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Paleoenvironmental bottom water conditions in the early Zanclean of the Capo Rossello area (Agrigento, Sicily)

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ABSTRACT – The Pliocene “Trubi” Formation outcropping in Southern Sicily, has been so far the object of numerous researches only on composite sections. To obtain a continuous succession of unweathered sediments considered more suitable for paleomagnetic studies and cyclostratigraphical analyses, a continuous core drilling has been performed in the area East of Capo Rossello, between Punta di Maiata and Punta Grande. The bore-hole crossed the basal part of the Monte Narbone Formation, all the “Trubi” Formation and about 1 m of the underlying Messinian “Arenazzolo” Formation with a recovery of 99%. The complete drilling reached 155.26 m below ground surface.

The present paper deals with the paleoecological bottom water changes during the Zanclean from M Pl 1 to the lower part of M Pl 3 Biozones by means of the detailed quantitative analysis of benthic foraminifers and ostracods. The assemblages are typical of lower epibathyal zone all along the succession with benthic foraminifers that document a depth-range from 600 to 800 m. The two faunal groups pointed out different colonization patterns. The benthic foraminifers show a quick re-colonization at the base of the succession, almost completed in the lower part of M Pl 2 Biozone, whereas the ostracods show a slow fluctuating re-colonization along M Pl 1 and M Pl 2 Biozones and a rapid increase only a few meters above the M Pl 2 – M Pl 3 boundary.

Moreover some principal bioevents have been identified. Above the initial re-colonization at the base of the M Pl 1 Biozone, the assemblages change rapidly in the upper part of the same biozone. This interval is characterized by the “Uvigerina pygmaea - peregrina Event”, among the benthic foraminifers, and by a remarkable reduction of the ostracods assemblages in both number of species and specimens, indicative of a clearly defined dysaerobic or kenoxic phase with bottom slowed circulation. These conditions quickly change at the base of the M Pl 2 Biozone with the beginning of improving bottom oxygenation characterized by the FOD of *Agrenocythere* pliocenica, typical psychrospheric ostracod, and of *Cibicoides robertsonianus*, a benthic foraminifer characteristic of the NADW. A second change starts from the middle part of the M Pl 2 Biozone. In fact, the benthic foraminiferal co-dominant assemblages are characterized by species related to increased productivity and circulation. This change begins a few meters below the FO of *Globorotalia puncticulata*, a species which testifies a slight cooling. Therefore the benthic foraminifers seem to show a paleoenvironmental cooling-related bottom change, which occurs shortly before the FO of this planktic foraminifer.

From the base of M Pl 2 upwards the ostracods testify the entrance of the psychrosphere which becomes stabilized within this biozone and a gradual improvement of bottom circulation. From M Pl 3 Biozone, after the paleoclimatic change, the assemblages are abundant and well diversified and indicate that the paleoceanographic conditions at the bottom improved and evolved to become more stable.

Finally a probable correlation of the quantitative distribution of *Planulina ariminensis* (benthic foraminifer) with a maximum in the eccentricity astronomical record of 400 ky has been pointed out.

RIASSUNTO – [Paleoecologia dei sedimenti batiali dello Zancleano inferiore dell'area di Capo Rossello (Agrigento, Sicilia)] – La Formazione dei “Trubi” che affiorano nella Sicilia meridionale, è stata finora oggetto di studi esclusivamente su sezioni composite. Allo scopo di ottenere una successione continua e sedimenti inalterati di questa formazione, considerati utili per studi paleomagnetici e per analisi di dettaglio paleoecologiche e ciclostratigrafiche, è stato effettuato il Pozzo TPM in carotaggio continuo nell'area ad Est di Capo Rossello tra Punta di Maiata e Punta Grande. Il Pozzo ha attraversato la parte basale della Formazione di Monte Narbone e l'intera Formazione dei “Trubi” raggiungendo il contatto con la sottostante Formazione dell'Arenazzolo a 154.20 m dal piano di campagna, con un recupero del 99%. Nel complesso la perforazione ha raggiunto 155.26 m.

In questo lavoro è stato sviluppato lo studio paleoecologico dei “Trubi” dello Zancleano inferiore dalla Biozona M Pl 1 fino alla parte inferiore della Biozona M Pl 3. A partire da una fitta campionatura è stata effettuata una dettagliata analisi quantitativa delle associazioni a foraminiferi bentonici ed ostracodi. La successione esaminata è stata stimata di ambiente epibatiale inferiore, con paleobatimetria compresa tra 600-800 m per i foraminiferi bentonici. I due gruppi faunistici hanno evidenziato due modelli distinti di colonizzazione. I foraminiferi bentonici mostrano una rapida ricolonizzazione già alla base della successione ed, in generale, fino alla parte inferiore della Biozona M Pl 2, mentre gli ostracodi presentano inizialmente una ricolonizzazione lenta con irregolari “input” lungo l'intervallo M Pl 1- M Pl 2 e registrano un rapido aumento solo pochi metri sopra la base della Biozona M Pl 3.

Inoltre, sono stati distinti alcuni bioeventi principali. La Biozona M Pl 1 è caratterizzata alla base da una prima fase di ricolonizzazione a cui segue una distinta fase disaerobica con rallentata circolazione al fondo più evidente durante la parte superiore della stessa biozona. Quest'ultima è caratterizzata dall'evento ad *Uvigerina pygmaea-peregrina*, tra i foraminiferi bentonici, e da una forte riduzione in numero di specie ed individui nell'associazione ad ostracodi. Queste condizioni cambiano rapidamente alla base della Biozona M Pl 2 con l'inizio di condizioni ben ossigenate al fondo caratterizzate dalla comparsa di *Agrenocythere* pliocenica, ostracode indicatore di psicosfera, e da *Cibicoides robertsonianus*, foraminifero bentonico caratteristico di NADW. Un secondo cambiamento è stato registrato durante la Biozona M Pl 2. In questo intervallo le associazioni co-dominanti a foraminiferi bentonici sono caratterizzate dall'aumento di specie indicative di un maggiore apporto di materia organica al fondo ed aumentata circolazione. Questo cambiamento precede di pochi metri la comparsa di *Globorotalia puncticulata*, specie che indica l'inizio di un lieve raffreddamento. Quindi le associazioni a foraminiferi bentonici sembrano registrare una variazione delle condizioni paleoceanografiche al fondo, legate al cambiamento del paleoclima, poco prima dell'ingresso del foraminifero planctonico. Invece gli ostracodi indicano un graduale miglioramento della circolazione al fondo e della stabilizzazione della psicosfera nell'ambito della Biozona M Pl 2 e presentano una associazione abbondante e diversificata solo a partire dalla Biozona M Pl 3, successivamente alla variazione paleoclimatica, a conferma di migliori e più stabili condizioni al fondo.

Infine, è stata evidenziata una probabile corrispondenza tra la distribuzione quantitativa di *Planulina ariminensis* (foraminifero bentonico) e la curva astronomica di eccentricità dei 400.000 anni.

INTRODUCTION

Southern Sicily is a classical reference region for the Pliocene bio- and cyclostratigraphy since numerous successions are well exposed and rich in microfossils. Several composite sections have been studied from a bio-, cyclo-stratigraphic and paleomagnetic point of view that are outcropping in the area between Eraclea Minoa to Punta Piccola, east of Capo Rossello (Cita & Gartner, 1973; Brolsma, 1978; Spaak, 1983; Guerrero *et al.*, 1984; Rio *et al.*, 1984; Hilgen, 1987). Since the magnetostratigraphic analyses did not yield good results in the basal part of the Lido Rossello section (Zijderveld *et al.*, 1986; Scheepers & Langereis, 1993), selected as the stratotype of the Zanclean (Cita, 1975), Hilgen & Langereis (1988; 1993) proposed the Eraclea Minoa section, which gives good magnetostratigraphic results in the basal Pliocene, as a candidate for the Miocene/Pliocene boundary stratotype.

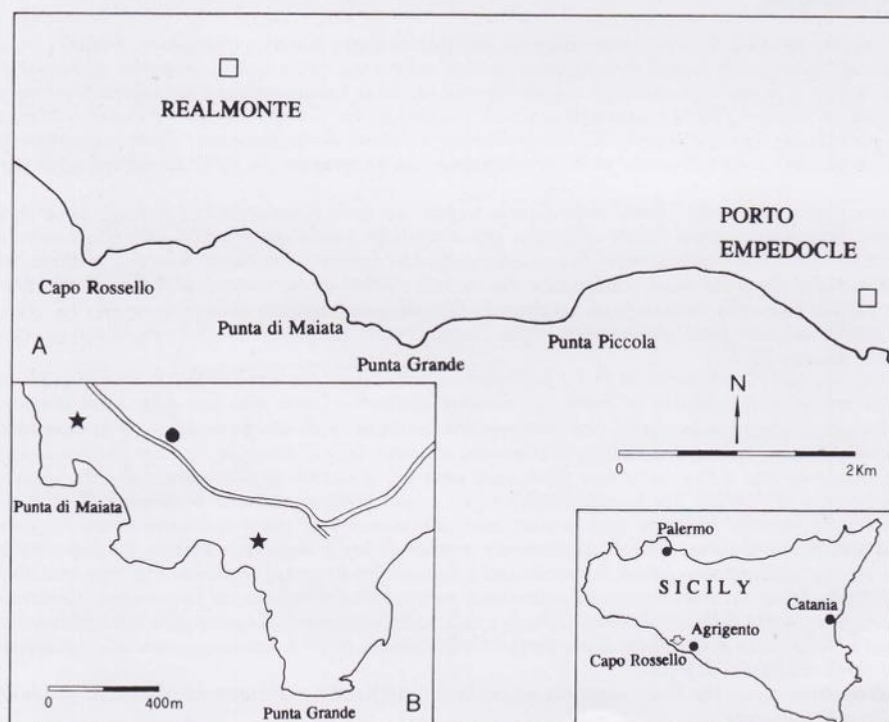
The analyses of planktonic foraminiferal assemblages (Zachariasse & Spaak, 1983) and on stable isotopes (van der Zwaan & Gudjonsson, 1986) carried out on Pliocene sediments from Southern Sicily allowed also the reconstruction of surface paleocirculation and paleoceanography of the Mediterranean Pliocene. Sprovieri (1978) and Brolsma (1978) on the basis of the benthic foraminiferal distribution reconstructed the paleobathymetric evolution and changes of bottom water conditions. Moreover, with the same purpose, an integrated study of

foraminifers, dinoflagellates, pollens and spores has been afforded by Guerrero *et al.* (1984).

However, all the previous researches are based on composite sections that are mainly widely sampled. Only Zachariasse *et al.* (1978) in their multidisciplinary paper performed a more detailed study but this was limited to a very short (8 m) segment.

In order to investigate in detail a continuous succession of the "Trubi" Formation a bore-hole was specifically drilled east of Lido Rossello, between Punta di Maiata and Punta Grande (Text-fig. 1). The drilling crossed part of the Monte Narbone Formation, the entire "Trubi" Formation and reached the contact with the Arenazzolo at 154.2 m below ground surface. According to Sprovieri (pers. communication, 1997) the bore-hole spans the M Pl 1 - M Pl 5 zonal interval, even if the boundary between M Pl 4a and M Pl 4b Biozones could not be exactly defined because of a slumpings in the upper part of the "Trubi".

The original project had the purpose of investigating three principal aspects: 1) the detailed paleoecological evolution based on a dense sampling; 2) the lithological and faunal cyclostratigraphy; and 3) an attempt to obtain paleomagnetic signals in the Capo Rossello area, with unweathered sediments. The present paper deals with the first aspect of the project. The paleoenvironmental evolution of bottom water conditions during the Early Pliocene is here attempted through quantitative benthic foraminiferal and ostracod analyses. This study is the continuation of the detailed reconstruction of bottom paleoenviron-



Text-fig. 1 - Map of Sicily. A) location of the Capo Rossello area; B) locations of the bore-hole (solid circle) and of the Hilgen (1987) sections of Punta di Maiata and Punta Grande (stars).

mental evolution based on benthic foraminifers, already accomplished both in the bore-hole and in Eraclea Minoa succession for the M Pl 1 Biozone by Sgarrella *et al.* (1997).

DRILLING SITE LOCATION AND FIELD OPERATION

The site has been selected in order to recover a continuous, undisturbed "Trubi" sequence. Since slumpings were found in the upper part of the "Trubi" succession of Punta di Maiata (Spaak, 1983), whereas they are absent at Punta Grande (Hilgen, 1987), we asked the local authorities the permission to drill in a locality as near as possible to Punta Grande. The drilling site permission was given for the locality of Sciabbarra along the coast road from Capo Rossello to Porto Empedocle (Agrigento) (Text-fig. 1B). In particular, the bore-hole site is situated 300 m east of the Punta di Maiata and about 400 m west of the Punta Grande successions studied by Hilgen (1987). The drilling site has been reported as TPM (Trivellazione Punta di Maiata). Unfortunately, slumpings affect the upper part of the "Trubi" also in the bore-hole preventing to place exactly the boundary between M Pl 4a and M Pl 4b Biozones (see above).

The continuous rotary coring was realized during Spring 1991. The ground surface is 54 m a.s.l. and the drilling started about 4 m below, where in situ rock was recovered. A double-tube T6S core-barrel (internal diameter 93 mm) was utilized in the topmost more clayey part and a simple tube T6 core-barrel in the harder "Trubi" Formation. The core penetrated first mostly well cemented marine Quaternary sands between 4 to 7.5 m, followed by the clayey Monte Narbone Formation down to 23 mbs, with two manganeseiferous layers, and the entire "Trubi" Formation down to the Arenazzolo Formation which has been penetrated for about 1 m. The Arenazzolo/Trubi boundary was reached at a drilling depth of 154.20 mbs. The complete drilling reached 155.26 mbs with an excellent recovery of 99 %. Taking into account the mean bedding dip of 16°, measured on the sea-side outcrop about 30 m above the Arenazzolo/Trubi boundary, the stratigraphic thickness has been corrected to 148.2 m. The strata direction is about N 60° E.

The complete drilling resulted in 61 core-sections, numbered from the top. Each core of about 3 m length was extracted, positioned horizontally in half a plastic tube, signed with a longitudinal incised line with arrows showing the base-core and measured in length. After being washed from the drilling mud, it has been photographed with a blackboard reporting the data of the core number, depth interval, and length. A preliminary field study of the cores was accomplished by W. Schwarzacher (School of Earth Science, Queen's University, Belfast) taking into account the changes in colour, sedimentology, stratification and dip, slumpings, bioturbations and their types. Each core has been subsequently cut into sec-

tions of 1 m (or less depending on the length of the core), each section sealed by enrolling it in plastic, labeled and housed in the suitable polyurethane boxes, each of which was sealed, numbered and the related content registered.

LABORATORY

The preparation of the cores was performed at the Micropaleontological Laboratory of the Department of Paleontology, University of Naples. Each core was cut lengthwise into 3 parts: one quarter was designated as the "archive", a second quarter assigned to paleomagnetic analyses and half of the core to paleontological, sedimentological and geochemical studies. The quarter for paleomagnetism has been sealed again just after cutting.

Each half-core was cleaned by washing and a colour-slide has been taken in wet conditions together with the drilling data, the reference colour index and sometimes at larger magnifications to show peculiar structures and other features. Acetate peels have been also prepared for all the suitable cores.

For the present study, the working half-core was cut into samples 5 cm-thick. The continuous sampling spans from the base up to 108.83 m drilling-depth at a distance of about 25 cm, except just above the Arenazzolo/Trubi boundary where the very base was sampled in more detail. Above 108.83 m, some scattered samples have been prepared for ostracod analysis. The sample list is reported in Tab. 1.

Each sample was subsequently cut lengthwise into slices resulting in 5 subsamples the largest of which (about 1/4 of the sample) was used for foraminiferal and ostracod study. The samples selected were distributed to the other specialists. Each sample for microfaunal study was cleaned carefully from the drilling mud, its volume and dry weight recorded, treated with the usual techniques to disaggregate it, washed through 63 mm and 125 mm sieves and the dried residue weighted.

The segment of the bore-hole studied spans the M Pl 1, M Pl 2 and the basal part of M Pl 3 Biozones (Sprovieri, pers. communication, 1997). Biostratigraphic subdivision is based on the scheme of Cita (1975) emended by Sprovieri (1992). The end of the *Sphaeroidinellopsis* acme is recorded at 151.03 mbs, the First Common Occurrence (FCO) of *Globorotalia margaritae* is recorded at 147.1 mbs and the First Occurrence (FO) of *Globorotalia puncticulata* is recorded at 122.2 mbs.

BENTHIC FORAMINIFERA (Sgarrella F.)

