

RELATIONSHIPS BETWEEN FORAMINIFERAL ASSEMBLAGES AND DEPOSITIONAL SEQUENCES IN THE MERLI EST SECTION (FIGOLS ALLOGROUP - SOUTH-CENTRAL PYRENEES - LOWER EOCENE)

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Key-words: Sequence stratigraphy, Foraminifera, Eocene, Spain.

Riassunto. Nel presente lavoro sono illustrate le relazioni tra le sequenze deposizionali e le associazioni a foraminiferi nella Sezione Merli Est. Questa sezione fa parte dell'Allogrupo di Figols che rappresenta una parte del riempimento terziario del Bacino Eocenico di Tremp-Pamplona (BETP, Pirenei centro-meridionali, Spagna) che si sviluppò dal Paleocene superiore all'Eocene superiore. L'Allogrupo di Figols rappresenta una sequenza deposizionale a grande scala di età ilderdiana; al suo interno sono state distinte sequenze deposizionali di 3° (FG1, FG2, FG3 e FG4), 4° e 5° ordine.

Le oscillazioni eustatiche del livello del mare che causano la deposizione di sedimenti sotto forma di sequenze deposizionali, influenzano in larga misura anche alcuni parametri biologici; le conseguenti variazioni all'interno delle associazioni a foraminiferi bentonici possono essere utilizzate per interpretare e riconoscere le sequenze deposizionali.

I parametri paleontologici mostrano un abbassamento del livello del mare dalla base al tetto della sezione; i limiti tra le quattro sequenze deposizionali a grande scala sono indicati da variazioni nell'associazione in cui i foraminiferi bentonici di acque più profonde diminuiscono e gli indicatori di acque più basse aumentano. La variazione più evidente della associazione a foraminiferi si osserva al limite FG2/FG3 ed indica un importante abbassamento del livello del mare.

All'interno delle sequenze deposizionali, inoltre, sono stati riconosciuti diversi trend di variazione nelle associazioni per quanto riguarda i Transgressive Systems Tract (TST) e gli Highstand Systems Tract (HST).

Abstract. This paper illustrates the relationships between sequence stratigraphy and foraminiferal assemblages in the Merli Est Section. This section belongs to the Figols Allogroup that represents part of the Tertiary infilling of the Eocene Tremp-Pamplona Basin (BETP, south-central Pyrenees, Spain) that developed from the Late Paleocene to the Late Eocene. The Figols Allogroup is a large-scale depositional sequence, Ilerdian in age; in it 3rd (named FG1, FG2, FG3, and FG4), 4th and 5th order depositional sequences have been recognized.

The eustatic variations largely influence some biological parameters; the relative changes in benthic foraminiferal assemblage can be used for interpreting and detect the depositional sequences.

The paleontological parameters show a shallowing of the water depth from the base to the top of the section. The boundaries between the four large-scale depositional sequences are marked by variations in foraminiferal assemblages in which deeper-water benthic foraminifera decrease and shallower-water foraminifera increase in abundance. The major change in the foraminiferal assemblages occurs

at the FG2/FG3 boundary indicating a remarkable sea-level fall. Within the depositional sequences, different trends in the Transgressive System Tract (TST) and in the Highstand System Tract (HST) were also recognized.

Introduction.

The foraminiferal assemblage response to eustasy-driven sea level variations is the main objective of this paper. Sea level variations have their sedimentological response in the depositional sequences, each of which consists of a stacking pattern of systems tracts (Posamentier et al., 1988). Depositional sequences are the response to sea level oscillations, and different water depths are responsible for great variations in the marine environment, mainly on the shelf which is shallower.

Palaeoenvironmental interpretation of the faunal assemblages is based on the assumption that similar assemblages indicate similar environmental conditions. There are many factors that influence the faunal assemblage (e.g. salinity, water depth, nutrients): the depth variation is considered the most important one. Generally, benthic faunas are considered the most useful for environmental considerations; foraminifera for their wide distribution and palaeoenvironmental meaning provide useful information on the depositional sequences and palaeoecology. The foraminiferal assemblage variations make it possible to recognize the large- and small-scale depositional sequences and the internal systems tracts (mainly TST and HST).

This paper illustrates the relationships between sequence stratigraphy and foraminiferal assemblages in the Merli Est Section; this section crops out in the south-central Spanish Pyrenees (Fig. 1) and belongs to the Eocene Figols Allogroup. This Allogroup is made up of four large scale depositional sequences subdivided into nine smaller-scale sequences as recognized by Carminatti

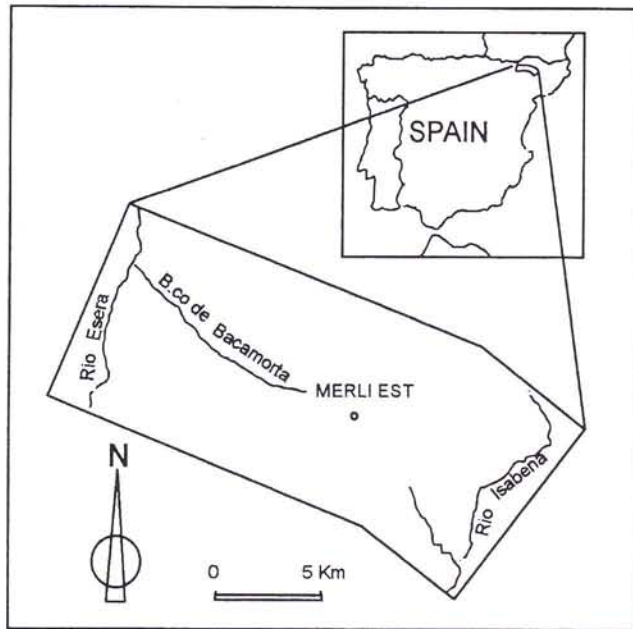


Fig. 1 - Location map of the studied area.

(1992), Gaboardi (1994) and Mutti et al. (1994). The investigated depositional sequences are made up only of TST and HST, the LST (Lowstand System Tract) being represented by erosional surfaces.

Stratigraphic Setting.

The Tremp-Pamplona Eocene Basin (BETP of Mutti et al., 1985) developed from the Late Paleocene to the Late Eocene and has been studied by many workers (e.g. Mutti et al., 1972; Njiman & Nio, 1975; Nio, 1976; Fonnesu, 1984; Nio et al., 1984; Puigdefabregas et al. 1985; Mutti et al., 1988; Yang & Nio, 1989; Crumeyrolle et al., 1990; Lopez Blanco et al., 1991; Nio & Yang, 1991; Carminatti, 1992; Mutti et al., 1994). The Figols Allogroup represents part of the infilling of the BETP; it is Ilerdian in age and has a duration of about 2.7 m.y. (Carminatti & Villa, 1993). It is made up of a fluvio-deltaic depositional system that grades westward into a predominantly shelfal mudstone succession and associated shelfal and shallow-water carbonates. Many studies have been carried out on the subdivision of the sedimentary succession of BETP; here the subdivision of Mutti et al. (1988) based on the concept of depositional sequence is utilized. As defined by Mutti et al. (1994), each allogroup consists of one or more large-scale composite depositional sequences and the boundary of each allogroup coincides with the boundaries of their component depositional sequences. These Authors recognized six allogroups; from the oldest one they are: Alveolina Limestones Group (Late Paleocene-Early Eocene), Figols Group (Early Eocene), Castigaleu Group (Early Eocene),

Santa Liestra Group (Middle Eocene), and Campodarbe Group (Middle to Late Eocene).

The Figols Allogroup was subdivided into sequence-stratigraphic units within a hierarchical framework strictly based on the relative physical scale of these units regardless of their duration (Mutti, 1989).

The Figols Allogroup, bounded by regional unconformities, was subdivided in many different ways in the past; the present subdivision of the allogroup is based both on field data (Carminatti, 1992; Mutti et al., 1994) and on micropaleontological data (Gaboardi, 1994; Gaboardi et al., 1994). Based on the present subdivision, the Figols Allogroup consists of four large-scale composite depositional sequences which, in ascending stratigraphic order, are named Figols 1 (FG1), Figols 2 (FG2), Figols 3 (FG3) and Figols 4 (FG4) (Mutti et al., 1994) (Fig. 2). These sequences are essentially 3rd order features (large-scale composite depositional sequences) (Mutti et al., 1994). The vertical succession of the Figols strata indicates that the FG3 and FG4 sequences record a marked shallowing of the basin, associated with basin widening (Mutti et al., 1994). This assumption is supported by the foraminiferal assemblages which show an abrupt change at the boundary between FG2 and FG3 sequences (see forward).

Each of these sequences is further subdivided into smaller-scale sequences (small-scale composite depositional sequences) which are the expression of a high-frequency cyclicity in terms of relative sea-level variations. Nine small-scale depositional sequences, named Unit 1 to 9, were recognized (Carminatti, 1992; Mutti et al., 1994). Large-scale depositional sequence FG1 includes Units 1, 2, and 3; FG2 coincides with Unit 4; FG3 comprises Units 5 and 6; the last sequence FG4 comprehends Units 7, 8, and 9 (Fig. 2).

The studied section is situated in the Huesca province, near the Merli village between the Rio Esera and the Rio Isabena (Fig. 1). Merli Est section is 765 m thick and spans the nine Units recognized in the Figols Allogroup.

Material and Methods.

The Merli Est section of Figols Allogroup was sampled in order to detect the cyclicity at different scales. Carminatti (1992) recognized many depositional sequences based on sedimentological characters; within this framework, sampling was carried out to detect the foraminiferal assemblage variations in the different systems tracts of large- and small-scale depositional sequences. The present analyses are based on foraminifera from 47 samples.

Samples of 400 g were disaggregated using H₂O₂ at low concentration, washed through a 63 µm sieve and dried. The micropa-

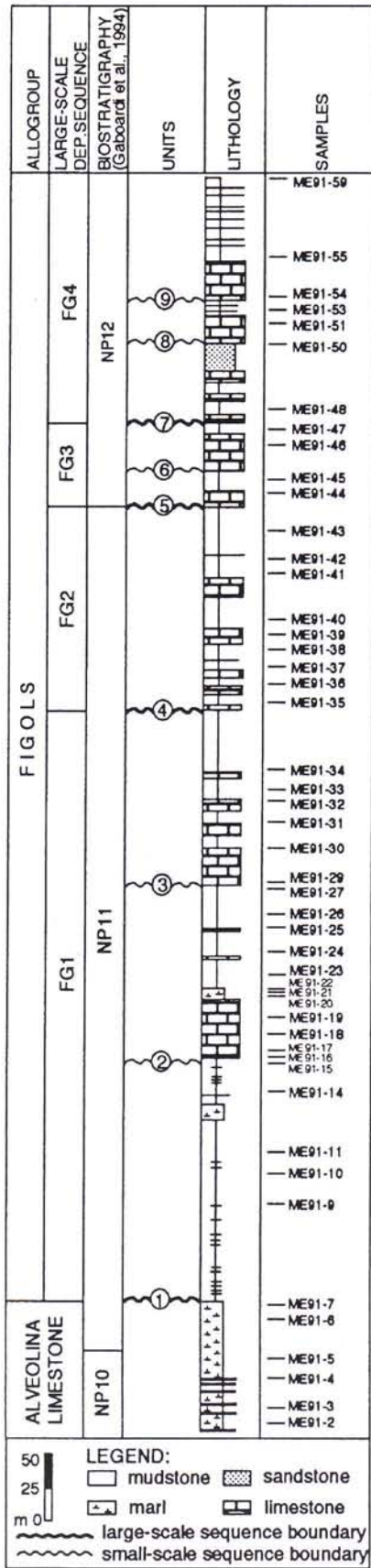


Fig. 2 - Lithostratigraphy of the Merli Est Section with the main subdivision of Figols Allogroup in large- and small-scale depositional sequences. The studied samples are also indicated.

leontological analyses were carried out on the fraction greater than 125 µm. Each sample was subdivided with a microsplitter many times in order to obtain about 300 specimens of benthic foraminifera which were picked and classified. Planktonic foraminifera, ostracods and test fragments were also counted. Because of bad preservation, planktonic foraminifera were considered as a group; for the same reason sometimes benthic specimens were identified only at generic level. Broken specimens are consistently present, so they were included in the counting when the identification was possible.

Miliolids were considered as a group; porcellaneous tests are less resistant to dissolution than the hyaline ones, so most of the porcellaneous specimens in Merli Est samples are represented only by internal casts with fragments of test. Miliolids are constituted mainly by *Quinqueloculina*, *Triloculina* and *Pentellina*, but often the identification even at generic level was prevented.

All the larger foraminiferal tests are broken; because of the preservation and because the study was carried out on washed samples and not on thin section, the larger foraminifera were subdivided only at generic level. Juvenile specimens of larger foraminifera were not identified because the external shape does not show the characters useful for classification, so they were considered as a group.

The detailed study on genera and species was made through a quantitative analysis and the classification is indicated below. Palaeoecological meanings of these taxa are described in the palaeoecological notes at the end of the work.

The following parameters were utilized:

- shallow to deep-water foraminiferal taxa variation in abundance: variations in percentage of many species, genera and/or groups were considered in order to detect water depth fluctuations. According to many Authors (e.g. Berggren, 1972; Sliter & Baker, 1972; Pujos, 1972; Berggren & Aubert, 1975; Blanc-Vernet & Clairefond, 1979-80; Grünig & Herb, 1984; Luterbacher, 1984; Elser, 1984; van Morkhoven et al., 1986; Murray, 1991), some of the most significant deep-water indicators are *Cibicidoides perlucidus*, *C. ungerianus*, *C. pseudoungerianus*, *C. acutimargo*, *Loxostomoides* gr. *applinae*, *Praeglobbulimina* gr. *ovata*, *Spiroplectammina*, *Gyroidinoides*, *Anomalinoidea*, and *Nodosariacea* (*Lenticulina*, *Marginulina*, *Dentalina*, *Lagena*, etc.). According to Ferrer et al. (1973), Aubert & Berggren (1973), Elser (1984), Luterbacher (1984), and Murray (1991), the most significant shallow-water indicators are considered the larger foraminifera (e.g. *Nummulites*, *Assilina*, *Discocyclina*), *Rotalia*, *Pararotalia*, the *Neoepionides* group, *Asterigerina*, the *Bulimina trigonalis* group, and *Cibicides carinatus*.

- variations in abundance of planktonic foraminifera: because planktonic foraminifera increase in abundance with the distance from the shoreline, we assumed the highest value of planktonic foraminiferal abundance as a signal of maximum deepening.

- species diversity: the diversity value represents the relationship of the number of species to the number of specimens in a given assemblage; it commonly increases with increasing water depth and distance from shore (Douglas, 1979). In this work the diversity was calculated through the Simpson's Index:

$$D = \frac{1}{\sum_{i=1}^S p_i^2}$$

in which "P_i" is the ratio between "n_i" and "N", "N" the total number of individuals, "n_i" the numbers of individuals of the ith species, and "S" the number of species.

In order to detect variations in water depth related to cyclicity, six groups of foraminifera were considered: planktonics, miliolids, agglutinants, larger foraminifera, the *Rotalia* group, and other calcareous perforate small benthic foraminifera. The *Rotalia* group includes the small-sized shallow-water indicators such as *Asterigerina*, *Cuvillierina*, the *Neoepionides* group, *Pararotalia*, and *Rotalia*.

Systematics.

