauffii* is easily recognized and common. *L. hauffii* is in fact an abundant and diagenesis resistant component of Jurassic assemblages. Apart from sporadic discrepancies (Fig. 7; Bown, 1987b), this event is generally dated as Late Pliensbachian.

FO *Lotharingius umbriensis* Mattioli, 1996

This species appears in the Upper Pliensbachian (*emaciatum* Zone) in the Umbria-Marche area (Fig. 7) shortly after the FO of *L. hauffii*, and represents a link in the evolutionary lineage from the most ancestral *Lotharingius* and the most complex shield structure of the genus *Watznaueria* (Mattioli, 1996).

FO *Lotharingius frodoi* Mattioli, 1996

In Central Italy this taxon first occurs in the uppermost Pliensbachian (*emaciatum* Zone) (Fig. 7). It is frequent in Toarcian and Aalenian assemblages.

FO *Lotharingius barozii* Noël, 1973

This species appears in the uppermost Pliensbachian (Fig. 7) and is rare and usually discontinuous in the studied sections. As in the case of *L. hauffii*, which displays a sporadic earlier occurrence in Portugal (Fig. 7; Bown, 1987b), in the literature this event is generally correlated to the Pliensbachian/Toarcian boundary.

FO *Bussonius prinsii* (Noël, 1973) Goy, 1979

In the Umbria-Marche sections this event occurs in the uppermost Pliensbachian (*emaciatum* = *spinatum* Zone); however, this species is rare and dissolution susceptible, and this may account also for the discrepancies observed in the literature.

Bown (1987b) discussed the synonyms and ranges of *B. prinsii*. This author recorded *B. prinsii* as rare and discontinuous from the Lower Pliensbachian (*ibex* Zone) in Portugal. The same distribution is given by de Kaenel & Bergen (1993) in Moroccan sections.

FO *Bussonius leufuensis* Bown & Kielbowicz, 1987

In Umbria-Marche sections this event was observed in the uppermost Pliensbachian (*emaciatum* = *spinatum* Zone), shortly after the FO of *B. prinsii*.

Although very rare and solution susceptible, this species is a typical constituent of Early Toarcian assemblages.

FO *Calyculus* spp.

The first specimens of the genus *Calyculus* were recognized in side view in the uppermost Pliensbachian (concomitant with the uppermost horizons containing *Emaciaticeras*) or in the lowermost Toarcian (Fig. 8). This event probably corresponds to a significant vertical development of the inner tube of *Calyculus*. The lack of structures in the central area of the observed specimens usually prevents any specific determination, although various subspecies may be recognized on the basis of differences in the vertical extension of the distal shield and in the width of the central area (i.e. *C. noelae depressa* and *C. noelae recondita*). In spite of the discrepancies in the literature, in the present work the FO of *Calyculus* spp. is considered as the most important event for the Pliensbachian/Toarcian boundary. In fact, this very distinctive taxon is solution resistant and common in assemblages of Early Toarcian age. Here we identify the FO of the genus *Calyculus* with the appearance of diagnostic basket-shaped specimens in side view.

Bown & Cooper (1998) recorded *Calyculus* spp. as sporadic in the *ibex* Zone (Pliensbachian) and continuous from the Upper Pliensbachian *spinatum* Zone (Fig. 8).

FO *Lotharingius sigillatus* (Stradner, 1961) Prins in Grün et al., 1974

This event is generally dated as earliest Toarcian (base of the *tenuicostatum* Zone; Fig. 7); however, in some sections the FO of *L. sigillatus* was observed in the uppermost Pliensbachian (Mattioli, personal observation). Although rare, *L. sigillatus* is a very characteristic taxon of Lower Toarcian assemblages. Bown (1987b) assimilated *L. sigillatus* to *L. crucicentralis*, but Bown et al. (1988) distinguished the two species. In the present work, *L. sigillatus* is distinguished from *L. crucicentralis* because of slightly smaller dimensions, more reduced central area and evident processes aligned with the major axis of the ellipse (Fig. 7).

Apart the anomalous early record in Portugal (Lower Pliensbachian; Hamilton, 1977; Bown, 1987b), this event is generally dated as earliest Toarcian (Fig. 7).

FO *Lotharingius crucicentralis* (Medd, 1971) Grün & Zweili, 1980

The FO of this species was found in the Lower Toarcian (*tenuicostatum* Zone) (Fig. 7). *Lotharingius crucicentralis* is an easily identifiable species, because of its distinctive rim shape, cross structure in the central area and bright birefringence colours. It appears shortly after the FO of *L. sigillatus* and becomes frequent in the Middle Toarcian-Aalenian. Based on the continuity of its distribution, *L. crucicentralis* is considered a good marker, typical of Toarcian assemblages.

This event was consistently recorded in the Lower Toarcian (*tenuicostatum* Zone) by most of the authors (Fig. 7). Conversely, Crux (1984) dated the entry of the *L. crucicentralis* group including *L. hauffii*, *L. crucicentralis* and *Noellithina prinsii* (synonym of *Bussonius prinsii*) as Late Pliensbachian. It is, however, difficult to distinguish the distribution of single species, and it is not excluded that also in the Northern European sections studied by Crux *L. crucicentralis* first occurs in the basal Toarcian.

FO *Carinolithus poulnabronei* Mattioli, 1996

This species first occurs in the Lower Toarcian (*tenuicostatum* Zone) of Central and Northern Italy (Fig. 8). It is a transitional form between the genera *Calyculus* and *Carinolithus*, characterized by a vertically extended distal shield slightly thicker than in *C. superbus* and with a wider axial canal.

Crux (1987) showed that the evolutionary lineage between the genera *Calyculus* and *Carinolithus* developed through a gradual extension of the distal shield and the reduction of the central opening. Bown (1987b) reported the transitional phase between the two genera as restricted to the *tenuicostatum* Zone.

FO *Carinolithus cantaluppii* Cobianchi, 1990

This event was found only in the Tethyan Realm. Cobianchi (1990, 1992) described this species as a transitional form between the genera *Calyculus* and *Carinolithus* appearing in the Lower Toarcian (*tenuicostatum* Zone) of the Lombardy Basin. In the Umbria-Marche area this taxon was probably included into *C. superbus*, future studies will therefore ascertain its presence in areas others than Northern Italy.

FO *Carinolithus superbus* (Deflandre, 1954) Prins in Grün et al., 1974

In the Umbria-Marche Basin, *C. superbus* first occurs in the Lower Toarcian (*tenuicostatum* Zone) (Fig. 8), shortly after the FO of *L. crucicentralis*. This species is dissolution resistant and continuous although not abundant. Its abundance increases considerably in the uppermost Lower Toarcian, where it becomes a very characteristic, common constituent of the assemblage. The rarity of *C. superbus* in the lowermost Toarcian sediments can account for some of the discrepancies existing in the literature (Fig. 8).

FO *Lotharingius velatus* Bown & Cooper, 1989

The FO of this species was observed in the Lower Toarcian (*tenuicostatum* Zone) in Central and Northern

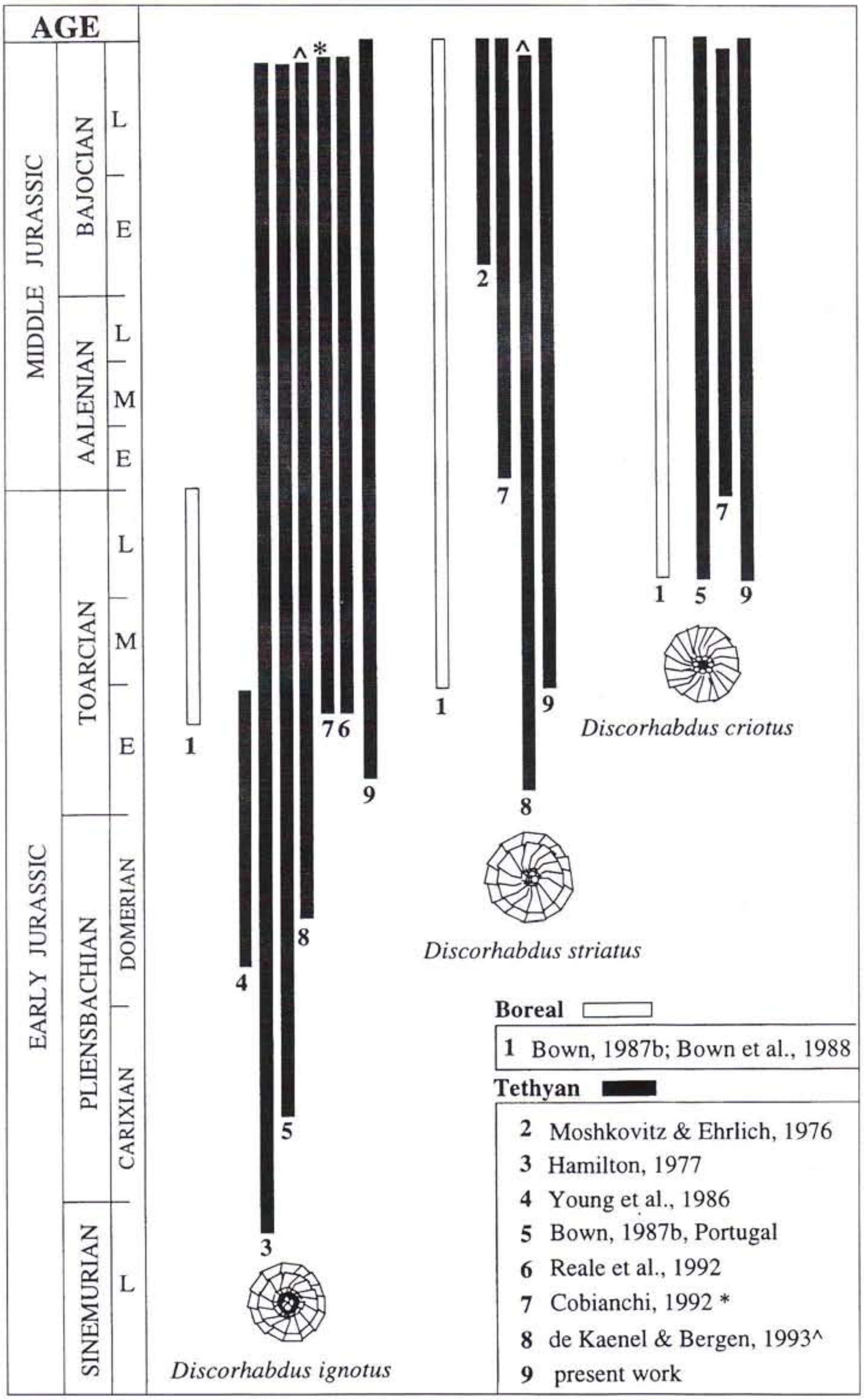


Fig. 9 - Distribution of the most important species of the genus *Discorhabdus*. *Discorhabdus* aff. *D. striatus* Cobianchi 1992 is included in *D. ignotus*. De Kaenel & Bergen (1993) found *Biscutum profundum* in the *algovianum* Zone of Portugal and in the *margaritatus* Zone of Morocco (Middle Upper Pliensbachian). However, they include in this new species both circular and elliptical specimens. The forms they figured (plate 3, figs. 6 and 7) seem very similar to *D. ignotus*. It is not excluded that they included in *B. profundum* two different species, with different stratigraphical ranges, distinguishable on the basis of the elliptical or circular shape. *Biscutum striatum* de Kaenel & Bergen 1993 is included in *D. striatus*. In Portugal Hamilton (1977) found this taxon from the Upper Sinemurian upward and *D. patulus* from the basal Middle Toarcian. However, the specimens of *D. ignotus* figured (plate 2, figs. 2 and 9; plate 4, figs. 10 and 11) and attributed to the Pliensbachian seem to be referable to *B. novum*.