METHODOLOGY

Benthic foraminifers have been studied from 162 samples. They were picked out, identified and count-

SAMPLES	WEIGHT	STUDIED	SAMPLES	WEIGHT	STUDIED	SAMPLES	WEIGHT	STUDIED
99.94-99.99	127	O	122.62-122.67	171	F - O	138.95-139.00	127	F - O
100.92-100.97	161	O	122.97-123.02	197	F	139.29-139.34	197	F - O
101.77-101.82	147	O	123.23-123.28	191	F	139.59-139.64	90	F - O
103.09-103.14	143	O	123.53-123.58	180	F - O	139.84-139.89	217	F - O
104.09-104.14	159	O	123.88-123.93	178	F	140.14-140.19	195	F - O
104.99-105.04	169	O	124.18-124.23	183	F	140.43-140.48	199	F - O
106.00-106.05	144	O	124.48-124.53	192	F - O	140.73-140.78	208	F - O
106.90-106.95	194	O	124.78-124.83	221	F	141.03-141.08	179	F - O
108.05-108.10	176	O	125.08-125.13	179	F	141.33-141.38	152	F - O
108.83-108.88	100	F - O	125.33-125.38	181	F - O	141.70-141.75	176	F - O
109.13-109.18	127	F - O	125.73-125.78	138	F	142.01-142.06	150	F - O
109.43-109.48	131	F - O	125.98-126.03	185	F	142.29-142.34	174	F - O
109.64-109.69	132	F - O	126.28-126.33	191	F	142.49-142.54	169	F - O
109.94-109.98	113	F - O	126.58-126.63	183	F - O	142.75-142.80	177	F - O
110.14-110.19	156	F - O	126.88-126.93	175	F	143.07-143.12	184	F - O
110.39-110.44	151	F - O	127.23-127.28	170	F - O	143.42-143.47	155	F - O
110.59-110.64	149	F - O	127.48-127.53	170	F	143.67-143.72	180	F - O
110.84-110.89	143	F - O	127.78-127.83	183	F - O	143.97-144.02	190	F - O
111.14-111.19	162	F - O	128.03-128.08	176	F	144.27-144.32	176	F - O
111.34-111.39	145	F - O	128.28-128.33	173	F	144.68-144.73	160	F - O
111.49-111.54	143	F - O	128.66-128.71	175	F	144.98-145.03	184	F - O
111.76-111.81	127	F	128.96-129.01	193	F - O	145.28-145.33	164	F - O
111.91-111.96	139	F - O	129.26-129.31	165	F	145.58-145.63	155	F - O
112.21-112.26	149	F - O	129.46-129.51	154	F	145.90-145.96	271	F - O
112.46-112.51	141	F - O	129.66-129.71	163	F	146.16-146.21	143	F - O
112.76-112.81	125	F	129.96-130.01	170	F - O	146.36-146.41	162	F - O
113.01-113.06	128	F - O	130.26-130.31	136	F	146.75-146.80	166	F - O
113.29-113.35	122	F	130.51-130.56	165	F	147.10-147.15	150	F - O
113.50-113.55	134	F	130.72-130.77	194	F	147.55-147.60	145	F - O
113.65-113.70	132	F - O	131.12-131.17	183	F - O	147.85-147.90	161	F - O
113.95-114.00	141	F - O	131.34-131.39	117	F	148.20-148.25	145	F - O
114.30-114.35	110	F - O	131.59-131.64	158	F	148.47-148.52	142	F - O
114.63-114.68	183	F - O	131.84-131.89	176	F	148.76-148.81	148	F - O
114.93-114.98	148	F	132.24-132.29	166	F - O	149.01-149.06	148	F - O
115.30-115.35	131	F - O	132.59-132.64	142	F	149.27-149.32	178	F - O
115.60-115.65	151	F	132.89-132.94	166	F	149.52-149.57	159	F - O
116.04-116.09	162	F	133.14-133.19	166	F	149.84-149.89	185	F - O
116.34-116.39	185	F - O	133.44-133.49	203	F - O	150.17-150.22	168	F - O
116.64-116.69	178	F	133.69-133.74	135	F	150.47-150.52	179	F - O
117.03-117.08	165	F	133.99-134.04	158	F - O	150.77-150.82	194	F - O
117.33-117.38	153	F - O	134.34-134.39	187	F	151.08-151.13	193	F
117.63-117.68	135	F	134.64-134.69	190	F - O	151.40-151.45	164	F - O
117.99-118.04	136	F - O	134.95-135.00	149	F	151.70-151.75	152	F - O
118.41-118.46	147	F - O	135.20-135.25	158	F - O	152.00-152.05	56	F - O
118.66-118.71	187	F	135.40-135.45	147	F	152.25-152.27	69	F - O
118.96-119.01	173	F	135.66-135.71	200	F - O	152.50-152.52	67	F - O
119.26-119.31	157	F	135.91-135.96	88	F	152.80-152.82	73	F - O
119.52-119.57	136	F - O	135.96-136.01	201	F	153.05-153.07	69	F - O
119.77-119.82	180	F	136.22-136.27	196	F - O	153.30-153.32	68	F - O
120.17-120.22	157	F	136.57-136.62	198	F	153.55-153.57	74	F - O
120.55-120.60	175	F - O	136.87-136.92	208	F - O	153.79-153.81	80	F - O
120.80-120.85	169	F	137.17-137.22	181	F - O	153.89-153.94	176	F - O
121.10-121.15	172	F - O	137.47-137.52	182	F	153.94-153.99	164	F
121.40-121.45	148	F	137.78-137.83	160	F - O	154.09-154.14	78	F - O
121.71-121.76	175	F - O	138.08-138.13	195	F	154.14-154.17	145	F - O
122.02-122.07	180	F - O	138.35-138.40	154	F	154.17-154.18	22	F - O
122.32-122.37	127	F	138.65-138.70	170	F	154.18-154.20	62	F - O

Tab. 1 - Samples list, dry weights (in gram) and samples studied for benthic foraminifers (F) and ostracods (O). Sample numbers refer to meter below surface.

ed from the fraction > 125 μ m and 122 species recognized. The list of the species is reported in appendix 1. The fraction was split if necessary with a

microsplitter to yield a subsample containing more than 200 specimens. Taxon abundance is expressed as percentage of the total fauna. The quantitative data

were elaborated by Q-mode Factor Analysis using CABFAC program (Imbrie and Kipp, 1971; Klován and Imbrie, 1971). The benthic number (BN) was calculated as the total number of specimens in the fraction $> 125 \mu\text{m}$ per gram of dry sediment and reported as BN $> 125 \mu\text{m}$.

DATA

ABUNDANCE AND DIVERSITY

The trends of BN $> 125 \mu\text{m}$ and of the number of species along the section are plotted in Text-fig. 2. Both curves show a marked increase at the base and frequent fluctuations all along the section. BN $> 125 \mu\text{m}$ is generally low, with 20 to 40 specimens per gram. Values lower than 10-20 specimens per gram are recorded at the very base of the section between 154.20 and 150.17 mbs and between 139.59 and 137.78 mbs. A strong minimum is also registered in sample 135.91-135.96 mbs. On the contrary, values higher than 40 specimens per gram occur only in three intervals as follows: 1) 149.84-147.85 mbs; 2) 133.99-128.28 mbs; 3) 113.01-111.34 mbs.

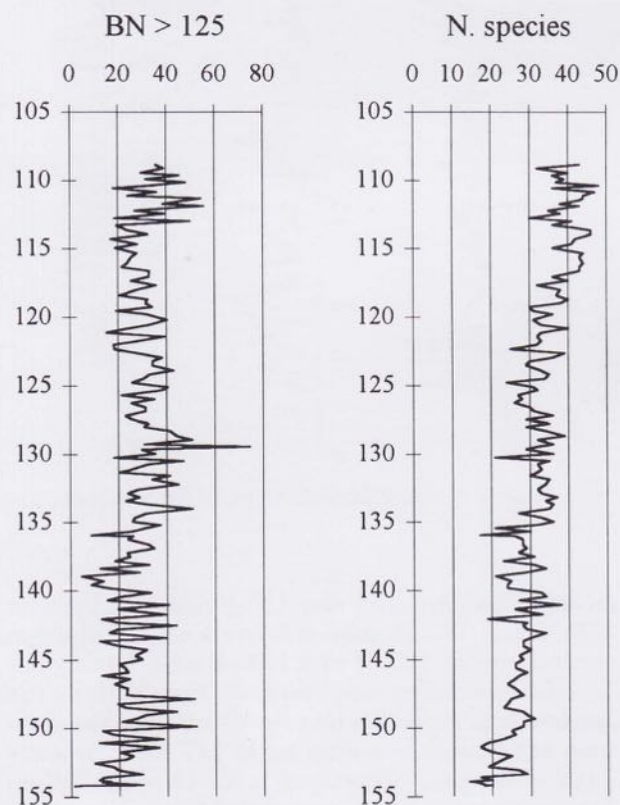
The number of species shows a gradual increase along the section. Four principal intervals have been

defined: 1) from the base to 151.03 mbs with values between 14 and 29; 2) from 150.77 to 135.2 mbs with values between 20 and 35; 3) from 134.95 to 117.03 mbs with values between 25 and 40; and 4) from 116.64 to the top of the studied section with values between 35 and 45, with a maximum peak of 47.

DISTRIBUTION OF FORAMINIFERAL SPECIES

The most common and abundant species throughout the segment studied are *Siphonina reticulata*, *Globocassidulina subglobosa*, *Gyroidina* spp., *Cibicidoides bradyi*, *C. robertsonianus*, *Oridorsalis tener stellatus*, *Cibicidoides italicus*, *Pullenia* spp., *Planulina ariminensis* and *Astrononion umbilicatum*. Since there is a morphological intergradation between *C. bradyi* and *C. robertsonianus* (Pflum & Ferichs, 1976), and *C. robertsonianus* is not abundant, their percentages are combined.

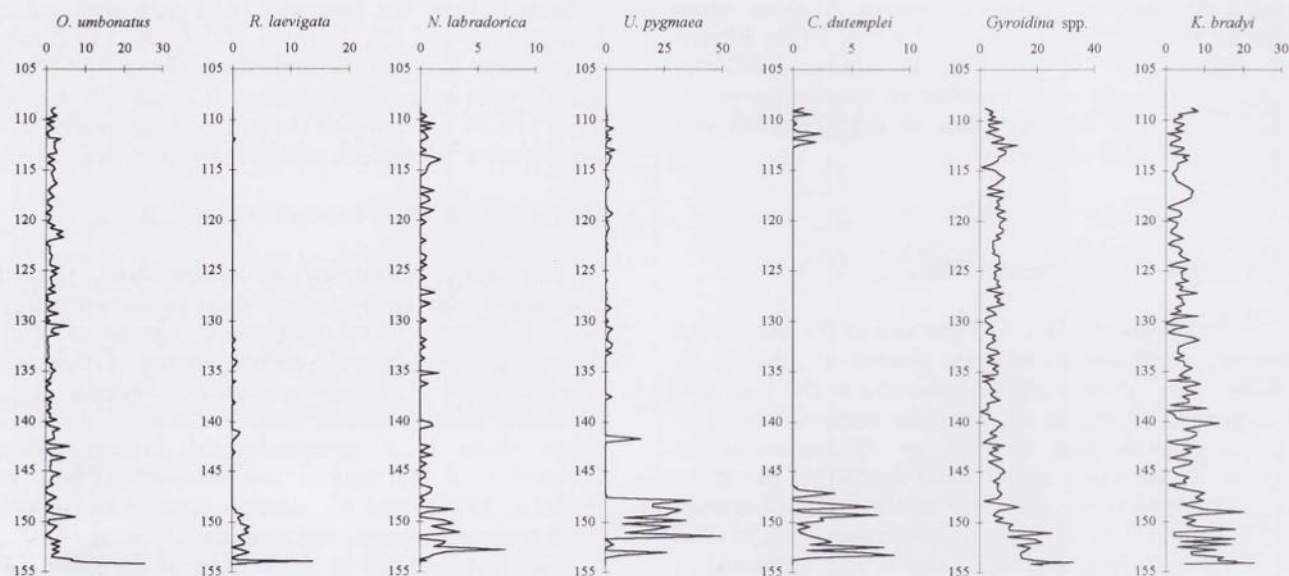
The first findings in the section of the most significant species are reported in Tab. 2. The quantitative stratigraphic distributions (percent values) of the most important species are plotted in Text-figs. 3-6. We point out that *Oridorsalis umbonatus*, *Rotamorphina laevigata*, *Nonionellina labradorica*, *Uvigerina pygmaea*, *Cibicidoides dutemplei*, *Gyroidina*



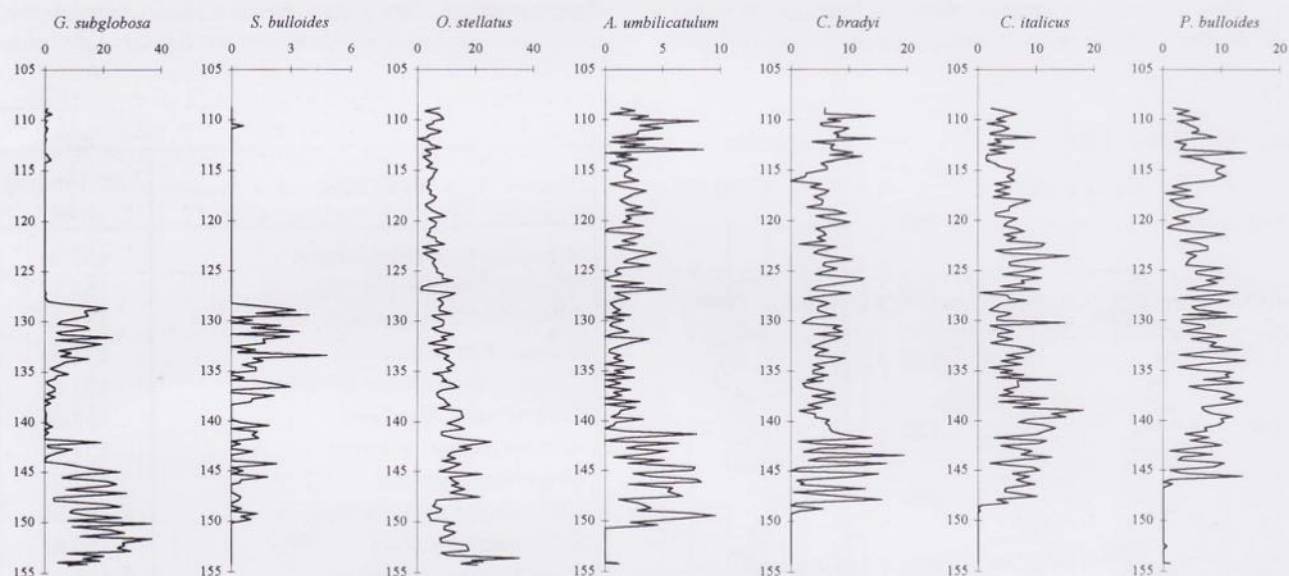
Text-fig. 2 - Benthic foraminifers number of specimens per gram of dry sediments (BN $> 125 \mu\text{m}$) and species number distributions in the bore-hole.

SPECIES	First Finding mbs
<i>Sigmoilopsis schlumbergeri</i>	153.94
<i>Nonionellina labradorica</i>	153.94
<i>Cibicidoides ungerianus</i>	153.94
<i>Ellipsoidina ellipsoides</i>	153.84
<i>Ellipsopolymorphina fornasinii</i>	153.84
<i>Cibicidoides dutemplei</i>	153.60
<i>Anomalinoidea helcinus</i>	153.60
<i>Uvigerina pygmaea</i>	153.35
<i>Cibicidoides agrigentinus</i>	153.35
<i>Siphonina reticulata</i>	150.82
<i>Sphaeroidina bulloides</i>	149.89
<i>Lagena gibbera</i>	149.57
<i>Cibicidoides bradyi - robertsonianus</i>	149.06
<i>Cibicidoides italicus</i>	149.06
<i>Uvigerina auberiana</i>	147.90
<i>Planulina ariminensis</i>	146.41
<i>Vulvulina pennatula</i>	146.41
<i>Cibicidoides ornatus</i>	139.00
<i>Cylindroclavulina rudis</i>	124.18
<i>Cassidulinoides bradyi</i>	119.31
<i>Bolivina albatrossi</i>	116.64
<i>Laticarinina pauperata</i>	114.00

Tab. 2 - First findings of the most significant benthic foraminiferal species in the bore-hole.



Text-fig. 3 - Relative abundance fluctuations (percentage values) of the most frequent benthic foraminifera taxa in the bore-hole.

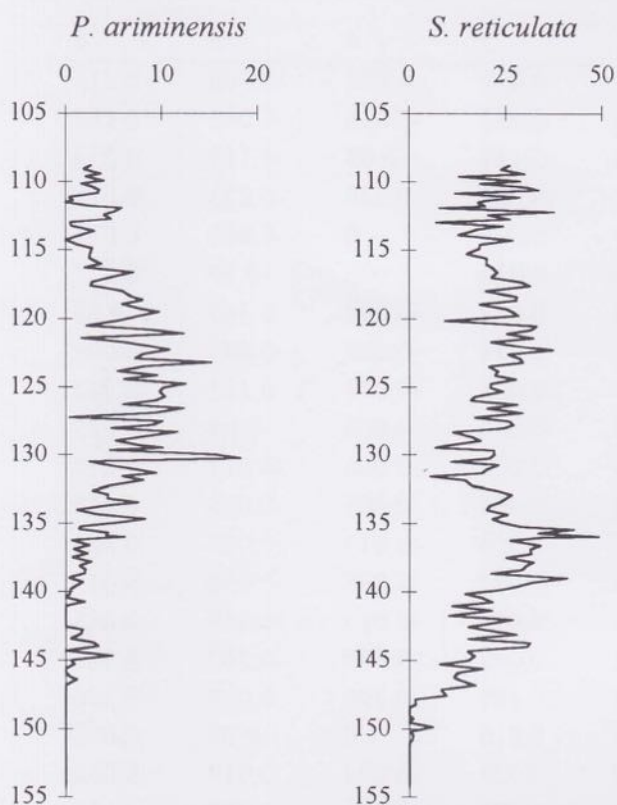


Text-fig. 4 - Relative abundance fluctuations (percentage values) of the most frequent benthic foraminifera taxa in the bore-hole.

spp. and *Karreriella bradyi* (Text-fig. 3) characterize, with higher values, the base of the section up to about 147 mbs, the interval corresponding to the M Pl 1 Biozone. On the contrary, the interval above 147 mbs, corresponding to the M Pl 2 and the basal part of the M Pl 3 Biozones, is characterized by *S. reticulata*, *C. bradyi-robertsonianus*, *C. italicus*, *A. umbilicatum* and *P. bulloides* (Text-figs. 4 and 5). *S. reticulata* is always the dominant species with percent values of more than 10-20% up to a maximum of 49% of the assemblage. The highest values have been

recorded between 144 and 135.4 mbs and between 128.28 and 116.64 mbs, whereas a slight reduction occurs between 132.24 and 128.66 mbs.