- Adelosina* cf. *laevigata* d'Orbigny - Loeblich & Tappan, 1988. Specimens of the Merli Est Section differ from that illustrated by Loeblich & Tappan (1988) in having a less tapered neck.
- Alabamina midwayensis* Brotzen - Aubert & Berggren, 1976.
- Alabamina wilcoxensis* Toulmin - Applin, 1964.
- Allomorphina cretacea* Reuss - von Hillebrandt, 1962.
- Allomorphina halli* Jennings - Ferrer et al., 1973.
- Altastavella kochi* (Pijpers) - Loeblich & Tappan, 1988.
- Anmodiscus cretaceus* (Reuss) - Hulsbos et al., 1989.
- Anmodiscus planus* Loeblich, 1946.
- Anomalina* cf. *A. macraglabra* Finlay, 1940. The specimens of Merli Est Section differs from *A. macraglabra* in being more circular in outline.
- Anomalina grosserugosa* Gumbel - Graham & Classen, 1955.
- Anomalinoidea acuta* (Plummer) - Aubert & Berggren, 1976.
- Anomalinoidea affinis* (Hantken) - Bolli et al., 1994.
- Anomalinoidea* cf. *A. affinis* (Hantken). Some specimens differ from *A. affinis* in having an umbilical area not so depressed and in being less evolute of the holotype.
- Anomalinoidea alazanensis* (Nuttall) - AGIP, 1982.
- Anomalinoidea alazanensis spissiformis* Cushman & Stainforth - AGIP, 1982.
- Anomalinoidea bilateralis* (Cushman) - Bolli et al., 1994.
- Anomalinoidea "cushmani"*. The specimens assigned to this species have a general shape very similar to *Cibicides cushmani* Nuttall but exhibit the characters of the genus *Anomalinoidea*. The most typical character of these specimens is the large depression in the umbilical area.
- Anomalinoidea dorri aragonensis* (Nuttall) - Graham & Classen, 1955.
- Anomalinoidea flinti* (Cushman) - AGIP, 1982.
- Anomalinoidea* cf. *helicinus* (Costa) - AGIP, 1982. These specimens have less thickened sutures on the ventral side and a smoother surface than the holotype.
- Anomalinoidea nobilis* Brotzen - von Hillebrandt, 1962.
- Anomalinoidea praeacuta* Vasilenko - von Hillebrandt, 1962.
- Anomalinoidea* cf. *saitoi* Kaiho, 1992. The specimens of this group differs from *A. saitoi* in being less evolute.
- Anomalinoidea umbonifera* (Schwager) - Aubert & Berggren, 1976.
- Anomalinoidea* sp. A. Test small, circular to slightly ovate. Rounded periphery, 7-8 chambers in the last whorl; sutures curved in the last chambers. The last chamber is high on the ventral side.
- Astacolus gratus* (Reuss) - Nyong & Olsson, 1984.
- Asterigerina bartoniana* (Ten Dam) - Ferrer et al., 1973.
- Asterigerina* aff. *ferussaci* (d'Orbigny) - Ferrer et al., 1973. The specimens of the Merli Est section are very close to those that Ferrer et al. (1973) named *A. aff. ferussaci*.
- Baggina cojimarensis* Palmer, 1941.
- Brizalina* gr. A. The specimens assigned to this group are characterized by broad tests with ornamented surface.
- Brizalina* gr. B. The specimens of this group have elongate test and smooth wall.
- Buccella* (?) sp. The assignment to this genus is doubtful because of the bad preservation and the small size of the detected specimens.
- Bulimina alazanensis* Cushman - Tjalsma & Lohmann, 1983.
- Bulimina aspensis* Colom, 1954.
- Bulimina* gr. *trigonalis* Ten Dam - Aubert & Berggren, 1976. The specimens of the Merli Est section are very close to *Bulimina* gr. *trigonalis* of Aubert & Berggren (1976).
- Bulimina* sp. A. Specimens of this species are characterized by very small size, almost spherical shape and poorly incised sutures.
- Chilostomelloides eocenica* Cushman - Aubert & Berggren, 1976.
- Chilostomelloides oviformis* (Sherborn & Chapman) - Ferrer et al., 1973.
- Chrysalogonium longicostatum* Cushman & Jarvis - Beckmann, 1953.
- Cibicides acutus* Samoilova, 1947.
- Cibicides americanus* (Cushman) - Graham & Classen, 1955.
- Cibicides beadnelli* Le Roy, 1953.
- Cibicides burlingtonensis* Jennings - Hulsbos et al., 1989.
- Cibicides cantii* Haynes - Wood & Haynes, 1957.
- Cibicides carinatus* (Terquem) - Ferrer et al., 1973.
- Cibicides cassivellauni* Haynes - Wood & Haynes, 1957.
- Cibicides* cf. *C. cassivellauni* Haynes. *C. cf. cassivellauni* differs from *C. cassivellauni* in having larger size and larger perforations.
- Cibicides* cf. *cushmani* Nuttall - Cita, 1950. *C. cf. C. cushmani* differs from *C. cushmani* in the absence of the umbilical depression.
- Cibicides dubius* Bykova, 1959.
- Cibicides* aff. *C. howelli* Terquem - Ferrer et al., 1973. Specimens from the Merli Est Section are close to that detected by Ferrer et al. (1973) in southern Pyrenees; they have concave dorsal side with a little knob in the central area.
- Cibicides lobatulus* (Walker & Jacob) - Sztrákó, 1979.
- Cibicides mauricensis* Howe & Roberts - Graham & Classen, 1955.
- Cibicides megalcephalus* Pijpers, 1933.
- Cibicides megaloperforatus* Said & Kenawy, 1956.
- Cibicides praecursorius* (Schwager) - Said & Kenawy, 1956.
- Cibicides punjabensis* Haque, 1960.
- Cibicides reinholdi* Ten Dam, 1944.
- Cibicides rigidus* (Schwager) - Le Roy, 1953.
- Cibicides robustus* Le Calvez, 1949.
- Cibicides simplex* (Brotzen) - Sztrákó, 1979.
- Cibicides succedens* (Brotzen) - Aubert & Berggren, 1976.
- Cibicides suzakensis* Bykova, 1953.
- Cibicides ventratumidus* Myatliuk - Sztrákó, 1982.
- Cibicides westi* Howe - Grünig, 1985.
- Cibicides* sp. 2 - Ferrer et al., 1973.
- Cibicidoides atratiensis* (Tolmachoff) - Bolli et al., 1994.
- Cibicidoides bradyi* (Trauth) - van Morkhoven et al., 1986.
- Cibicidoides laurisiae* (Mallory) - van Morkhoven et al., 1986.
- Cibicidoides perlucidus* (Nuttall) - van Morkhoven et al., 1986.
- Cibicidoides proprius* Brotzen - Ferrer et al., 1973.
- Cibicidoides proprius acutimargo* Ten Dam - Ferrer et al., 1973.
- Cibicidoides pseudoungerianus* (Cushman) - Hulsbos et al., 1989.
- Cibicidoides ungerianus* (d'Orbigny) - Tjalsma & Lohmann, 1983.
- Clavulina angularis* d'Orbigny - Loeblich & Tappan, 1988.
- Clavulina columnatortilis* (d'Orbigny) - Ferrer et al., 1973.
- Clavulinoides trilatera* Cushman - Said & Kenawy, 1956.
- Coleites* aff. *C. reticulosus* (Plummer) - Ferrer et al., 1973.
- Conorboides mitra* (Hofker) - Loeblich & Tappan, 1988.
- Conorboides umiatensis* (Tappan) - Loeblich & Tappan, 1988.
- Cribrorobulina dicampyla* (Franzenau) - AGIP, 1982.
- Cristellaria mexicana* Cushman - Beckmann, 1953.

- Cristellaria occidentalis* Cushman - Beckmann, 1953.
- Cuvillierina* (?) *yarzai* (Ruiz de Gaona) - Ferrer et al., 1973.
- Dentalina* "canulina" Marie - Loeblich & Tappan, 1988. The specimens have the same characters of *Dentalinoides canulina*, but they have a *Dentalina*-like aperture.
- Dentalina communis* d'Orbigny - Said & Kenawy, 1956.
- Dentalina consobrina* d'Orbigny - Grünig, 1985.
- Dentalina havanensis* Cushman & Bermudez - Graham & Classen, 1955.
- Dentalina inornata* d'Orbigny - Kaiho, 1992.
- Dentalina leguminiformis* (Batsch) - AGIP, 1982.
- Dentalina* cf. *leguminiformis* (Batsch). These specimens differ from *D. leguminiformis* in having few chambers (maximum 5) and a small tail in the first chamber.
- Eponides frankiei* Brotzen - Ferrer et al., 1973.
- Eponides lunata* Brotzen - Kalantari, 1983.
- Eponides* cf. *E. lunata* Brotzen. The specimens differs from *E. lunata* in having higher and narrow chambers on dorsal side, mainly in the last whorl.
- Eponides ouachitaensis* Howe & Wallace - Ferrer et al., 1973.
- Fissurina laevigata* Reuss - Jones, 1984.
- Fissurina orbignyana* Seguenza - Grünig, 1985.
- Gaudryina pyramidata* Cushman - Tjalsma & Lohmann, 1983.
- Gavelinella danica* (Brotzen) - Tjalsma & Lohmann, 1983.
- Gavelinella micra* (Bermúdez) - Tjalsma & Lohmann, 1983.
- (?) *Gavelinopsis* Hofker - Loeblich & Tappan, 1988. The specimens grouped here have a general features of *Gavelinopsis*, but the assignment is doubtful because of the small size and the bad preservation of the tests.
- Glandulina laevigata* (d'Orbigny) - Said & Kenawy, 1956.
- Globocassidulina subglobosa* (Brady) - AGIP, 1982.
- Globulina gibba* d'Orbigny - Loeblich & Tappan, 1988.
- Guttulina communis* d'Orbigny - Beckmann, 1953.
- Guttulina lactea elongata* Haynes, 1958.
- Guttulina problema* (d'Orbigny) - Haynes, 1958.
- Gyroidina* sp. A. This species is very similar to *G. octocamerata*, but it has a very small size; the small size and the bad preservation prevented to define the number of the chambers.
- Gyroidinoides globosus* (Hagenow) - von Hillebrandt, 1962.
- Gyroidinoides planulata* (Cushman & Renz) - Beckmann, 1953.
- Gyroidinoides soldanii otocamerata* (Cushman & Hanna) - von Hillebrandt, 1962.
- Hanzawaia* cf. *ammophila* (Gümbel) - van Morkhoven et al., 1986. These specimens differs from *H. ammophila* in having larger sized tests.
- Hensonia tricarinata* Marie - Loeblich & Tappan, 1988.
- Heterolepa mexicana* (Nuttall) - AGIP, 1982.
- Hoeglundina eocenica* (Cushman & Hanna) - Grünig, 1985.
- Hoeglundina* sp. A. Test biconvex with dorsal side more convex than the ventral one; keeled lobate periphery with circular to faintly ovate outline. On the dorsal side are visible the last two whorls with eight chambers in the last whorl; the faintly recurved sutures are thickened and the central area is covered by shell material. The ventral side is characterized by straight sutures and an umbilical knob.
- Karrereria fallax* Rzehak - Ferrer et al., 1973.
- Lagena acuticosta* Reuss - Grünig, 1985.
- Lagena advena* Cushman - Beckmann, 1953.
- Lagena alveolata caudigera* Brady - Beckmann, 1953.
- Lagena gracilicosta* Reuss - Haynes, 1958.
- Lagena laevigata* (Reuss) - Beckmann, 1953.
- Lagena* gr. *striata* (d'Orbigny) - Grünig, 1985.
- Lagena sulcata* (Walker & Jacob) - Le Roy, 1953.
- Lenticulina crassa* (d'Orbigny) - AGIP, 1982.
- Lenticulina cultrata* (de Montfort) - Ferrer et al., 1973.
- Lenticulina curvisepata* (Seguenza) - AGIP, 1982.
- Lenticulina gibba* (d'Orbigny) - AGIP, 1982.
- Lenticulina inornata* (d'Orbigny) - AGIP, 1982.
- Lenticulina midwayensis carinata* (Plummer) - Ferrer et al., 1973.
- Lenticulina* cf. *rosetta* (Gümbel) - Aubert & Berggren, 1976. The detected specimens have large size and irregular pentagonal outline.
- Lenticulina rotulata* (Lamarck) - Said & Kenawy, 1956.
- Lenticulina trinitatensis* (Cushman & Jarvis) - Ferrer et al., 1973.
- Lenticulina vortex* (Fichtel & Moll) - AGIP, 1982.
- Lenticulina* sp. A. Test with circular outline and no keeled periphery; it is characterized by a knob and faintly recurved sutures.
- Lenticulina* sp. B. This group includes very small specimens of *Lenticulina* with slightly elongate shape without keel, in which the umbilical knobs and the sutures are not evident.
- Loxostomoides* gr. *applinae* (Plummer) - van Morkhoven et al., 1986. These specimens are characterized by very small size which along with bad preservation prevented to recognize the diagnostic characters.
- Marginulina glabra* d'Orbigny - AGIP, 1982.
- Marginulina inconspicua* Hussey - Ferrer et al., 1973.
- Marginulina longiforma* (Plummer) - Premoli Silva, 1970.
- Marginulina* sp. A. Test large and compressed; surface with longitudinal costae extending along the whole test and few horizontal costae in the medium part of the test.
- Marginulina* sp. B. Test slightly enrolled with pustules on the sutures in the early stage and thickened sutures in the last chambers.
- Marginulinopsis fragraria* (Gümbel) - Grünig, 1985.
- Neoeponides* group. This group includes specimens assignable to the genus *Neoeponides*; they have tests very concave on dorsal side and convex on ventral one, but the bad preservation prevents to recognize all the characters of this genus, mainly on the ventral side.
- Neoeponides* sp. A. Test flattened, slightly biconvex or flat on ventral side. Circular outline and acute periphery; dorsal side consisting of two whorls with very narrow chambers separated by strongly curved thickened sutures. On the ventral side the chambers are wedge-shaped.
- Neorotalia alicantina* Colom, 1954.
- Nodosarella paleocenica* (Cushman & Todd) - Beckmann, 1953.
- Nodosarella robusta* Cushman - Beckmann, 1953.
- Nodosaria affinis* Reuss - Le Roy, 1953.
- Nodosaria longiscata* d'Orbigny - Graham & Classen, 1955.
- Nodosaria raphanistrum* (Linnaeus) - Dubois, 1929.
- Nonion commune* (d'Orbigny) - Ferrer et al., 1973.
- Nonion florinense* Cole - Cushman, 1939.
- Nonion graniferum* (Terquem) - Cushman, 1939.
- Nonion labradoricum* (Dawson) - Cushman, 1939.
- Nonion laeve subexcavatum* Bhatia - Ferrer et al., 1973.
- Nonion mexicanus* Cole - Cushman, 1939.
- Nonion scaphum* (Fichtel & Moll) - Grünig, 1985.
- Nonionella cretacea* Cushman - Cushman, 1939.
- Nonionella* cf. *cretacea* Cushman - von Hillebrandt, 1962.
- Nonionella extensa* Brotzen - Cushman, 1939.
- Nonionella japonica* (Asano) - Cushman, 1939.
- Nummodiscorbis elegantissima* (Rutgers) - Ferrer et al., 1973.
- Oolina* gr. *globulosa* (Montagu) - Mc Dougall, 1987. This group includes specimens characterized by spherical shape without ornamentation.
- Oolina hexagona* (Williamson) - Jones, 1984.
- Oolina simplex* Reuss - Kaiho, 1992.
- Ornatanomalina geei* Haque - Loeblich & Tappan, 1988.
- Pandaglandulina dinapolii* Loeblich & Tappan - AGIP, 1982.
- Pentellina pseudosaxorum* Schlumberger - Ferrer et al., 1973.
- Planulina* aff. *P. burlingtonensis* (Jennings) - Ferrer et al., 1973.
- Pleurostomella rapa recens* Dervieux - AGIP, 1982.
- Praeglobobulimina* gr. *ovata* (d'Orbigny) - Hulsbos et al., 1989.
- Pseudoglandulina manifesta* Reuss - Aubert & Berggren, 1976.
- Pseudoglandulina pygmaea* (Reuss) - Kalantari, 1983.
- Pseudonodosaria discreta* (Reuss) - Loeblich & Tappan, 1988.
- Pseudonodosaria hantkeni* (Franzenau) - Sztrákos, 1987.
- Pullenia quinqueloba* (Reuss) - Tjalsma & Lohmann, 1983.
- Quadriformina allomorphinoides* (Reuss) - Hulsbos et al., 1989.

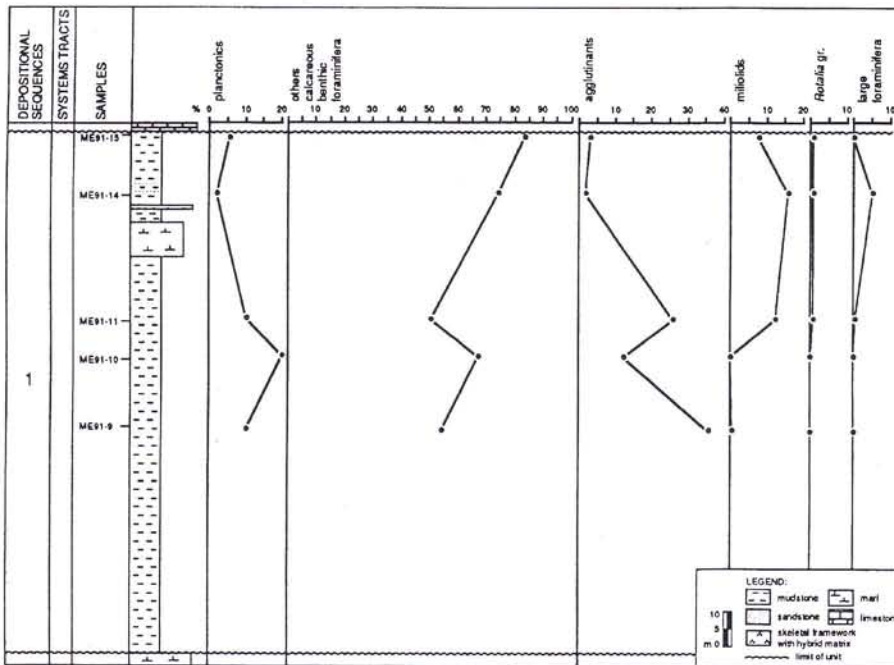


Fig. 3 - Distribution and percentages of the six groups of foraminifera detected in Unit 1, Merli Est Section.

Rotalia calcariformis (Schwager) - LeRoy, 1953.

Rotalia trochidiformis (Lamarck) - Ferrer et al., 1973.

Rotalia cf. *R. trochidiformis* (Lamarck). Some specimens differ from *R. trochidiformis* on the ventral side, which exhibits sutures not indented and a smooth umbilical knob with one fissure in the centre.

Rotalia trochus d'Orbigny, 1852.

Rotalia tuberculifera Reuss, 1862.

Rotalia viennoti Greig - Ferrer et al., 1973.

Saracenaria trigonata (Plummer) - Ferrer et al., 1973.

Siphotextularia concava (Karrer) - Barbin & Keller-Grünig, 1991.

Spiroloculina canaliculata d'Orbigny - AGIP, 1982.

Spiroplectammina adamsi Lalicker - Graham & Classen, 1955.

Spiroplectammina dentata (Alth) - Aubert & Berggren, 1976.

Spiroplectammina deperdita (d'Orbigny) - Barbin & Keller-Grünig, 1991.

Stilostomella curvatura (Cushman) - Beckmann, 1953.

Stilostomella decurta (Bermudez) - Beckmann, 1953.

Stomatorbina torrei (Cushman & Bermudez) - Ferrer et al., 1973.

Textularia pseudotrochus Cushman, 1922.

Trifarina gr. *bradyi* Cushman - AGIP, 1982. These specimens are generally of small size and show the general features of *T. bradyi*.

Trifarina muralis (Terquem) - Grünig, 1985.

Triloculina trigonula (Lamarck) - von Hillebrandt, 1953.

Turrilina brevispira Ten Dam, 1944.

Uvigerina elongata Cole - Tjalsma & Lohmann, 1983.

Uvigerina eocaena Gümbel - Grünig, 1985.

Vaginulinopsis mexicana alticostata Cushman & Barksdale - Bignot, 1962.

Valvulamina globularis (d'Orbigny) - Ferrer et al., 1973.

Valvulina limbata Terquem, 1882.

Valvulineria cubana Cushman & Bermudez, 1936.

Valvulineria aff. *texana* Cushman & Ellisor - Ferrer et al., 1973.

Vulvulina spinosa Cushman - Tjalsma & Lohmann, 1983.

Hypotheses of assemblages in the depositional sequences.