Italy (Fig. 7). Although rare and with delicate central area structures, *L. velatus* is very characteristic and easy to recognize. Its abundance increases in the Aalenian and the common findings in this interval could explain some discrepancies in the published data.

FO *Discorhabdus ignotus* (Gorka, 1957) Perch Nielsen, 1968

In Central Italy, this event was detected in the youngest horizons containing ammonites of the genus *Dactylioceras* and below the oldest horizons with *Hildaites* (Fig. 9). Because it is the first species of the genus to appear at the top of the *tenuicostatum* Zone, the FO of *D. ignotus* is proposed as a marker for the *tenuicostatum/serpentinus* Zones boundary (Early Toarcian). After its FO, *D. ignotus* is usually rare but becomes quite common in the Middle Toarcian and this could explain the different distributions reported in literature. We attribute to *D. ignotus* only the circular specimens. The discrepancies among various authors (Fig. 9)

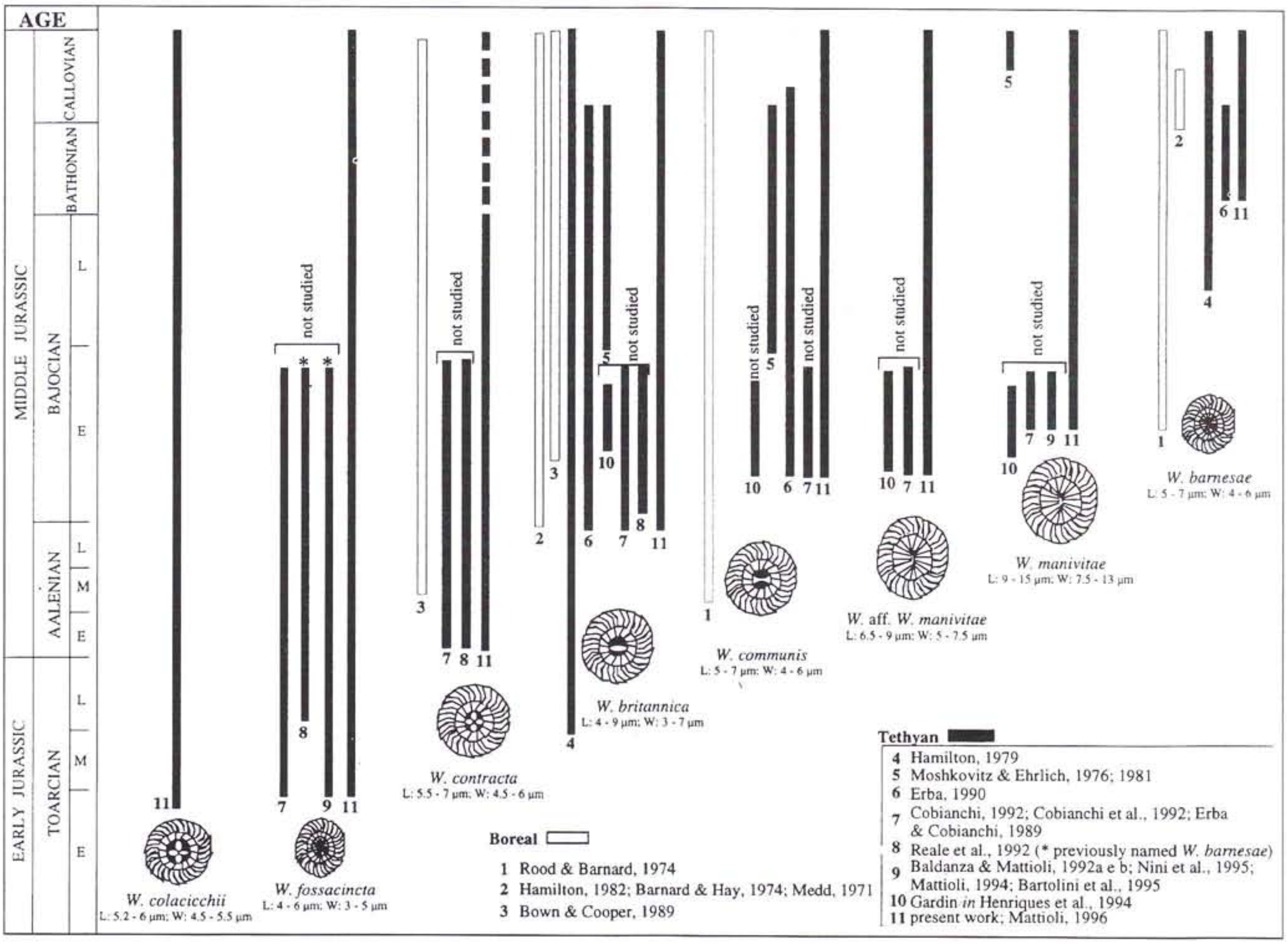


Fig. 10 - Distribution of the most important Jurassic species of the genus *Watznaueria*. The distribution of *Watznaueria contracta* includes that of *Lotharingius contractus* Bown et al, 1988. *Watznaueria fossacincta* previously called *Watznaueria* sp. 1 by Cobianchi (1992) and Cobianchi et al. (1992), *W. barnesae* by Baldanza & Mattioli (1992a and b), Nini et al. (1995), Reale et al. (1992).

probably result from both taxonomic uncertainities and differences in ammonite biozonations or palaeoprovincialism.

LO *Mitrolithus jansae* (Wiegand, 1984) Bown & Young in Young et al., 1986

The LO of *M. jansae* has been recorded in the uppermost Lower Toarcian, but sporadic occurrences are observed in Middle and Upper Toarcian Italian sections (Cobianchi, 1992; Reale et al., 1992; Baldanza & Mattioli, 1992b). The LO of *M. jansae* can be regarded as a synchronous event in literature, and sporadic younger ages are probably due to reworking.

FO *Watznaueria colacicchii* Mattioli, 1996

This species was first observed in the uppermost Lower Toarcian (top of the *serpentinus* Zone) in Central Italy and its appearance corresponds to the entry of the genus *Watznaueria* (Fig. 10). This taxon is quite similar in shape to *W. contracta* but is smaller than the type species and has slightly different width and shape of the central area (Mattioli, 1996).

After a careful revision of slides and photographs, the specimens previously referred to as *L. contractus*, observed in the Middle Toarcian of Greece and the Upper Toarcian of Portugal by Baldanza & Mattioli (1992a) and those recorded in the Middle and Lower Toarcian respectively by Baldanza & Mattioli (1992b) and Mattioli (1993) in Central Italy, should be attributed to *W. colacicchii*.

FO *Watznaueria fossacincta* (Black, 1971) Bown in Bown & Cooper, 1989

The entry of *W. fossacincta* was observed, both in Lombardy and in Umbria-Marche, in the upper Lower Toarcian (uppermost part of the *serpentinus* Zone) (Fig. 10). In the Umbria-Marche area the FO of *W. barnesae* was previously reported from the Middle Toarcian (Reale et al., 1992; Baldanza & Mattioli, 1992b). However, the taxonomic characters of the specimens found in the Middle Toarcian of Central Italy seem to be slightly different from those of *W. barnesae*. The most evident differences are in the central area, still not completely closed in *W. fossacincta*, and the relatively brighter birefringence colours.

FO *Discorhabdus striatus* Moshkovitz & Ehrlich 1976

D. striatus appears at the boundary between the *serpentinus* and the *bifrons* Zones (Early/Middle Toarcian boundary; Fig. 9). According to Bown et al. (1988) this species can be distinguished from *D. ignotus* because of its larger size, completely closed central area and brighter birefringence colours in polarizing light. This event can be considered as synchronous in different domains and is therefore a good biostratigraphic marker for the Early/Middle Toarcian boudary. It is an abundant and characteristic component of Middle Toarcian-Aalenian assemblages.

LO *Parhabdolithus liasicus* Deflandre, 1954

The LO of *P. liasicus* occurs in the Middle Toarcian (*bifrons* Zone) in the study areas. This record is not consistent with the literature data.

In Portugal Bown (1987b) dated the disappearance of *P. liasicus distinctus* as Late Domerian (*spinatum* Zone) and the LO of *P. liasicus liasicus* as Carixian (*davoei* Zone). Hamilton (1977, 1979) found this event at the Lower/Upper Pliensbachian boundary in Portugal. Baldanza & Mattioli (1992a) found the extinction of this taxon in the Upper Toarcian (*meneghinii* Zone) of Portugal and in the Lower Toarcian (*tenuicostatum* Zone) of Hungary. In Italian sections, Baldanza & Mattioli (1992b) recorded the presence of *P. liasicus* through the Lower Toarcian, while Erba & Cobianchi (1989), Reale et al. (1992) and Cobianchi (1992) found this species in the Middle Toarcian. In one section from Central Italy Mattioli (1994) found *P. liasicus* discontinuously up to the Aalenian.

In the Boreal Realm most Authors found *P. liasicus* continuous, although rare, through the Lower Toarcian (Prins, 1969; Bown, 1987b; Bown et al., 1988) or Middle Toarcian (Crux, 1984; 1987) and discontinuous up to the Dogger (Deflandre & Fert, 1954; Stradner, 1963; Thierstein, 1976; Medd, 1982). Such discrepancies could be due to reworking phenomena.

FO *Triscutum sullivanii* de Kaenel & Bergen, 1993

This species is never abundant in the assemblage, however its FO can be considered as an important event in the upper Middle Toarcian (*variabilis* Subzone) in the Umbria-Marche area. This record is consistent with literature data from the Tethyan Realm (Bown, 1987b; Mattioli, 1994; Sciunnach & Erba, 1994; Bartolini et al., 1995). According to de Kaenel & Bergen (1993), *Triscutum* sp. 1 of Bown (1987b) (plate 9, figs. 6-9; plate 14, figs. 26 and 27) has to be considered as a synonym of *T. sullivanii*. The distribution of this species seems to be restricted to the Tethyan and Pacific Realms.

FO *Biscutum depravatus* Bown, 1987

B. depravatus is never abundant in the assemblage, but is, however, easily distinguishable from other species of *Biscutum*, because of its very open central area and cross structure. Its FO can be considered as an important event of late Middle Toarcian age (*variabilis* Subzone; Fig. 6).

FO *Discorhabdus criotus* Bown, 1987

In the studied Umbria-Marche sections, this event was found in ammonite biohorizons of late Middle Toarcian age (*variabilis* Subzone; Fig. 9). Although rare, *D. criotus* shows consistent distribution in various areas.

LO *Calyculus* spp.

This group is present discontinuously through the Aalenian (Fig. 8). However, the smaller forms (< 6 µm) disappear in the Late Toarcian (*meneghinii* Zone). In the literature some discrepancies exist concerning this event, probably due to reworking.

The disappearance of the "small" *Calyculus* is correlatable to the LO of *Calyculus* spp. dated as Late Toarcian (*erbaense* Zone) by Reale et al. (1992) and Baldanza & Mattioli (1992b), and correlated to the *meneghinii* Zone by Cobianchi (1992).