Globocassidulina subglobosa, *O. tener stellatus* and *Sphaeroidina bulloides* (Text-fig. 4) are the most common and abundant species up to 127 mbs, whereas *Lenticulina* spp., *Sigmoilopsis schlumbergeri*, *Melonis barleeanum*, *Vulvulina pennatula*, *Uvigerina auberiana*, *Cibicidoides ornatus* and *Cassidulinoides bradyi* show a co-variant trend since they are the most common species above about 130 mbs (Text-fig. 6).



Text-fig. 5 - Relative abundance fluctuations (percentage values) of two most significant benthic foraminifers taxa in the bore-hole.

Only *P. ariminensis* shows a very peculiar distribution with a gradual increase of percentage values from about 135 mbs, a maximum at about 130 mbs

and a gradual reduction in the following part up to a minimum at about 114 mbs (Text-fig. 5). Above this level and in the interval of M Pl 3- M Pl 5 Biozones (not included in the present paper), this species shows numerous fluctuations with percentage values which again reach 20% of the assemblage (personal observation).

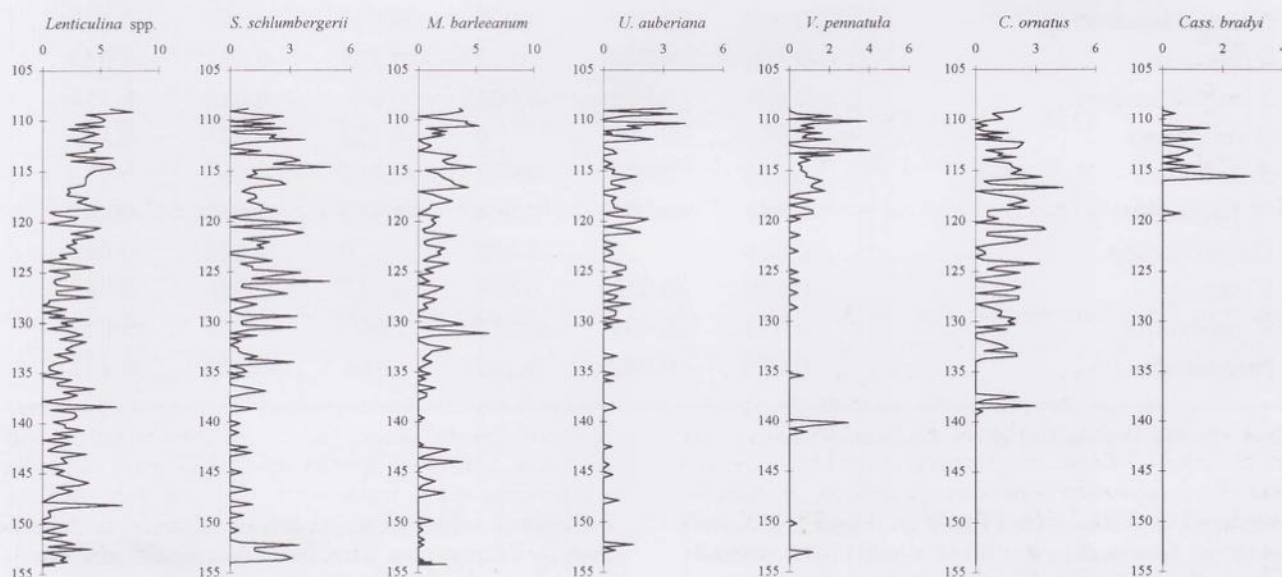
Summarizing, the distribution of the more significant species shows a marked difference between the interval corresponding to the M Pl 1 Biozone and those of the M Pl 2 and M Pl 3 (pars) Biozones. Moreover, a further subdivision in the segment is recognized in the interval 130 -127 mbs, in which a second change in the most common species is registered.

DISTRIBUTION OF FORAMINIFERAL ASSEMBLAGES

Q-mode Factor Analysis was performed on the relative abundance of 37 taxonomic units and 162 samples. From the original list of the identified taxa, some species were lumped together (for instance, *Bolivina* spp., *Ellipsoidinids*, *Lenticulina* spp., *Martinottiella* spp., *Quinqueloculina* spp., and *Nodosarids*). All the remaining species exhibiting relative abundance values of less than 2% were discarded. Six factors were rotated. They explain a total variance of 92%, with high to very high communalities. Rotated Varimax Factor Scores are reported in Tab. 3. Varimax Factor Loadings are plotted in Text-fig. 7.

Factor 1, which explains a variance of 59%, is dominated by *S. reticulata*, with *C. italicus* and *P. ariminensis* as second low scored components. This factor is generally represented by high to very high fluctuating values in the M Pl 2 and M Pl 3 Biozones.

Factor 2, which explains 15% of variance, is domi-



Text-fig. 6 - Relative abundance fluctuations (percentage values) of the most frequent benthic foraminifers taxa in the bore-hole.

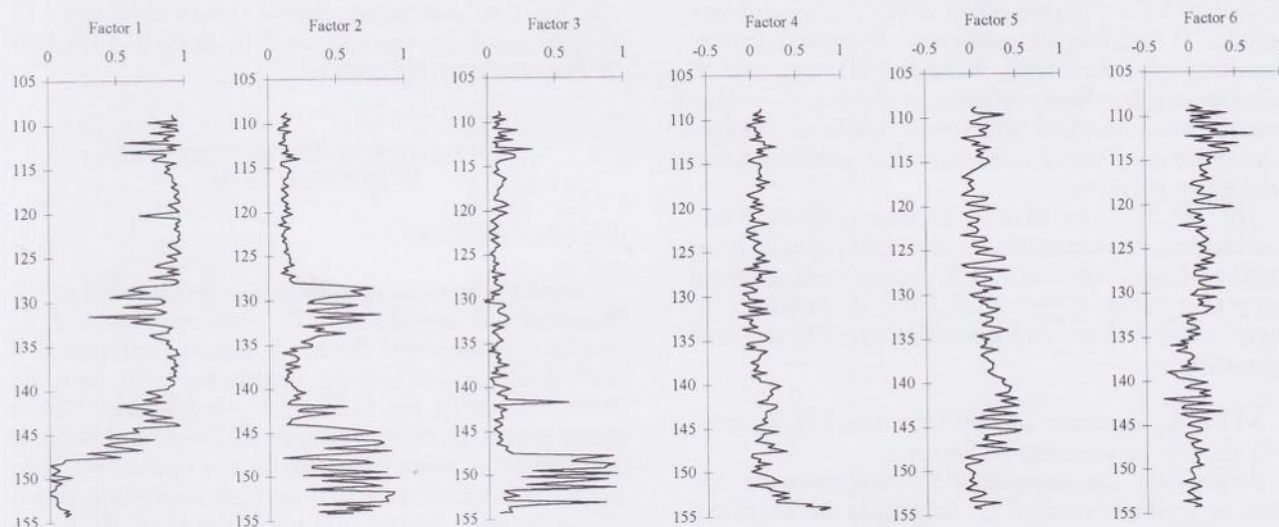
Taxa	1	2	3	4	5	6
<i>A. helacinus</i>	0.079	0.075	0.019	-0.032	-0.068	-0.015
<i>A. umbilicatum</i>	0.049	0.042	0.081	-0.018	-0.003	0.163
<i>B. nodosaria</i>	0.11	0.028	0.111	0.08	-0.112	0.222
<i>Bolivina</i> spp.	0.005	0.001	-0.001	0.036	-0.023	0.021
<i>Cassidulinoides bradyi</i>	0.002	-0.003	0.001	0	-0.003	0.031
<i>C. ungerianus</i>	0.111	0.028	0.032	0.006	-0.19	0.224
<i>Cibicidoides bradyi</i>	0.097	-0.038	0.048	-0.098	0.465	0.59
<i>C. dutemplei</i>	-0.005	0.051	0.074	-0.008	-0.053	-0.009
<i>C. italicus</i>	0.184	0.045	-0.031	-0.078	0.272	-0.088
<i>C. ornatus</i>	0.045	0.004	-0.005	-0.006	-0.08	0.035
<i>C. rudis</i>	0.009	-0.005	0.002	0.006	-0.017	0.014
<i>D. bertheloti</i>	0.029	-0.002	0.004	0.005	-0.058	0.136
<i>Ellipsoidina</i> spp.	0.021	0.014	0.013	-0.013	-0.007	0.081
<i>G. subglobosa</i>	-0.1	0.939	-0.007	-0.245	-0.058	-0.017
<i>G. laevigata</i>	0.021	0.069	0.028	-0.015	0.016	0.045
<i>G. soldanii</i>	0.077	0.152	0.047	0.588	-0.262	0.206
<i>K. bradyi</i>	0.062	0.083	0.189	0.398	0.028	0.106
<i>Lenticulina</i> spp.	0.096	0.028	0.016	0	-0.09	0.093
<i>Martinottiella</i> spp.	0.046	0.019	0.023	0.074	0.019	0.068
<i>M. barleeianum</i>	0.056	0.004	-0.001	0.005	-0.085	0.054
<i>N. labradorica</i>	-0.003	0.019	0.025	0.013	0.001	0.03
<i>O. stellatus</i>	0.121	0.229	0.06	0.467	0.537	-0.318
<i>O. umbonatus</i>	0.021	0.028	-0.007	0.319	-0.063	0.078
<i>P. ariminensis</i>	0.175	0.09	-0.091	-0.1	-0.233	0.27
<i>P. alternans</i>	0.034	0.019	0.038	0.004	-0.026	0.123
<i>P. bulloides</i>	0.152	0.029	-0.048	-0.145	0.419	0.21
<i>Pullenia</i> spp.	0.04	0.008	0.041	-0.015	0.071	0.2
<i>Quinqueloculina</i> sp.	-0.005	0.009	0.005	-0.014	0.047	0.052
<i>R. laevigata</i>	-0.004	0.006	0.03	0.104	-0.037	-0.014
<i>S. schlumbergeri</i>	0.024	0.012	-0.003	0.006	-0.019	0.158
<i>S. reticulata</i>	0.896	-0.001	0	-0.122	-0.125	-0.249
<i>S. bulloides</i>	0.001	0.034	-0.003	-0.042	0.045	0.013
<i>U. pygmaea</i>	-0.031	-0.037	0.954	-0.163	-0.019	-0.082
<i>Uvigerina</i> spp.	0.016	0	-0.002	0	-0.026	0.049
<i>V. minuta</i>	0.009	-0.013	0.009	0.017	-0.016	0.082
<i>V. pennatula</i>	0.031	-0.004	-0.002	0.007	-0.041	0.023
<i>Nodosarids</i>	0.089	0.042	0.044	0.01	-0.005	0.178

Tab. 3 - Benthic foraminiferal varimax factor score matrix.

nated by *G. subglobosa*. This Factor has significant loadings at the base and in the middle part of the studied interval. In the last interval the increase of this factor coincides with the decrease in the loadings of Factor 1.

Factor 3, which explains 6% of variance, is dominated by *U. pygmaea*. This factor has significant loadings only in the M Pl 1 Biozone.

Factor 4, which explains only 5% of variance, is



Text-fig. 7 - Stratigraphic distribution of varimax loadings of each factor in the bore-hole.

dominated by *Gyroidina soldanii*, *O. tener stellatus*, *K. bradyi* and *O. umbonatus*. This factor has significant loadings only in the lowest part of the M Pl 1 Biozone of the bore-hole.

Factor 5, which explains only 4% of variance, is dominated by *O. tener stellatus*, *C. bradyi-robertsonianus* and *P. bulloides*. This Factor has significant loadings from the end of M Pl 1 to the middle part of the M Pl 2 Biozones.

Factor 6, which explains only 3% of variance, is dominated by *C. bradyi-robertsonianus*. This Factor has significant loadings only at the top of the studied interval.

As a result of the stratigraphic distribution of Varimax Factor Loadings through the succession six stages can be recognized.

STEP 1 - From 154.20 (= bore-hole "Trubi" base) to 153.60 mbs, with very high values of Factor 4 (lowest part of the M Pl 1 Biozone).

Fourteen species occur in the basal sample. The assemblages are always oligotypic during this interval; in fact the dominant species *Gyroidina soldanii*, *O. umbonatus*, *Oridorsalis tener stellatus*, *Karrieriella bradyi* and *Globocassidulina subglobosa* constitute from 73% to 84% of the assemblages. *O. umbonatus* is abundant only in this interval with percentage values between 7 and 26%. Also *Rotamorphina laevigata* and *Bigenerina nodosaria* are relatively frequent but less abundant than the previous ones.

STEP 2 - Between 153.35 and 147.85 mbs, with significant loadings of Factor 3 (upper part of the M Pl 1 Biozone). In this interval the species number increases and their mean values fluctuate between 14 and 31 (Text-fig. 2) and other 16 species join those

present in the previous step. *U. pygmaea*, *G. subglobosa*, *Gyroidina* spp. and *K. bradyi* are the dominant species in the assemblage (Text-figs. 3 and 4) with *O. tener stellatus*, *B. nodosaria*, *Anomalinoidea helacinus*, *C. dutemplei*, *A. umbilicatulum*, *N. labradorica*, *R. laevigata* and *P. alternans* as co-dominant species. In particular, we noted the strong abundance of *U. pygmaea* which characterizes 2 intervals at the base of the section. The first is recorded between 153.35 and 153.05 mbs, the second between 151.45 and 147.85 mbs. The second more important peak shows the highest percentage values from 7 to 50% of the assemblage. Above 147.55 mbs, this species is poorly represented, with the exception of a peak in sample 141.70 -141.75 mbs (15%). The top of the step coincides with the strong reduction of *U. pygmaea*, *C. dutemplei*, *N. labradorica*, *R. laevigata*, *Gyroidina* spp. and *Karrieriella bradyi* and increase of percentage values of *C. bradyi-robertsonianus* and *C. italicus* (Text-fig. 4).

STEP 3 - Between 147.60 and 134.34 mbs, with significant loadings of Factor 1.

From the base of this step *S. reticulata* is the dominant species (Text-fig. 5), whereas the co-dominant assemblages show numerous fluctuations. In this interval 23 species appear, among which *P. ariminensis*, *V. pennatula* and *Cibicidoides ornatus*. From 146.41 mbs *Pullenia bulloides* is more frequent and abundant.

Two sub-steps are recognized:

3A) 147.60 -141.7 mbs, with significant loadings of the Factors 2 and 5. *O. tener stellatus* and *G. subglobosa* are the co-dominant species associated with *C. italicus* and *C. bradyi-robertsonianus*, with scattered

percentage values higher than 10%. The assemblage includes *P. bulloides*, *B. nodosaria*, *A. umbilicatum*, *Gyroidina* spp., *K. bradyi*, *Martinottiella* spp. and *A. helicinus* as subordinate species. At the top *G. subglobosa* shows a marked reduction, while *C. bradyi-robertsonianus*, *O. tener stellatus* and *A. umbilicatum* are slightly reduced.

3B) 141.38 - 134.34 mbs, *O. tener stellatus*, *P. bulloides* and *C. italicus* are the co-dominant species associated with *B. nodosaria* and *K. bradyi*, with scattered percentage values higher than 10%. *A. helicinus*, *C. bradyi-robertsonianus* and *Gyroidina* spp. are also well represented.

STEP 4 - Between 133.99 mbs and 128.28 mbs, with significant loadings of Factor 2.

At the base, the decrease of *S. reticulata* and a new increase in abundance of *G. subglobosa* are recorded. *G. subglobosa*, *O. tener stellatus* and *P. ariminensis* are the co-dominant species, associated with *P. bulloides* and *C. italicus*, with scattered percentage values higher than 10%. *C. bradyi-robertsonianus*, *G. soldanii* and *K. bradyi* are well represented. In particular *P. ariminensis* shows higher values in the interval above 130.31 mbs. From this step to the top of the section *M. barleeianum*, *S. schlumbergeri*, *C. ornatus*, *Uvigerina* spp. and *Vulvulina pennatula* increase in frequency. On the contrary, *G. subglobosa* strongly decrease in abundance at the top of this step together with *S. bulloides* and *O. tener stellatus*. In this interval 5 species appear.

STEP 5 - Between 128.03 mbs and 114.3 mbs, with significant loadings of Factor 1.

S. reticulata is the dominant species. During this interval 7 species are added to the previous ones, including *Cylindroclavulina rudis*, *Cassidulinoides bradyi* and *Bolivina albatrossi*.