Some hypotheses were made on the assemblages of the LST, TST, and HST. On shelf, the LST is charac-

terized by erosion and/or no deposition; only in the higher part of the system tracts one can observe the sedimentation of proximal sediments. These sediments should contain assemblages characteristic of very shallow waters. Outside the shelf, the base of the LST should be characterized by reworked tests displaced by gravitational flows due to the erosion of the shelf; these sediments should yield foraminifera *in situ* and should show a deepening trend toward the top of the system tracts (increase in planktonic and in deep-water foraminifera and decrease of shallower-water fauna). At the very top of the lowstand, a decrease in nutrients could be responsible of a stratification of the water column; at this level an increase of taxa diagnostic of anoxic environment is possible (e.g. *Bolivina*). The LST and the SMST (Shelf Margin System Tract) are deposited during the relative sea-level fall, the lowstand, and the initiation of the sea-level rise.

The TST is sedimented when the sea-level rise is greater than the subsidence. From the base to the top of TST the foraminiferal assemblages should show an increase in abundance of deep-water and planktonic foraminifera and a decrease of shallower-water specimens. An increase in the value of the diversity should be also detected.

The base of the HST should be characterized by the maximum value of deep-water indicators corresponding to the MFS (Maximum Flooding Surface); then a decrease of these indicators and an increase of shallower-water foraminifera should be expected due to the aggradational and progradational trend that causes a relative sea-level fall. Because of the progradation this effect should be present first of all in the more proximal environments, and later in the outer ones.

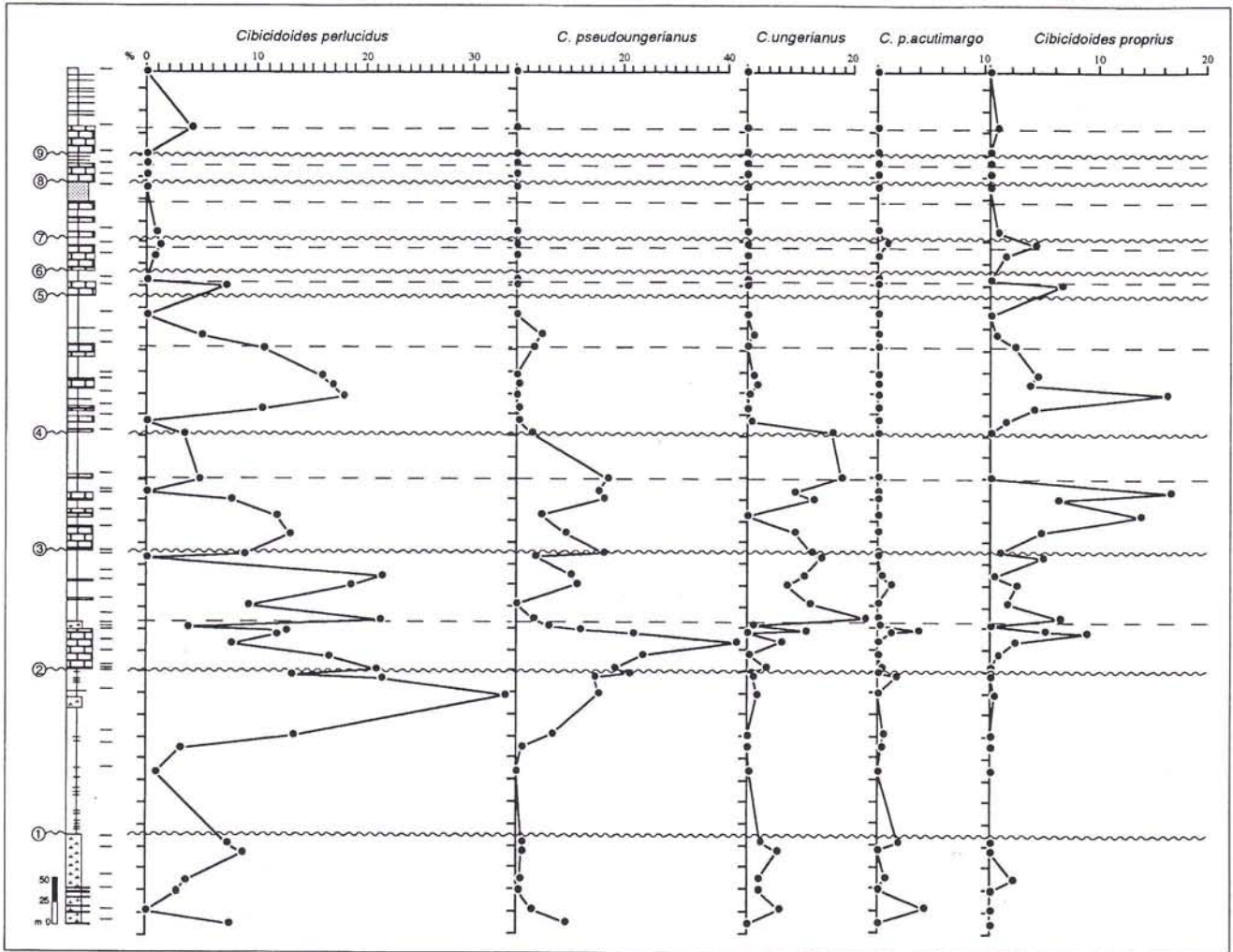


Fig. 4 - Percentages of *Cibicidoides perlucidus*, *C. pseudoungerianus*, *C. ungerianus*, *C. proprius acutimargo*, and *C. proprius* in Merli Est Section. Waved lines indicate the sequence boundaries; dashed lines indicate the Maximum Flooding Surfaces; for the legend see Fig. 2.

Description of Units 1 to 9.

Unit 1.

Unit 1 consists mostly of brown-gray clays with intercalations of thin-bedded turbidites that decrease toward the top (Fig. 3); the upper part of the unit is characterized by the presence of a thick bed of marls and of a storm layer rich in test fragments. At the very top the clays are intercalated by thin arenaceous levels (Carmignati, 1992). The presence of turbidites can influence the assemblages in many ways: tests are partially displaced, and the turbidity of water due to the presence of terrigenous material causes the decrease of planktonic foraminifera and the relative increase of agglutinated foraminifera (Turco, 1995).

The foraminiferal assemblages of the first three samples (ME91-9, ME91-10, and ME91-11) could be partially displaced because of the presence of thin-bedded turbidites. The percentages of planktonic and agglutinated foraminifera, in fact, show an opposite trend in these

three samples of Unit 1. Probably samples ME91-9 and ME91-11 are the most affected by the thin-bedded turbidites. However, the assemblages seem to indicate a shallowing of water depth toward the top.

The foraminiferal assemblages, in fact, show a general decrease of planktonic and agglutinated foraminifera and an increase of miliolids from the base toward the top of the sequence. The *Rotalia* gr. is present, with percentages lower than 1%, only in the three highest samples. Only sample ME91-14 yields a small percentage of larger foraminifera that are represented mostly by juvenile specimens.

Among the group of the "other calcareous perforate small benthic foraminifera", the most common taxa in Unit 1 are: *Cibicidoides perlucidus*, *C. pseudoungerianus*, *Loxostomoides* gr. *applinae*, *Brizalina* gr. B, *Praeglobulimina* gr. *ovata*, *Lenticulina cultrata*, *Spiroplectamina* spp., *Gyroidinoides octocamerata* (Fig. 4, 5, and 6). The mentioned taxa are considered as deeper-water indicators. *Trifarina* gr. *bradyi* is a taxon present with low

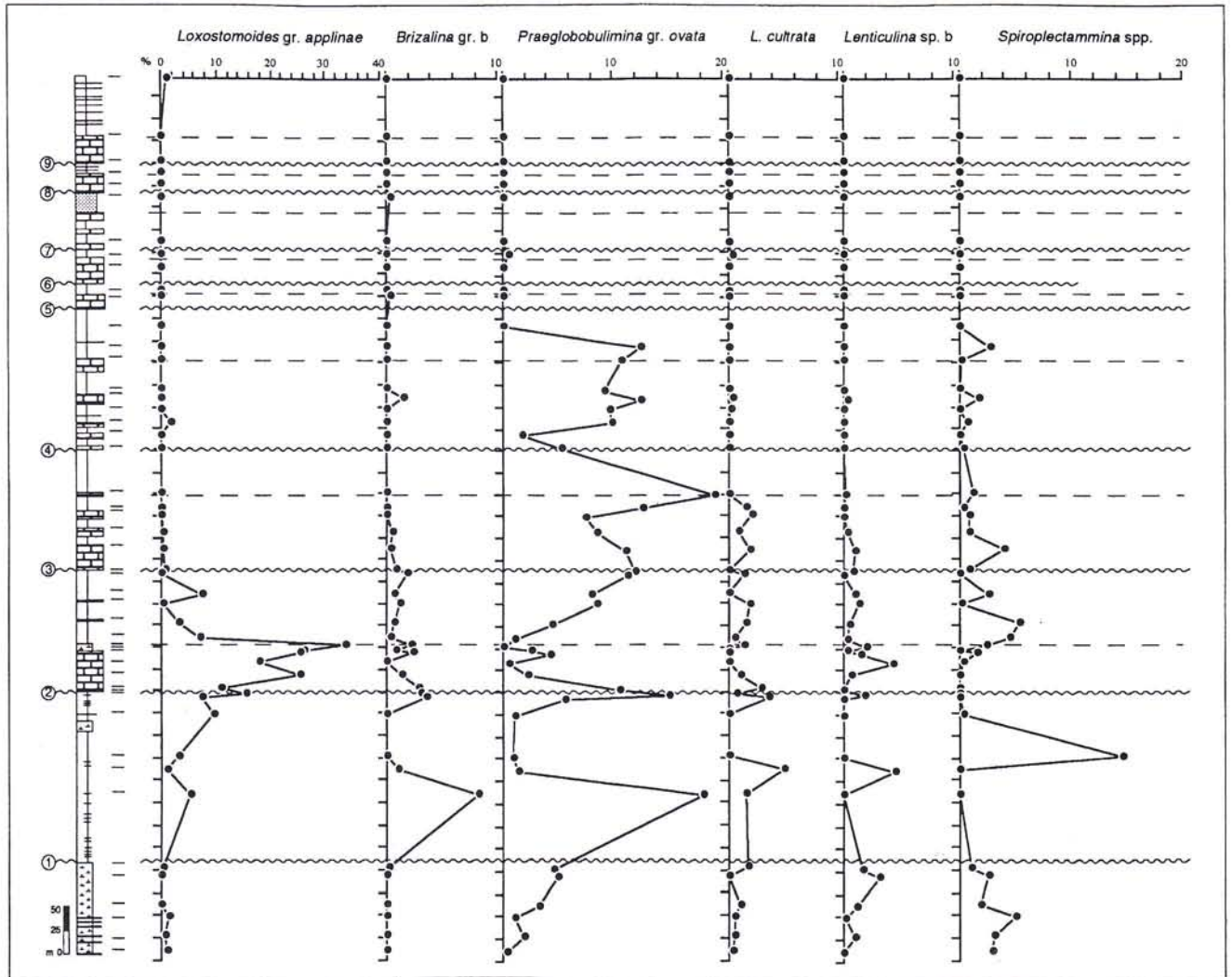


Fig. 5 - Percentages of *Loxostomoides gr. applinae*, *Brizalina gr. B*, *Praeglobobulimina gr. ovata*, *Lenticulina cultrata*, *Lenticulina sp. b*, and *Spiroplectamina spp.* in Merli Est Section. For the symbols and the legend see Fig. 2 and 4.

percentages (2.4% maximum in sample ME91-11), but it is remarkable that it occurs almost only in Unit 1 (Fig. 6). This genus was found by Murray (1991) in shelf and upper bathyal sediments and by Pujos (1972) only in water deeper than 150 m in the Bay of Biscay, so it is here considered as a deep-water indicator.

Unit 2.

The boundary between Unit 1 and Unit 2 is defined on the basis of both paleontological and lithological considerations. Lithologically there is an abrupt change from arenaceous clay to well stratified pelitic limestones named "Puebla de Roda Limestones". The thick bed of limestone is overlain by a bioturbated level of marl about 5 meters thick; the upper part of the sequence is constituted by mudstone with two calcareous levels of skeletal framework with hybrid matrix (the upper one is named "Roda storm") (Fig. 7).

Planktonic foraminifera do not show great variations in percentages, but the increase of miliolids and large foraminifera indicate the HST. Sample ME91-22 shows the highest percentage of planktonic foraminifera and low abundance of miliolids; the larger foraminifera are absent.

Samples from ME91-22 to ME91-27 are characterized by large fluctuations in the percentage of taxa. Larger foraminifera (Fig. 7) are present below sample ME91-22 only in samples ME91-18 and ME91-19 with low percentages. Above this sample they are present from sample ME91-24, few meters below the Roda Storm with higher percentages. Larger foraminifera have a trend according to that of agglutinants and opposite to the small benthic calcareous foraminifera.

Some of the most important taxa show the following trend: *L.gr. applinae* and *Lenticulina sp. B* (Fig. 5) have the highest abundances in the lowest part of this unit; *L. gr. applinae* shows percentages from 10.6% (sam-

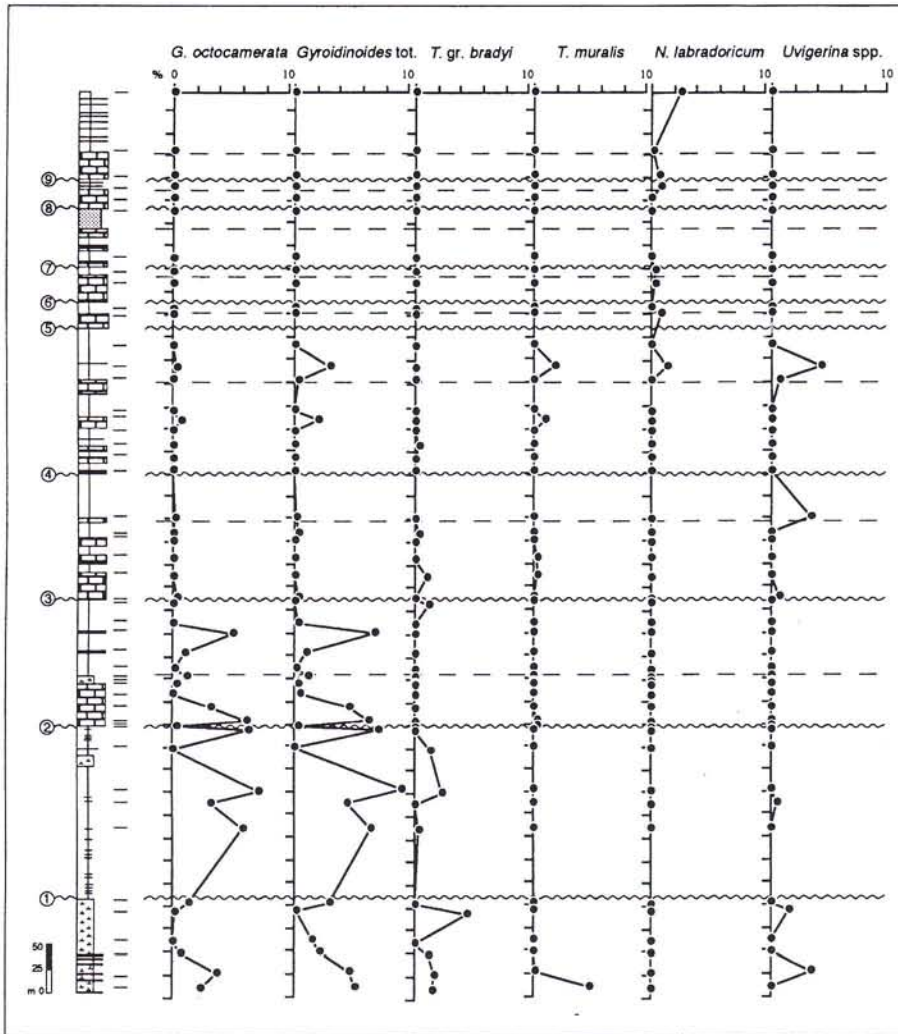


Fig. 6 - Percentages of *Gyroidinoides octocamerata*, *Gyroidinoides* spp., *Trifarina* gr. *bradyi*, *T. muralis*, *Nonion labradoricum*, and *Uvigerina* spp. in Merli Est Section. For the symbols and the legend see Fig. 2 and 4.

ple ME91-17) to 33.8% (sample ME91-22). *C. pseudoungerianus* and *C. ungerianus* show high percentages in this unit (Fig. 4); the lowest abundance of *C. pseudoungerianus* occurs in samples ME91-22, ME91-23 and ME91-24 placed at the base of the HST and *C. ungerianus* is abundant in the HST. *C. perlucidus* is absent in sample ME91-27, at the very top of the unit; among the other samples, the lowest percentages are shown in sample ME91-22. The highest abundances of *Spiroplectammina* genus are in samples ME91-22, ME91-23 and ME91-24 with values increasing from the first to the latter. The abundance of *Brizalina* gr. B decreases discontinuously from the base to the top of the unit. *Cibicides mauricensis* has the highest value in samples ME91-21 and ME91-22 (Fig. 8).

Unit 3.

Unit 3 is characterized by the alternation of mudstone and limestone comprised of skeletal framework with hybrid matrix; the thickness of mudstone strata increases toward the top (Fig. 9). The recognition of MFS is based only on lithological observations: the mudsto-

nes at the top of the sequence are the distal expression of the Roda Sandstone and are interpreted as the response to a highstand phase (Carminatti, 1992).

The fauna does not show great variations within this unit; only little fluctuations in abundance of planktonic foraminifera and shallow-water indicators (miliolids, *Rotalia* gr. and larger foraminifera) were observed, which are interpreted as the response to minor fluctuations of sea-level (very small-scale cycles).

Deep-water indicators, like *Cibicidoides acutimargo*, *Lenticulina* sp.B, *L. gr. applinae*, *Gyroidinoides* spp. and *Trifarina muralis*, decrease in abundance in respect to Unit 2 and/or disappear (Figs. 5 and 6). On the contrary the shallower-water indicators, like *Allomorphina halli*, *Conorboides umiatensis*, *Anomalinoidea "cushmani"*, *Asterigerina* spp., *Operculina* spp. and *Discocyclina* spp. (Fig. 10, 11, and 12) increase in abundance and/or appear in this unit.