LO *Carinolithus cantaluppii* Cobianchi, 1992

This event was reported in the Upper Toarcian of Northern Italy by Cobianchi (1990; 1992), but Perilli (*in* Goy et al., 1994) found *C. cantaluppii* in the *opalinum* Subzone of the Fuentelsaz section in Spain (Fig. 8).

FO *Retecapsa incompta* Bown & Cooper, 1989

R. incompta is a very rare taxon but its FO was consistently dated as Late Toarcian (*meneghinii* Zone; Baldanza & Mattioli, 1992b; Mattioli, 1994; Bown & Cooper, 1998).

LO *Carinolithus poulnabronei* Mattioli, 1996

Carinolithus poulnabronei has a stratigraphic range restricted to the Toarcian, as it disappears at the base of the Aalenian in an interval dated only by means of other calcareous nannofossil events (Mattioli, 1994; Fig. 8).

FO *Diazomatolithus lehmanii* Nöel, 1965

This event occurs at the Toarcian/Aalenian boundary in the Lombardy Basin and *D. lehmanii* seems to be a typical form of the basal Aalenian, at least in the

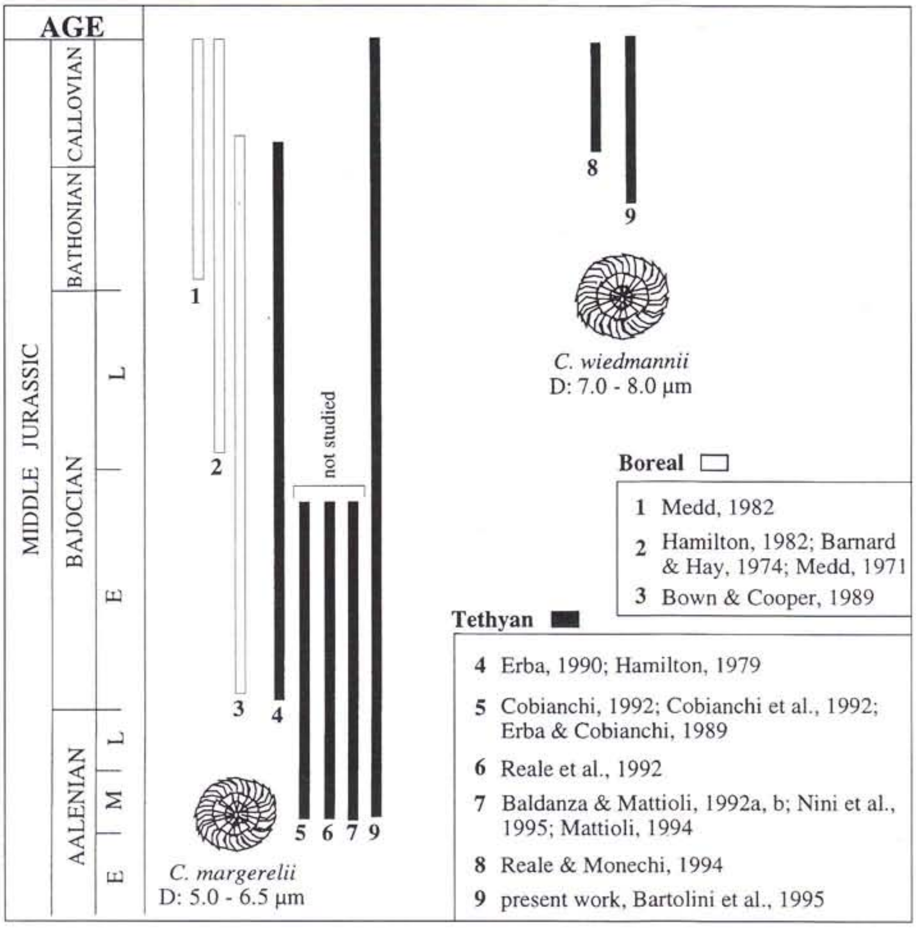


Fig. 11 - Distribution of the species of the genus *Cyclagelophaera*.

Tethyan Realm. Some differences are observed with respect to the distribution in Northern Europe, as already discussed by Erba (1990).

LO *Biscutum finchii* (Crux, 1984) Bown, 1987

In the present work the LO of *B. finchii* is dated as latest Aalenian (Fig. 6), although a precise disappearance level of this species is difficult to determine probably due to reworking.

FO *Watznaueria contracta* (Bown & Cooper, 1989) Cobianchi et al., 1992

This event is characteristic of the basal Aalenian (Fig. 10). *Watznaueria contracta* was a new combination for *Lotharingius contractus* Bown and Cooper, 1989, because of the presence of a Watznaueriacean rim in this form. After a revision of the specimens previously found in the Umbria-Marche sections, the writers agree with Cobianchi et al. (1992) in this new combination and distribution.

FO *Hexalithus magharensis* Moshkovitz & Ehrlich, 1976

In the studied sections the FO of *H. magharensis* was found at the base of the Aalenian. Although some discrepancies emerge from the literature and *H. magharensis* is usually rare in the studied areas, it can be considered as a significant component of Middle Jurassic assemblages. This taxon seems to have a distribution restricted to the Tethyan and Pacific Realms, as it has never been recorded in Northern European sections (Bown, & Cooper, 1998).

FO *Cyclagelosphaera margerelii* Noël, 1965

The first appearance of this species is an important event of Middle Aalenian age, although the oldest specimens are rare in the studied sections (Fig. 11). Some discrepancies exist in the literature concerning this event, as already discussed by Erba (1990). It is not excluded that the discrepancies are due to different taxonomic concepts and to a little confusion related to the presence of other circular Watznaueriaceae in the uppermost Middle Jurassic (i.e. *C. deflandrei*).

FO *Watznaueria britannica* (Stradner, 1963) Reinhardt, 1964

Some taxonomic uncertainties exist in the literature concerning this species and its relationship with *W. communis*, consequently different distributions have been reported (see Erba, 1990, for further details). In the present work *W. britannica* is considered a very important marker for the Aalenian/Bajocian boundary in the Tethyan Realm, as it is found in the uppermost Aalenian or at the base of the Bajocian (Fig. 10). It is not excluded that the latest Pliensbachian and Toarcian occurrences for this taxon (Hamilton, 1979) may be related to the presence of species of *Lotharingius* (see *L. frodoi*) with a transverse bar in the central area.

FO *Watznaueria communis* Reinhardt, 1964

The relationships between this species and *W. britannica* were discussed by Erba (1990). The entry of *W. communis* is considered as a good event of Early Bajocian age (Fig. 10).

FO *Watznaueria* aff. *W. contracta* Cobianchi et al., 1992

Watznaueria aff. *W. contracta* was reported as *Watznaueria* sp. 2 by Cobianchi (1992) and Cobianchi et al.

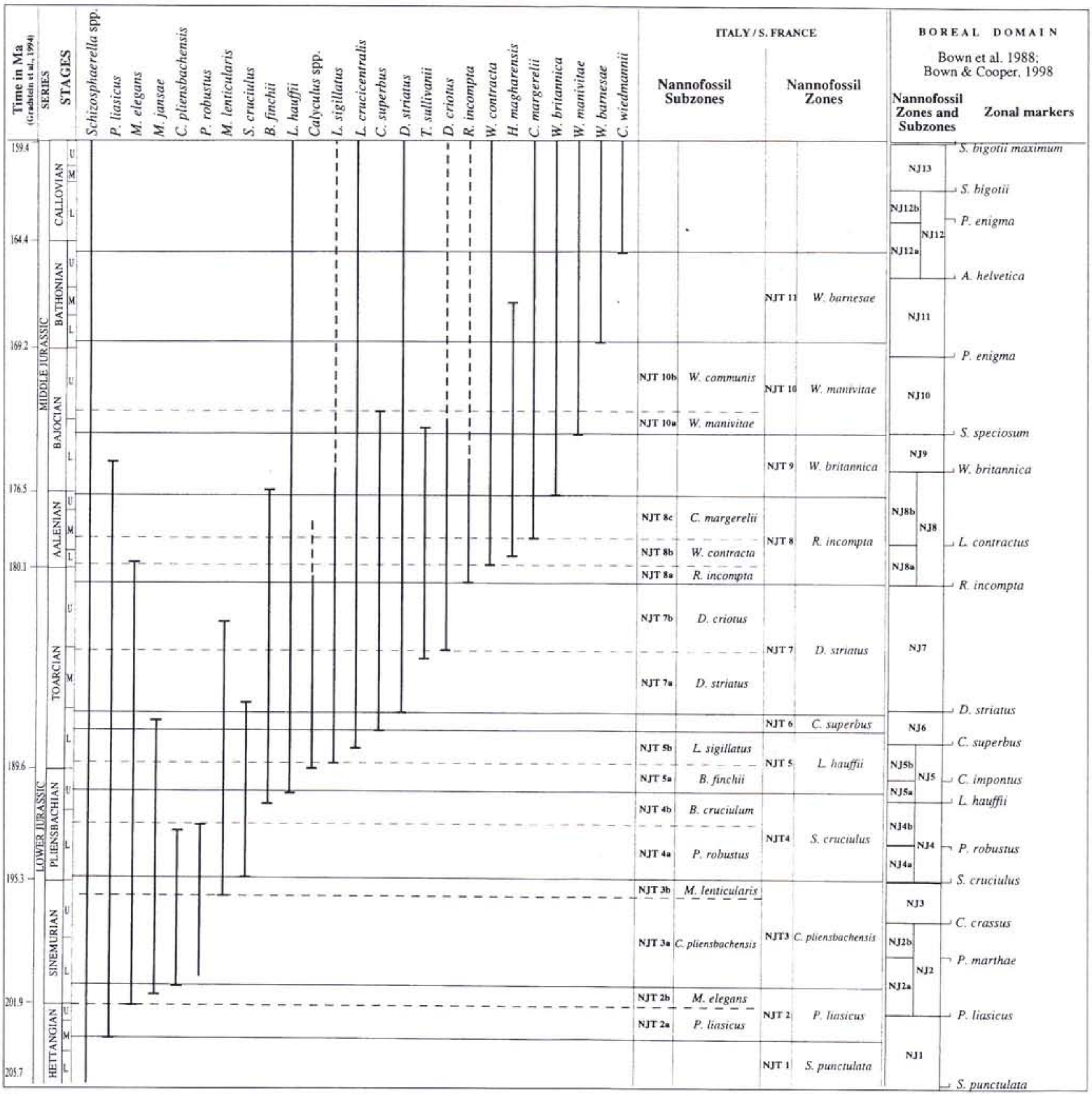


Fig. 12 - Biozonation scheme proposed for Italy and Southern France (Mediterranean Province) compared to the scheme proposed by Bown et al. (1988) and Bown & Cooper (1998) for the Boreal Realm. Time scale after Gradstein et al. (1994).

(1992) and as *Watznaueria* sp. 4 by Erba (1990). This taxon is here considered as a transitional form between *W. contracta* and *W. manivitae*, its dimensions being larger than the type species of *W. contracta* (Fig. 10).

FO *Watznaueria* aff. *W. manivitae* Cobianchi et al., 1992

This event was calibrated to the *discites* Zone (Early Bajocian). This taxon, never exceeding the length of 9 µm, is considered transitional from *Watznaueria* aff. *W. contracta* to *W. manivitae* (Cobianchi et al., 1992; Fig. 10).