This step can also be divided into two sub-intervals:

5A) 128.03-120.55 mbs. *P. ariminensis* is the co-dominant species, associated with *P. bulloides*, *C. italicus* and *C. bradyi-robertsonianus*, with scattered percentage values higher than 10%. The assemblage includes *O. tener stellatus*, *B. nodosaria*, *Gyroidina* spp., *K. bradyi*, *A. helicinus* and *C. agrigentinus* as subordinate species. *P. ariminensis* gradually decreases at the top, whereas *S. reticulata* increases.

5B) 120.17 - 114.3 mbs with *P. bulloides*, *C. bradyi-robertsonianus*, *C. italicus* and *Gyroidina* spp. as co-dominant species.

STEP 6 - Between 114 mbs and the top of the succession with significant intercalated loadings of Factor 1 and Factor 6.

From the base, strong fluctuations in abundance of *S. reticulata* are recorded. *C. bradyi-robertsonianus* is the co-dominant species. The assemblage includes *C. italicus*, *Gyroidina* spp., *P. bulloides*, *Lenticulina* spp., *O. tener stellatus*, *Discorbinella bertheloti*, *B. nodosaria* and *A. umbilicatum* as subordinate

species. *Cassidulinoides bradyi*, *Lenticulina* spp., *G. subglobosa*, *Uvigerina* spp. and *C. dutemplei* increase in frequency in this interval.

BOTTOM PALEOENVIRONMENTAL INTERPRETATION

PALEOBATHYMETRY

Among the most abundant species recorded in the bore-hole, *P. ariminensis*, *O. tener stellatus* and *C. bradyi-robertsonianus* have, in Recent sediments, a well defined bathymetric distribution. In fact, *O. tener stellatus* in the Gulf of Mexico is found from outer neritic to 900 m (Pflum & Frerichs, 1976), *P. ariminensis* is more frequent in the epibathyal zone from outer neritic to 1,000 m, with maximum abundance between 200 to 500 m in the Gulf of Mexico (Pflum & Frerichs, 1976) and from lower circalittoral to about 1,000 m in the Mediterranean Sea (Sgarrella & Moncharmont Zei, 1993), while *C. bradyi-robertsonianus* is recorded deeper than 450 m in the Gulf of Mexico (Pflum & Frerichs, 1976) but it is generally more common deeper than 600-700 m (Phleger et al., 1953; Lutze & Colbourn, 1984; Cole, 1981, *inter alios*). Consequently, the concomitant presence of the previous species should indicate the lower epibathyal zone in the depth-range of 600-800 m. Displaced specimens of *Elphidium* and *Rosalina* species are very rare in the studied part of the bore-hole.

BOTTOM EVENTS

Tab. 4 reports the 6 previously defined steps, the related drilling depth-ranges, the dominant assemblages, the first finding number of species (FFN) which appear in each step, the intervals with high BN > 125 mm and the most important events which are discussed below. The 3 peaks of BN > 125 mm are considered important events since abundance of benthic foraminifers (> 150 mm) is generally related to increase in productivity (Berger & Diester-Haass, 1988; Herguera & Berger, 1991; Herguera, 1992).

Benthic foraminiferal distribution shows a clear change in the assemblages between the M Pl 1 and the M Pl 2 - M Pl 3 (pars).

M Pl 1 Biozone (steps 1 and 2)

The benthic foraminiferal assemblages of the M Pl 1 Biozone from the bore-hole and the complete section of Eraclea Minoa have been described in detail and the main bioevents compared and correlated with those recorded at Capo Spartivento (Calabria) and from the Southern Tyrrhenian Sea (Sgarrella et al., 1997). The assemblage of Factor 4, which is significant in the lowest part of the segment studied, is constituted by most of the species recorded at the base of the Eraclea Minoa section, and therefore, it can be

STEPS	mbs	HIGH FACTORS LOADING	DOMINANT SPECIES	ASSOCIATED SPECIES	FFN	HIGH BN > 125 μ m INTERVALS	BOTTOM EVENTS		
6	114.15 - top	Factor 1 and Factor 6	<i>S. reticulata</i>	<i>C. bradyi-robertsonianus</i>	1	113.01-111.34	SLIGHTLY UNDER-OXYGENATED	INCREASED PRODUCTIVITY	COOLING
5 B	120.35-114.15	Factor 1	<i>S. reticulata</i>	<i>P. bulloides</i> , <i>C. bradyi-robertsonianus</i> , <i>C. italicus</i> , <i>Gyroidina</i> spp.	5		NORMAL OXYGEN LEVEL		COOLING
5 A	128.47-120.35	Factor 1	<i>S. reticulata</i>	<i>P. ariminensis</i> , <i>P. bulloides</i> , <i>C. italicus</i> , <i>C. bradyi</i>	2		NORMAL OXYGEN LEVEL		COOLING
4	134.17-128.47	Factor 2	<i>S. reticulata</i> , <i>G. subglobosa</i>	<i>O. tener</i> var. <i>stellatus</i> , <i>P. ariminensis</i>	5	133.99-128.08	NORMAL OXYGEN LEVEL	INCREASED PRODUCTIVITY	INCREASED CIRCULATION AND GRADUAL COOLING
3 B	141.54-134.17	Factor 1	<i>S. reticulata</i>	<i>O. tener</i> var. <i>stellatus</i> , <i>P. bulloides</i> , <i>C. italicus</i>	7		NORMAL OXYGEN LEVEL		
3 A	147.72-141.54	Factor 1, Factor 2 and Factor 5	<i>S. reticulata</i>	<i>O. tener</i> var. <i>stellatus</i> , <i>G. subglobosa</i> , <i>C. italicus</i> , <i>C. bradyi-robertsonianus</i>	16		NORMAL OXYGEN LEVEL		SLIGHTLY INCREASED CIRCULATION
2	153.45-147.72	Factor 3	<i>U. pygmaea</i> , <i>G. subglobosa</i> , <i>Gyroidina</i> spp., <i>K. bradyi</i>	<i>O. tener</i> var. <i>stellatus</i> , <i>B. nodosaria</i> , <i>A. helicinus</i> , <i>C. dutemplei</i> , <i>A. umbilicatum</i> , <i>N. labradorica</i> , <i>R. laevigata</i>	16	149.84-147.85	DYSAEROBIC	INCREASED PRODUCTIVITY and/or PRESERVATION ORGANIC MATTER	SLUGGISH CIRCULATION
1	154.20-153.45	Factor 4	<i>Gyroidina</i> spp., <i>O. umbonatus</i> , <i>O. tener</i> var. <i>stellatus</i> , <i>K. bradyi</i> , <i>G. subglobosa</i>	<i>R. laevigata</i> , <i>B. nodosaria</i>	7		RE-COLONIZATION		

Tab. 4 - Benthic foraminiferal steps related to drilling depth-range, dominant assemblages, first finding number of species (FFN), high BN > 125 μ m intervals and bottom events interpretation.

considered to be related to the beginning of the Mediterranean re-colonization (Step 1). This study shows that about 40 ky are lacking in the bore-hole.

The Factor 3 assemblage, with *U. pygmaea* dominant, is very evident in the upper part of the M Pl 1 Biozone and named the "*Uvigerina pygmaea-peregrina* Event", recorded in the bore-hole between 151.4 and 147.85 mbs. It has been related to low oxygen content at the bottom during the dysaerobic interval (Step 2). According to Sgarrella *et al.* (1997) these under-oxygenated bottom conditions are related to an increase of productivity and/or preservation of organic matter due to restricted and sluggish circulation. An increase in bottom food supply is supported by high BN >125 mm between 149.84 and 147.85 mbs. *C. dutemplei* also characterizes, even with lower percent values, the "*Uvigerina pygmaea-peregrina* Event" and, therefore, it seems tolerant of oxygen depleted conditions.

M Pl 2 and M Pl 3 Biozones (steps 3-6)

Beginning from step 3 upwards the assemblages show "normal" paleoceanographic bottom conditions

as supported by the strong decrease of *U. pygmaea* and the increase of *C. bradyi-robertsonianus*. Particularly, *C. robertsonianus* is considered among the typical NADW (North Atlantic Deep Water) species (Schnitker, 1980; 1994).

During steps 3 and 4 (up to about 128 mbs), the assemblages of Factors 1 and 2 are dominant. The assemblage of Factor 1, dominated by *Siphonina reticulata*, shows significant loadings. This species is common and dominant in epibathyal Pliocene sediments in the Tyrrhenian Sea up to about the M Pl 5 Biozone (Sprovieri & Hasegawa, 1990) and in the Capo Spartivento section (Thunell *et al.*, 1991), but it is not abundant in the Recent sediments of the Mediterranean Sea, even if it is widely distributed in the depth-range of about 100 -1,000 m (Sgarrella & Moncharmont Zei, 1993). It is recorded in the Sulu Sea, where dissolved oxygen values are of about 1.25 ml/l (Rathburn & Corliss, 1994; Rathburn & Miao, 1995). *Siphonina bradyana*, a species morphologically very close to *S. reticulata*, is recorded in the Gulf of Mexico as an infaunal form (Corliss & Fois, 1991). *S. bradyana* and *S. bulloides* are included in the Factor 4 assemblage of Denne & Sen Gupta (1991). This

factor has been correlated with OMW (Oxygen Minimum Water) of the Gulf of Mexico, with the minimum content of oxygen not very low (2.5 and 2.9 ml/l) and is included in the oxic environment *sensu* Tyson & Pearson (1991). In the study on Mio-Pliocene sapropelitic sediments of the Eastern Mediterranean, Katz & Thunell (1984) defined *S. reticulata* with *G. subglobosa* as "non-sapropel" assemblage. Therefore, it seems that *S. reticulata* is tolerant of relatively low oxygen conditions, but in an oxic environment.

Factor 2, dominated by *G. subglobosa*, has significant loadings only in two separate intervals. The first interval ranges between the base and 144.68 mbs and includes the dysaerobic phase of step 2, even if the species is recorded as co-variant with *U. pygmaea*. The second interval coincides with step 4. It represents a transitional interval characterized by a second change in the assemblages which is less strong than the previous one (between M Pl 1 and M Pl 2 Biozones). In fact, *S. reticulata* is always the dominant species, and a change is recorded only in the co-dominant assemblages, with reduction of *G. subglobosa*, *O. tener stellatus* and *S. bulloides* at the top and a gradual increase of *P. ariminensis*, *Vulvulina pennatula*, *Lenticulina* spp., *M. barleeaanum*, *C. ornatus* and *U. auberiana* from this step to the top of the studied bore-hole.

The species which decrease in abundance at the top of step 4 are tolerant of different environmental factors, as discussed below.

G. subglobosa is a shallow infaunal species (Corliss & Chen, 1988; Corliss & Fois, 1991). It is considered opportunistic (Weston & Murray, 1984) since it is abundant in North Atlantic bathyal areas affected by more saline water of the Mediterranean Outflow, where typical stenotopic Atlantic species are excluded. It is reported from the North East Atlantic included in phytodetritus aggregates and considered adapted to seasonal fluctuations of food supply in environments with reduced food (Gooday, 1993). It is also reported as abundant, but not exclusive, in some areas of oxygen minimum water off northwest Africa (Lutze, 1980) and in the South China Sea with relatively high organic carbon content (Miao & Thunell, 1993). Sen Gupta *et al.* (1991) and Sen Gupta & Machain Castillo (1993) recorded relatively high abundance of *G. subglobosa*, associated with *Bolivina* species, in an upwelling area of the Florida continental slope, where dissolved oxygen values reach a minimum of 3-3.5 ml/l and organic carbon values reach 7%. Therefore, this species seems very tolerant of different environmental factors and it increases under bottom conditions unfavorable to the development of other species. Factor 2 may be interpreted as indicative of relatively "anomalous" conditions, slightly under-oxygenated.

Also *S. bulloides*, which in the bore-hole has a distribution similar to that of *G. subglobosa* (Text-fig. 4),

is considered an opportunistic species. It is tolerant of relatively low oxygen content (Factor 4 of Denne & Sen Gupta, 1991). Moreover, it is regarded as a versatile species changing from epifaunal to infaunal habitats depending on food availability and/or changing environmental conditions (Linke & Lutze, 1993).

O. tener stellatus is an epifaunal species in the North Atlantic (Corliss, 1985). Epifaunal species have been reported to prefer a low organic carbon environment. In the bore-hole, this species shows a marked reduction during step 2, which is considered to have high organic matter at the bottom. Also *O. umbonatus*, a very similar species, has been reported to prefer a low organic carbon environment (Mackensen *et al.*, 1985; Miao & Thunell, 1996).

On the contrary, the species which increase above step 4 are related to high food supply and good bottom circulation. *P. ariminensis* and *V. pennatula* have been found as epibenthic foraminifers from elevated microhabitats (Lutze & Thiel, 1989). The species of this particular habitat are related to the bottom water hydrodinamism because they are generally suspensivore and from an elevated substrate they are able to obtain the food supply transported by bottom currents (Linke & Lutze, 1993). *Lenticulina* spp. are related to high food availability (Miao & Thunell, 1993); *Uvigerina auberiana* is recorded in areas of high surface production (Boersma, 1984); *S. schlumbergeri* occurs in the Adriatic Sea mostly on muddy bottoms rich in organic matter (Jorissen, 1987) and in the Gulf of Mexico among the species "delta elevated" off the Mississippi and consequently related to high organic matter content. Also *M. barleeaanum* is related to high organic matter content (Jorissen, 1987; Caralp, 1989), and in the Northeast Atlantic it is abundant in areas with active bottom currents (Murray, 1984). Abnormal individuals of this species occur in conditions of very abundant food availability, like those occurring in the upwelling areas (Caralp, 1989). The specimens recorded in the bore-hole do not show any anomaly testifying, consequently, bottom conditions characterized by high, but not excessive, food supply.

Therefore, it is possible to infer a paleoceanographic change of the bottom water conditions with increase of bottom circulation from step 4 upwards. It favoured the species of elevated microhabitat together with improved bottom food availability. This gradual change begins a few meters below the FO of *G. puncticulata*, which is considered indicative of a cooling interval (warm-temperate) in the lower Pliocene (Zachariasse & Spaak, 1983; Sprovieri, 1990) together with a significant change, with cooler water assemblage, in the calcareous nannofossils (Rio *et al.*, 1990).

Furthermore, step 4 and the interval of about 8 m in which 6 laminated layers occur, studied in detail by Zachariasse *et al.* (1978) and Broelsma (1978), seem correlatable. In fact, *G. subglobosa* shows two abun-

dance intervals in the fraction $> 125 \mu\text{m}$ in the bore-hole and in the outcropping section (Brolsma, 1978, fig. 16). The second interval is recorded in the middle-upper part of the M Pl 2 Biozone of the two sections, and coincides with the laminated interval of the outcropping section. Brolsma (1978) found *G. subglobosa* $> 125 \mu\text{m}$ in the non laminated layers, while in the laminated ones this species is present only with small sized specimens $< 125 \mu\text{m}$. It seems probable that step 4 can be correlated with the laminated interval studied by Zachariasse *et al.* (1978) by means of the second interval of *G. subglobosa*. The laminated layers were considered by these Authors as corresponding to high productivity phases and interpreted as due to upwelling, with increased quantities of planktonic foraminifers, diatoms and radiolarians in some laminated intervals, deposited under cooler-water conditions and oxygen depletion at the bottom. *G. subglobosa* $> 125 \mu\text{m}$ is consequently abundant in layers included between the high productivity intervals. On the other hand, in this step also a second marked increase of BN $> 125 \mu\text{m}$ is recorded, with maximum values corresponding with the maxima of *G. subglobosa* $> 125 \mu\text{m}$. Taking into account that the increase of BN generally corresponds to an increase in productivity, probably this step represents a period of intermittent, but generally high, productivity.

The FO of *G. puncticulata* allows the correlation of step 4 with both the laminated layer (or diatomaceous laminated interval) and the reddish diatomitic layer of the Lido Rossello section. In fact, the FO of *G. puncticulata* is recorded about 6 m below the top of step 4 in the bore-hole; about 7 m below the top of the younger laminated layer (Spaak, 1983) and about 5 m below the reddish diatomitic layer of the Lido Rossello section (Sprovieri, 1978). Consequently, the diatomitic layer may well represent the extreme lateral variation of the laminated layers sedimented during a high productivity period and corresponding with step 4.

Finally, during part of step 4 and all along step 5, a peculiar bell-shaped distribution of *P. ariminensis* (Text-fig. 5) is recorded. If a constant sedimentation rate is hypothesized between the FCO of *G. margaritae* estimated at 5.1 Ma and the FO of *G. puncticulata* estimated at 4.5 Ma (Hilgen, 1991), the bell-shaped trend occurs between 4.8 and 4.4 Ma. According to Berger & Loutre (1991) this interval is included between 2 minima of the 400 ky orbital eccentricity. The maximum values of *P. ariminensis* correspond to a maximum in the eccentricity astronomical record and consequently, to the maximum of seasonality.