Unit 4.

Unit 4 has the same lithologies of Unit 3 and in this unit mudstone strata increase in thickness toward

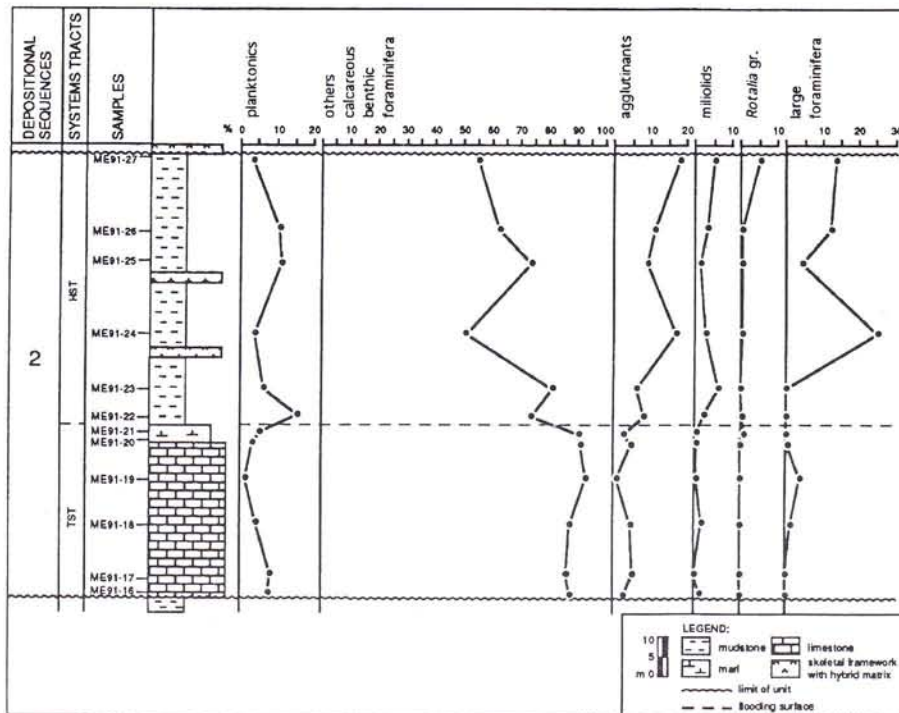


Fig. 7 - Distribution and percentages of the six groups of foraminifera detected in Unit 2, Merli Est Section.

the top, too (Fig. 13). Carminatti (1992) placed the MFS below sample ME91-41 which is rich in molluscs (gastropods and bivalvs).

Similarities between Units 3 and 4 are observed also in the distribution of taxa, and the same considerations can be made about the very small-scale cycles and the MFS. Sample ME91-42 shows the highest value of planktonic foraminifera (Fig. 13) and high values of deep-water indicators; *Anomalinoidea affinis*, *C. pseudoungerianus*, *Cibicides americanus*, *C. cassivellauni*, *Gyroidinoides* spp., *N. labradoricum*, *Uvigerina* spp. have the highest percentages in sample ME91-42. The same sample has the highest value of diversity, and the ratio between fragments of foraminiferal tests and the unbroken test is the lowest of this unit (Fig. 14).

Only few taxa first occur in this unit (Fig. 15); *Rotalia* spp. is rather continuously present in this unit and was almost absent in the units below; *Anomalinoidea* sp. A, present in Alveolina Limestone Allogroup with percentages lower than 2%, occurs rarely only in Unit 4 as well as *Allomorphina halli*. Many deep-water indicators decrease in abundance (e.g. *L. gr. applinae*, *V. alticostata*, *C. pseudoungerianus* and *C. ungerianus*) and/or disappear in this unit.

Units 5 to 9.

In the higher part of the Merli Est Section the lithologies change: limestones increase, mudstones become rarer, and sandstones appear in thick but rare strata. A new increase in mudstone lithology is observed in the topmost part of the section (Fig. 16 and 17).

Units 5 to 9 are on a smaller scale than the others examined. These five units constitute the medium-scale depositional sequences FG3 and FG4. Foraminiferal assemblages show that these units were deposited in shallow water: planktonic foraminifera are rare, except in sample ME91-44 (Unit 5) where they represent 20,7% of the foraminiferal assemblage, and shallow-water indicators generally have high percentages. The absence of planktonic foraminifera makes it more difficult to detect sea-level fluctuations; the recognition of Units 5 to 9 is based mainly on lithological characters (Carminatti, 1992).

Many taxa disappear at the FG2/FG3 boundary (e.g. most of the *Nodosariaceae*, *P. gr. ovata*, *Gyroidinoides* spp., *C. pseudoungerianus*, *C. ungerianus* and *A. wilcoxensis*; Fig. 15); all these taxa are interpreted as deeper-water indicators. Some other taxa decrease and/or disappear within the FG3 sequence: *Cibicidoides perlucidus*, *C. proprius*, *Cibicides acutus*, *A. "cushmani"*, *Ammodiscus* spp., *Dentalina* spp., *Lagena gr. striata* (Fig. 18). These taxa could be considered as indicators of intermediate depth. Another important signal of the sea-level fall is the appearance and/or increase in abundance of some shallow-water taxa: *Assilina* spp., *Asterigerina* spp., *Bulimina gr. trigonalis*, *Cuvillierina (?) yarzai*, *Neoepionides* gr., *Pararotalia* spp., *Rotalia* spp. The ratio between fragments and unbroken tests is generally high in FG3 and FG4 sequences, and, on the contrary, the diversity is low (Fig. 14). Larger foraminifera of Units 5 and 6 are mostly represented by the genus *Assilina*.

Unit 7 marks the lower boundary of FG4 sequence because of the variations in foraminiferal assemblage: larger foraminifera have generally lower percentages and

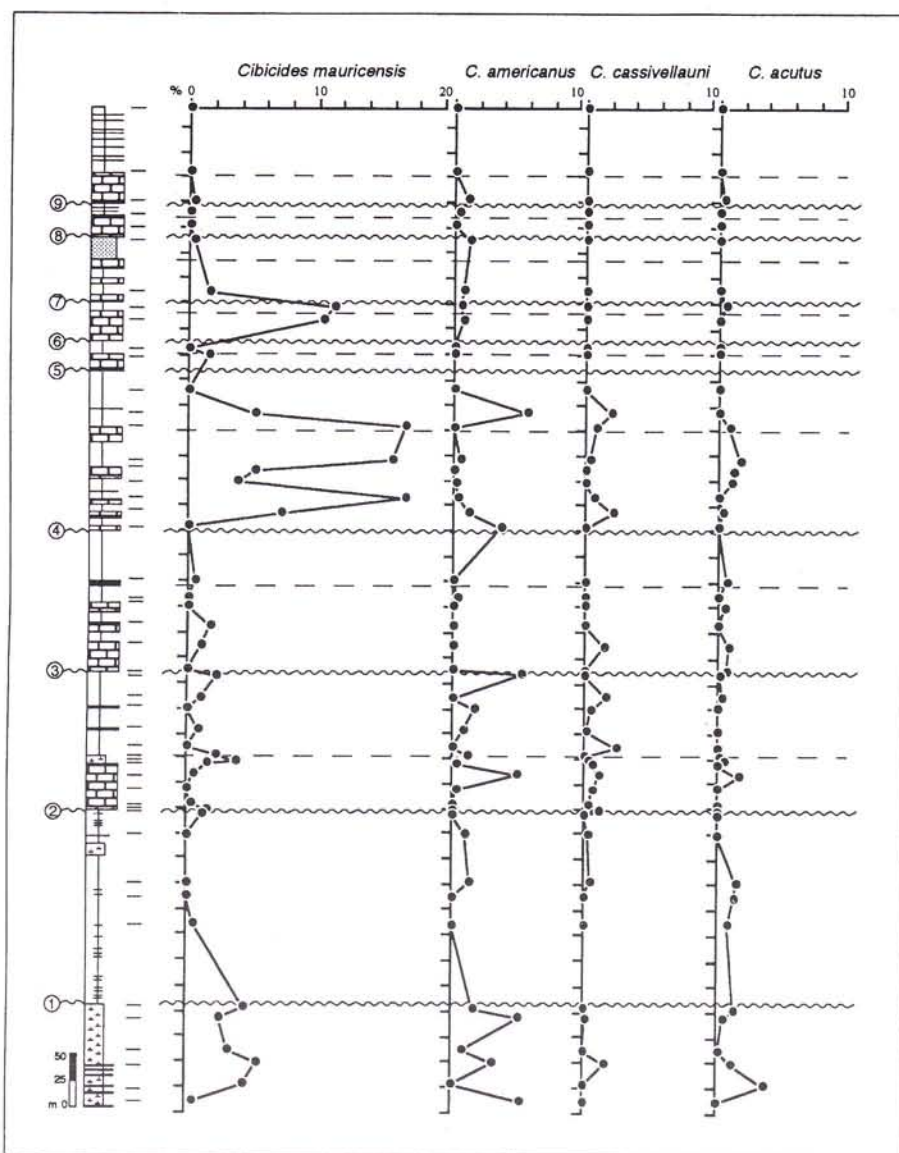


Fig. 8 - Percentages of *Cibicides mauricensis*, *C. americanus*, *C. cassivellauni*, and *C. acutus* in Merli Est Section. For the symbols and the legend see Fig. 2 and 4.

are mostly constituted of *Nummulites* spp.; *C. mauricensis*, *C. proprius* and *C. perlucidus* percentages decrease; on the other hand, *Pararotalia* spp. and *C. (?) yarzai* first occur, and miliolids reach in Unit 7 the highest percentages of the Allogroup. *Asterigerina* spp. (Fig. 11) percentages abruptly increase from values <5% in Unit 6 to values >30% in Unit 7 and above (the highest values are 37.8% in sample ME91-48 and 58.5% in sample ME91-53).

The absence of the genus *Operculina* (present in Units 3 and 4) could be due to the substrate unfavorable to the life; in fact *Operculina* is a herbivore genus living in muddy carbonate sediments (Murray, 1991).

General variation trends in foraminiferal assemblages in Merli Est Section and interpretation.

A general shallowing of water depth is showed upward by the foraminiferal assemblages in the Merli Est Section.

The most important variations in foraminiferal assemblages are (Fig. 15):

- *Cibicoides proprius acutimargo* disappears at the boundary between Units 2 and 3.
- *Trifarina* gr. *bradyi* is mainly distributed in Unit 1. *T. muralis* is scattered distributed in Units 2 and 4 with low percentages. The genus *Trifarina* is completely absent in FG3 and FG4 sequences.
- *Loxostomoides* gr. *applinae*, *Gavelinella danica* and *Cibicoides atratiensis* are present in Units 1, 2, and 3. *G. danica* and *C. atratiensis* are rare and show discontinuous occurrence; *L. gr. applinae* is more abundant in Units 1 and 2 and decreases significantly at the Unit 2/3 boundary.
- *Vaginulinopsis alticostata*, *Lenticulina cultrata* and *Lenticulina* sp. B are continuously present in FG1 sequence and their abrupt decrease marks the FG1/FG2 sequences boundary.

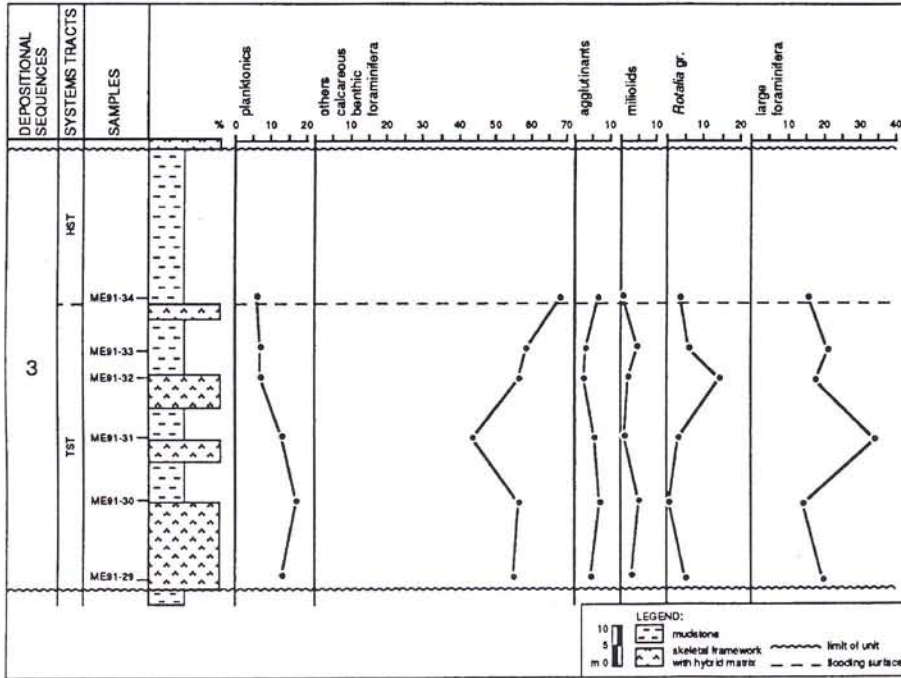


Fig. 9 - Distribution and percentages of the six groups of foraminifera detected in Unit 3, Merli Est Section.

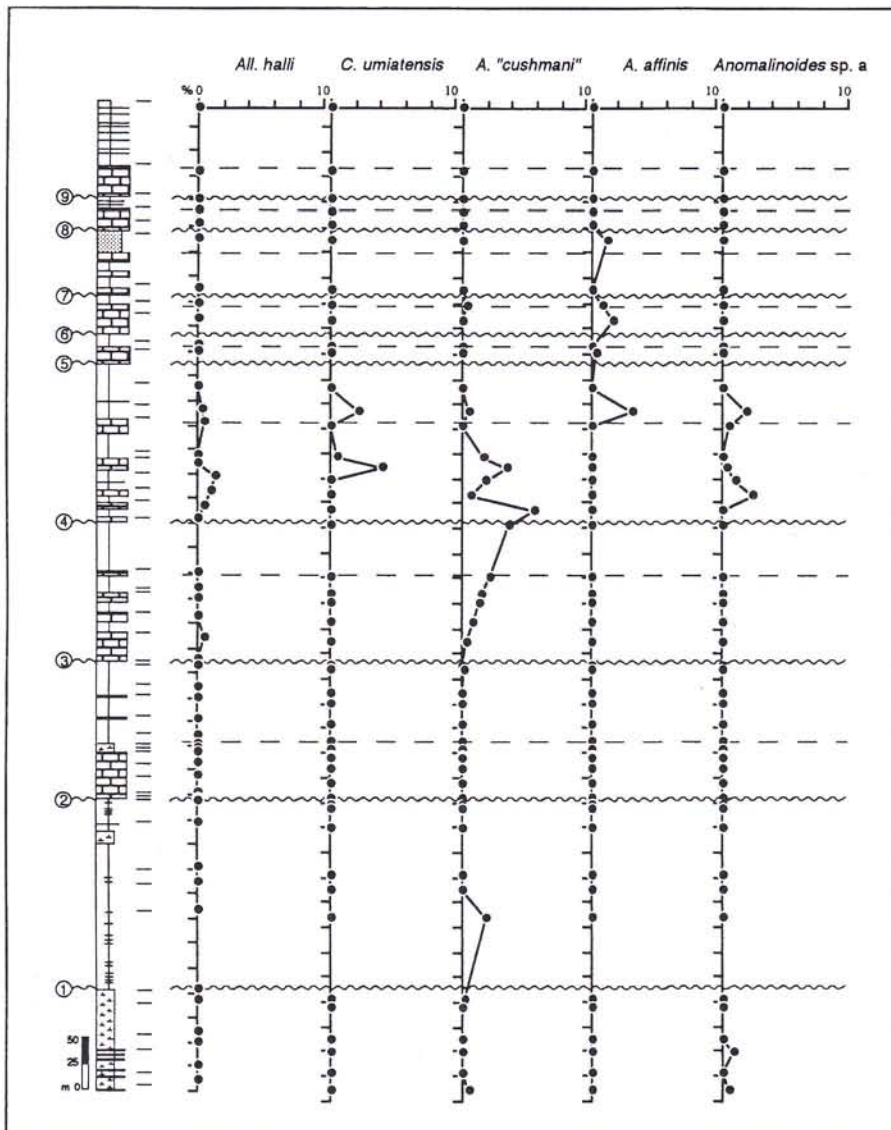


Fig. 10 - Percentages of *Allomorphina halli*, *Conorboides umiatensis*, *Anomalinoidea "cushmani"*, *A. affinis*, *Anomalinoidea* sp. A in Merli Est Section. For the symbols and the legend see Fig. 2 and 4.