Baldanza et al. (1990), Baldanza & Mattioli (1992b) and Reale et al. (1992) recorded *W. manivitae* respectively in the Middle and Upper Aalenian of the Umbria-Marche Basin. However, after a revision of the material, these specimens resulted to have dimensions smaller than *W. manivitae*, and they should therefore be assimilated into *Watznaueria* aff. *W. manivitae*.

FO *Watznaueria manivitae* Bukry, 1973

Moshkovitz & Ehrlich (1987) reviewed the taxonomy of *W. manivitae* and distinguished it from

Cyclagelosphaera deflandrei. In the literature these two taxa were often assimilated, as discussed by Erba (1990). *W. manivitae* is easily recognizable and very solution resistant and its FO is regarded as an excellent event of middle Early Bajocian age (*laeviuscula* Zone) (Fig. 10).

Baldanza et al. (1990) noticed an increase in size of *W. manivitae* occurring in the *sauzei* Zone. As the specimens of *W. manivitae* of Baldanza et al. (1990) are smaller than 9 µm and appear in the Aalenian, they should be considered the same as *Watznaueria* aff. *W. manivitae*, and probably only the specimens which are larger in size (> 9 µm) should be attributed to *W. manivitae*.

LO *Watznaueria* aff. *W. contracta* Cobianchi et al., 1992

This species shows a short range, restricted to the Lower Bajocian. In fact, it last occurred in the *sauzei* Zone, according to Erba (1990).

LO *Carinolithus superbus* (Deflandre, 1954) Prins in Grün et al., 1974

This taxon becomes very rare and discontinuous from the Bajocian upwards and its LO is calibrated to the beginning of the Late Bajocian (Fig. 8). This event is usually placed in the Bajocian (Moshkovitz & Ehrlich, 1976; de Kaenel et al., 1996; Bown et al., 1988).

LO *Hexalithus magharensis* Moshkovitz & Ehrlich, 1976

Erba (1990) recorded this event in the *parkinsoni* Zone (latest Bajocian) of the Digne sections. This distribution is consistent with the range given by Moshkovitz & Ehrlich (1976) in Israel and Northern Sinai. Sciunnach & Erba (1994) consider this event as significant of a Bajocian age, as *H. magharensis* has never been found in younger sediments. de Kaenel et al. (1996) calibrated the LO of *Carinolithus magharensis* between the end of the Early Bajocian and the beginning of the Late Bajocian, shortly after the LO of *C. superbus*.

FO *Watznaueria barnesae* (Black in Black & Barnes, 1959) Perch Nielsen, 1968

Some discrepancies emerge from the literature about this very distinctive event, as already observed by Erba (1990), probably partly related to taxonomic problems (Fig. 10). In the studied sections this event is characteristic of the base of the Bathonian (*zigzag* Zone).

The specimens of *W. barnesae* reported in the Early Jurassic by Reale et al. (1992) and Baldanza & Mattioli (1992b) should be ascribed to *W. fossacincta*, because of the presence of a not completely closed central area.

FO *Cyclagelosphaera wiedmannii* Reale & Monechi, 1994

Cyclagelosphaera wiedmannii was originally described from DSDP Site 534, the Quissac section (SE France), Valdorbia section (central Italy) and Bihendula section (Somalia) (Reale & Monechi, 1994). Calibration of the stratigraphic range of this taxon is poorly constrained. In fact, the FO of *C. wiedmannii* was correlated with the *macrocephalus* Zone in the Quissac section and dated as earliest Callovian. At Site 534, *C. wiedmannii* was observed in the lowermost sediments above basalts and therefore this occurrence cannot be univocally considered as the first appearance of the taxon. Moreover, there is no documentation of the nannofossil distribution of the Quissac section and it is not clear if this marker is present in sediments older than Callovian.

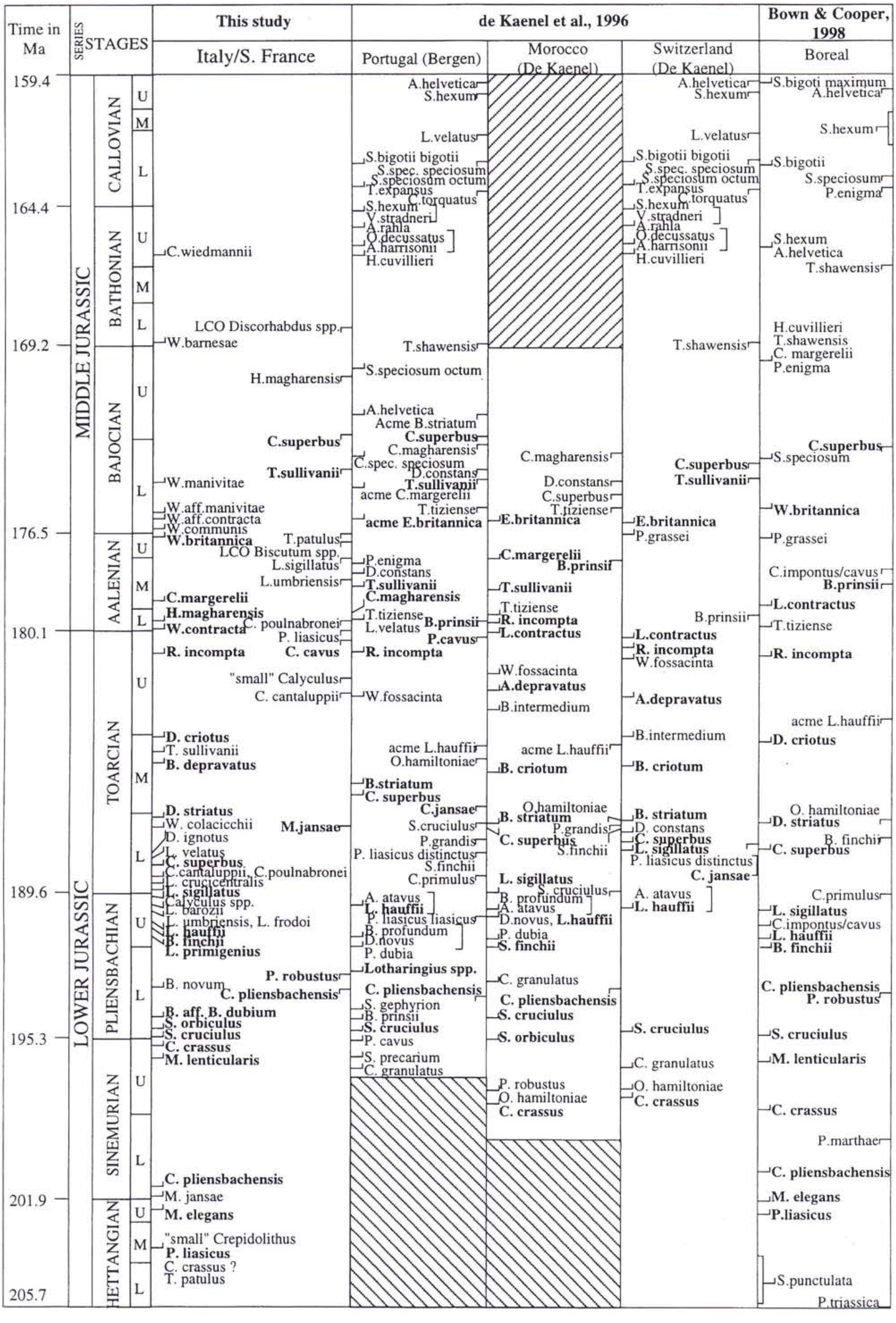
Recent studies of the Terminilletto section (Bartolini et al., 1995) revealed the occurrence of *C. wiedmannii* in siliceous limestones attributed to the base of the radiolarian Zone UAZ 7. The base of this zone has been equated to the Middle/Late Bathonian boundary as determined by ammonites in sections from Spain (O'Dogherty et al., 1995; Bartolini et al., 1995). Revision of the radiolarian biostratigraphy for Site 534 resulted in an updated biostratigraphic age for the basal sediments. The UAZ 6 Zone was defined on a single sample at 167 cm above the occurrence of *C. wiedmannii*. Therefore, the FO of this taxon is older than previously reported and as old as latest Middle Bathonian (Fig. 11).

Recent syntheses of Jurassic calcareous nannofossil biostratigraphy (de Kaenel et al., 1996; Bown, 1996; Bown & Cooper, 1998) do not report *C. wiedmannii*. Consequently, the occurrence and/or the stratigraphic distribution of this taxon in other areas are still uknown. However, this taxon has been observed in Oxfordian sediments from Southern Germany (Mattioli, personal observation).

Tethyan nannofossil zones.

For the Hettangian-Bathonian interval, we propose here a biozonal scheme consisting of 11 zones and 15 subzone based on ammonite-calibrated nannofossil events (Fig. 12). Each zone is described in stratigraphic order: in addition to the definition of lower and upper boundaries, the assemblages are discussed and the

Fig. 13 - Comparison of calcareous nannofossil events found in Italy and Southern France with data summarized for Northern Europe, Portugal and Morocco by Bown (1996) and de Kaenel et al. (1996). The events in bold are reproducible in various areas and allow interregional correlations. Time scale after Gradstein et al. (1994).


Time in Ma
SERIES
STAGES
This study
Italy/S. France
de Kaenel et al., 1996
Portugal (Bergen)
Morocco (De Kaenel)
Switzerland (De Kaenel)
Bown & Cooper, 1998
Boreal
159.4
164.4
169.2
176.5
180.1
189.6
195.3
201.9
205.7
MIDDLE JURASSIC
LOWER JURASSIC
CALLOVIAN
BATHONIAN
BAJOCIAN
AALENIAN
TOARCIAN
PLIENSBACHIAN
SINEMURIAN
HETTANGIAN
U
M
L
C.wiedmannii
LCO Discorhabdus spp.
W.barnesae
H.magharensis
C.superbus
T.sullivanii
W.manivitae
W.aff.manivitae
W.aff.contracta
W.communis
W.britannica
T.patulus
LCO Biscutum spp.
L.sigillatus
L.umbriensis
C.margerelii
H.magharensis
C. poulnabronei
W.contracta
P. liasicus
R. incompta
C. cavus
"small" Calyculus
C. cantaluppii
D. criotus
T. sullivanii
B. depravatus
D. striatus
W. colacicchii
M.jansae
D. ignotus
L. velatus
C. superbus
C.cantaluppii, C.poulnabronei
L. crucicentralis
L. sigillatus
Calyculus spp.
L. barozii
L. umbriensis, L. frodoi
L. hauffii
B. finchii
L. primigenius
P. robustus
B. novum
C. pliensbachensis
B. aff. B. dubium
S. orbiculus
S. cruciulus
C. crassus
M. lenticularis
C. pliensbachensis
M. jansae
M. elegans
"small" Crepidolithus
P. liasicus
C. crassus ?
T. patulus
A.helvetica
S.hexum
L.velatus
S.bigotii bigotii
S.spec. speciosum
S.speciosum octum
T.expansus
C.torquatus
S.hexum
V.stradneri
A.rahla
O.decussatus
A.harrisonii
H.cuvillieri
T.shawensis
S.speciosum octum
A.helvetica
Acme B.striatum
C.superbus
C.magharensis
C.spec. speciosum
D.constans
T.sullivanii
acme C.margerelii
T.tiziense
acme E.britannica
P.enigma
D.constans
T.sullivanii
C.magharensis
T.tiziense
B.prinsii
L.velatus
P.cavus
R. incompta
W.fossacinta
acme L.hauffii
O.hamiltoniae
B.striatum
C. superbus
C.jansae
S.cruciulus
P.grandis
P. liasicus distinctus
S.finchii
C.primulus
A. atavus
L. hauffii
P. liasicus liasicus
B. profundum
D.novus
P. dubia
Lotharingius spp.
C. pliensbachensis
S. gephyrion
B. prinsii
S. cruciulus
P. cavus
S. precarium
C. granulatus
C.magharensis
D.constans
C.superbus
T.tiziense
E.britannica
C.margerelii
B.prinsii
T.sullivanii
T.tiziense
R. incompta
L.contractus
W.fossacinta
A.depravatus
B.intermedium
acme L.hauffii
B. criotum
O.hamiltoniae
B. striatum
P.grandis
C. superbus
S.finchii
L. sigillatus
S. cruciulus
B. profundum
A. atavus
D.novus, L.hauffii
P. dubia
S. finchii
C. granulatus
C. pliensbachensis
S. cruciulus
S. orbiculus
P. robustus
O. hamiltoniae
C. crassus
A.helvetica
S.hexum
L.velatus
S.bigotii bigotii
S.spec. speciosum
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W.fossacinta
A.depravatus
B.intermedium
B. criotum
B. striatum
D. constans
C. superbus
L. sigillatus
P. liasicus distinctus
C. jansae
A. atavus
L. hauffii
S. cruciulus
C. granulatus
O. hamiltoniae
C. crassus
S.bigoti maximum
A.helvetica
S.hexum
S.bigotii
S.speciosum
P.enigma
S.hexum
A.helvetica
T.shawensis
H.cuvillieri
T.shawensis
C. margerelii
P.enigma
C.superbus
S.speciosum
W.britannica
P.grassei
C.impontus/cavus
B.prinsii
L.contractus
T.tiziense
R. incompta
acme L.hauffii
D. criotus
O. hamiltoniae
D. striatus
B. finchii
C. superbus
C.primulus
L. sigillatus
C.impontus/cavus
L. hauffii
B. finchii
C. pliensbachensis
P. robustus
S. cruciulus
M. lenticularis
C. crassus
P.marthae
C. pliensbachensis
M. elegans
P.liasicus
S.punctulata
P.triassica