During step 6 the increase of Factor 6, characterized by *C. bradyi-robertsonianus*, together with a slight increase of the Factor 3 loadings, previously interpreted as an indicator of low bottom oxygen content, have been registered. In this interval *Lenticulina* spp., *C. dutemplei* and *Uvigerina* spp., previously regarded as tolerant of low bottom water

oxygenation, increase in frequency like *Cassidulinoides bradyi*, a species included in the "delta-elevated" group of the Gulf of Mexico, related to higher organic carbon content (Pflum & Frerichs, 1976). *C. bradyi-robertsonianus* seems tolerant of low oxygen conditions. In fact, it is recorded in deep-water of the modern Sulu Sea (oxygen 1.25 ml/l) as a dominant species with *O. umbonatus* (Miao & Thunell, 1993). Although this species is reported by these Authors in areas with low organic carbon content, it is also recorded as abundant during glacial conditions with a probably higher flux of organic carbon to the sea floor (Miao & Thunell, 1996). It seems possible that this species is able to tolerate a higher productivity because *C. bradyi-robertsonianus* in the bore-hole increases during step 6 together with BN > 125 .

At the same time *P. ariminensis*, previously considered as an indicator of good bottom circulation, decreases.

Therefore it seems that step 6 represents a slightly dysaerobic interval possibly due to increased bottom food supply coinciding with a relatively reduced bottom circulation.

Summarizing, the benthic foraminiferal assemblages show two main paleoceanographic changes. The first separates the M Pl 1 Biozone, characterized by dysaerobic bottom water conditions, abundance of organic matter and sluggish circulation, from the M Pl 2 Biozone with a more normal oxygen level and active bottom circulation. The second change separates the lower and middle part of the M Pl 2 Biozone, with gradually increasing circulation, from the upper part of the M Pl 2 to lower part of M Pl 3 which is characterized by good bottom circulation and gradual cooling. The three high BN $> 125 \mu\text{m}$ intervals occur in 3 different paleoceanographic conditions and with 3 distinct characteristic assemblages. They probably testify high bottom organic matter content in different environments. In the basal interval a sluggish circulation may have favored the organic matter preservation. On the contrary, the second and the third intervals are related to increased productivity, together with a gradual increase of circulation and cooling in the second one and slight decreased circulation in the third one.

THE OSTRACODS

(Barra D. & Bonaduce G.)

The deep-water Pliocene Mediterranean ostracods are rather well known, as far as their systematics is concerned (Colalongo & Pasini, 1980; Sissingh, 1972). Recent papers deal with the genera *Parakrithe* (Aiello *et al.*, 1993), *Krithe* (Abate *et al.*, 1993), *Kunihirella* (Bonaduce *et al.*, 1994), *Xestoleberis* (Abate *et al.*, 1994), *Anchistrocheles* (Aiello *et al.*, 1995), *Cytheropteron* (Aiello *et al.*, 1996a), *Cytherella* (Aiello *et al.*, 1996b) and *Argilloecia* (Barra *et al.*,

1996). Their stratigraphic value and paleoecological interpretation are still at the beginning, especially for the Lower Pliocene whose outcrops have not been studied in detail with the exception of the Ionian Calabria (Ciampo, 1992) and deep-sea drillings did not yield sufficient material for both qualitative and quantitative analyses (Colalongo *et al.*, 1990).

Data on the evolution of the Mediterranean Basin, based on relatively few ostracod species, are given by Benson (1973, 1978). Some stratigraphic data concern the Late Pliocene and the Pliocene/Pleistocene boundary (Colalongo & Pasini, 1988; Colalongo *et al.*, 1990) and the interval from M Pl 3 Biozone to the Early Pleistocene for a few marker species (Bonaduce & Sprovieri, 1985).

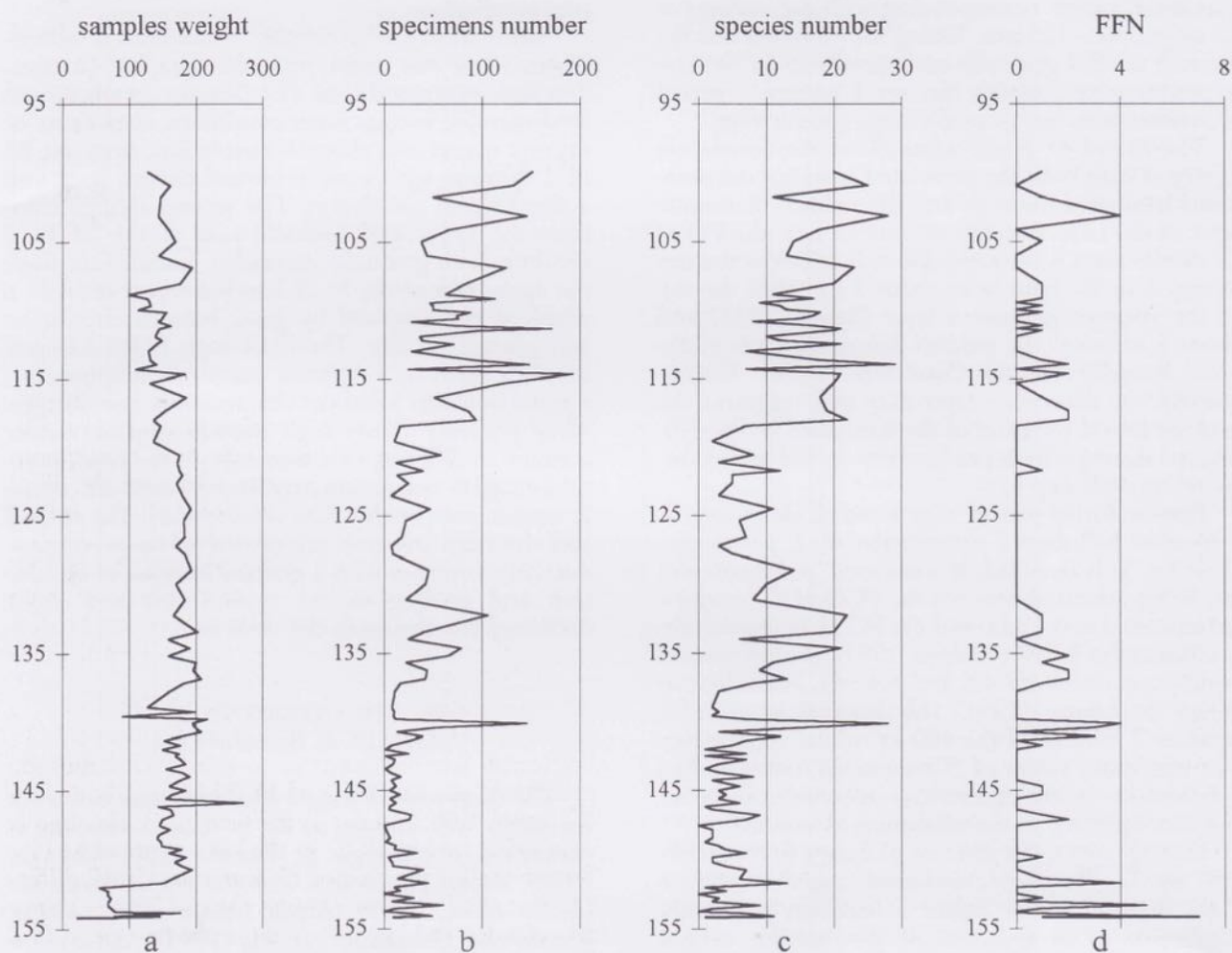
METHODOLOGY

The material studied deals with 114 samples, generally spaced every 25 cm from the bore-hole base in

the "Trubi" up to the drilling depth of 138.95 mbs, and above this level up to 99.94 mbs with samples at a maximum distance of about 1 m. For each sample the total picking has been accomplished in the size fraction $> 125 \mu\text{m}$, the species identified and counted (for adults and quasi-adults) and the presence of juveniles registered. The quantitative results have been standardized to 270 gr, corresponding to the largest sample at our disposal. From 154.20 to 152.26 mbs the fraction 63-125 μm has also been qualitatively studied for particularly small species.

For each sample the number of specimens, the number of species and the number of first findings of species (FFN) along the section have been calculated. The related quantitative diagrams are illustrated in Text-figs. 8b, 8c, 8d, respectively.

The weight of dried samples (Text-fig. 8a) plotted against the number of specimens and species seems to show that the sample-weights do not influence the data and consequently are also considered adequate



Text-fig. 8 - a) Samples weights. Ostracod; b) standardized number of specimens, c) species number and d) first finding number of species (FFN) distribution in the bore-hole.

for statistical analyses. Below 154.20 mbs a set of 10 samples from about 1 m of the Arenazzolo Formation has been examined.

DATA

MIocene: ARENAZZOLO FORMATION

The samples yielded a typical fresh-brackish water ostracod assemblage mostly pertaining to the genera *Cyprideis*, *Amnicythere*, *Loxoconcha*, *Cypria*, *Euxinocythere*, *Tyrrhenocythere* and are not taken into consideration in the present paper because of their obvious significance.

PLIOCENE: "TRUBI" FORMATION

The bore-hole material studied is characterized by the presence of 79 autochthonous species. Two species are reported as *nomina nuda* (*Bairdia profunda* n. sp. and *Occultocythereis culter* n. sp.) and a few doubtfully identified or reported in open nomenclature mainly because of their poor preservation. The list of the species is reported in the appendix 2.

A few young instars of the genera *Aurila*, *Cyprideis*, *Eucytherura*, *Hemicytherura*, *Kangarina*, *Sagmatocythere*, *Semicytherura* and *Urocythereis* (restricted to a few scattered samples) have been considered contaminants from shallow environments and disregarded.

COLONIZATION AND ECOBIOSTRATIGRAPHY

The stratigraphic distribution of all the species identified throughout the section is shown in Textfig. 9. The first finding in the section of the better represented species is reported in Tab. 5.

Since in the bore-hole a short basal "Trubi" interval (40 ky) is lacking as compared to the Eraclea Minoa section (Sgarrella *et al.*, 1997), we included also our unpublished data from the latter to have a better overview of the marine re-colonization.

The most significant "events", listed from the base of Eraclea Minoa and the bore-hole sections upwards, can be possibly useful for stratigraphic correlations of different Mediterranean sections characterized by similar environmental conditions. We selected the following ones:

- Distribution of *Kunihirella eracleaensis*.

Kunihirella eracleaensis (present only in the fraction 63-125 µm) occurs at the "Trubi" base of Eraclea Minoa section up to 1.4 m, showing a range wider than in the bore-hole where it is restricted to the interval 154.20-154.09 mbs (11 cm). This fact seems to confirm that in the bore-hole, as shown by the foraminiferal analysis, a short basal interval is lacking (Sgarrella *et al.*, 1997).

- FO of *Henryhowella asperrima*.

Henryhowella asperrima appears at Eraclea Minoa

SPECIES	First Finding mbs
<i>Monoceratina mediterranea</i>	103.14
<i>Buntonia textilis</i>	105.04
<i>Cytherella robusta</i>	105.04
<i>Quasibuntonia radiatopora</i>	111.19
<i>Bairdia profunda</i>	133.49
<i>Paijenborchella malaiensis cymbula</i>	140.19
<i>Oblitocythereis mediterranea</i>	141.75
<i>Cytherella vulgatella</i>	145.03
<i>Occultocythereis culter</i>	145.33
<i>Agrenocythere pliocenica</i>	146.80
<i>Henryhowella asperrima</i>	147.15
<i>Anchistrocheles interrupta</i>	151.75
<i>Parakrithe dimorpha</i>	152.85
<i>Parakrithe ariminensis</i>	153.35
<i>Xestoleberis prognata</i>	153.35
<i>Krithe pernoides</i>	153.60
<i>Krithe iniqua</i>	154.14
<i>Cytheropteron (A.) pinarense gillesi</i>	154.14
<i>Paijenborchella iocosa</i>	154.17
<i>Paracytherois acuminata</i>	154.17
<i>Argilloecia kissamovens</i>	154.17
<i>Krithe compressa</i>	154.18
<i>Tuberculocythere infelix</i>	154.20
<i>Kunihirella eracleaensis</i>	154.20

Tab. 5 - First findings of the most important ostracod taxa in the bore-hole.

and in the bore-hole at the top of cycle 10 and in particular in the bore-hole is recorded in sample 147.10-147.15 mbs. In the bore-hole this event corresponds to the FCO of *G. margaritae* (base of M Pl 2 Biozone). In the Pliocene sections of the Ionian Calabria, *H. asperrima* occurs at the base of M Pl 2 Biozone (Ciampo, 1992) and in the ODP Leg 107, Hole 654 A, drilled in the Tyrrhenian Sea, it has been found shortly above the boundary between M Pl 1 and M Pl 2 Biozones (Colalongo *et al.*, 1990).

- FO of *Agrenocythere pliocenica*.

This species appears in the bore-hole in sample 146.75-146.80 mbs just after that of *H. asperrima*. In the Ionian sections it occurs in the M Pl 2 Biozone just above the M Pl 1 - M Pl 2 biozonal boundary (Ciampo, 1992). In the Tyrrhenian Sea Colalongo *et al.*, (1990) find its FOD in the lowest part of M Pl 2 Biozone following that of *H. asperrima*. Small differences in the FODs of *H. asperrima* and *A. pliocenica* are recorded in Hole 654 A above the base of M Pl 2 Biozone where the two "events" appear in the same sequence but a little delayed, probably due to the very scarce quantity of sediments at disposal (10 cc).

- FCO of *Bairdia profunda* (= *Bairdia* sp. 1 Bonaduce & Sprovieri, 1985; *Bairdia* sp. 1 Ciampo, 1992).

This species appears with few specimens in the bore-hole in sample 133.44-133.49 mbs (upper part of M Pl 2 Biozone) and becomes common just above the M Pl 2 / M Pl 3 boundary (Text-fig. 12). Ciampo (1992), in his distribution chart, cites this species approximately at the base of M Pl 3.

If these events will be confirmed in other sections the FCO will be useful also for biostratigraphic correlation in the Mediterranean Basin.

ABUNDANCE AND DIVERSITY

Overall, the studied segment is characterized by a generally increasing colonization of the ostracod fauna with fluctuations in number of specimens and species throughout.

In the basal part of Early Zanclean age (from the bore-hole base in the "Trubi" up to 141.70 mbs) the number of specimens (Text-fig. 8b) shows relatively low values (in average less than 30 per sample), the interval 149.06-147.55 mbs displays extremely low values and some samples are devoid of ostracods (153.79-153.815 mbs; 152.50-152.525 mbs; 147.55-147.60 mbs).

From the M Pl 2 Biozone to 118.41 mbs highly fluctuating values (from 2 to 146 specimens) are recorded. Two minima were observed between 139.89 and 137.17 mbs (8-17 specimens per sample) and between 127.83 to 118.41 mbs (average 7-20 specimens per sample), whereas maxima are recorded in the following short intervals: 141.08-140.14 mbs, with an "anomalous" peak in sample 140.14-140.19 mbs (146 specimens), and 136.92-128.96 mbs (on average over 40 specimens per sample).

The uppermost interval (118.04 mbs - top of the studied succession) is characterized by more than 50 specimens per sample on average with a maximum of 193 specimens in sample 114.63-114.68 mbs.

The diagram representing the number of species (Text-fig. 8c) shows almost exactly the same trend of that described for the number of specimens.

The stratigraphic distribution of FFN (Text-fig. 8d) shows a striking correspondence with those of both the number of specimens and species. This diagram shows a general trend of increasing colonization up to the top of the section, even if with strong fluctuations. The maximum values occur from the base of the section up to about 130 mbs, followed by a long interval (131.17-118.41 mbs) in which the colonization is almost absent. Then, the colonization resumes with a more constant trend up to the top of the succession, although some fluctuations are still present and in short intervals reach zero. When the colonization shows minimum values, the disappearance of numerous species is temporarily recorded.

ASSEMBLAGES AND THEIR FLUCTUATIONS

Text-figs. 10 to 12 show the quantitative distribution of the most significant species throughout the succession. The fluctuations in number of species, specimens, and first findings together with the changes in assemblage composition and the fluctuation in abundance of some species allowed the subdivision of the segment studied into 6 steps. Moreover, the number of specimens, species and FFN of the M Pl 1 Biozone are reported in detail in Text-fig. 13 to illustrate more precisely the first colonization phase, never previously so closely studied.

STEP 1: (bore-hole "Trubi" base - 153.20 mbs)

In the interval 154.20-154.17 mbs only *Krithe compressa* and *Tuberculocythere infelix* are present in the fraction > 125 μ m together with *K. eracleaensis* in the fraction 63-125 μ m. On the whole, step 1 is characterized by the dominance of *K. compressa* and above 154.17 mbs by a rapid re-colonization, even if one sample is devoid of ostracods (153.79-153.815 mbs). *Argilloecia kissamovensis*, *Argilloecia* sp. 1, *Krithe iniqua* and *Paijenborchella iocosa* represent the co-dominant assemblage (Text-fig. 10).

STEP 2: (153.20 - 147.35 mbs)

This interval, still characterized by the dominance of *K. compressa*, can be subdivided in three subintervals on the basis of different co-dominant species.

Subinterval 2A (153.20-151.87 mbs): co-dominant species are *A. kissamovensis* and *K. iniqua*; on the whole the ostracod fauna shows a medium abundance; the diversity is low due to the temporary disappearance of 11 species and the first appearance of only 1 species.