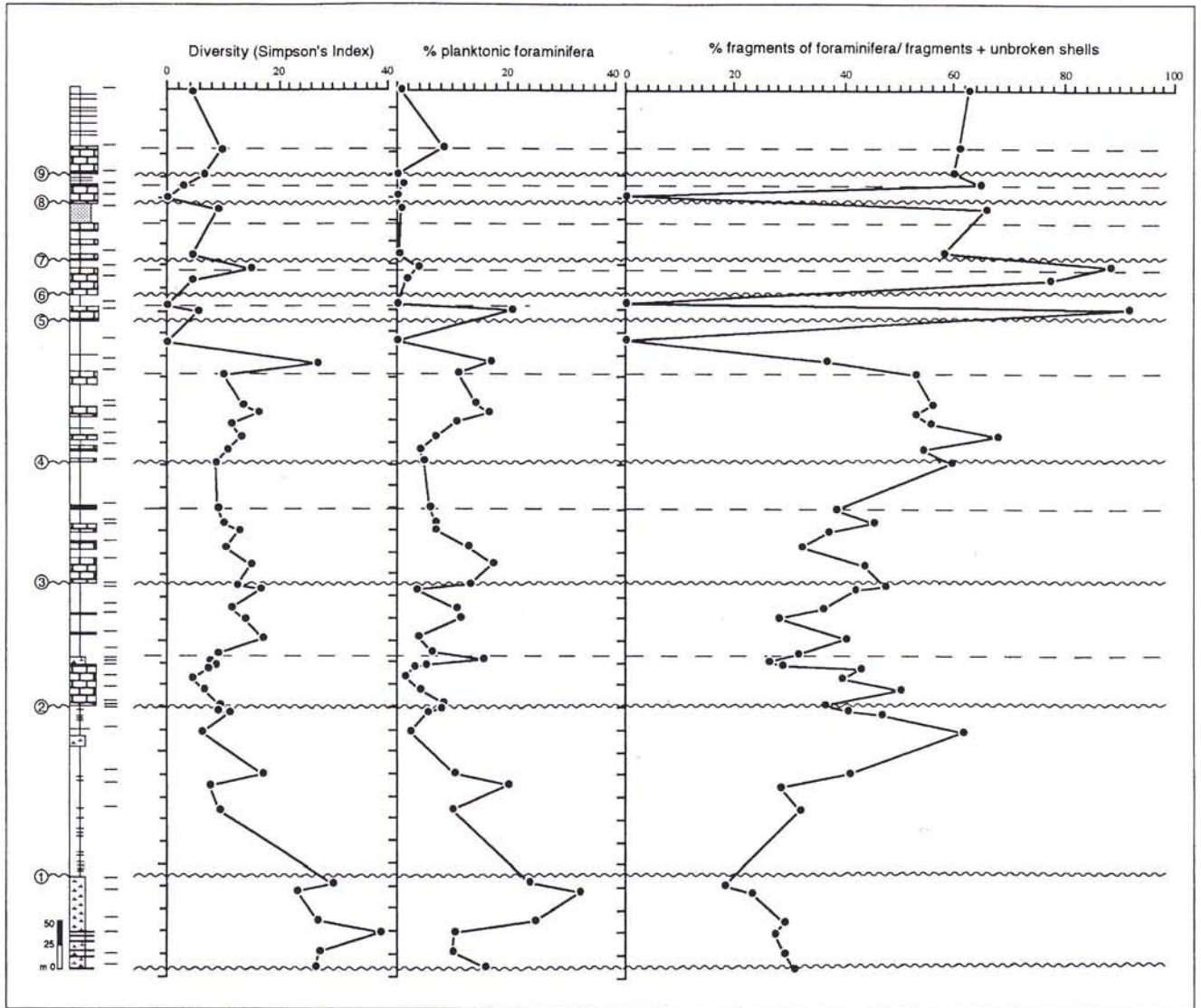


Fig. 14 - Values of species diversity, tests fragments and percentages of planktonic foraminifera in Merli Est Section. For the symbols and the legend see Fig. 2 and 4.

In Unit 2, fossil assemblage reveals that sample ME91-16 was deposited in waters a little deeper than that of ME91-15. Such assemblage variation make possible to locate the Unit 1/2 boundary between samples ME91-15 and ME91-16. This is correct considering that the LST is absent in the depositional sequences of this section, and sample ME91-16 could represent the early TST of Unit 2. Based on percentages of shallow-water fauna and planktonic foraminifera, there is an evident deepening trend from the base of Unit 2 to sample ME91-22, and a shallowing from sample ME91-23 to the top of the sequence due to the prograding sediment. Sample ME91-22 represents the maximum deepening of Unit 2; for these reasons the MFS is placed near this sample.

According to lithological criteria, Carminatti (1992) placed the MFS of this unit at the boundary be-

tween the limestones and the overlying marls. However sample ME91-20 does not show any deepening character: planktonic foraminiferal percentage is very low (3.2%) and most of the taxa considered in the present work as deeper-water indicators have percentages lower than in sample ME91-22 (e.g. *L. gr. applinae*, *G. octocamerata*, *A. wilcoxensis*, *Eponides frankei*, *Nonion* spp., *Oolina* spp.; Fig. 5 and 19). Nevertheless the assemblage of samples ME91-20 and ME91-21 could be biased by the bioturbation which affects the marls.

The high percentages of larger foraminifera and the low percentages of planktonic foraminifera indicate a relative shallowing of water depth in the HST of this sequence due to the progradation of sediments. The signal of the relative lowering of the sea-level in the HST was emphasized by the presence of shallower-water taxa displaced by the prograding sediments. The presence of the *Rotalia* gr.,

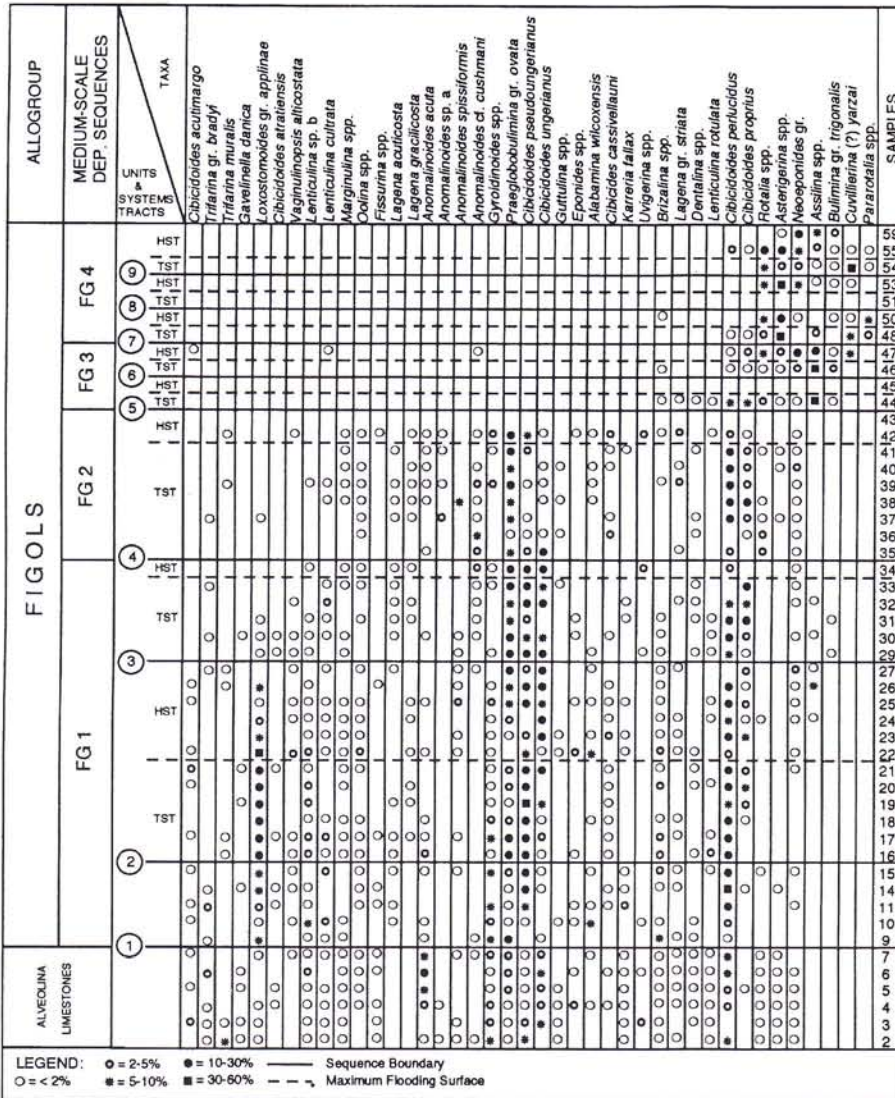


Fig. 15 - Distribution of the most indicative species of benthic foraminifera in Merli Est Section plotted against large- and small-scale units and systems tracts.

the increase of the *Neoeponides* gr., and the absence and/or decrease of the most important deep-water indicators (e.g. *L. gr. applinae*, *C. perlucidus*, *C. proprius acutimargo*, *C. pseudoungerianus*, *Gyroidinoides* spp.) indicate the lowest sea-level of Unit 2 falls in sample ME91-27. Within this unit, many minor oscillations of the sea-level in a general deepening trend can be recognized; they are indicated mainly by the fluctuations of percentages of planktonic foraminifera, miliolids and larger foraminifera and are considered as very small scale cycles due to minor oscillations of the water depth. Sedimentological features well show sea-level fluctuations in the lower part of the unit where the limestone stratification is evident, but the small-scale cycles are recognizable through foraminiferal assemblage also in the mudstone levels of the HST of the sequence where the sea-level oscillations cannot be detected by lithological considerations.

The decrease of deep-water indicators and the increase and/or appearance of shallow-water foraminifera indicates a general shallowing of water depth from Unit 2 to Unit 3.

Unit 3 does not show great variations in percentages of the detected foraminiferal groups. As in Unit 2, the oscillations of the planktonic foraminifera and the shallow-water taxa values are interpreted as the response to minor sea-level oscillations. The MFS was placed only by sedimentological characters (Carminatti, 1992); the foraminiferal assemblage, in fact, does not show any indication of the MFS.

Figols 2 (FG2).

The lithologies of Units 3 and 4 are very similar, nevertheless (Fig. 15) the appearance and/or increase of some shallow-water taxa (e.g. *Rotalia*) and the decrease of some deeper-water indicators was observed (see before).

Such a distribution of foraminifera indicates that Unit 4 was deposited in water depth shallower than that of Unit 3. The signal of sea-level fall at the lower boundary of Unit 4 is more significant than the one marking the boundary between Units 2 and 3; these

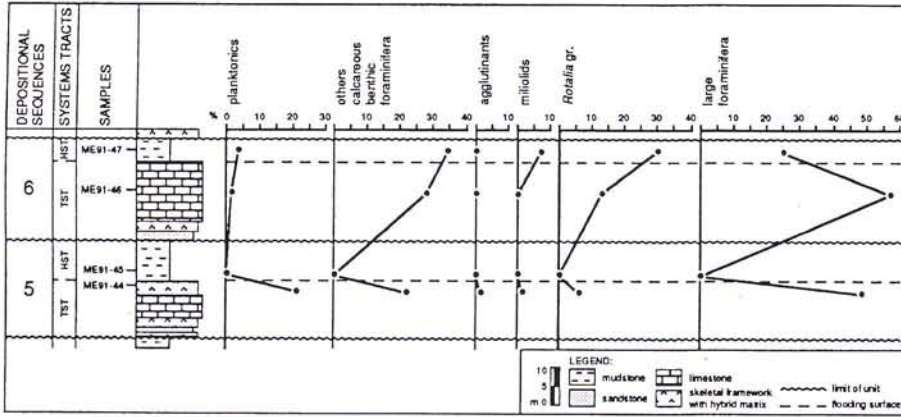


Fig. 16 - Distribution and percentages of the six groups of foraminifera detected in Units 5 and 6, Merli Est Section.

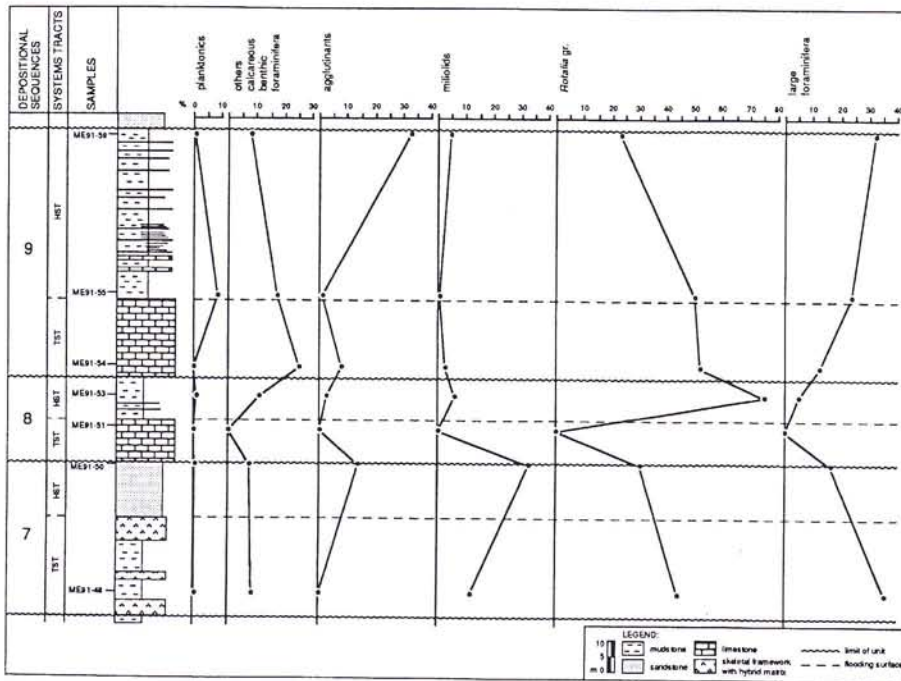


Fig. 17 - Distribution and percentages of the six groups of foraminifera detected in Units 7, 8, and 9, Merli Est Section.

data confirm the sedimentological considerations and the Unit 3/4 boundary is considered coincident with the lowest one of the medium-scale depositional sequence FG2.

In Unit 4, the assemblage of sample ME91-42 seems to better indicate the MFS of this unit in respect to the sample ME91-41 indicated by Carminatti (1992). The TST is characterized by a general deepening trend (Fig. 13); only sample ME91-41 show an opposite trend of planktonic and large foraminifera. The HST of this sequence was not described because it is represented only by the barren sample ME91-43.

As described before, many species decrease and/or disappear at the top of Unit 4, marking the boundary between FG2 and FG3 sequences.

Figs 3 (FG3).

The abrupt sea-level fall at the FG2/FG3 boundary is marked by a great change of foraminiferal assemblages (Fig. 15).

This boundary is well marked also by the abrupt decrease of the values of planktonic foraminifera and the diversity and by the increase in tests fragments (Fig. 14). The boundaries of the small-scale sequences, well recognizable in FG1 sequence, are not well enhanced in the topmost part of the section by foraminiferal assemblages; the sequence boundaries detected by Carminatti (1992) were considered.

In Unit 5, one of the two studied samples is barren, so it was not possible to make considerations about the trend of the foraminiferal assemblages.

In Unit 6 a deepening trend was detected from sample ME91-46 to ME91-47 where the MFS was placed.

Figs 4 (FG4).

The almost complete disappearance of planktonic foraminifera and the above mentioned changes in foraminiferal assemblage, indicate a step corresponding to FG3/FG4 boundary. The absence of planktonic forami-

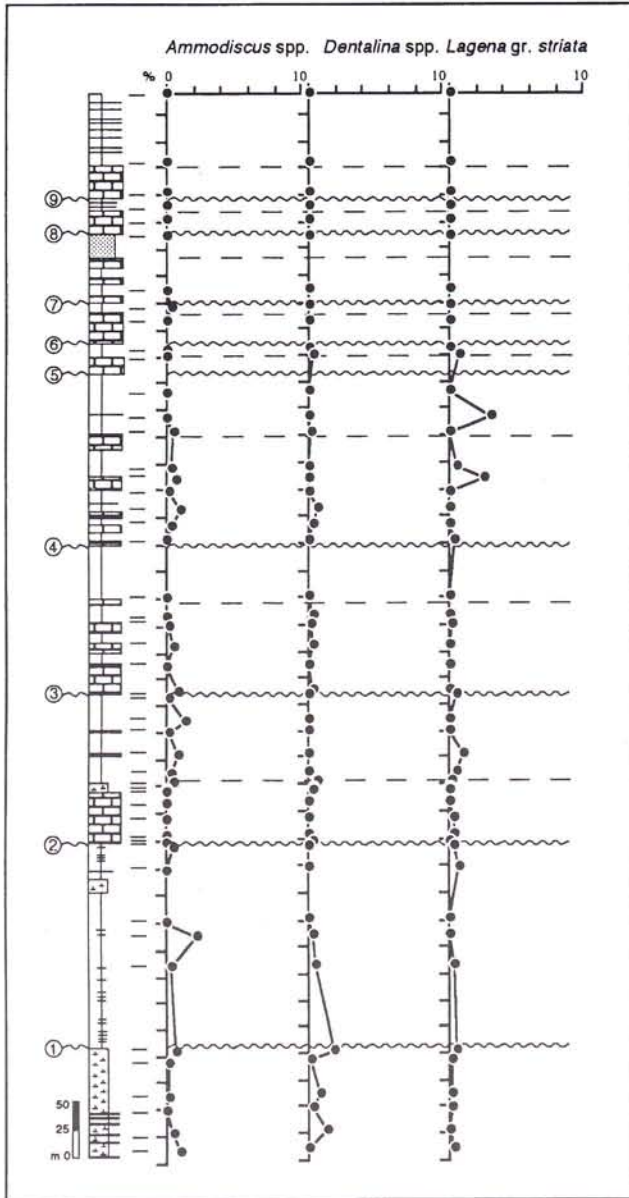


Fig. 18 - Percentages of *Ammodiscus* spp., *Dentalina* spp., and *Laguna* gr. *striata* in Merli Est Section. For the symbols and the legend see Fig. 2 and 4.

nifera and the high values of shallow-water foraminifera in both samples of Unit 7, and the barren sample ME91-51 in Unit 8, hindered the recognition of the MFS and of the boundaries between Units 7, 8, and 9. In Unit 9 the MFS indicated by Carminatti (1992) is confirmed only by the presence of planktonic foraminifera in sample ME91-56.

Conclusions.

Species with palaeobathymetric meanings show variations in abundance and distribution in response to sea level oscillations; nevertheless many other factors

(e.g. salinity, temperature, substrate) participate to create the foraminiferal assemblages and sometimes make more difficult to understand the sea-level oscillation.

This work demonstrates that the recognition of depositional sequences and their systems tracts through an integration between sedimentological and paleontological data is possible.

The Merli Est Section shows a clear regressive trend upward: from the base to the top of the section, deeper water indicators decrease and shallow-water foraminifera increase and/or appear. This regressive trend is not continuous, but is characterized by some steps that made it possible to recognize the four large scale depositional sequences in which the Figols Allogroup is subdivided. The FG2/FG3 boundary is the most evident because a great change in foraminiferal assemblage occurs; the severe sea level fall is enhanced by a great increase of shallow water taxa (e.g. larger foraminifera and *Rotalia*) and by the almost total disappearance of deeper-water taxa.