chronostratigraphical extent reported. The nannofossil zones and subzones are coded with a number, according to the method introduced by Martini (1971) for the Cenozoic, and previously adopted by Bown (1987b) and Bown et al. (1988) for the Jurassic. Zones and subzones are also labeled with NJT = nannofossil Jurassic in the Tethyan domain, followed by increasing numbers from bottom to top. For subzones, progressive alphabetic letters (a, b, c) are applied following the stratigraphic order within each zone.

Description of Tethyan Nannofossil Zones.

NJT 1 - *Schizosphaerella punctulata* Zone

Author: Bown (1987b).

Definition: First occurrence of *Schizosphaerella punctulata* to the first occurrence of *Parhabdolithus liasicus*.

Age: Triassic/Jurassic boundary to Middle Hettangian.

Reference section: Pradalunga section, Lombardy Basin (Lozar, 1995).

Comments: The FO of *P. liasicus* has been recorded in the Tethyan Realm earlier (Middle Hettangian; Lozar, 1995) than in the Boreal (Late Hettangian), therefore the duration of Zone NJT 1 is shorter in the Tethyan Realm.

Associated species: the assemblage is generally very poor and the only taxon continuously present is *Schizosphaerella* spp.; sporadically *C. primulus* is also observed.

NJT 2 - *Parhabdolithus liasicus* Zone

Author: Bown (1987b) emended here.

Definition: First occurrence of *Parhabdolithus liasicus* to the first occurrence of *Crepidolithus pliensbachensis*.

Age: Middle Hettangian to Early Sinemurian.

Reference section: Pradalunga section, Lombardy Basin (Lozar, 1995).

Comments: the assemblage is very poor, only *Schizosphaerella* spp. is recorded continuously and constitutes the most abundant taxon in the assemblage. The first occurrences of *T. patulus*, small forms of *Crepidolithus*, *M. elegans* and *M. jansae* are also observed in this zone.

Zone NJT 2 corresponds to the upper part of the NJ 1 and to the lower part of the NJ 2 of Bown (1987b) and Bown et al. (1988).

NJT 2a - *Parhabdolithus liasicus* Subzone

Author: defined here.

Definition: First occurrence of *Parhabdolithus liasicus* to the first occurrence of *Mitrolithus elegans*.

Age: Middle Hettangian to the Hettangian/Sinemurian boundary.

Reference section: Pradalunga section, Lombardy Basin (Lozar, 1995).

Comments: This subzone corresponds to the upper part of the NJ 1 of Bown et al. (1988) and is not correlatable with their Zone NJ 2a.

Associated species: *Schizosphaerella* spp., *P. liasicus*, *C. primulus* and *T. patulus*.

NJT 2b - *Mitrolithus elegans* Subzone

Author: defined here. Name previously used for NJ 2b Subzone of Bown (1987b).

Definition: first occurrence of *Mitrolithus elegans* to the first occurrence of *Crepidolithus pliensbachensis*.

Age: Hettangian/Sinemurian boundary to Early Sinemurian.

Reference section: Pradalunga section, Lombardy Basin (Lozar, 1995).

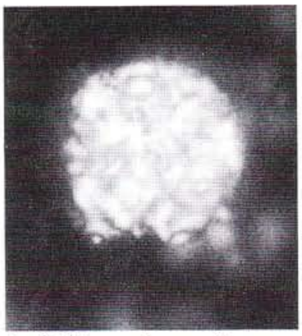
Comments: In this subzone the first occurrence of *M. jansae* is recorded. The assemblage is still dominated by *Schizosphaerella* spp. Subzone NJT 2b does not correspond to the NJ 2a Subzone of Bown (1987b), whose base is defined by the LO of *P. marthae* and its top by the FO of *C. crassus*. The NJT 2a is partly overlapping with the NJ 1 of Bown (1987b).

Associated species: *Schizosphaerella* spp., *P. liasicus*, *C. crassus*, *M. elegans*, *M. jansae*, *C. primulus* and *T. patulus*.

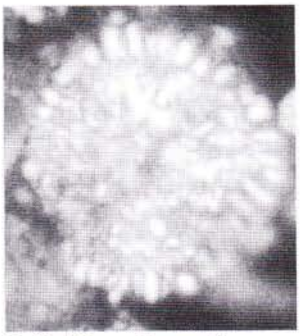
PLATE 1

All light micrographs crossed nicols, approximately X 3000.

1. *Schizosphaerella* spp., sample S1 1.30, Genuardo (Sicily), Early Pliensbachian; **2.** *Schizosphaerella* spp., sample FLE 25.10, Fiuminata (Central Italy), Early Aalenian; **3.** *P. robustus*, sample PCR 8, Piana degli Albanesi (Sicily), Late Sinemurian; **4.** *P. robustus*, sample PCR 8, Piana degli Albanesi (Sicily), Late Sinemurian; **5.** *P. liasicus*, sample PCR 8, Piana degli Albanesi (Sicily), Late Sinemurian; **6.** *M. pulla*, sample S1 1.30, Genuardo (Sicily), Early Pliensbachian; **7.** *C. pliensbachensis*, sample PCR 8, Piana degli Albanesi (Sicily), Late Sinemurian; **8.** *C. crassus*, sample PCR 8, Piana degli Albanesi (Sicily), Late Sinemurian; **9.** *M. elegans*, sample PCR 8 (Sicily), Late Sinemurian; **10.** *M. elegans*, sample PCR 8, Piana degli Albanesi (Sicily), Late Sinemurian; **11.** *M. elegans*, sample PCR 8, Piana degli Albanesi (Sicily), Late Sinemurian; **12.** *M. lenticularis*, sample PCR 8, Piana degli Albanesi (Sicily), Late Sinemurian; **13.** *S. cruciulus*, sample S1 1.30, Genuardo (Sicily), Early Pliensbachian; **14.** *M. jansae*, sample S1 1.30, Genuardo (Sicily), Early Pliensbachian; **15.** *M. jansae*, sample S1 1.30, Genuardo (Sicily), Early Pliensbachian; **16.** *M. lenticularis*, sample PCR 8, Piana degli Albanesi (Sicily), Late Sinemurian; **17.** *S. orbiculus*, sample S1 1.30, Genuardo (Sicily), Early Pliensbachian; **18.** *B. finchii*, sample MBE 2.30, Somma (Central Italy), Early Toarcian, specimen smaller than 6 µm; **19.** *B. finchii*, sample MBE 2.30, Somma (Central Italy), Early Toarcian; **20.** *B. finchii*, sample MBE 2.30, Somma (Central Italy), Early Toarcian.



1. *Schizosphaerella* spp.



2. *Schizosphaerella* spp.

3. *P. robustus*

4. *P. robustus*

5. *P. liasicus*

6. *M. pulla*

7. *C. pliensbachensis*

8. *C. crassus*

9. *M. elegans*

10. *M. elegans*

11. *M. elegans*

12. *M. lenticularis*

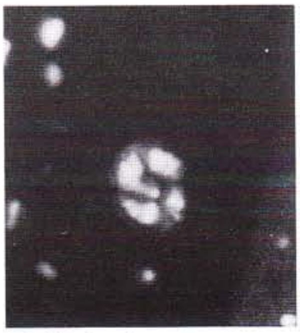
13. *S. cruciulus*

14. *M. jansae*

15. *M. jansae*

16. *M. lenticularis*

17. *S. orbiculus*



18. *B. finchii*

19. *B. finchii*

20. *B. finchii*

NJT 3 - *Crepidolithus pliensbachensis* Zone

Author: defined here. Name previously used for the NJ 4a Subzone of Bown (1987b).

Definition: first occurrence of *Crepidolithus pliensbachensis* to the first occurrence of *Similiscutum cruciulus.*

Age: Sinemurian to earliest Pliensbachian.

Reference section: Pradalunga section, Lombardy Basin (Lozar, 1995).

Comments: This zone corresponds to the upper part of the NJ 2 Zone and to the entire NJ 3 Zone of Bown (1987b).

Associated species: dominant *Schizosphaerella* spp. and rare *P. liasicus*, *P. robustus*, *C. crassus*, *M. elegans*, *M. jansae*, *C. primulus*, *C. pliensbachensis* and *T. patulus.*

NJT 3a - *Crepidolithus pliensbachensis* Subzone

Author: defined here. Name previously used for the NJ 4a Subzone of Bown (1987b).

Definition: first occurrence of *Crepidolithus pliensbachensis* to the first occurrence of *Mitrolithus lenticularis.*

Age: Sinemurian.

Reference section: Pradalunga section, Lombardy Basin (Lozar, 1995).

NJT 3b - *Mitrolithus lenticularis* Subzone

Author: defined here.

Definition: first occurrence of *Mitrolithus lenticularis* to the first occurrence of *Similiscutum cruciulus.*

Age: Sinemurian/Pliensbachian boundary interval.

Reference section: Pradalunga section, Lombardy Basin (Lozar, 1995).

Comments: This subzone corresponds to the upper part of the NJ 3 Zone of Bown (1987b). The Sinemurian/Pliensbachian boundary lies in this subzone.

NJT 4 - *Similiscutum cruciulus* Zone

Author: defined here.

Definition: first occurrence of *Similiscutum cruciulus* to the first occurrence of *Lotharingius hauffii.*

Age: Pliensbachian.

