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CALCAREOUS PLANKTON HIGH RESOLUTION BIOSTRATIGRAPHY (FORAMINIFERA AND NANNOFOSSILS) OF THE UPPERMOST LANGHIAN - LOWER SERRAVALLIAN RAS IL-PELLEGRIN SECTION (MALTA)

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Riassunto. Vengono presentati i risultati di uno studio di biostratigrafia ad alta risoluzione, basato su foraminiferi planctonici e nannofossili calcarei, della sezione Ras il-Pellegrin di età Langhiano superiore-Serravalliano inferiore affiorante nell'Isola di Malta. I sedimenti studiati appartengono alla Formazione delle Blue Clay. In questa formazione che consiste di marne grigio-azzurre, sono ben visibili alcune bande di colore chiaro e spessore decimetrico, più ricche in $CaCO_3$. La successione studiata, composta da due subsezioni ben correlate e distanti fra loro circa 300 m, ha uno spessore complessivo di circa 70 m; vi sono stati raccolti 451 campioni, in media ogni 15 cm; per ognuno di essi è stata eseguita l'analisi micropaleontologica quantitativa del contenuto in plancton ed i dati sono stati resi in forma grafica. Sono state inoltre effettuate analisi qualitative con cadenze di un campione per metro di successione.

La sezione è stata studiata, in un lavoro a parte, anche dal punto di vista ciclostratigrafico. Tale studio ha consentito la calibrazione della sezione con la curva astronomica ed ha quindi permesso la datazione con metodo astrocronologico di tutti i bio-eventi contenuti. Fra i più significativi si ricordano la scomparsa di *Globorotalia peripheroronda* a 13,39 Ma, la comparsa di *Paragloborotalia partimlabiata* a 12,62 Ma e la prima presenza comune di *Paragloborotalia mayeri* a 12,34 Ma per i foraminiferi planctonici; la scomparsa di *Sphenolithus heteromorphus* a 13,59 Ma, l'ultima presenza comune di *Cyclicargolithus floridanus* a 13,39 Ma, la prima presenza comune di *Reticulofenestra pseudoumbilicus* a 13,32 Ma, la comparsa di *Calcidiscus macintyrei* a 12,57 Ma e l'ultima presenza comune di *Calcidiscus premacintyrei* a 12,51 Ma. La base della formazione delle Blue Clay è stata datata a 13,76 Ma. Inoltre, i risultati ottenuti hanno confermato che la scomparsa di *S. heteromorphus* si realizza pressoché allo stesso tempo nel Mediterraneo e negli oceani Atlantico e Pacifico. Perciò, viene suggerito di utilizzare un livello litologico vicino o coincidente con quello in cui si realizza questo evento per la definizione del GSSP del Serravalliano. A questo scopo, la Sezione di Ras il-Pellegrin può essere considerata un buon candidato per questa definizione.

Abstract. Results of an integrated biostratigraphic (calcareous nannofossils and planktonic foraminifera) study of the uppermost Langhian/lower Serravallian Ras il-Pellegrin section (Fomm ir-Rih Bay - Malta) are presented. This high resolution study allowed us to recognize several useful lower Serravallian bio-events in the Mediterranean and to provide a detailed distribution pattern of the recognized taxa. The astrochronological calibration, reported in a different paper of this volume, provided absolute ages of the bio-events of the studied section. The LO (Last Occurrence) of *Globorotalia peripheroronda* at 13.39 Ma, the *Paragloborotalia partimlabiata* FO (First Occurrence) at 12.62 Ma and the *Paragloborotalia mayeri* FCO (First Common Occurrence) at 12.34 Ma among the planktonic foraminifera, and the *Sphenolithus heteromorphus* LO at 13.59 Ma, the *Cyclicargolithus floridanus* LCO (Last Common Occurrence) at 13.39 Ma, the *Reticulofenestra pseudoumbilicus* FCO at 13.32 Ma, the *Calcidiscus macintyrei* FO at 12.57 Ma and the *Calcidiscus premacintyrei* LCO at 12.51 Ma among the calcareous nannofossils, were recorded. Moreover, our results confirm the LO of *S. heteromorphus* as a fairly synchronous event in the Mediterranean and in the Atlantic and Pacific Oceans. Therefore, a lithological level near or coincident with this event maybe considered a good candidate for the definition of the GSSP of the Serravallian.