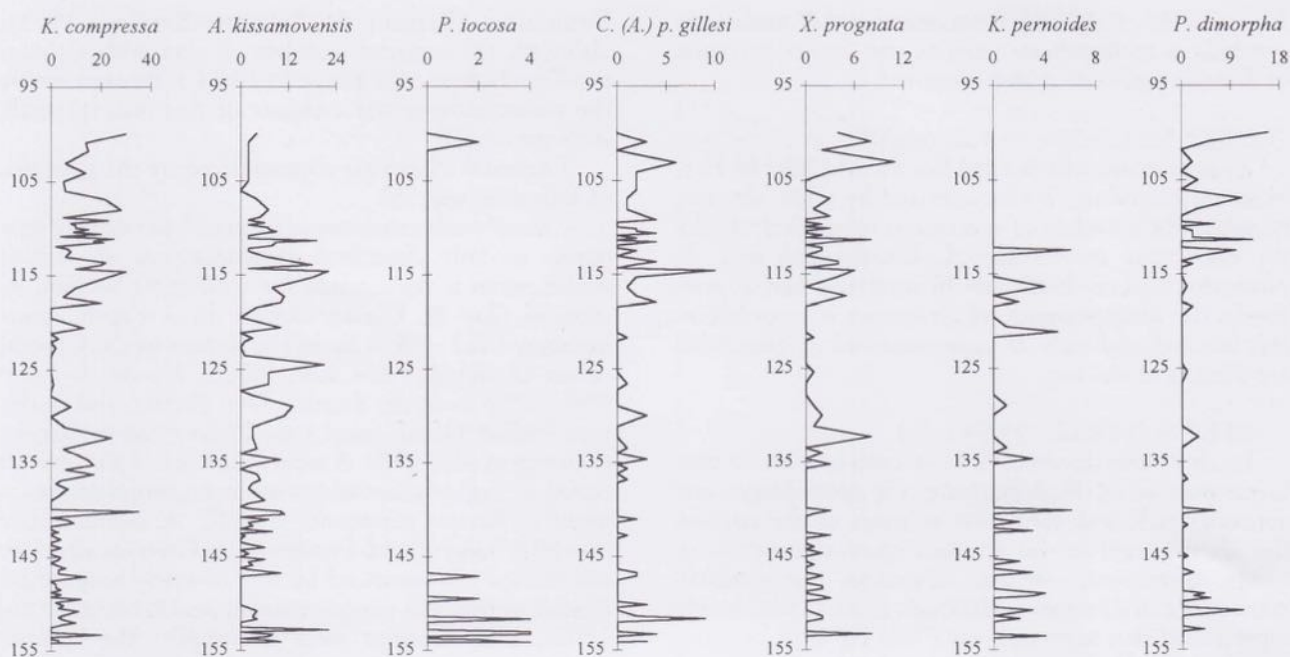
Subinterval 2B (151.87-149.14 mbs): together with *A. kissamovensis*, common in the previous subinterval, *Cytheropteron (Aversovalva) pinarense gillesi* and *Parakrithe dimorpha* become co-dominant. The high diversity characterizing this subinterval corresponds to a new phase of colonization.

Subinterval 2C (149.14-147.35 mbs): *Krithe pernoides* and *Xestoleberis prognata* become co-dominant. The subinterval is characterized by low abundance and diversity due to the temporary disappearance of 14 species and the presence of only *K. compressa* and *X. prognata* in its central part.

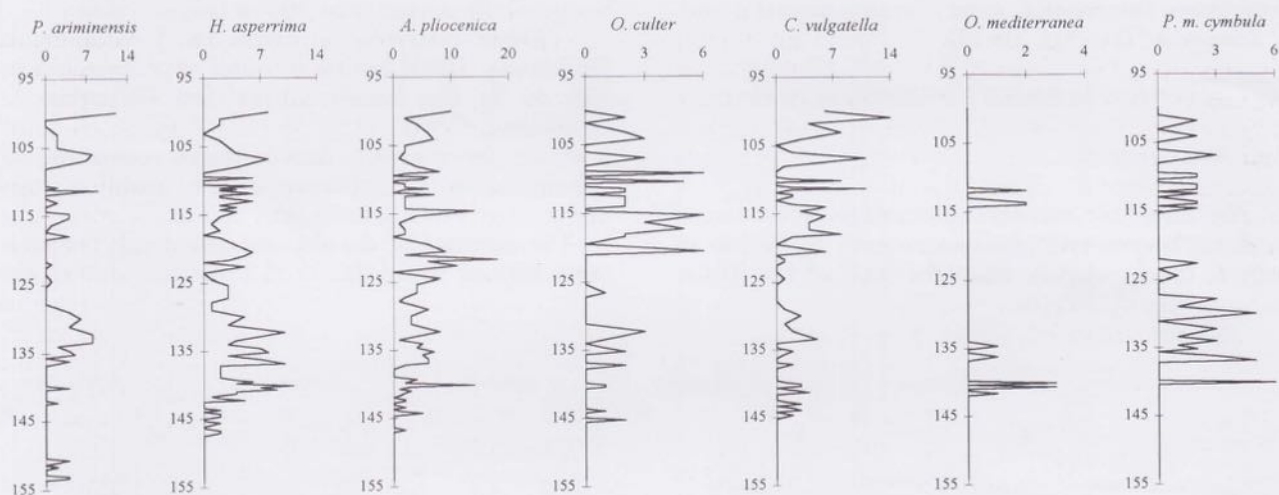
STEP 3: (147.35 - 137.04 mbs)

This interval is characterized by *K. compressa*, *A. kissamovensis* and *H. asperrima* with fluctuating abundance. It has been subdivided in three subintervals.

Subinterval 3A (147.35-141.54 mbs): the dominant species are *K. compressa* and *A. kissamovensis*, the co-dominant *H. asperrima*, *Cytherella vulgatella*, *K. pernoides* and *X. prognata*; on the whole the ostracod faunas show a low diversity and medium abundance values.



Text-fig. 10 - Abundance fluctuations (standardized number of specimens) of the most frequent ostracod taxa in the bore-hole.



Text-fig. 11 - Abundance fluctuations (standardized number of specimens) of the most frequent ostracod taxa in the bore-hole.

Subinterval 3B (141.54-140.01 mbs): *H. asperima* becomes dominant together with the species dominant in subinterval 3A, while *A. pliocenica* and *C. vulgatella* become co-dominant; the diversity and abundance increase as compared to the previous subinterval.

Subinterval 3C (140.01-137.04 mbs): the dominant species are *H. asperima* and *A. kissamovens*, whereas *A. pliocenica* remains co-dominant; this subinterval is characterized by low diversity and abundance with the temporary disappearance of 17 species and the appearance of only one species; in the middle of this subinterval the assemblage becomes

oligotypic with the occurrence of only two species, *H. asperima* and *A. kissamovens*.

Along step 3 several species first appear in succession such as *H. asperima*, *A. pliocenica*, *Occultocythereis culter*, *C. vulgatella* and, near the top, *Oblitocythereis mediterranea* and *Paijenborchella malaiensis cymbula* (Text-fig. 11).

STEP 4: (137.04 - 128.39 mbs)

This interval is characterized by high diversity and abundance with the return of *K. compressa* as dominant and of *H. asperima*, *A. pliocenica*, *A.*

kissamovensis, *Parakrithe ariminensis* and *P. malaiensis cymbula* as co-dominant species; the first occurrence of *Bairdia profunda* is also recorded.

STEP 5: (128.39 - 118.22 mbs)

This interval, which straddles the M Pl 2 / M Pl 3 biozonal boundary, is characterized by a low diversity, while the number of specimens is relatively high; the dominant species are *A. kissamovensis* and *A. pliocenica*, and co-dominant *H. asperrima* and *B. profunda*; the disappearance of 23 species is recorded in this interval and only *H. asperrima* and *A. pliocenica* are present at the top.

STEP 6: (118.22 - 99.94 mbs)

In this wide interval, which corresponds to the lower part of M Pl 3 Biozone, the assemblages are generally rich and abundant as most of the species that disappeared in the previous interval are present again. Moreover, we also observed the gradual appearance of 23 species, although most of which are represented in a scattered way (Text-fig. 9).

The assemblage is characterized by the dominance of *K. compressa* and co-dominance of *K. iniqua*, *A. kissamovensis*, *A. pliocenica*, *Anchistrocheles interrupta*, *Argilloecia acuminata*, *B. profunda*, *C. vulgatella*, *Bythocypris bosquetiana*, *Paracytherois acuminata* and *P. dimorpha* (Text-figs. 10-12).

PALEOENVIRONMENT INTERPRETATION

PALEOBATHYMETRY

The bore-hole ostracod assemblages allow us to confirm previous estimates of an overall deposition at bathyal depth, already from the base of the Trubi

Formation (Benson & Sylvester-Bradley, 1971), although the reduced number of taxa with defined modern bathymetric range in M Pl 1 Biozone made the palaeobathymetric estimate of this interval more difficult overall.

The basal 11 cm are characterized by the presence of following species:

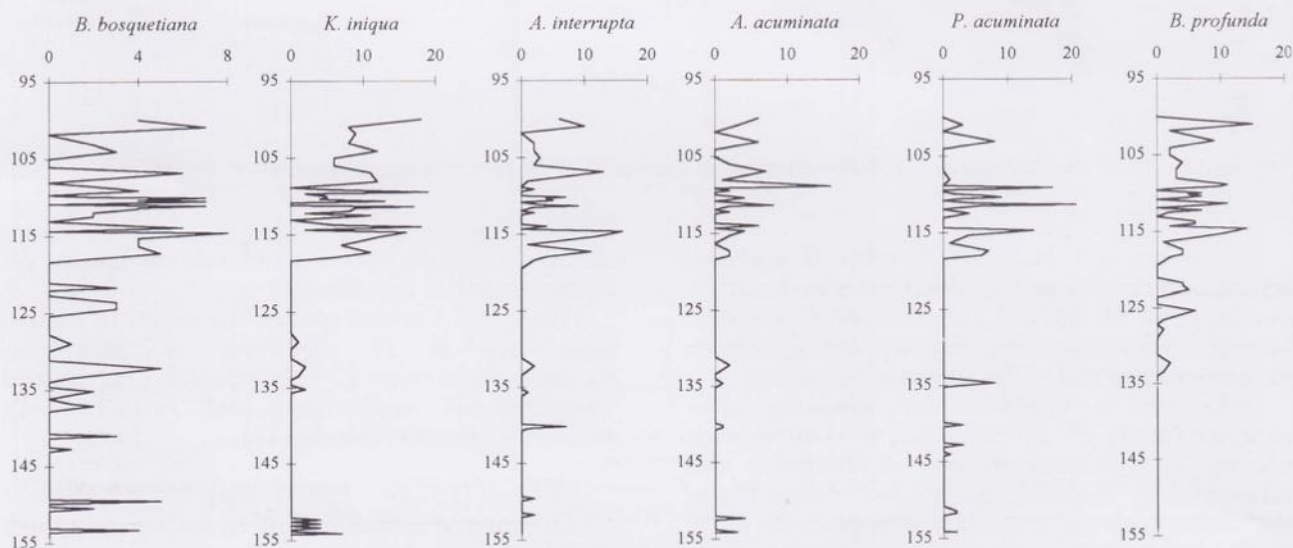
- *Kunihirella eracleaensis*, a species pertaining to a genus recently described (Bonaduce *et al.*, 1994) which, even if represented by a different species, *K. nanseni* (Joy & Clark), occurs in a depth range between 1351 - 2810 m in the Recent of the Central Arctic Ocean (Joy & Clark, 1977), in a depth range 950 - 2793 m in the South - West Pacific, and in the East Indian Ocean from Late Pleistocene to Recent (Correge *et al.*, 1992). A second species of *Kunihirella* (cited as *Paijenborchella* sp.) has been found (1 specimen) in Recent sediments at 1262 m depth in the Scoresby Sund Fjord System (East Greenland) in an assemblage characterized by low diversity considered related to reduced oxygen conditions (Whatley *et al.*, 1996). Our findings seem to support the bathyal environment (and presence of reduced oxygen conditions at the base of the bore-hole).

- *Paijenborchella iocosa* (slender form) has been found in Recent bathyal setting of the South China Sea generally deeper than 500 m (Keiji, 1966);

- *Krithe compressa* (= *Krithe* sp. 5 Whatley & Qunhong, 1993) has been found alive deeper than 900 m in the South China Sea (Whatley & Qunhong, 1993).

From the previous data it seems reasonable to hypothesize at the beginning of the "Trubi" deposition a water depth greater than 500 m.

The estimate of the depositional depth becomes more defined above the M Pl 1 Biozone due to the



Text-fig. 12 - Abundance fluctuations (standardized number of specimens) of the most frequent ostracod taxa in the bore-hole.

generally common occurrence of *A. pliocenica*, pertaining to a typically psychrospheric genus able to live in normal oceanic conditions with the upper boundary at about 1000 m (Benson, 1972).

In the remaining of the M Pl 1 Biozone, together with *K. compressa*, *K. eracleaensis* and *P. iocosa*, the ostracode fauna consists of *K. iniqua*, *K. pernoides*, *A. kissamovens*, *C. (A.) pinarense gillesi*, *P. dimorpha* and *X. prognata*. These species, even if most of them are represented only in the fossil record, have been found in the bore-hole always associated with *A. pliocenica* from M Pl 2 Biozone upwards and also in the Pliocene Monte Narbone Formation of Monte S. Nicola (Gela, Sicily). The Monte Narbone Fm. sedimentation depth has been estimated around 1000 m (Bonaduce & Sprovieri, 1984).

In our opinion, the delayed appearance of *A. pliocenica* is probably due to the normalization of the paleoceanographic conditions with the delayed onset of the psychrosphere in the Mediterranean. If the previous hypothesis will be confirmed, the paleodepth of the entire section can be estimated around 1000 m.

PALEOECOLOGICAL EVOLUTION

The previously described intervals constitute the key of the paleoecological interpretation summarized

in Tab. 6. In the table, the data concerning dominant and co-dominant species, first findings data, fluctuations in the number of first appearances, the highest number of specimens and species recorded in each step are condensed. The paleoecological interpretation (see the last column in Tab. 6) is discussed below.

The benthic ostracod assemblages allow a clear differentiation between steps 1 and 2 (roughly corresponding to the M Pl 1 Biozone) and steps 3 to 6 (M Pl 2 - M Pl 3 *pars* Biozones).

M Pl 1 Biozone (steps 1 - 2)

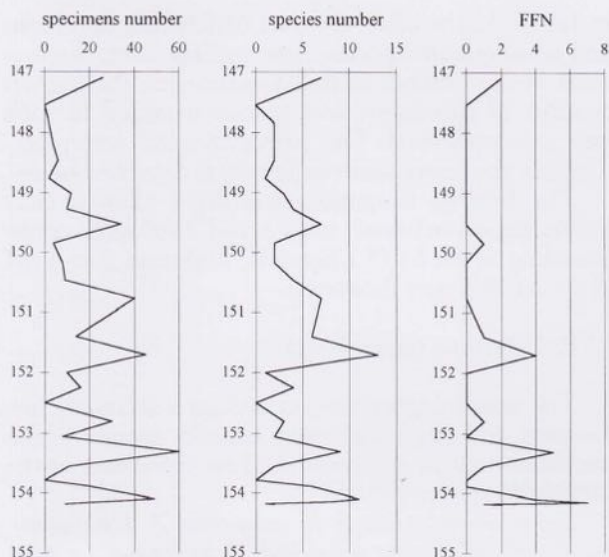
The assemblages show on average a relatively low diversity and abundance and contain species which are considered to represent the first colonizers of the previously sterilized basin.

Some species, such as *K. compressa*, *A. kissamovens*, *C. (A.) pinarense gillesi* and *X. prognata*, are considered opportunistic and able to tolerate unfavorable conditions. They occur also subsequently all along the section with variable quantitative values. Also the genus *Kunihirella* from previous studies (i.e., Whatley *et al.*, 1996) seems characteristic of oxygen depleted environment.