Reference section: Bosso/Burano section, Umbria-Marche Apennines (Faraoni et al., 1996; Mattioli & Morettini, in progress).

Comments: This zone corresponds to the entire NJ 4 Zone of Bown (1987b). Nannofossil abundance and species richness notably increase in this zone. Representatives of the Family Biscutaceae, such as *S. orbiculus* and *B. dubium* appear in the Early Pliensbachian. *P. robustus* and *C. pliensbachensis* disappear.

Associated species: dominant *Schizosphaerella* spp. and rare *P. liasicus*, *P. robustus*, *C. crassus*, *M. elegans*, *M. jansae*, *C. primulus*, *C. pliensbachensis*, *B. grande* and *T. patulus*.

NJT 4a - *Parhabdolithus robustus* Subzone

Author: defined here.

Definition: first occurrence of *Similiscutum cruciulus* to the last occurrence of *Parhabdolithus robustus.*

Age: Early Pliensbachian.

Reference section: Bosso/Burano section, Umbria-Marche Apennines (Faraoni et al., 1996; Mattioli & Morettini, in progress).

Comments: This subzone is correlative of the entire NJ 4a and part of the NJ 4b Subzones of Bown (1987b).

NJT 4b - *Similiscutum cruciulus* Subzone

Author: defined here.

Definition: last occurrence of *Parhabdolithus robustus* to the first occurrence of *Lotharingius hauffii.*

Age: late Early Pliensbachian to Late Pliensbachian.

Reference section: Bosso/Burano section, Umbria-Marche Apennines (Faraoni et al., 1996; Mattioli & Morettini, in progress).

Comments: This subzone corresponds to the upper part of the NJ 4b Subzone of Bown (1987b). *B. finchii* first appears in the Late Pliensbachian.

PLATE 2

All light micrographs crossed nicols, approximately X 3000.

1. *B. dubium*, sample MBE 2.30, Somma (Central Italy), Early Toarcian; **2.** *B. grande*, sample MBE 2.30, Somma (Central Italy), Early Toarcian; **3.** *L. barozii*, sample MBE 2.60, Somma (Central Italy), Early Toarcian; **4.** *L. frodoi*, sample MBE 2.60, Somma (Central Italy), Early Toarcian; **5.** *L. hauffii*, sample MBE 2.30, Somma (Central Italy), Early Toarcian; **6.** *L. hauffii*, sample MBE 2.30, Somma (Central Italy), Early Toarcian; **7.** *L. sigillatus*, sample FLE 23.75, Fiuminata (Central Italy), Early Aalenian; **8.** *L. sigillatus*, sample MBE 2.60, Somma (Central Italy), Early Toarcian; **9.** *L. crucicentralis*, sample MBE 2.60, Somma (Central Italy), Early Toarcian; **10.** *L. crucicentralis*, sample FLE 23.75, Fiuminata (Central Italy), Early Aalenian; **11.** *L. velatus*, sample FLE 25.10, Fiuminata (Central Italy), Early Aalenian; **12.** *L. velatus*, sample FLE 25.10, Fiuminata (Central Italy), Early Aalenian; **13.** *Calyculus* sp. ind., sample MBE 2.30, Somma (Central Italy); **14.** *Calyculus* sp. ind., sample MBE 2.60, Somma (Central Italy); **15.** *C. superbus*, sample FLE 25.10, Fiuminata (Central Italy), Early Aalenian; **16.** *D. striatus*, sample FLE 23.75, Fiuminata (Central Italy), Early Aalenian; **17.** *D. ignotus*, sample FLE 25.10, Fiuminata (Central Italy), Early Aalenian; **18.** *D. ignotus*, sample MBE 2.30, Somma (Central Italy), Early Toarcian; **19.** *D. striatus*, sample FLE 23.75, Fiuminata (Central Italy), Early Aalenian; **20.** *D. striatus*, sample FLE 25.10, Fiuminata (Central Italy), Early Aalenian.


1. *B. dubium*

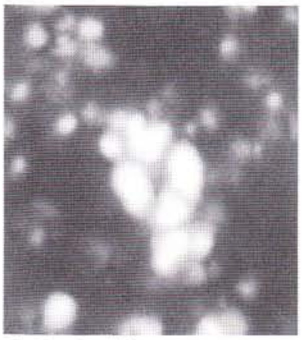

2. *B. grande*

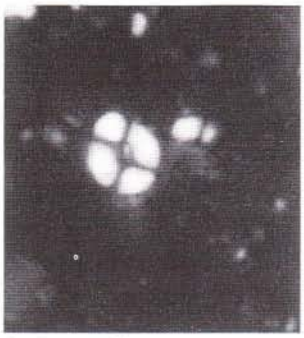

3. *L. barozii*


4. *L. frodoi*


5. *L. hauffii*


6. *L. hauffii*

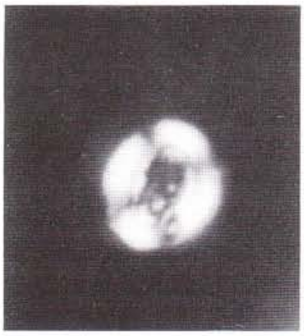

7. *L. sigillatus*

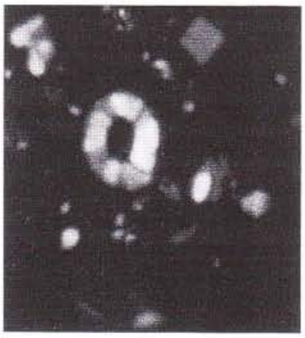

8. *L. sigillatus*


9. *L. crucicentralis*


10. *L. crucicentralis*


11. *L. velatus*


12. *L. velatus*

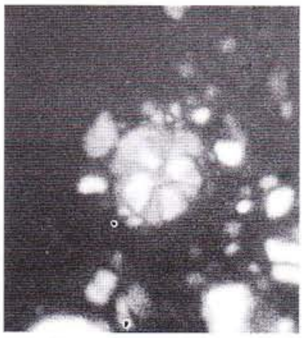

13. *Calyculus* sp. ind.

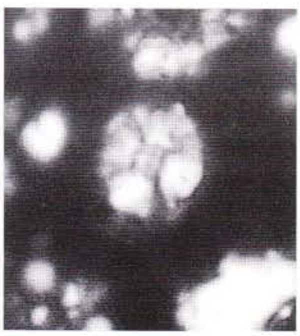

14. *Calyculus* sp. ind.


15. *C. superbus*


16. *D. striatus*


17. *D. ignotus*


18. *D. ignotus*


19. *D. striatus*


20. *D. striatus*

NJT 5 - *Lotharingius hauffii* Zone

Author: Bown (1987b).

Definition: first occurrence of *Lotharingius hauffii* to the first occurrence of *Carinolithus superbus.*

Age: Late Pliensbachian to Early Toarcian.

Comments: A progressive increase in abundance and species richness marks the Pliensbachian/Toarcian boundary.

NJT 5a - *Biscutum finchii* Subzone

Author: defined here.

Definition: first occurrence of *Lotharingius hauffii* to the first occurrence of *Lotharingius sigillatus.*

Age: Late Pliensbachian to earliest Toarcian.

Reference section: Pozzale section, Umbria-Marche Apennines (Mattioli, 1995).

Comments: This subzone corresponds to the NJ 5a and part of the NJ 5b Subzones of Bown (1987b). *L. umbriensis*, *L. frodoi*, *L. barozii*, *B. prinsii*, *B. leufuensis* and *S. lowei* first occur in this subzone. Subzone NJT 5a roughly corresponds to the *spinatum* ammonite Zone.

NJT 5b - *Lotharingius sigillatus* Subzone

Author: defined here.

Definition: first occurrence of *Lotharingius sigillatus* to the first occurrence of *Carinolithus superbus.*

Range: Early Toarcian, *tenuicostatum* Zone.

Reference section: Pozzale section, Central Italy (Mattioli, 1995).

Comments: This subzone corresponds to the upper part of the NJ 5b Subzone and the base of the NJ 6 Zone of Bown (1987b). *L. crucicentralis* first appears in the Early Toarcian. In this subzone also the first appearence of the genus *Carinolithus* is observed, with *C. cantaluppii* and *C. poulnabronei*. The assemblages become richer and more diversified.

Associated species: *Schizosphaerella* spp., *L. hauffii*, *Calyculus* spp., *L. sigillatus*, *L. crucicentralis*, *L. barozii*, *C. crassus*, *C. cavus*, *M. jansae*, *B. novum*, *B. finchii*, *B. grande*, *B. prinsii*, *B. leufuensis* and *S. lowei*.

NJT 6 - *Carinolithus superbus* Zone

Author: Bown (1987b).

Definition: first occurrence of *Carinolithus superbus* to the first occurrence of *Discorhabdus striatus.*

Age: Early Toarcian (*tenuicostatum* to *serpentinus* Zones).

Comments: This zone is correlative of the NJ 6 Zone of Bown (1987b). *L. velatus*, *D. ignotus*, *W. colacicchii* and *W. fossacincta* first occur in this zone. Conversely, some typical representatives of Early Jurassic assemblages, such as *M. jansae*, disappear. *Calyculus* spp. is a characteristic constituent of this zone, whereas *C. superbus* is still quite rare.

Associated species: *Schizosphaerella* spp, *Calyculus* spp., *B. finchii*, *L. sigillatus*, *L. crucicentralis*, *L. velatus*, *L. barozii*, *C. crassus*, *C. cavus*, *M. jansae*, *B. novum*, *B. finchii*, *B. grande*, *S. lowei*, *C. superbus* and *D. ignotus*.

NJT 7 - *Discorhabdus striatus* Zone

Author: Bown (1987b).

Definition: first occurrence of *Discorhabdus striatus* to the first occurrence of *Retecapsa incompta.*

Age: Early Toarcian (*serpentinus* Zone) to Late Toarcian (*meneghinii* Zone).

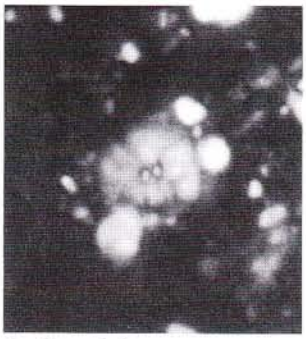
Comments: This zone first introduced by Bown (1987b) as *D. ignotus* Zone, was successively named *D. striatus* Zone in Bown et al. (1988), who considered *D. ignotus* as a synonim of *D. striatus*. In this paper some diagnostic characters, allowing the distinction between these two species are described, and a different stratigraphic distribution is also discussed. In this zone *C. superbus* becomes common and *D. criotus*, *B. depravatus* and *T. sullivanii* first occur. *C. cantaluppii*, *M. lenticularis* and small specimens of *Calyculus* spp. disappear.

Associated species: *Schizosphaerella* sp., *Calyculus* spp., *L. hauffii*, *L. sigillatus*, *L. crucicentralis*, *L. velatus*, *L. barozii*, *C. crassus*, *D. ignotus*, *B. novum*, *B. finchii*, *B. grande*, *C. superbus*, *D. ignotus*, *D. striatus*, *W. fossacincta*.

PLATE 3

All light micrographs crossed nicols, approximately X 3000.