It is not possible to detect the TST or the HST through "typical" assemblages, but they are recognizable only through the variations of the assemblages in a sequence. TST and HST are characterized by different trends of the foraminiferal assemblage. A deepening trend, recognizable by an increase in planktonic foraminifera and in deeper-water taxa and by a relative decrease of shallower water species, characterizes the TST and an opposite shallowing trend due to the prograding sediments characterizes the HST. The topmost part of TST and the lowest part of HST yield very similar assemblages; using foraminiferal assemblages the maximum flooding is identified as the interval of maximum deepening in which the maximum abundance of deeper-water taxa, the highest value of P/B ratio and relative lower percentages of shallow-water taxa occur.

Because of the presence of smaller-scale cycles, sometimes it is difficult to recognize the depositional sequences at a large scale. The minor variations of the percentages of indicative taxa (related to smaller-scale cycle variations), could hide the major variation trend of the foraminiferal assemblages.

Acknowledgments.

The author is indebted to Prof. S. Iaccarino for her support on this study and the discussion of the results; to Prof. E. Mutti and Dr. M. Carminatti for the fruitful discussions about the sequence stratigraphy and their help in the field. The author would like to thank Prof. I. Premoli Silva for her valuable suggestions which improved this paper; Prof. H.P. Luterbacher for his helpful discussion on systematics; Prof. M. Gaetani for his suggestions for the final manuscript review. Financial support for this research was provided by CNR grants to G. Papani and I. Premoli Silva.

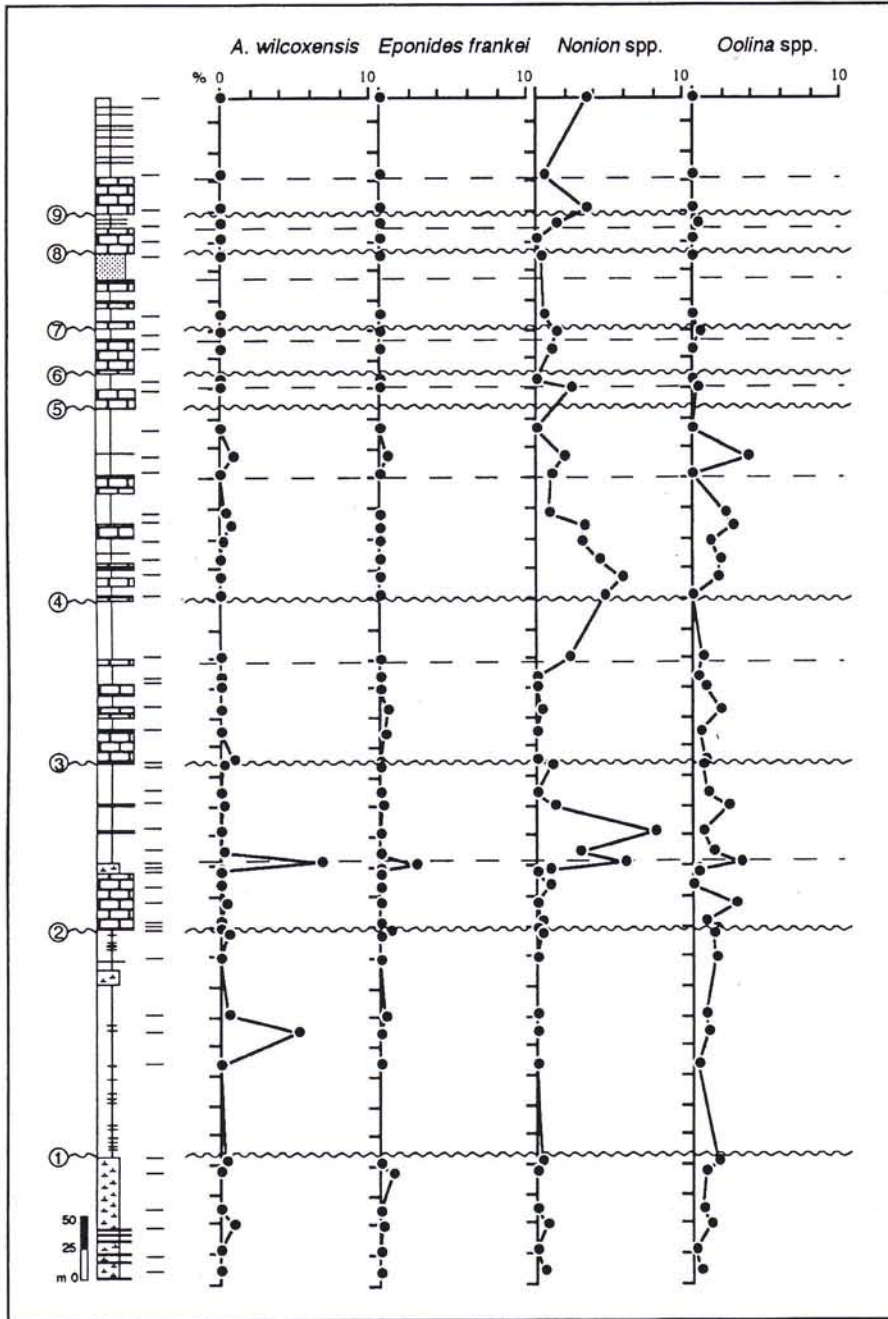


Fig. 19 - Percentages of *Alabamina wilcoxensis*, *Eponides frankei*, *Nonion* spp., and *Oolina* spp. in Merli Est Section. For the symbols and the legend see Fig. 2 and 4.

Palaeoecological notes.

Alabamina Toulmin, 1941

Sliter & Baker (1972) found this genus at middle-slope depths along the eastern Pacific margin. The same Authors considered, in the Cretaceous assemblages of Carlsbad, *Alabamina* as a genus indicating middle to outer shelf depths. Berggren (1974) found *Alabamina midwayensis* at depth less than 30 meters in the Late Paleocene - Early Eocene of the North Atlantic.

Allomorpha Reuss, 1849

Allomorpha is common in circalittoral and epibathyal environments (110-900 meters) (Sztrákos, 1979). Sliter & Baker (1972) found this genus at middle-slope depths along the eastern Pacific margin. The same Authors report in the Cretaceous assemblages of Carlsbad *Allomorpha* as a genus indicating middle- to outer-shelf depths.

At this depth there are few specimens but their abundance increases with increasing depth. Elser (1984) indicates this genus as dominant in middle- and upper-slope in the Maastrichtian of the southern Pyrenees. Nyong & Olsson (1984) found *A. balli* in the Campanian to lower Maastrichtian sediments of the North American Basin where this species is present at depth less than 1000 meters.

Ammobaculites Cushman, 1910

This genus was found from inner shelf to upper bathyal (Murray, 1991).

Ammodiscus Reuss, 1862

In the eastern Pacific margin the modern bathymetric distribution of *Ammodiscus* is from middle shelf through deeper water (Sliter & Baker, 1972); in the Cretaceous ocean-margin foraminiferal assemblages from southern California, the same Authors report this genus with increasing abundance from the middle-slope.

Anomalina d'Orbigny, 1826

Berggren (1974) indicates depth comprised between 200 and 600 meters (outer shelf - upper slope) for the species *A. grosserugosa* (*Gavelinella*) in the Late Paleocene - Early Eocene of the North Atlantic.

Anomalinoides Brotzen, 1942

Berggren (1974) indicates for *A. acuta*, a life-depth between 20 and 100 meters in the Late Paleocene - Early Eocene of the northern Atlantic; however, Berggren & Aubert (1975) indicate *A. acuta* as a cosmopolitan species with a large bathymetric range, but showing a decrease in abundance at major depth. Berggren & Aubert (1976) include this species among the neritic taxa (< 200 meters) with an increase in abundance toward the outer neritic (Aubert & Berggren, 1976).

A. praeacuta has a wide bathymetric range, but its highest abundances are found at the deeper sites (Tjalsma & Lohmann, 1983).

Van Morkhoven et al. (1986) indicate *A. dorri aragonensis* as a synonym of *Anomalinoides capitatus* which is primarily a bathyal species ranging to abyssal depth. The same Authors indicate the depth limits of some species of *Anomalinoides*: the upper depth boundary of *A. flintii* and *A. helcinus* is considered middle-upper bathyal (about 600 meters) in the Neogene of Hispaniola; the upper depth boundary of *Anomalina bilateralis* is considered the middle-neritic environment in Jackson-Claiborne and Barbados Faunas. *Anomalina alazanensis* is primarily an upper and middle bathyal species. It is occasionally observed in outer neritic deposits but is absent in abyssal sediments. This species was found at middle upper-bathyal depths (300-600 meters) of the Caribbean and Mediterranean regions in the Oligocene (Berggren, 1972). The same Author found *A. alazanensis* at bathyal depth (> 600 meters) in the Oligocene of the Bay of Biscay.

Assilina d'Orbigny, 1839

The palaeobathymetry of *Assilina* in the Eocene of the Tremp-Ager area (Pyrenees - Spain) is similar to that of *Nummulites*. *Assilina* is more common in marl facies and in lagoonal or littoral deposits (Ferrer et al., 1973). Luterbacher (1984) in the Paleogene of the southern Pyrenees recognizes four morphogroups among the genus *Assilina* and *Nummulites* with different palaeoecological distribution: small specimens (diameter less than 8 mm), lensiform are typical of littoral facies; small specimens (< than 8 mm) disc-shaped are typical of shallower water environments and common in carbonate sediments; large and flat specimens (> than 8 mm) are typical of beach deposits; other lensiform specimens of large size are common in the transgressive deposits of the Middle Eocene in the north-western Ebro Basin and in the Sierras Marginales in association with lagoonal deposits.

Asterigerina d'Orbigny, 1839

This herbivorous genus lives in the inner shelf in tropical-subtropical water (Murray, 1991). Grünig & Herb (1984) found this species in outer neritic environments in the Eocene of Biarritz.

Brizalina Costa, 1856 and *Bolivina* d'Orbigny, 1839

These two genera have the same palaeoecological requirements: muddy substrate and cold to warm temperature; they are distributed from the inner shelf to bathyal depths (Murray, 1991).

Bolivina prefers the outer-shelf environment (Boersma, 1984). In the Mediterranean Sea, Blanc-Vernet (1969) found *Bolivina* in muddy substrate. It is particularly abundant in circalittoral environment and the highest percentages are found at depth of about 80-100 meters; this genus is present also at major depth, but it is less common. Caralp et al. (1970) found *Bolivina* in sublittoral environment of the Bay of Biscay. Sliter & Baker (1972) found this genus in the shelf assemblage, with higher abundance in the outer-shelf. Sztrákos (1979) indicates the presence of *Bolivina* from circalittoral to epibathyal environment (110-900 meters). Douglas (1979) divided the genus *Bolivina* into two morphological groups: the first, characteristic of the neritic environment, groups small and elongate specimens; the second one groups specimens with tests bigger and compressed and is typical of bathyal environment. Asioli & Borsetti (1989) in submarine cores from the Adriatic Sea found this genus in circalittoral environment at depth deeper than 70 meters.

In the present work the group "*Brizalina*" includes all the specimens of the two genus *Brizalina* and *Bolivina* because the bad preservation prevented the observation of the sutures. Two groups were recognized: *Brizalina* gr. A resembles the "bathyal *Bolivina*" of Douglas (1979) and was here considered of deeper environment than *Brizalina* gr. B. The latter could be similar to the "neritic *Bolivina*" of Douglas (1979).

Buccella Andersen, 1952

Murray (1991) found this genus in inner shelf mud deposits.

Bulimina d'Orbigny, 1826

Bulimina is distributed from the inner-shelf to bathyal depths and requires muddy substrate and cold-temperate waters (Murray, 1991). Sliter & Baker (1972) report this genus in the upper- to lower-slope assemblages of the eastern Pacific margin. Sztrákos (1979) reports this genus from 110 and 900 meters (circalittoral and epibathyal environments); in the Adriatic Sea, Asioli & Borsetti (1989) found this genus at depth deeper than 10 meters. Aubert & Berggren (1976) report the presence of *B. trigonalis* in the Paleocene and Ypresian of Turkey as a good marker of littoral marine (restricted) facies. Tjalsma & Lohmann (1983) found *B. alazanensis* in the lowest facies of the Paleocene-Eocene of the Atlantic; on the contrary, Caralp et al. (1970 a) found this species in the modern Biscay Bay at depth of about 2000-2500 meters.

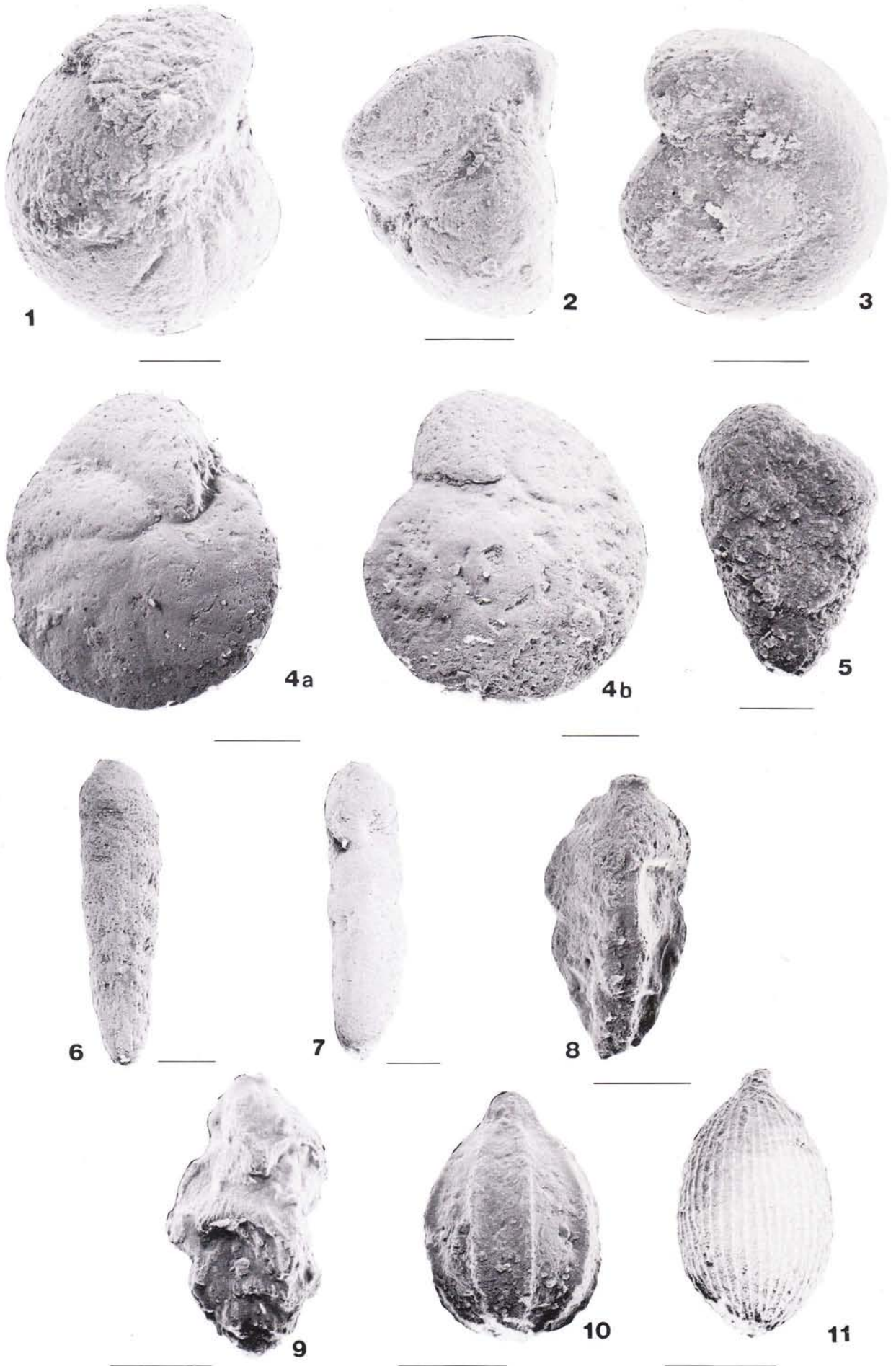
Cassidulina d'Orbigny, 1826

Sztrákos (1979) indicates the presence of this genus at depth of 110 to 900 meters (circalittoral and epibathyal). Murray (1991) reports this genus in muddy or sandy sediments from shelf to bathyal environment in temperate to cold waters.

PLATE 1

- Fig. 1-3 - *Gyroidinoides octocamerata*. (1) Sample ME91-11, umbilical view; (2) sample ME91-11, side view; (3) sample ME91-9, spiral view.
 Fig. 4 a, b - *Cibicidoides proprius*. Sample ME91-23; (a) umbilical view; (b) spiral view.
 Fig. 5 - *Siphotextularia concava*. Sample ME91-37.
 Fig. 6 - *Brizalina* gr. B. Sample ME91-27.
 Fig. 7 - *Loxostomoides* gr. *applinae*. Sample ME91-32.
 Fig. 8 - *Trifarina* gr. *bradyi*. Sample ME91-27.
 Fig. 9 - *Trifarina muralis*. Sample ME91-42.
 Fig. 10 - *Lagena acuticosta*. Sample ME91-25.
 Fig. 11 - *Lagena* gr. *striata*. Sample ME91-27.

Scale bar: 100 μ m.



Chilostomelloides Cushman, 1926

Luterbacher (1984) found this genus in the Paleogene of the southern Pyrenees restricted to bathyal deposits.

Cibicides Montfort, 1808

This genus is distributed from 0 to more than 2000 meters (shelf to bathyal) on hard substrates in cold-warm waters, but the environment is different for each species (Murray, 1991). Different environmental distribution is also indicated for fossil species.

At the Eocene/Oligocene boundary in Hungary, Sztrákos (1982) reports *C. americanus*, *C. lobatulus*, and *C. carinatus* in the infralittoral environment.