Two short intervals in step 2 (2A and 2C) are characterized by a reduction in diversity associated

STEPS	mbs	DOMINANT SPECIES	CO-DOMINANT SPECIES	FIRST FINDING	FFN	max specimen numbers	max species number	DIVERSITY AND ABUNDANCE	PALEOECOLOGICAL EVOLUTION
6	118.22-99.94	<i>K. compressa</i>	<i>K. iniqua</i> , <i>A. kissamovens</i> , <i>A. pliocenica</i> , <i>A. interrupta</i> , <i>B. profunda</i> , <i>C. vulgatella</i> , <i>B. bosquetiana</i> , <i>P. acuminata</i> , <i>P. dimorpha</i>	<i>C. robusta</i> <i>Q. radiatopora</i>	23	193	29	max diversity max abundance	GOOD CIRCULATION
5	128.39-118.22	<i>A. kissamovens</i> <i>A. pliocenica</i>	<i>H. asperrima</i> , <i>B. profunda</i>		1	58	12	low diversity medium abundance	CRISIS
4	137.04-128.39	<i>K. compressa</i>	<i>H. asperrima</i> , <i>A. pliocenica</i> <i>A. kissamovens</i> , <i>P. ariminensis</i> , <i>P. m. cymbula</i>	<i>B. profunda</i>	10	106	22	high diversity high abundance	PSYCHROSHERE STABILIZATION GOOD CIRCULATION
3	C 140.01-137.04	<i>H. asperrima</i> <i>A. kissamovens</i>	<i>A. pliocenica</i>		1	17	8	low diversity low abundance	CRISIS
	B 141.54-140.01	<i>K. compressa</i> <i>A. kissamovens</i> <i>H. asperrima</i>	<i>A. pliocenica</i> <i>C. vulgatella</i>	<i>P. m. cymbula</i>	10	146	28	high diversity high abundance	ENTRANCE OF PSYCHROSHERE BEGINNING OF BOTTOM CIRCULATION
	A 147.35-141.55	<i>K. compressa</i> <i>A. kissamovens</i>	<i>H. asperrima</i> <i>C. vulgatella</i> <i>K. pernoides</i> <i>X. prognata</i>	<i>O. mediterranea</i> <i>C. vulgatella</i> <i>O. culter</i> <i>A. pliocenica</i> <i>H. asperrima</i>	7	28	9	low diversity medium abundance	
2	C 149.14-147.35		<i>K. pernoides</i> <i>X. prognata</i>		0	12	3	low diversity low abundance	KENOXIC
	B 151.87-149.14	<i>K. compressa</i>	<i>A. kissamovens</i> , <i>C. (A.) p. gillesi</i> , <i>P. dimorpha</i>	<i>A. interrupta</i>	6	40	13	medium diversity medium abundance	2° COLONIZATION
	A 153.20-151.87		<i>A. kissamovens</i> <i>Krithe iniqua</i>	<i>P. dimorpha</i>	1	45	4	low diversity medium abundance	KENOXIC
1	154.20-153.20	<i>K. compressa</i>	<i>A. kissamovens</i> , <i>Argilloecia</i> sp. 1, <i>K. iniqua</i> <i>P. iocosa</i>	<i>A. kissamovens</i> <i>K. compressa</i> <i>K. eracleaensis</i>	18	60	11	medium diversity medium abundance	1° RE-COLONIZATION <i>Kunihirella</i> EVENT (154.20-154.09)

Tab. 6 - Ostracod steps related to drilling depth-range, dominant assemblages, first findings of the most important taxa, first finding number of species (FFN), diversity and abundance and paleoecological interpretation.



Text-fig. 13 - Detailed fluctuations of the ostracod standardized specimens number, species number and first finding number of species (FFN) along the M Pl 1 Biozone.

with by a drastic reduction in the number of specimens in the second interval (2C). These particularly unfavorable conditions are interpreted to be due to the absence or very sluggish bottom circulation which results in a decrease of dissolved oxygen concentration at the bottom defining a kenoxic environment (Cepek & Kempfer, 1981; Whatley, 1990).

The M Pl 1 Biozone in the bore-hole is not so poor in species and specimens as found by Colalongo *et al.* (1990) in Hole 654 A of the ODP Leg 107 in the Tyrrhenian Sea. In fact, in the bore-hole the first basal meter is characterized by the presence of 18 species to which 7 additional species are recorded in the following parts of this biozone. The same trend is confirmed in the Eraclea Minoa section where the samples are of larger size and in which the first faunal cycle (0.02 my), as also shown by Sgarrella *et al.* (1997) for the benthic foraminifers, is already characterized by the occurrence of 15 ostracod species (personal observation).

Consequently, the ostracod colonization is rather well developed at the base of the Pliocene, even if restricted to relatively few tolerant taxa, adapted to stressed bottom water conditions as expected after the Mediterranean flooding.

M Pl 2 - M Pl 3 *pars* Biozones (steps 3 - 6)

At the beginning of step 3, roughly corresponding to the M Pl 1 - M Pl 2 boundary, an important event occurs such as the appearance of *A. pliocenica*, a typical psychrospheric ostracod, which characterizes oceanic water masses generally deeper than 1000 m at

temperatures estimated in the range 4-8°C (Benson, 1973). The presence of *A. pliocenica* demonstrates consequently the entrance of the Atlantic psychrosphere into the Mediterranean which caused the initiation of an active circulation. The onset of the psychrosphere can be justified only by an estuarine type of circulation in the Mediterranean as suggested by van Harten (1984), Rio *et al.*, (1990), Hay (1993), which allowed the entrance of the deep Atlantic water into this satellite basin.

Fluctuations in diversity and abundance are recorded from the base of step 3 up to the base of step 6. High values in diversity and specimen numbers correspond to favourable and stable bottom conditions and low values to unfavourable ones. The high values, corresponding also to times of new colonization, in steps 3B e 4 are considered to correspond to favorable bottom conditions with improved bottom water circulation, oxygenation and food supply. Between them, 2 episodes (steps 3C and 5) are characterized by low values and temporary disappearance of a notable number of species: the first is interpreted as due to unfavourable bottom conditions and due principally to reduction of dissolved bottom oxygen. The poverty of the second (step 5) can be related to the gradual cooling, which begins with the entrance of *G. punctulata* in the Mediterranean, and possibly due to the delayed adaptation of the ostracods to the evolving paleoceanographic conditions at the bottom.

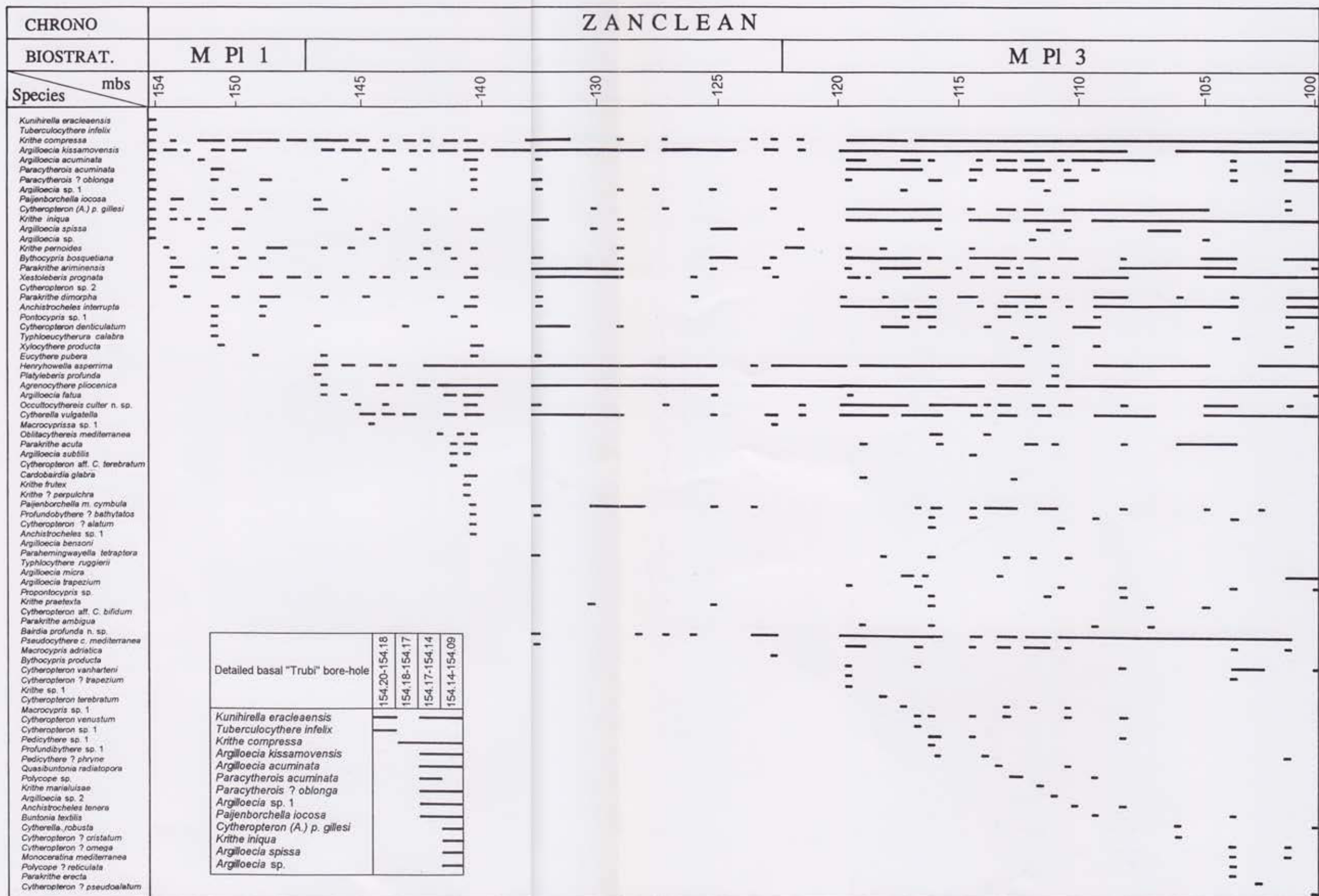
The long ranging step 6, characterized by the maximum in diversity and abundance of the all section, seems to show that favourable bottom conditions became stable in the basin at that time.

FINAL REMARKS

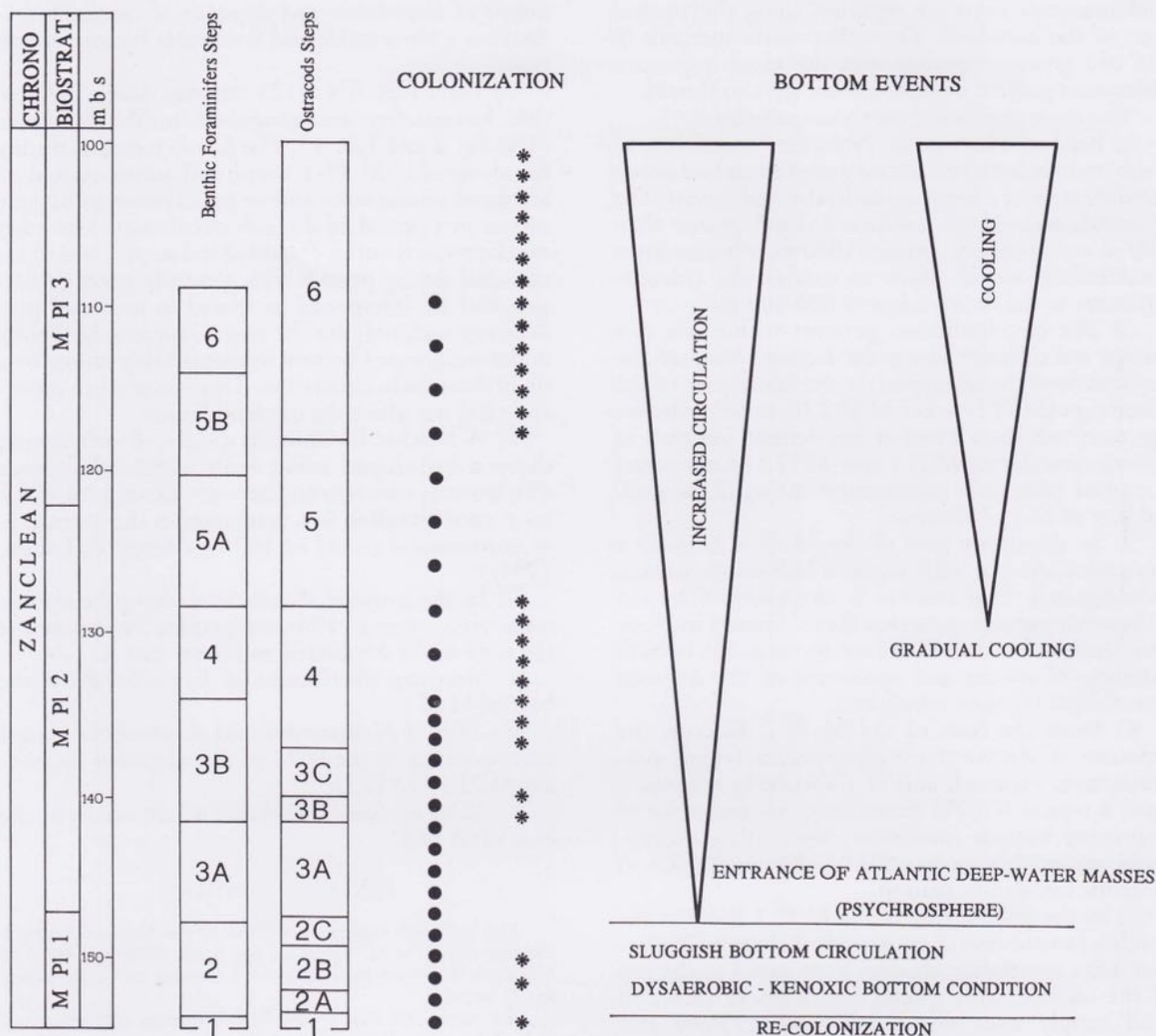
In summary, from the Pliocene bore-hole base to the top of step 5, the colonization is not continuous but characterized by well defined and discrete "inputs". From the base of M Pl 3 Biozone upwards, on the contrary, the colonization increases gradually, clearly demonstrating that the environment became stable.

Two species, *A. pliocenica* and *O. mediterranea* appear especially supporting this interpretation.

In agreement with Benson (1972), we point out that the common occurrence in Pliocene sections of *A. pliocenica* along the south-western Calabria (Ciampo, 1992) and Vrica section (Colalongo & Pasini, 1980) demonstrates that the psychrosphere was well developed also east of the present threshold Sicily - Cap Bon. Moreover, the rare findings of *A. pliocenica* in the Early Pliocene along the Hellenic arc (van Harten, 1984; Peters *et al.*, 1985) show that the psychrosphere also extended to the entire eastern basin, even if probably as an extreme thin upper tongue. Anyway the common occurrence of *A. pliocenica* in Calabria seems to demonstrate that the



Text-fig. 9 - Stratigraphic distribution of all the autochthonous ostracod taxa in the bore-hole and detailbase.



Text-fig. 14 - Synthesis and stratigraphic distributions of paleoenvironmental results from benthic foraminifers and ostracods in the bore-hole.

threshold Sicily - Cap Bon was morphologically "different" from the modern one and much deeper during the Pliocene, at least from M Pl 2 Biozone, as previously stressed by Benson (1972).

Oblitacythereis mediterranea is an important upper bathyal thermospheric ostracod proliferating at bottom temperatures $> 10^{\circ}\text{C}$ (Benson, 1977); the latter species is considered to commonly co-occur with the psychrospheric *A. pliocenica* only in particular paleoceanographic conditions such as in upwelling areas, especially near thresholds (Benson, 1977). This interpretation is further confirmed by the data from the Messinian Atlantic sections near Rabat, which according to Benson *et al.*, (1991) were clearly identified as an upwelling area.

In normal oceanographic conditions *O. mediterranea* most probably lived just above the thermosphere - psychrosphere boundary at middle latitudes and deeper in thermospheric basins (Benson, 1977).

In the bore-hole *O. mediterranea* is rather rare and confined to the intervals 141.75-140.14 mbs; 136.27-134.64 and 114.00-111.91 mbs in which its occurrence together with *A. pliocenica* in well diversified and abundant assemblages may suggest the onset of temporary upwelling regime.

CONCLUSIONS

A synthesis of the results is reported in Text-fig. 14. Stratigraphic distribution of benthic foraminifers

and ostracods steps are reported along the studied part of the bore-hole. The colonization intervals of the two groups, together with the more important paleoceanographic interpretations, are also shown.

The more significant events are as follows:

1) Basal re-colonization. From the "Trubi" base of the bore-hole both benthic foraminifers and ostracods are indicative of a lower epibathyal environment. The ostracods assemblages indicate a depth greater than 500 m and, possibly, around 1000 m, whereas some foraminiferal species allow to confine the paleobathymetry to the depth-range of 600-800 m.

2) The re-colonization patterns within the two groups are different along the section. Most of the foraminiferal species appear in the lower part of the succession (M Pl 1 - lower M Pl 2 Biozones), whereas the ostracods show more or less defined intervals of colonization during M Pl 1 and M Pl 2 Biozones and a marked increase in colonization during all the studied part of M Pl 3 Biozone.

3) In the upper part of the M Pl 1 Biozone a dysaerobic interval with sluggish bottom circulation is recognized. This interval is characterized by the "*Uvigerina pygmaea-peregrina* Event" among the benthic foraminifers, and by the strong reduction in both numbers of species and specimens of the ostracod assemblages (kenoxic condition).

4) From the base of the M Pl 2 Biozone the entrance of *Agrenocythere pliocenica*, a typical psychrospheric ostracod, and of *Cibicidoides robertsonianus*, a typical NADW foraminifer, are indicative of improving bottom conditions, with Atlantic deep-water masses flowing into the Mediterranean due to estuarine circulation pattern.

5) In the middle part of the M Pl 2 Biozone the benthic foraminifers show a gradual change. The dominant assemblage changes from step 4 to the top of the section, with species indicative of increased food supply and bottom circulation. Since this change is recorded few meters below the FO of *Globorotalia puncticulata*, a warm-temperate species, it is probably due to the beginning of a gradual cooling. Benthic foraminiferal step 4 is correlatable with ostracod step 4. In this period high diversity and abundance in the ostracod assemblages testify the psychrosphere stabilization and good bottom circulation.

Moreover, benthic foraminifers allow to correlate this interval with the laminated sediments recorded by Zachariasse *et al.* (1978) and with the reddish diatomitic layer outcropping in the classical Lido Rossello section. This period is generally interpreted as characterized by increased productivity.

6) From the upper part of the M Pl 2 to the lowest part of the M Pl 3 Biozones the ostracods show a period of crisis (step 5). This crisis is possibly a consequence of the delayed adaptation to the change in bottom conditions related to the gradual cooling. From the M Pl 3 Biozone, and all along step 6, maximum

imum of abundance and diversity of ostracods evidenciate a more stable and favourable bottom conditions.