1. *D. criotus*, sample FLE 23.75, Fiuminata (Central Italy), Early Aalenian; **2.** *D. criotus*, sample FLE 25.10, Fiuminata (Central Italy), Early Aalenian; **3.** *D. criotus*, sample FLE 25.10, Fiuminata (Central Italy), Early Aalenian; **4.** *R. incompta*, sample DB2 130, Digne (South France), Early Bajocian; **5.** *B. depravatus*, sample DB2 130, Digne (South France), Early Bajocian; **6.** *W. colacicchii*, sample FLE 25.10, Fiuminata (Central Italy), Early Aalenian; **7.** *W. contracta*, sample DB2 130, Digne (South France), Early Bajocian; **8.** *W.* aff. *contracta*, sample DB2 130, Digne (South France), Early Bajocian; **9.** *W. britannica*, sample DB2 130, Digne (South France), Early Bajocian; **10.** *W. britannica*, sample DB2 130, Digne (South France), Early Bajocian; **11.** *W. fossacincta*, sample FLE 25.10, Fiuminata (Central Italy), Early Aalenian; **12.** *W. barnesae*, sample AUL 13, Aulfingen (South Germany), Late Oxfordian; **13.** *W. manivitae*, sample DB2 130, Digne (South France), Early Bajocian; **14.** *W. manivitae*, sample DB2 130, Digne (South France), Early Bajocian; **15.** *W. barnesae*, sample AUL 13, Aulfingen (South Germany), Late Oxfordian; **16.** *W. barnesae*, sample AUL 13, Aulfingen (South Germany), Late Oxfordian; **17.** *C. margerelii*, sample AUL 13, Aulfingen (South Germany), Late Oxfordian; **18.** *C. margerelii*, sample AUL 13, Aulfingen (South Germany), Late Oxfordian; **19.** *H. magharensis*, sample DB2 130, Digne (South France), Early Bajocian; **20.** *H. magharensis*, sample DB2 130, Digne (South France), Early Bajocian.



1. *D. criotus*

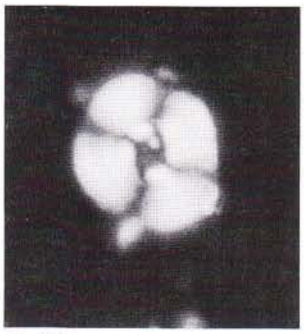
2. *D. criotus*

3. *D. criotus*

4. *R. incompta*

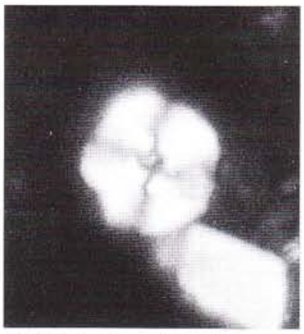
5. *B. depravatus*

6. *W. colacicchii*



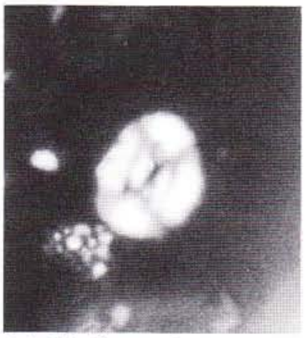
7. *W. contracta*

8. *W.* aff. *contracta*

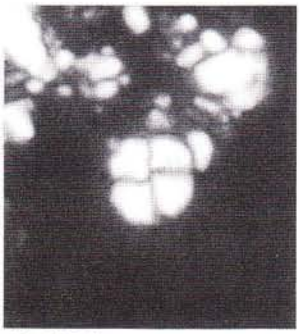


9. *W. britannica*

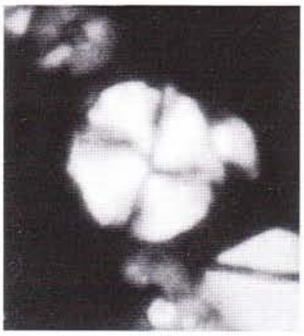
10. *W. britannica*



11. *W. fossacincta*



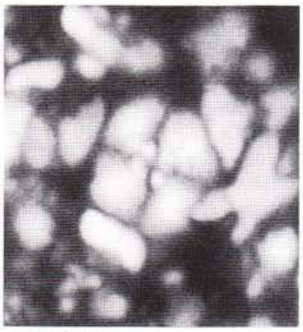
12. *W. barnesae*



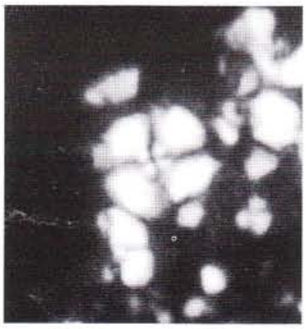
13. *W. manivitae*

14. *W. manivitae*

15. *W. barnesae*



16. *W. barnesae*



17. *C. margerelii*

18. *C. margerelii*

19. *H. magharensis*

20. *H. magharensis*

NJT 7a - *Discorhabdus striatus* Subzone

Author: defined here.

Definition: first occurrence of *Discorhabdus striatus* to the first occurrence of *Discorhabdus criotus.*

Age: Middle Toarcian (*bifrons* Zone) to Middle-Late Toarcian (*variabilis-insigne* Subzone).

Reference section: Colle d'Orlando section, Umbria-Marche Apennines (Parisi et al., 1998).

Comments: *Calyculus* spp. becomes rarer, while *C. superbus* and *D. ignotus* increase in abundance. The assemblages are occasionally dominated by Biscutaceae.

Associated species: *Schizosphaerella* spp., *L. crucicentralis*, *L. velatus*, *L. hauffii*, *C. crassus*, *D. ignotus*, *B. novum*, *B. finchii*, *B. grande*, *D. striatus*, *C. superbus*, *W. colacicchii* and *W. fossacincta.*

NJT 7b - *Discorhabdus criotus* Subzone

Author: defined here.

Definition: first occurrence of *Discorhabdus criotus* to the first occurrence of *Retecapsa incompta.*

Age: Middle-Late Toarcian (*variabilis-insigne* Subzone) to Late Toarcian (*meneghinii* Zone).

Reference section: Fiuminata section, Umbria-Marche Apennines (Mattioli, 1994).

Comments: the FO of *R. incompta* (Late Toarcian) is recorded in this zone characterized by common *D. ignotus* and *D. striatus.*

Associated species: *Schizosphaerella* spp., *L. crucicentralis*, *L. velatus*, *L. hauffii*, *C. crassus*, *B. novum*, *B. finchii*, *B. grande*, *D. striatus*, *D. ignotus*, *W. colacicchii* and *C. superbus.*

NJT 8 - *Retecapsa incompta* Zone

Author: Bown et al. (1988; *B. intermedium* Zone), emended here. Name first used for the NJ 8a Subzone of Bown et al. (1988).

Definition: first occurrence of *R. incompta* to the first occurrence of *Watznaueria britannica*.

Age: Late Toarcian (*meneghinii* Zone) to latest Aalenian (*concavum* Zone).

Reference section: Colle d'Orlando section, Umbria-Marche Apennines (Parisi et al., 1998).

Comments: *D. ignotus* and *D. striatus* are commonly found. This zone is correlative of the NJ 8 Zone of Bown et al. (1988).

Associated species: *Schizosphaerella* spp., *L. crucicentralis*, *L. velatus*, *L. hauffii*, *C. crassus*, *B. novum*, *B. finchii*, *B. grande*, *D. striatus*, *D. ignotus*, *W. colacicchii* and *C. superbus.*

NJT 8a - *Retecapsa incompta* Subzone

Author: Bown et al. (1988).

Definition: first occurrence of *Retecapsa incompta* to the first occurrence of *Watznaueria contracta.*

Age: Late Toarcian (*meneghinii* Zone) to Early Aalenian (*opalinum* Zone).

Comments: this subzone comprises the Toarcian/Aalenian boundary. *R. incompta* is a quite rare species and its occurrence is subordinated to the preservation of different lithotypes. *L. velatus* and species belonging to the genus *Watznaueria* become frequent. Early Jurassic species display limited abundances.

NJT 8b - *Watznaueria contracta* Subzone

Author: Bown et al. (1988), emended here.

Definition: first occurrence of *Watznaueria contracta* to the first occurrence of *Cyclagelosphaera margerelii.*

Age: Early Aalenian (*opalinum* Zone) to Middle Aalenian (*murchisonae* Zone).

Reference section: Colle d'Orlando section, Umbria-Marche Apennines (Parisi et al., 1998).

Comments: *H. magharensis* first appears in this interval. The diversity slightly diminishes with respect to the previous zone. *L. hauffii* becomes less abundant, *D. ignotus* and *D. striatus* are common, and various species of the genus *Watznaueria* begin to be predominant. This subzone corresponds to the upper part of the NJ 8a Subzone and lower part of NJ 8b Subzone of Bown et al. (1988).

Associated species: *Schizosphaerella* spp., *L. crucicentralis*, *L. velatus*, *D. ignotus*, *D. striatus*, *D. criotus*, *W. contracta*, *W. colacicchii*, and *C. superbus.*

NJT 8c - *Cyclagelosphaera margerelii* Subzone

Author: defined here.

Definition: first occurrence of *Cyclagelosphaera margerelii* to the first occurrence of Watznaueria *britannica.*

Range: Middle Aalenian (*murchisonae* Zone) to Late Aalenian (*concavum* Zone).

Reference section: Colle d'Orlando section, Umbria-Marche Apennines (Parisi et al., 1998).

Comments: this zone marks the definitive transition to assemblages dominated by Watznaueriaceae. Subzone NJT 8c corresponds to part of the NJ 8b Subzone of Bown et al. (1988).

Associated species: *Schizosphaerella* spp., *L. velatus*, *D. ignotus*, *D. striatus*, *D. criotus*, *W. contracta*, *W. colacicchii*, *C. margerelii* and *C. superbus.*

NJT 9 - *Watznaueria britannica* Zone

Author: Bown et al. (1988), emended here. *Watznaueria britannica* (or synonyms) was previously used as biozonal marker by Barnard & Hay (1974), Thierstein (1976), Hamilton (1979; 1982), Medd (1982) and Bown et al. (1988). This zone is comparable to the homonymous zone of Bown et al. (1988).

Definition: first occurrence of *Watznaueria britannica* to the first occurrence of *Watznaueria manivitae.*

Age: latest Aalenian (*concavum* Zone) to Early Bajocian (*laeviuscula* Zone).

Reference section: Presale section, Umbria-Marche Apennines Baldanza et al., 1990).

Comments: *W. britannica* can be considered as a good marker for the Aalenian/Bajocian boundary. In this zone *W. communis*, *Watznaueria* aff. *W. contracta* and *Watznaueria* aff. *W. manivitae* first occur. The assemblages become completely dominated by species of the genus *Watznaueria*. The correlations between Tethyan and Boreal nannofossil zones become more difficult because of marked provincialism. The species used as zonal markers in the Boreal domain are sporadically found or virtually absent in the studied sections. Zone NJT 9 is corretabale the upper part of the NJ 8 Zone and to the entire NJ 9 Zone of Bown et al. (1988).

Associated species: *Schizosphaerella* spp., *L. velatus*, *D. ignotus*, *D. striatus*, *D. criotus*, *W. contracta*, *W. colacicchii*, *C. margerelii*, *W. britannica*, *W. communis* and *C. superbus*.

NJT 10 - *Watznaueria manivitae* Zone

Author: Reale et al. (1991), emended here.

Definition: first occurrence of *Watznaueria manivitae* to the first occurrence of *Watznaueria barnesae*.

Age: late Early Bajocian to earliest Bathonian (*zigzag* Zone).