In the Upper Paleocene - Lower Eocene of North Atlantic, Berggren (1974) indicates the presence of *C. burlingtonensis* and *C. howelli* in the intermediate shelf (30-100 meters) and dubiously in outer shelf (maximum depth about 180 meters), *C. simplex* in the inner shelf (less than 30 meters), and *C. succedens* from inner (about 30 meters) to outer (200 meters) shelf.

C. lobatulus is an infralittoral species with very different morphology, living fixed or free in the sediments (Mediterranean Sea, Recent) (Blanc-Vernet, 1969). Pujos (1972) in the Biscay Bay found this species on muddy sediments at depth of 30-90 meters and in fine sands at depth from 15 to 200 meters; the Author indicates the highest percentages of *C. lobatulus* in medium to coarse sands in infralittoral environment to outer continental margin. Grünig & Herb (1984) found *C. westi* restricted to the outer neritic in the Eocene of Biarritz.

Cibicidoides Thalmann, 1939

This genus lives in cold waters and shelf to bathyal depths (Murray, 1991). In the Eocene of Tremp-Ager area (Pyrenees - Spain) this genus was found in all marine facies, but it is more abundant in terrigenous deposits (Ferrer et al., 1973). Van Morkhoven et al. (1986) found *C. bradyi* from outer neritic environment to abyssal depth, and *C. laurissae* from medium bathyal to abyssal depths.

Berggren (1972) recognized *C. perlucidus* at middle-upper bathyal depths (300-600 meters) in the Oligocene of the Caribbean and Mediterranean areas. This species commonly occurs in bathyal facies together with *C. mexicanus* and *C. eocaenus* (van Morkhoven et al., 1986). Berggren (1972) found *C. proprius* in the shelf at depth less than 200 meters in the Paleogene of the North Atlantic.

C. ungerianus and *C. pseudoungerianus* are open-marine dwellers living in muddy substrate with no tolerance to oxygen deficiency or increased salinities (van der Zwaan, 1982). Sztrákos (1979) report the presence of these species with high abundance in circalittoral environment (from 100 to 150-200 meters) in the Oligocene of Hungary. In the Eocene of Biarritz *Heterolepa ungeriana* was found only in bathyal environment (Grünig & Herb, 1984). *C. pseudoungerianus* was found from circalittoral to bathyal environment in the Mediterranean Sea (Blanc-Vernet, 1969). Pujos (1972) found this species in fine sands in Bay of Biscay with percentages less than 1% at depths comprised between 90 and 110 meters, and between 5 and 10% from 110 to 200 meters. In general *C. pseudoungerianus* is present from the circalittoral zone and increases in abundance toward the outer circalittoral.

Clavulinoides Cushman, 1936

Olsson & Nyong (1984) found *C. trilater* in the Campanian-Maastrichtian of New Jersey at depth from 20 to 150 meters (maximum abundance from 60 to 110 meters).

Coleites Plummer, 1934

Aubert & Berggren (1976) report the presence of *C. aff. C. reticulosus* in the Paleocene of Tunisia in deep basin.

Cuvillierina Debourle, 1955

In the Ager Formation (Pyrenees-Spain) this genus is particularly abundant in calcareous and terrigenous littoral deposits and is rare in the others facies (Ferrer et al., 1973).

Dentalina d'Orbigny, 1826

This genus prefers bathyal depths (Blanc-Vernet & Clairefond, 1979-80). Blanc-Vernet (1969) report the presence of *D. communis* in the Mediterranean Sea in bathyal environments with low percentages.

Discocyclusina Gümbel, 1870

Representatives of this genus can be considered as a key-taxa that indicate the presence of submarine reefs in the Late Paleocene of Lybia (Sirte Basin) (Hamaoui, 1976). Fermont (1982) indicates that the relatively thick *Discocyclusina* are more frequent near the coast-line in the Eocene Bakony mountains, whereas flat *Discocyclusina* are more frequent in the deeper parts of the Eocene Bakony Basin; the flat types of *Discocyclusina* (*D. hexagonalis*, *D. sevensi*, and *D. augustae*) must have lived in the deepest part of the photic zone.

Eponides Montfort, 1808

This genus lives from shelf to abyssal depth environments in cold and temperate waters (Murray, 1991).

Fissurina Reuss, 1850

This genus, like *Oolina* and *Lagena*, are common in circalittoral deposits of the Mediterranean Sea, but is present also in infralittoral and deeper deposits (Blanc-Vernet, 1969); the presence of this genus is mainly associated with fine sediments. In the Cretaceous ocean-margin foraminiferal assemblages from southern California this genus was typical of outer shelf deposits (Sliter & Baker, 1972).

Gaudryina d'Orbigny, 1839

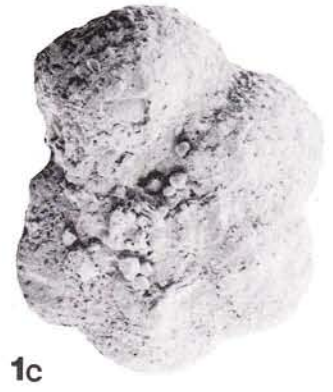
Murray (1991) states that this genus lives from 50 to 200 meters (shelf to upper bathyal) in hard substrate and warm-temperate waters. Blanc-Vernet (1969) found this genus in the Mediterranean Sea in association with *Textularia* in circalittoral environment on muddy and detritic substrates. Ferrer et al. (1973) report the presence of *Gaudryina* in the Eocene Ager Formation (Pyrenees - Spain) in terrigenous deposits. Sliter & Baker (1972), in the Cretaceous, indicate the upper boundary of this genus as the outer shelf, but indicates that it is more important on the slope.

G. pyramidata is abundant in outer shelf-upper bathyal envi-

PLATE 2

- Fig. 1 a, b, c - *Pararotalia* sp. Sample ME91-41; (a) spiral view; (b) side view; (c) umbilical view.
 Fig. 2, 3 - *Rotalia viennoti*. Sample ME91-55; (2) spiral view; (3) umbilical view.
 Fig. 4, 5 - *Rotalia calcariformis*. Sample ME91-53; (4) umbilical view; (5) spiral view.
 Fig. 6 - *Neoeponides* sp. A. Sample ME91-59, umbilical view.
 Fig. 7, 8 - *Cibicides mauricensis*. Sample ME91-22; (7) spiral view; (8) umbilical view.

Scale bar: 100 μ m.



ronment (200-400 meters) in the Maastrichtian of the southern Pyrenees (Elser, 1984). Tjalsma & Lohmann (1983) indicate for this species a wide bathymetric range in the Paleocene, but stated that it is more restricted at the deepest environment in the Early-Middle Eocene. Van Morkhoven et al. (1986) indicate the upper distribution boundary of this species at upper bathyal depths (Paleocene - Midway and Velasco Fauna); they state that in the Eocene such boundary was placed at lower bathyal depths (Jackson-Claiborne and Barbados Fauna).

Gavelinella Brotzen, 1942

Sliter & Baker (1972) found this genus in the Cretaceous ocean-margin foraminiferal assemblage from southern California from the outer-shelf to the lower-slope. Elser (1984) found many species of *Gavelinella* in the Maastrichtian of the Southern Pyrenees in shelf environment (100-200 meters).

In the Paleogene of Tunisia *G. danica* is common in outer-shelf and deeper deposits and absent in shallow-water deposits (Aubert & Berggren, 1976). This species has a wide bathymetric range during the Early Paleocene, narrowing to the shallower sites during the Late Paleocene (Tjalsma & Lohmann, 1983). In Late Paleocene - Early Eocene of the northern Atlantic, Berggren (1972, 1974) reports the presence of this species in shelf environment (30-200 meters). Van Morkhoven et al. (1986) indicate for the species *G. micra* a life-depth from outer neritic to abyssal.

Gavelinopsis Hofker, 1951

This genus is present from the shelf to bathyal depths on hard substrate in temperate-cold waters (Murray, 1991).

Globocassidulina Voloshinova, 1960

This genus is present in temperate-cold waters on muddy substrate from the shelf to bathyal depths (Murray, 1991). Tjalsma & Lohmann (1983) indicates a wide bathymetric range for *G. subglobosa*. Blanc-Vernet (1969) found *G. subglobosa* in modern bathyal sediments in the Mediterranean Sea; also van Morkhoven et al. (1986) indicate the upper bathyal as the upper depth boundary of this species in the Neogene (Hispaniola and Vienna Basin Fauna).

Globulina d'Orbigny, 1839

In the Cretaceous, this genus is present mainly in the inner to intermediate shelf, but also in the upper slope (Sliter & Baker, 1972). Nyong & Olsson (1984), in the Campanian-Maastrichtian of the northern Atlantic, found *G. gibba* at depths between 10 and 60 meters. Barbin & Keller-Grünig (1991) found this species in the Priabonian of northern Italy in the intermediate to outer shelf (70-100 meters).

Guttulina d'Orbigny, 1839

Sliter & Baker (1972) report this genus in intermediate- to inner-shelf Cretaceous deposits of southern California.

Gyroidinoides Brotzen, 1942

In the Cretaceous foraminiferal assemblages of southern California, Sliter & Baker (1972) found this genus in the upper slope. Asioli & Borsetti (1989) report the presence of this genus in the Adriatic Sea at depths deeper than 70 meters. Olsson & Nyong (1984) report the presence of *G. globosus* in Campanian-Maastrichtian of the northern Atlantic at depth deeper than 200 meters.

Hanzawaia Asano, 1944

This genus is present in inner shelf in temperate-warm waters on hard substrate (Murray, 1991).

Heterolepa Franzenau, 1884

This genus is characteristic of temperate-cold waters on hard substrate from the shelf to the bathyal depths (Murray, 1991). Van Morkhoven et al. (1986) found *Cibicidoides mexicanus* in the Oligo-

ene at medium-lower bathyal depths. They consider the *Heterolepa simplex-costata* group as the morphotype of lower depth; it is present in upper bathyal to middle neritic deposits. Also Berggren (1972) relates this species in the Oligocene of the Caribbean and Mediterranean at middle-upper bathyal depths (300-600 meters). Berggren (1974), instead, found this species in the Late Paleocene - Early Eocene of the Northern Atlantic in outer shelf to upper slope (180-300 meters).

Hoeglundina Brotzen, 1948

This genus is typical of cold waters from the outer shelf to bathyal (Murray, 1991). Sliter & Baker (1972) found this genus from the intermediate shelf to deeper depths in the modern and Cretaceous sediments of the eastern Pacific margin.

Karreria Rzehak, 1891

Berggren (1974) found *K. fallax* distributed in the inner- to middle shelf (at depth less than 50 meters) in the Late Paleocene of the northern Atlantic.

Lagena Walker & Boys, 1784

This genus, like *Oolina* and *Fissurina*, is common in circalittoral deposits of the Mediterranean Sea, but is present also in infralittoral and deeper deposits (Blanc-Vernet, 1969); the presence of this genus is mainly associated to fine sediments. *Lagena* is considered a good palaeoecological marker in association with clay sediments. This genus is dominant in medium- and upper-slope (600-1000 meters) in the Maastrichtian of the southern Pyrenees (Elser, 1984).

Lenticulina Lamarck, 1804

The coiled *Lenticulina* clearly predominate in shelf margin wedges (Cubaynes et al., 1989); the same Authors state that the specimens of this genus are more abundant in HST in respect to the TST where the uncoiled *Nodosariidae* dominate. The maximum abundance of coiled *Lenticulina* (70-80%) is reached at the shelf edge. Murray (1991) indicates for this genus cold water with depths from the outer shelf to bathyal. Blanc-Vernet (1969) found this genus in the Mediterranean Sea in circalittoral and bathyal environments; in the latter it is more abundant. *Lenticulina* dominates medium- and upper-slope environments (600-1000 meters) in the Maastrichtian of the southern Pyrenees (Elser, 1984).

Loxostomoides Reiss, 1957

In the Mediterranean Sea, this genus is typical of circalittoral environment; the highest abundances were found at depths less than 80-100 meters. This genus was found also at deeper water depths but in very low percentages (Blanc-Vernet, 1969).

L. applinae is characteristic of epicontinental facies. It is predominantly a neritic taxon also occurring at upper bathyal depths (van Morkhoven et al., 1986). Berggren & Aubert (1976) indicate a large ecologic range for *L. applinae*; they found this species in outer-shelf and lagunal sediments in Gafsa-Metlaoui area. The same Authors indicate this species from Late Cretaceous to Late Paleocene deposits in shelf facies (inner to outer) in Tunisia. Berggren & Miller (1989) found this species in neritic environment (depth less than 200 meters) and upper bathyal (200-600 meters) in the Paleocene.

Marginulina d'Orbigny, 1826

Ferrer (1971) reports the maximum abundance of this genus in clay deposits and Blanc-Vernet & Clairefond (1979-80) in bathyal deposits. Blanc-Vernet (1969) found *M. glabra* in bathyal environment in Mediterranean Sea with low abundance.

Berggren (1974) report the presence of *M. longiforma* in the Late Paleocene - Early Eocene from the northern Atlantic from inner to intermediate shelf environment (10-100 meters). In Paleocene of Tu-

nia this species is particularly common in shallow water (Aubert & Berggren, 1976)

Marginulinopsis Silvestri, 1904

In the Eocene of the Possagno section deep-water specimens are long and slender with many tubercles on the sutures. Toward the shallower environment they gradually become stouter and the tubercles are transformed into ribs on the sutures (Grünig, 1985). *M. fragaria* occurs with reduced ornamentation on its initial chambers during regressive cycles in the Priabonian of the Brendola section (northern Italy) (Barbin & Keller-Grünig, 1991). This species in the Eocene of Biarritz is restricted to the outer neritic environment (Grünig & Susedka, 1988).

Melonis de Montfort, 1808

Murray (1991) reports the presence of this genus from shelf to bathyal in waters with temperature less than 10°C and on muddy substrate. Berggren & Miller (1989) observed the migration of this genus from neritic environment (<200 meters) to bathyal at the Early-Middle Eocene boundary.

Nodosaria Lamarck, 1812

Boersma (1984) reports this genus mainly in outer shelf. Nyong & Olsson (1984) in the Campanian-Maastrichtian of the northern Atlantic indicates the presence of *N. affinis* in intermediate shelf (50-100 meters). Blanc-Vernet (1969) found *N. raphanistrum* in the Mediterranean Sea in bathyal environment.

Nonion Montfort, 1808

This genus lives in shelf environment at depth between 0 and 180 meters; it is a herbivore taxon and needs a salinity of 30-35‰ (Murray, 1991). Asioli & Borsetti (1989) found this genus in cores from the Adriatic Sea in circalittoral environment at depths between 50 and 70 meters.

N. scaphum is restricted to the outer neritic environment in the Eocene of Biarritz (Grünig & Herb, 1984). This species is dominant in clastic sediments, interpreted as a sublittoral deposits in low energy environment, from the Oligocene reef of northern Italy (Grünig & Susedka, 1988).

Nonionella Cushman, 1926

It is found in shelf to upper bathyal environments (10-1000 meters) on muddy substrate in temperate-cold waters (Murray, 1991). Boersma (1984) stated that this genus is mainly distributed in the inner shelf and Blanc-Vernet (1969) also founds high abundance of *Nonionella* in the Mediterranean Sea in coastal terrigenous muds at depth comprised between 40 and 100 meters.

Nummulites Lamarck, 1801

This is an epifaunal herbivore taxon that needs muddy carbonate substrate at depths of 0-130 meters (lagoon to inner shelf) (Murray, 1991). See also *Assilina*.

Oolina d'Orbigny, 1839

Pujos (1972) reports the presence of *Oolina hexagona* (<1%) at depth between 100 and 150 meters in the Bay of Biscay. See also *Fissurina*.

Operculina d'Orbigny, 1826

This genus is present in inner-shelf deposits (less than 30 meters) in the Late Paleocene - Early Eocene of the North Atlantic (Berggren, 1974). Murray (1991) indicates depths of 0-130 meters (inner shelf, lagoons) with muddy carbonate substrate. Ferrer et al. (1973) report a low abundance of this genus in littoral deposits with terrigenous mud at the base of the Ager Formation. The bathymetric distri-

bution of the smaller (less than 8 mm) representatives of the genus *Operculina* is similar to that of *Nummulites* (see above) of comparable size (Luterbacher, 1984).

Pararotalia Le Calvez, 1949

A herbivorous genus living in inner shelf on sandy substrate in warm-water environment (Murray, 1991). Sliter & Baker (1972) found this genus in inner-shelf Cretaceous assemblages of southern California. *Pararotalia* is one of the most important genera in the inner-neritic environment (depths less than 40 meters) in the Maastrichtian of the Pyrenees (Elser, 1984).

Planulina d'Orbigny, 1926

This genus lives from shelf to bathyal environments on hard substrate (Murray, 1991). Sliter & Baker (1972) report the presence of *Planulina* in modern intermediate to outer shelf of the eastern Pacific margin and in outer shelf in Cretaceous sediments.

Pleurostomella Reuss, 1860

This genus was found in outer shelf Cretaceous sediments (Sliter & Baker, 1972).

Pseudonodosaria Boomgaard, 1949

This genus was found in outer shelf Cretaceous sediments (Sliter & Baker, 1972).

Pullenia Parker & Jones, 1862

Sliter & Baker (1972) report the presence of this genus in modern deposits of intermediate shelf to intermediate slope in the eastern margin of the Pacific Ocean; in the Cretaceous, the Authors indicate the intermediate shelf as the upper distribution boundary of *Pullenia*. The same Authors report the increase in species number of this genus with the increase of the depth. Sztrákos (1979) reports a high frequency of this genus at depth from 110 to 900 meters (circalittoral and epibathyal). Murray & Wright (1974) and Murray (1991) indicate muddy substrate, cold waters, and outer shelf to bathyal depths as life environment of this genus. Blanc-Vernet (1969) found *P. quinqueloba* at bathyal depths in modern Mediterranean sediments; also Pujos (1972), in the Biscay Bay, found this species from the outer continental margin (deeper than 200 meters).