7) Three high BN > 125 μ m intervals in the benthic foraminifers are recognized in the bore-hole (Text-fig. 2 and Tab. 4). The first is recorded during the dysaerobic M Pl 1 event and seems related to increased productivity and/or preservation of organic matter in a period of sluggish circulation. The other two intervals (benthic foraminiferal steps 4 and 6) are recorded during periods with generally good circulation and are interpreted as related to increased productivity and, only for the step 6, apparently slightly under-oxygenated bottom water probably caused by a slight decrease in circulation. This minor event apparently did not affect the ostracod faunas.

8) A benthic foraminifer species, *P. ariminensis*, shows a bell-shaped curve in its relative abundance distribution, with maxima between about 4.8 and 4.4 m. y. corresponding to a maximum in the eccentricity astronomical record of 400 ky (Berger & Loutre, 1991).

9) In the ostracod distribution along the section some events seems of biostratigraphic importance at the scale of the Mediterranean basin that is:

a - restricted distribution of *K. eracleaensis* at the base of M Pl 1;

b - FOs of *H. asperrima* and *A. pliocenica* almost corresponding to the FCO of *G. margaritae* (boundary M Pl 1 - M Pl 2);

c - FCO of *Bairdia profunda* which occurs at the base of M Pl 3.

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APPENDIX 1

BENTHIC FORAMINIFERA

Angulogerina angulosa (Williamson) = *Uvigerina angulosa* Williamson, 1858

Anomalinoidea helcinus (Costa) = *Nonionina helicina* Costa, 1857

Astacolus crepidulus (Fichtel & Moll) = *Nautilus crepidula* Fichtel & Moll, 1803

Asterigerinata planorbis (d'Orbigny) = *Asterigerina planorbis* d'Orbigny, 1846

- Astrononion umbilicatum* Uchio, 1952
Bigenerina nodosaria d'Orbigny, 1826
Bolivina albatrossi Cushman, 1922
Bolivina cistina Cushman, 1936
Bolivina pseudoplicata Heron - Allen & Earland, 1930
Bolivina robusta Brady, 1881
Bolivina variabilis (Williamson) = *Textularia variabilis* Williamson, 1858
Bulimina inflata Seguenza, 1862
Cassidulina carinata Silvestri, 1896
Cassidulina crassa d'Orbigny, 1839
Cassidulinoides bradyi (Norman) = *Cassidulina bradyi* Norman, 1881
Chrysalogonium lanceolum Cushman & Jarvis, 1934
Chrysalogonium obliquatum (Batsch) = *Nautilus obliquatum* Batsch, 1791
Cibicides lobatulus (Walker & Jacob) = *Nautilus lobatulus* Walker & Jacob, 1798
Cibicides refulgens de Montfort, 1808
Cibicidoides ungerianus (d'Orbigny) = *Rotalina ungeriana* d'Orbigny, 1846
Cibicidoides agrigentinus (Schwager) = *Discorbina agrigentina* Schwager, 1878
Cibicidoides bradyi (Trauth) = *Truncatulina bradyi* Trauth, 1918
Cibicidoides dutemplei (d'Orbigny) = *Rotalina dutemplei* d'Orbigny, 1846
Cibicidoides italicus (di Napoli) = *Cibicides italicus* di Napoli, 1952
Cibicidoides mundulus (Brady, Parker & Jones) = *Truncatulina mundula* Brady, Parker & Jones, 1888
Cibicidoides ornatus (Costa) = *Nonionina ornata* Costa, 1856
Cibicidoides robertsonianus (Brady) = *Planorbulina* (*Truncatulina*) *robertsoniana* Brady, 1881
Cylindroclavulina rudis (Costa) = *Glandulina rudis* Costa, 1855
Dentalina aciculata (d'Orbigny) = *Nodosaria aciculata* d'Orbigny, 1826
Dentalina communis (d'Orbigny) = *Nodosaria communis* d'Orbigny, 1826
Dentalina filiformis (d'Orbigny) = *Nodosaria filiformis* d'Orbigny, 1826
Dentalina intorta (Devrieux) = *Nodosaria intorta* Devrieux, 1894
Dentalina sp.
Discorbinella bertheloti (d'Orbigny) = *Rosalina bertheloti* d'Orbigny, 1839
Ellipsoidina ellipsoides Seguenza, emen. Brady, 1868
Ellipsoidopolymorphina fornasinii Galloway, 1933
Elphidium complanatum (d'Orbigny) = *Polystomella complanata* d'Orbigny, 1839
Elphidium crispum (Linneo) = *Nautilus crispus* Linneo, 1758
Elphidium macellum (Fichtel & Moll) = *Nautilus macellus* Fichtel & Moll, 1798
Elphidium pulvereum Todd, 1958
Epistominella exigua (Brady) = *Pulvinulina exigua* Brady, 1884
Epistominella rugosa convexa Parker, 1958
Fissurina annectens (Burrow & Holland) = *Lagena annectens* Burrow & Holland, 1895
Fissurina apiculata Reuss, 1863
Fissurina aurifera (Buchner) = *Lagena aurifera* Buchner, 1940
Fissurina bradyana (Fornasini) = *Lagena bradyana* Fornasini, 1888
Fissurina clathrata (Brady) = *Lagena clathrata* Brady, 1884
Fissurina eburnea (Buchner) = *Lagena eburnea* Buchner, 1940
Fissurina lacunata (Burrows & Holland) = *Lagena lacunata* Burrow & Holland, 1895
Fissurina longirostris Seguenza, 1862
Fissurina marginata (Montagu) = *Vermiculum marginatum* Montagu, 1803
Fissurina pseudoorbignyana (Buchner) = *Lagena pseudoorbignyana* Buchner, 1940
Fissurina quadricostulata (Reuss) = *Lagena quadricostulata* Reuss, 1870
Fissurina seguenziana (Fornasini) = *Lagena seguenziana* Fornasini, 1886
Fissurina sp.1
Globocassidulina subglobosa (Brady) = *Cassidulina subglobosa* Brady, 1881
Globulina inaequalis Reuss, 1850
Guttulina problema (d'Orbigny) = *Polymorphina problema* d'Orbigny, 1826
Gyroidina soldanii (d'Orbigny) = *Rotalia soldanii* d'Orbigny, 1826
Gyroidinoides laevigatus (d'Orbigny) = *Gyroidina laevigata* d'Orbigny, 1826
Gyroidinoides neosoldanii (Brotzen) = *Gyroidina neosoldanii* Brotzen, 1936
Heronallenia lingulata (Burrows & Holland) = *Discorbina lingulata* Burrows & Holland, 1895
Karreriella bradyi (Cushman) = *Gaudryina bradyi* Cushman, 1911
Lagena gibbera Buchner, 1940
Lagena nebulosa Cushman, 1923

Lagena radiata (Seguenza) = *Fissurina radiata* Seguenza, 1862

Lagena squamoso-alata Brady, 1881

Laticarinina pauperata (Parker & Jones) = *Pulvinulina repanda* Fichtel & Moll var. *menardi* d'Orbigny subvar. *pauperata* Parker & Jones, 1865

Lenticulina cultrata (de Montfort) = *Robulus cultratus* de Montfort, 1808

Lenticulina curvisepa (Seguenza) = *Robulina curvisepa* Seguenza, 1880

Lenticulina dilecta (Seguenza) = *Robulina dilecta* Seguenza, 1880

Lenticulina gibba (d'Orbigny) = *Cristellaria gibba* d'Orbigny, 1839

Lenticulina orbicularis (d'Orbigny) = *Robulina orbicularis* d'Orbigny, 1826

Lenticulina rotulata (Lamarck) = *Lenticulites rotulatus* Lamarck, 1804

Lenticulina sp.

Marginulina glabra d'Orbigny, 1826

Martinottiella communis (d'Orbigny) = *Clavulina communis* d'Orbigny, 1826

Martinottiella perparva (Cushman) = *Listerella communis* (d'Orbigny) var. *perparva* Cushman, 1936

Melonis barleeianum (Williamson) = *Nonionina barleeana* Williamson, 1858

Neolenticulina peregrina (Schwager) = *Cristellaria peregrina* Schwager, 1866

Nodosaria raphanistrum (Linneo) = *Nautilus raphanistrum* Linneo, 1758

Nodosaria raphanus (Linneo) = *Nautilus raphanus* Linneo, 1758

Nonionellina labradorica (Dawson) = *Nonionina labradorica* Dawson, 1860

Oolina feildeniana (Brady) = *Lagena feildeniana* Brady, 1878

Oolina foveolata (Seguenza) = *Orbulina foveolata* Seguenza, 1862

Oolina hexagona (Williamson) = *Entosolenia squamosa* (Montagu) var. *hexagona* Williamson, 1848

Oolina seminuda Brady, 1884

Oolina squamosa (Montagu) = *Vermiculum squamosum* Montagu, 1803

Oolina williamsonii (Alcock) = *Entosolenia williamsonii* Alcock, 1865

Oridorsalis tener var. *stellatus* (Silvestri) = *Truncatulina tenera* Brady var. *stellata* Silvestri, 1898

Oridorsalis umbonatus (Reuss) = *Rotalina umbonata* Reuss, 1851

Orthomorphina challengeriana (Thalman) = *Nodogenerina challengeriana* Thalman, 1937

Orthomorphina jedlitsckai (Thalman) = *Nodogenerina jedlitsckai* Thalman, 1937

Parafissurina staphyllearia (Schwager) = *Fissurina staphyllearia* Schwager, 1866

Planularia cymba d'Orbigny, 1826

Planulina ariminensis d'Orbigny, 1826

Pleurostomella alternans Schwager, 1866

Pullenia bulloides (d'Orbigny) = *Nonionina bulloides* d'Orbigny, 1846

Pullenia quadriloba Reuss = *Pullenia compressiuscula* Reuss var. *quadriloba* Reuss, 1867

Pullenia quinqueloba (Reuss) = *Nonionina quinqueloba* Reuss, 1851

Pullenia salisburyi R.E. & K.C. Stewart, 1930

Pyrgo sp.

Quinqueloculina sp.

Rectuvigerina gaudryinoides (Lipparini) = *Uvigerina tenuistriata* Reuss var. *gaudryinoides* Lipparini, 1932

Rosalina obtusa d'Orbigny, 1846

Rotamorphina laevigata (Phleger & Parker) = *Valvulinaria laevigata* Phleger & Parker, 1951

Sigmoilina tenuis (Czjzek) = *Quinqueloculina tenuis* Czjzek, 1848

Sigmoilopsis schlumbergeri (Silvestri) = *Sigmoilina schlumbergeri* Silvestri, 1904

Siphonina reticulata (Czjzek) = *Rotalina reticulata* Czjzek, 1848

Siphotextularia curta (Cushman) = *Textularia flintii* Cushman var. *curta* Cushman, 1922

Sphaeroidina bulloides d'Orbigny, 1826

Spiroloculina sp.

Spiroplectinella wrighti (Silvestri) = *Spiroplecta wrighti* Silvestri, 1903

Stilostomella monilis (Silvestri) = *Nodosaria monilis* Silvestri, 1872

Textularia pseudorugosa Lacroix, 1932

Uvigerina auberiana d'Orbigny, 1839

Uvigerina proboscidea Schwager, 1866

Uvigerina pygmaea d'Orbigny, 1826

Uvigerina rutila Cushman & Todd, 1941

Vaginulinopsis carinata Silvestri = *Vaginulinopsis inversa* (Costa) *carinata* Silvestri, 1904

Valvulinaria minuta Parker, 1954

Vulvulina pennatula (Batsch) = *Nautilus pennatula* Batsch, 1791

APPENDIX 2

OSTRACODA

Agrenocythere pliocenica (Seguenza) = *Cythereis pliocenica* Seguenza, 1880

Anchistrocheles interrupta Aiello, Barra & Bonaduce, 1995

Anchistrocheles tenera (Bremner) = *Bythocypris tenera* Bremner, 1975

Anchistrocheles sp. 1

Argilloecia acuminata G.W. Müller, 1894

Argilloecia bensoni Barra, Aiello & Bonaduce, 1996

Argilloecia fatua Barra, Aiello & Bonaduce, 1996

Argilloecia kissamovensensis Sissingh, 1972

Argilloecia micra Bonaduce, Ciampo & Masoli, 1976

Argilloecia spissa Barra, Aiello & Bonaduce, 1996

Argilloecia subtilis Barra, Aiello & Bonaduce, 1996

Argilloecia trapezium Barra, Aiello & Bonaduce, 1996

Argilloecia sp. 1

Argilloecia sp. 2

Argilloecia sp.

Bairdia profunda, n. sp., *nomen nudum*

Buntonia textilis Bonaduce, Ciampo & Masoli, 1976

Bythocypris bosquetiana (Brady) = *Bairdia bosquetiana* Brady, 1866

Bythocypris obtusata producta (Seguenza) = *Bairdia obtusata* var. *producta* Seguenza, 1880

Cardobairdia asymmetrica (van den Bold) = *Krausella asymmetrica* van den Bold, 1946

Cytherella robusta Colalongo & Pasini, 1980

Cytherella vulgatella Aiello, Barra, Bonaduce & Russo, 1996

Cytheropteron ? *alatum* G.O. Sars, 1866

Cytheropteron aff. *C. bifidum* Colalongo & Pasini, 1980

Cytheropteron ? *cristatum* Colalongo & Pasini, 1980

Cytheropteron (*Aversovalva*) *denticulatum* Aiello, Barra & Bonaduce, 1996

Cytheropteron ? *omega* Aiello, Barra & Bonaduce, 1996

Cytheropteron (*Aversovalva*) *pinarense gillesi* Aiello, Barra & Bonaduce, 1996

Cytheropteron ? *pseudoalatum* Colalongo & Pasini, 1980

Cytheropteron terebratum Colalongo & Pasini, 1980

Cytheropteron aff. *terebratum* Colalongo & Pasini, 1980

Cytheropteron ? *trapezium* Colalongo & Pasini, 1980

Cytheropteron vanharteni Aiello, Barra & Bonaduce, 1996

Cytheropteron venustum Bonaduce, Ciampo & Masoli, 1976

Cytheropteron sp. 1

Cytheropteron sp. 2

Eucythere pubera Bonaduce, Ciampo & Masoli, 1976

Henryhowella asperrima (Reuss) = *Cypridina asperrima* Reuss, 1850

Krithe compressa (Seguenza) = *Ilyobates compressa* Seguenza, 1880

Krithe frutex Abate, Barra, Aiello & Bonaduce, 1993

Krithe iniqua Abate, Barra, Aiello & Bonaduce, 1993

Krithe marialuisae Abate, Barra, Aiello & Bonaduce, 1993

Krithe pernoides (Bornemann) = *Bairdia pernoides* Bornemann, 1855

Krithe ? *perpulchra* Abate, Barra, Aiello & Bonaduce, 1993

Krithe praetexta (Sars) = *Ilyobates praetexta* Sars, 1866

Krithe sp. 1

Kunihirella eracleaensis Bonaduce, Abate & Barra, 1994

Macropyxis adriatica (Bremner) = *Macrocypris adriatica* Bremner, 1975

Macrocypris sp. 1

Macrocypris sp. 1

Monoceratina mediterranea Sissingh, 1972

Oblitacythereis mediterranea Benson, 1977

Occultocythereis culter, n. sp., *nomen nudum*

Paijenborchella iocosa Kingma, 1948

Paijenborchella malaiensis cymbula Ruggieri, 1950

Paracytherois acuminata G.W. Müller, 1894

Paracytherois ? *oblonga* G.W. Müller, 1894

Parahemingwayella tetraptera (B., C. & M.) = ? *Cytheropteron tetrapteron* Bonaduce, Ciampo & Masoli, 1976

Parakrithe acuta Aiello, Barra, Abate & Bonaduce, 1993

Parakrithe ambigua Ciampo, 1980

Parakrithe ariminensis (Ruggieri) = *Krithe ariminensis* Ruggieri, 1967

Parakrithe dimorpha Bonaduce, Ciampo & Masoli, 1976

Parakrithe erecta Aiello, Barra, Abate & Bonaduce, 1993

Pedicythere ? *phryne* Bonaduce, Ciampo & Masoli, 1976

Pedicythere sp. 1

Platyleberis profunda (Bremner) = *Microxestoleberis profunda* Bremner, 1975

Polycopse ? *reticulata* G.W. Müller, 1894

Polycope sp.

Pontocypris sp. 1

Profundobythere? *bathytatos* (Whatley & Coles, 1987)

Profundobythere sp. 1

Propontocypris sp.

Pseudocythere caudata mediterranea Bonaduce, Masoli, Pugliese & McKenzie, 1980

Quasibuntonia radiatopora (Seguenza) = *Cythere radiatopora* Seguenza, 1880

Tuberculoocythere infelix (B., C. & M.) = ? *Cytheropteron infelix* Bonaduce, Ciampo & Masoli, 1976

Typhlocythere ruggierii Bonaduce, Ciampo & Masoli, 1976

Typhloeocytherura calabra Colalongo & Pasini, 1980

Xestoleberis prognata Bonaduce & Danielopol, 1988

Xylocythere producta (Colalongo & Pasini) = "*Typhlocythere*" *producta* Colalongo & Pasini, 1980.

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