Reference section: Terminilletto section, central Apennines (Bartolini et al., 1995).

Comments: this zone corresponds to a very long time interval and is calibrated in the examined sections with radiolarian Unitarian Association Zones (Bartolini et al., 1995). Zone NJT 10 is correlative of the NJ 10 Zone of Bown et al. (1988)

Associated species: *W. contracta*, *W. colacicchii*, *C. margerelii*, *W. britannica*, *W. communis* and *W. manivitae*.

NJT 10a - *Watznaueria manivitae* Subzone

Author: defined here.

Definition: first occurrence of *Watznaueria manivitae* to the last occurrence of *Carinolithus superbus*.

Age: Early Bajocian (*laeviuscula* Zone) to early Late Bajocian (*subfurcatum* Zone).

Reference section: Digne area, Southern France (Erba, 1990).

Comments: this subzone is comparable to the lower part of the NJ 10 Zone of Bown et al. (1988).

NJT 10b - *Watznaueria communis* Subzone

Author: defined here.

Definition: last occurrence of *Carinolithus superbus* to the first occurrence of *Watznaueria barnesae*.

Range: Late Bajocian to earliest Bathonian (*zigzag* Zone).

Reference section: Digne area, Southern France (Erba, 1990).

Comments: In this subzone *H. magharensis* disappears. This subzone corresponds to the upper part of the NJ 10 Zone and the lower part of the NJ 11 Zone of Bown et al. (1988). The species used for defining Zones NJ 10 and NJ 11 (Bown et al., 1988) are extremely rare or absent in Tethyan sections, whereas the markers of Subzone NJT 10b are common both in Tethyan and Boreal areas and constitutes a potential tool for correlations.

NJT 11 - *Watznaueria barnesae* Zone

Author: defined here.

Definition: first occurrence of *Watznaueria barnesae* to the first occurrence of *Cyclagelosphaera wiedmannii*.

Age: Bathonian.

Reference section: Terminilletto section, central Appennines (Bartolini et al., 1995).

Comments: *Watznaueria barnesae* is an easily identifiable species and dominates the assemblages. The duration of this zone is quite long. Zone NJT 11 is comparable to most of the NJ 11 Zone and NJ 12a Subzone of Bown et al. (1988). The lowermost part of Zone NJT 11 is marked by a strong decrease of all the species of the genus *Discorhabdus*.

Associated species: *W. barnesae*, *W. contracta*, *W. colacicchii*, *C. margerelii*, *W. britannica*, *W. communis* and *W. manivitae*.

Discussion.

The proposed biozonation scheme is based on Tethyan sections and is aimed to overcome the difficulties in applying to such areas the zonal schemes proposed for the Boreal domain. The nannofossil events choosen as biomarkers in the Boreal domain are often scarce or absent in Tethyan sections, due to palaeoprovincialism and to the poor preservation of several lithotypes (es. Calcari Diasprigni).

The resolution of the proposed biozonation is affected by the nannoplankton evolution in the Jurassic. Periods of rapid speciation, such as the Domerian/Toarcian and Aalenian/Bajocian boundary intervals, alternated with periods of relative evolutionary stasis, such as the Early Pliensbachian and the Bathonian-Kimmeridgian time intervals. Variable evolutionary rates are therefore responsible for a non uniform biostratigraphic resolution of calcareous nannofossils in the Jurassic. As illustrated in Figs. 12 and 13, some time intervals display an extremely high resolution. In the Late Domerian-Early Bajocian interval, several nannofossil zones or subzones have a duration shorter than one ammonite zone, and are shorter than 1 My. On the contrary, in intervals with low evolutionary rates zones and subzones are much longer and their duration is of a few million years. Despite the low stratigraphic resolution provided by nannofossils for the aforementioned intervals, nannofossil biostratigraphy is still important because ammonites are scarce or absent and nannofossils virtually constitute the only biostratigraphic tool available.

The nannofossil scheme here proposed has been directly calibrated with ammonite biostratigraphy and several zonal and subzonal boundaries correspond to chronostratigraphic boundaries. For example, the Domerian/Toarcian boundary is well defined by the base of the NJT 5b Subzone; the Early/Middle Toarcian boundary coincides with the base of the NJT 7a Subzone; the beginning of the Late Toarcian corresponds to the base of the NJT 7b Subzone; the Toarcian/Aalenian boundary lies within the very short NJT 8b Subzone; the Aalenian/Bajocian is marked by the *Watzanueria* speciation and is identifiable with the base of the NJT 9 Zone; the Early /Late Bajocian boundary corresponds to the base of the NJT 10 Zone; the lower and upper boundaries of the NJT 11 Zone are correlatable with base and top of the Bathonian.

The comparison between the Tethyan nannofossil scheme here proposed and the biozonation for the Boreal Realm (Bown et al., 1988) shows a high correlability (Fig. 12). Therefore, the proposed biostratigraphy represents a potential tool for correlation among different palaeogeographic domains. Moreover, in the Early and Middle Jurassic the stratigraphic resolution of the proposed bioscheme is very high and comparable to other proposed nannofossil biozonations (Figs. 12 and 13); conversely, for the late Middle Jurassic the detail provided by the scheme of Bown et al. (1988) is higher.

Conclusions.

The biostratigraphic synthesis here proposed for the Mediterranean Province is compared to recent schemes compiled for Portugal, Morocco and Switzerland (de Kaenel et al., 1996) and the Boreal Realm (Bown et al., 1988; Bown, 1996) (Figs. 12 and 13). Such a comparison is not always easy, due to different reasons: 1) in most papers, range charts displaying relative abundances and occurrences of single taxa are often lacking. This prevents an exhaustive comparison of abundances of different taxa and of assemblage composition between various areas; 2) stratigraphic logs with precise positions of ammonite and nannofossil biohorizons are often not published; 3) most papers do not describe the lithologies from which samples have been collected, therefore neither the preservation state nor the potential presence of resedimented beds can be evaluated; 4) a distinct paleoprovincialism in the ammonite fauna characterizes the entire Jurassic, preventing an unequivocal and independent check on the synchroneity of nannofossil events in different paleogeographic domains. It must be noted that the resolution achieved for Italy/France is very high, similar to that documented for Portugal and much higher than the resolution obtained in the other areas. The Sinemurian and Bathonian are characterized by low resolution, but very few sections with ammonite control and/or favourable lithology are available for an improvement of the nannofossil biostratigraphy.

We highlighted (in bold) the nannofossil events reproducible in various areas and allowing inter-regional correlations (Fig. 13). Some events appear to be diachronous, but we believe that most discrepancies are biased by different ammonite biostratigraphies applied in different areas. The LOs are in general more diachronous than the FOs, probably due to reworking phenomena (and therefore to apparent diachronism) and/or to the survival of taxa in particular micro-environments.

The major differences in type and number of nannofossil events occur in the Bajocian-Bathonian interval. In fact, calcareous nannofloras show a very different assemblage composition essentially due to preservation. In the studied sections, diagenesis-resistant taxa dominate and after the major speciation of the *Watznaueria* group at the Aalenian/Bajocian boundary, very few events were detected. In contrast, in the Submediterranean Province and in the Boreal Realm better preserved nannofloras are dominated by delicate forms showing high rate of speciation in the Bajocian-Bathonian.

The present study highlights the importance of calcareous nannofossil biostratigraphy in the Lower and Middle Jurassic and shows the high resolution achievable for intra- and inter-regional correlations.

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Appendix 1

Index of cited species

Genus *Biscutum* Black in Black & Barnes, 1959
Biscutum depravatus (Grün & Zweili, 1980) Bown, 1987b
Biscutum dubium (Noël, 1965) Grün in Grün et al., 1974
Biscutum finchii (Crux, 1984) Bown, 1987
Biscutum grande Bown, 1987b
Biscutum novum (Goy, 1979) Bown, 1987b

Genus *Bussonius* Goy, 1979
Bussonius prinsii (Noël, 1973) Goy, 1979
Bussonius leufuensis Bown & Kielbowicz, 1987 in Bown, 1987b

Genus *Calyculus* Noël, 1973
Calyculus sp. indet.

Genus *Carinolithus* (Prins in Grün et al., 1974) Bown, 1987b
Carinolithus cantaluppii Cobianchi, 1990
Carinolithus poulnabronei Mattioli, 1996
Carinolithus superbus (Deflandre, 1954) Prins in Grün et al., 1974

Genus *Crepidolithus* Noël, 1965
Crepidolithus cavus Rood, Hay & Barnard, 1973
Crepidolithus crassus (Deflandre, 1954) Noël, 1965
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Genus *Cyclagelosphaera* Noël 1965
Cyclagelosphaera margerelii Noël, 1965
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Genus *Discorhabdus* Noël, 1965
Discorhabdus criotus Bown, 1987b
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Genus *Lotharingius* Noël, 1973 emend. Goy, 1979
Lotharingius barozii Noël, 1973
Lotharingius crucicentralis (Medd, 1971) Grün & Zweili, 1980
Lotharingius umbriensis Mattioli, 1996
Lotharingius frodoi Mattioli, 1996
Lotharingius hauffii Grün & Zweili in Grün et al., 1974
Lotharingius sigillatus (Stradner, 1961) Prins in Grün et al., 1974
Lotharingius velatus Bown & Cooper, 1989

Genus *Mazaganella* Bown, 1987b
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Genus *Mitrolithus* (Deflandre, 1954) Bown & Young, 1986
Mitrolithus jansae (Wiegand, 1984) Bown & Young in Young et al., 1986
Mitrolithus elegans Deflandre, 1954
Mitrolithus lenticularis Bown, 1987b

Genus *Parhabdolithus* Deflandre, 1952
Parhabdolithus liasicus Deflandre, 1952
Parhabdolithus robustus Noël, 1965

Genus *Retecapsa* Black, 1971
Retecapsa incompta Bown & Cooper, 1989

Genus *Similiscutum* de Kaenel & Bergen, 1993
Similiscutum avitum de Kaenel & Bergen, 1993
Similiscutum cruciulus de Kaenel & Bergen, 1993
Similiscutum orbiculus de Kaenel & Bergen, 1993

Genus *Sollasites* Black, 1967
Sollasites lowei (Bukry, 1969) Rood et al., 1971

Genus *Triscutum* Dockerill, 1987
Triscutum sullivanii De Kaenel & Bergen, 1993

Genus *Tubirhabdus* Prins ex Rood, Hay & Barnard, 1973
Tubirhabdus patulus Reinhardt, 1965

Genus *Watznaueria* Reinhardt 1964
Watznaueria barnesae (Black in Black & Barnes,1959) Perch-Nielsen, 1968
Watznaueria britannica (Stradner, 1963) Reinhardt, 1964
Watznaueria colacicchii Mattioli, 1996
Watznaueria communis Reinhardt, 1964
Watznaueria contracta (Bown & Cooper, 1989) Cobianchi, Erba e Pirini Radrizzani, 1992
Watznaueria aff. *W. contracta* Erba, 1990
Watznaueria fossacincta (Black, 1971) Bown in Bown & Cooper, 1989
Watznaueria manivitae Bukry, 1973
Watznaueria aff. *W. manivitae* Cobianchi, Erba & Pirini Radrizzani, 1992

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Genus *Hexalithus* Gardet, 1955
Hexalithus magharensis Moshkovitz & Ehrlich, 1976

Genus *Schizosphaerella* Deflandre & Dangeard, 1938
Schizosphaerella punctulata Deflandre & Dangeard, 1938