Quinqueloculina d'Orbigny, 1826

This genus characterizes the shelf environment, but rarely is present also at bathyal depths. It prefers high salinity (32-65‰) and can live in hypersaline lagoons (Murray, 1991). Sliter & Baker (1972) found this genus also in the inner-shelf deposits from the Cretaceous of southern California. The agglutinated *Quinqueloculina* are present only in infralittoral environment in presence of fine sand (Blanc-Vernet, 1969 - Mediterranean Sea).

Recurvoides Earland, 1934

This genus lives in cold waters from shelf to bathyal (Murray, 1991).

Rotalia Lamarck, 1804

Blanc-Vernet (1969) reports the presence of this genus in infralittoral environment of the Mediterranean Sea. The large size and heavy construction of *Rotalia trochidiformis* suggest that it probably preferred depths from 20 to 40 meters (Levin, 1957). Ferrer et al. (1973) report the highest abundance of this species in littoral sediments of the Eocene from the Tremp-Ager area (Pyrenees - Spain).

Saracenaria Defrance, 1824

Blanc-Vernet (1969) found *S. italica* in modern Mediterranean sediments at bathyal depths.

Siphotextularia Finlay, 1939

Blanc-Vernet (1969) found *S. concava* in modern Mediterranean sediments from circalittoral to bathyal. Pujos (1972) reports the presence of this species in the Biscay Bay at depths deeper than 100 meters (circalittoral) on medium to coarse sand substrate.

Spiroloculina d'Orbigny, 1826

This genus lives in temperate-warm waters at depths of 0-40 meters (Murray, 1991). Also Sliter & Baker (1972) found this genus in the Cretaceous in the inner shelf. Pujos (1972) reports the presence of *Spiroloculina* in medium to coarse sands of the Biscay Bay from depth of 70 meters; the Author supposes that *Spiroloculina* is present from the outer circalittoral.

S. canaliculata was found by Pujos (1972) in the Biscay Bay on fine sands from depths of 70 meters.

Spiroplectammina Cushman, 1927

Ferrer et al. (1973) report the absence of this genus in the littoral deposits. Sliter & Baker (1972) found *Spiroplectammina* in slope assemblages in the Cretaceous of southern California. This genus is considered as deep-water indicator in the Paleogene of southern Pyrenees (Luterbacher, 1984).

Barbin & Keller-Grünig (1991) stated that, in the Priabonian of Northern Italy, *S. carinata* is present in outer shelf (70-100 meters) sediments; the same Authors indicate that this species prefers muddy substrate, and the non-carinate species (*S. deperdita*) prefers nearshore silt and sands. These Authors consider the carinate species of *Spiroplectammina* as the deepest waters indicators with respect to the non-carinate ones. Van der Zwaan (1982) indicates that *S. carinata* has no tolerance for variations in oxygen content and salinity. Sztrákos (1979) found *S. carinata* in the Oligocene of Hungary in circalittoral environment (100-200 meters)

Stilostomella Guppy, 1894

Sliter & Baker (1972) found this genus from the lower slope in the Eastern Pacific Ocean.

Textularia DeFrance, 1824

This genus is lagoonal and marine (shelf to bathyal) and lives on hard or sandy substrate (Murray, 1991). Boersma (1984) found this genus mainly in inner deep shelf. Blanc-Vernet (1969) found *Textularia* in modern Mediterranean Sea in circalittoral environment, frequently in association with *Gaudryina*, on muddy or detrital substrate.

Trifarina Cushman, 1927

This genus is distributed from shelf to upper bathyal depth

(0-400 meters) in temperate-cold waters (Murray, 1991). Caralp et al. (1970) found *T. bradyi* restricted to sublittoral environment in the Bay of Biscay and Pujos (1972) found this species in circalittoral environment of the Bay of Biscay at depths deeper than 150 meters with very low percentages (<1%).

Triloculina d'Orbigny, 1826

This genus needs temperate-warm waters and prefers marine-hypersaline (32-55‰) environments; it is present mainly in hypersaline lagoons and marine inner shelf; some cold species are bathyal (Murray, 1991). Sliter & Baker (1972) found this genus in inner shelf of southern California in the Cretaceous. *T. trigonula* is an infralittoral species that prefers algal substrate. This genus seems to be more littoral than *Quinqueloculina* (Blanc-Vernet, 1969 - Mediterranean Sea).

Turrilina Andreae, 1884

The species *T. brevispira* is more common in outer neritic to bathyal environments, but is present also in abyssal deposits (van Morkhoven et al., 1986).

Uvigerina d'Orbigny, 1826

This is a cold water genus typical of shelf to bathyal environments (100-4500 meters) (Murray, 1991). Sztrákos (1979) reports this genus in circalittoral and epibathyal environments (110-900 meters). Blanc-Vernet (1969) found this genus at depth deeper than 200 meters in the Mediterranean Sea. Asioli & Borsetti (1989) report the presence of *Uvigerina* in circalittoral environment at depths deeper than 70 meters in the Adriatic Sea. In the Eocene of the southern Atlantic, Müller-Merz & Oberhänsli (1991) found this genus in bathyal environments only.

The upper depth boundary of *U. elongata* in the Oligocene of Hispaniola and Vienna Basin is upper bathyal (van Morkhoven et al., 1986). Barbin & Keller-Grünig (1991) indicate depths of about 70 to 100 meters (middle and outer shelf area) for *U. eoacaena*. Berggren & Aubert (1976) found this species in the Eocene of Labrador Sea in bathyal environment.

Valvulina d'Orbigny, 1826

In the Eocene of the Ager Formation (Pyrenees - Spain), Ferrer et al. (1973) found this genus mainly in lagoonal and littoral deposits.

Valvulineria Cushman, 1926

Nyong & Olsson (1984), in the Campanian and Maastrichtian of the Northern Atlantic, report the presence of this genus at bathyal depths.

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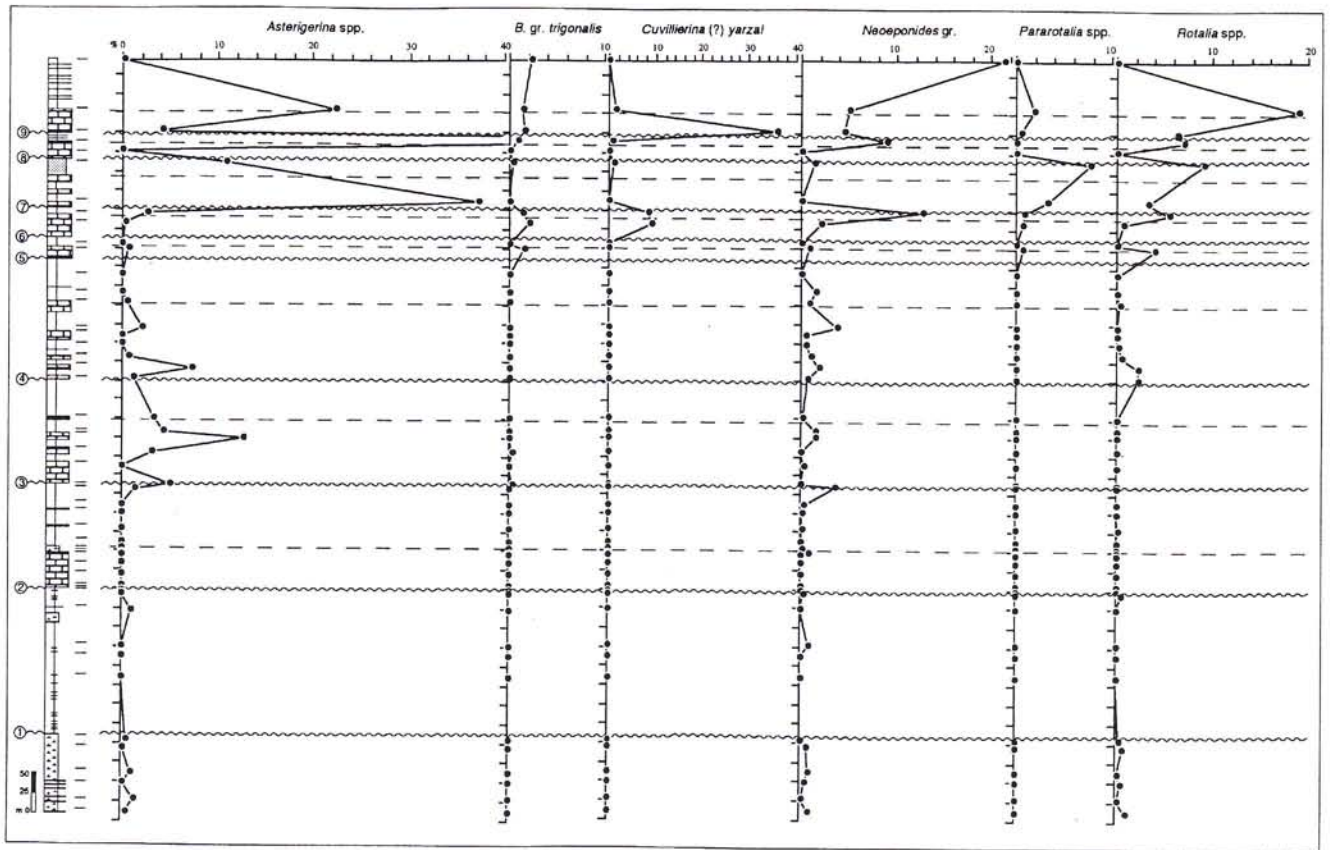


Fig. 11 - Percentages of *Asterigerina* spp., *Bulimina* gr. *trigonalis*, *Cuvillierina* (?) *yarzai*, *Neoeponides* gr., *Pararotalia* spp., and *Rotalia* spp. in Merli Est Section. For the symbols and the legend see Fig. 2 and 4.

- Many Nodosariacea taxa (mainly represented by *Marginulina* spp., *Oolina* spp., *Fissurina* spp., *Lagena acuticosta*, *Lagena gracilicosta*, *Dentalina* spp.), *Anomalinoidea* spp., *Gyroidinoidea* spp., *Praeglobobulimina* gr. *ovata*, *Cibicidoides pseudoungerianus*, *C. ungerianus*, *Guttulina* spp., *Eponides* spp., *Alabamina wilcoxensis*, *Cibicides cassivellauni*, *Karrerina fallax*, *Uvigerina* spp., and *Briozalina* spp. disappear within or at the top of Unit 4 corresponding to the FG2/FG3 boundary.

- At the same level *Lagena* gr. *striata*, *Dentalina* spp., *Lenticulina rotulata* and *Cibicidoides perlucidus* abruptly decrease. Most of the taxa of the two last groups are indicator of deep water environment and their disappearance was interpreted as an important shallowing of the water depth.

- *Assilina* spp., *Rotalia* spp., *Asterigerina* spp., *Neoeponides* gr., and *Bulimina* gr. *trigonalis* are present in Units 1 to 4 with low percentages, but from Unit 5 toward the top they reach the highest percentages in this section. The great increase of these taxa confirms the hypothesis of a remarkable shallowing at the Units 4/5 boundary.

- *Cuvillierina* (?) *yarzai* and *Pararotalia* spp. appear in the topmost part of the section, respectively in Units 6 and 7. Their appearance indicate a further shall-

lowing of water depth at the FG3/FG4 boundary, enhanced by the increase of *Asterigerina* spp. percentages. This boundary is also marked by the decrease of percentages of *Cibicidoides proprius*. Based on the distribution and the abundance of the mentioned taxa, there is an evident shallowing of water depth from the base toward the top of the section. This trend is discontinuous and shows some steps corresponding to the major depositional sequences boundaries.

Figs 1 (FG1).

In Unit 1 the highest value of planktonic foraminifera and the low percentages of shallow-water indicators in sample ME91-10, could indicate the MFS of this sequence. In the upper part of the sequence a shallowing upward trend was detected. The benthic foraminiferal assemblage indicates that Unit 1 could be considered the deepest one in Figs 1 Allogroup and seems to be deposited in water deeper than those at the top of Alveolina Limestone Allogroup. Nevertheless the diversity values and the planktonic foraminiferal percentages are not indicative of such interpretation; the signal of deep water of this unit could be interpreted as the result of the presence of the thin-bedded turbidites responsible of the displacement of part of the specimens and cannot be considered as a true signal.

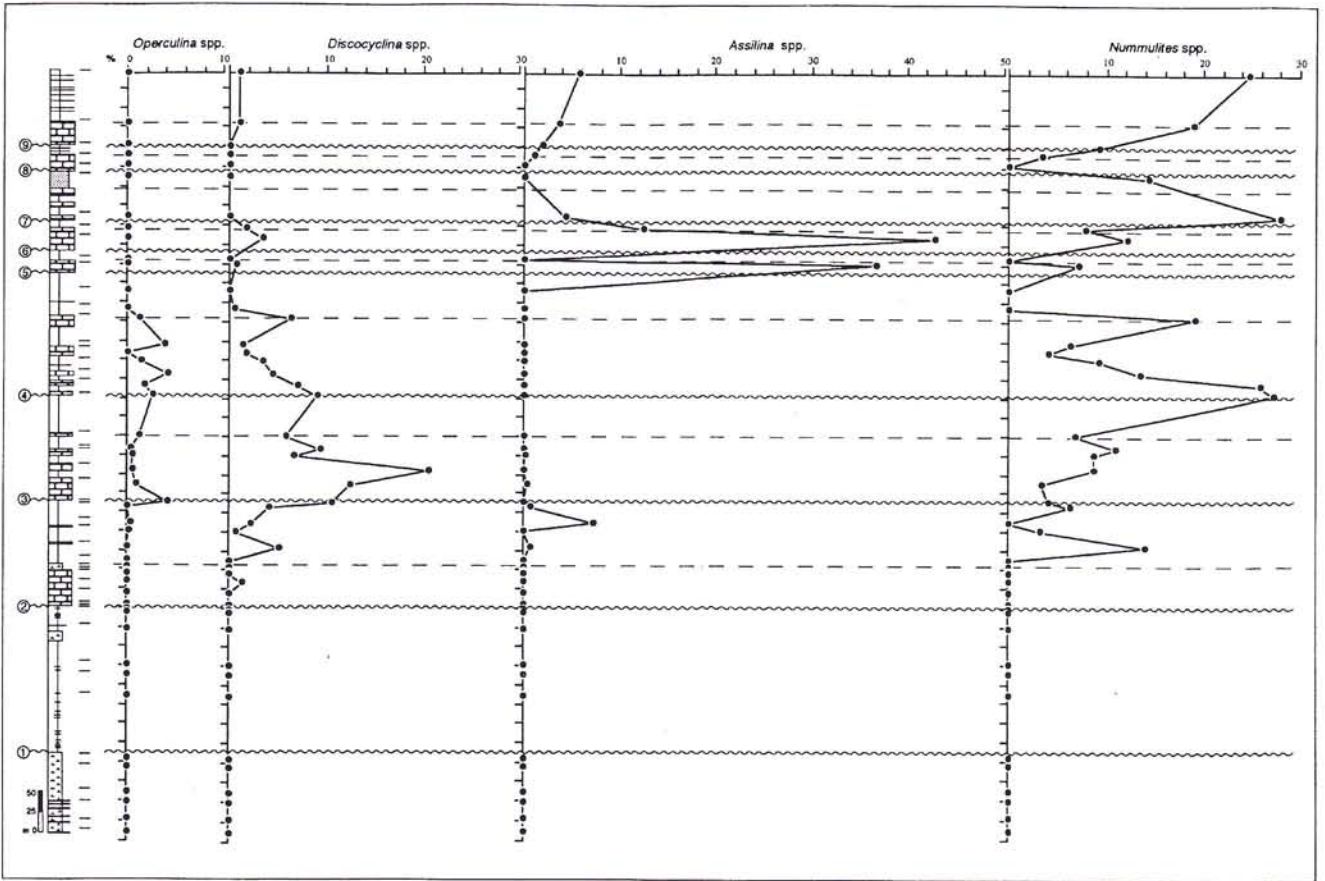


Fig. 12 - Percentages of *Operculina* spp., *Discocyclus* spp., *Assilina* spp. and *Nummulites* spp. in Merli Est Section. For the symbols and the legend see Fig. 2 and 4.

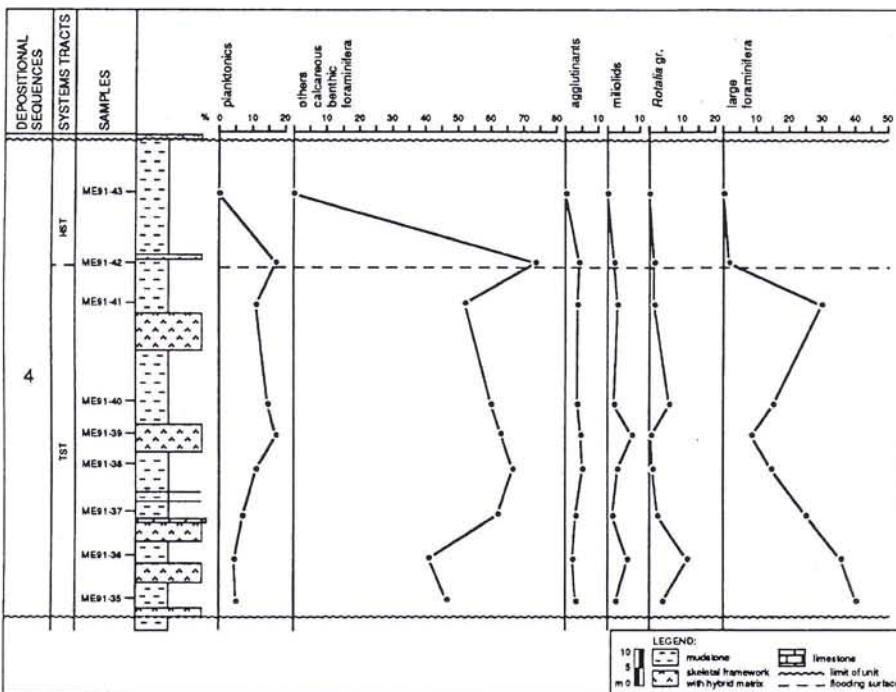


Fig. 13 - Distribution and percentages of the six groups of foraminifera detected in Unit 4, Merli Est Section.

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