Introduction

Modern Neogene biostratigraphy is closely linked to accurate biochronology. During the past decade the Astronomical Time Scale (ATS) proposed for the Pliocene (Shackleton et al. 1990, Hilgen 1991a,b), strongly supported by the Geomagnetic Polarity Time scale (GPTS) of Cande & Kent (1995), gave a consistent input to the biochronological research. More recently, several authors (e.g. Hilgen et al. 1995, 2000; Krijgsman et al. 1995; Lourens et al. 1996; Shackleton & Crowhurst 1997) extended the ATS downwards into the Miocene. Consequently, many calcareous plankton bio-events have been dated with high precision (see also Glaçon et al. 1990; Rio et al. 1990; Channel et al. 1992; Sprovieri 1992, 1993; Sprovieri et al. 1996 a,b,c, 1998). Until now, the oldest astrochronological studies on Serravallian have been performed only on sediments not older than 12.1 Ma (Hilgen et al. 2000). The astrochronology of the interval between the middle Serravallian and the early Tortonian has been obtained from the S. Nicola

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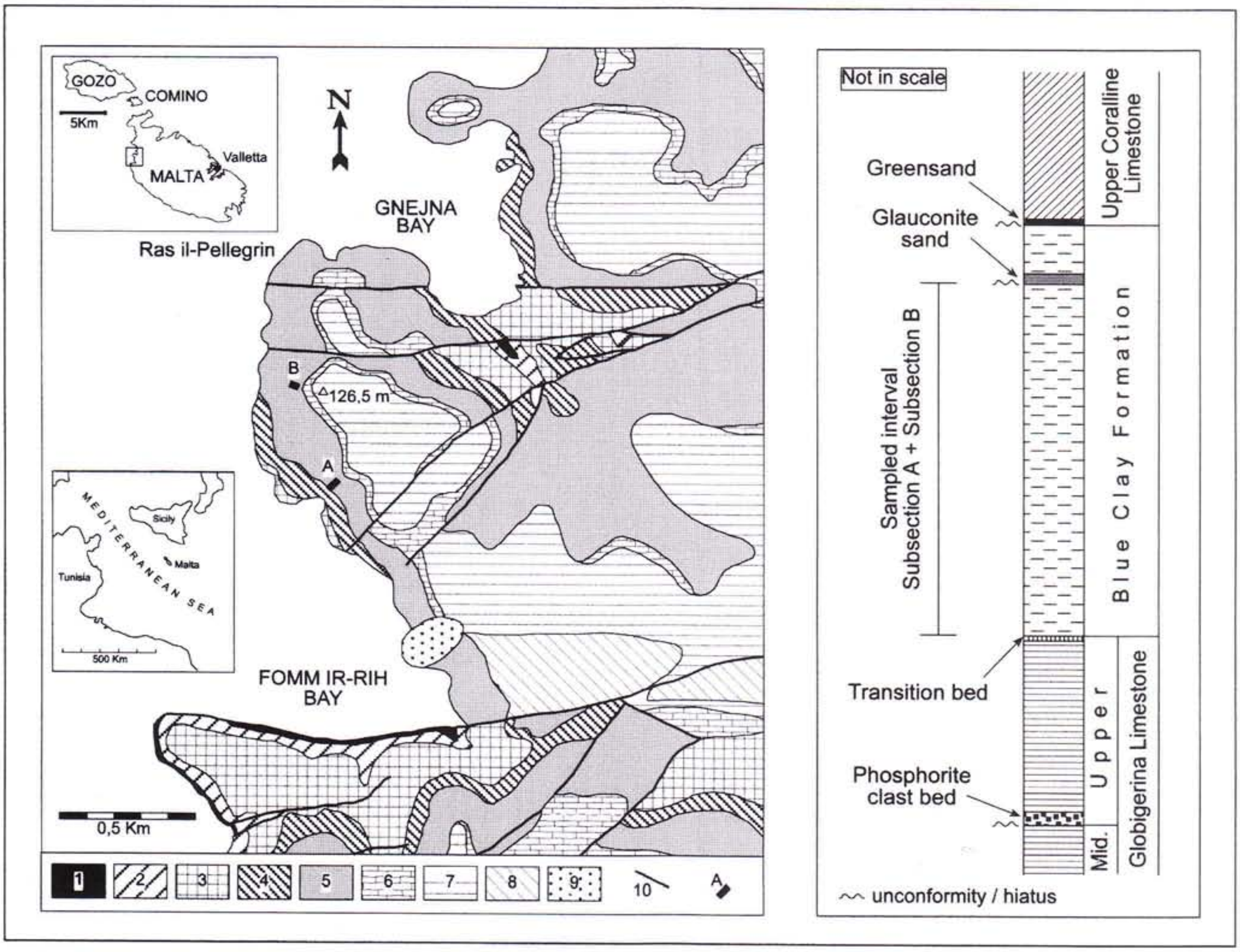


Fig. 1 - Location map of the studied sections. Geology modified after Debono et al. (1993) 1) - Lower Coralline Limestone; 2,3,4) - Lower, Middle and Upper Globigerina Limestone; 5) - Blue Clay Formation; 6-8) - Upper Coralline Limestone: 6 - Mtarfa Member, 7 - Tal-Pitkal Member, 8 - Gebel Imbark Member; 9) - detritus; 10) - faults; A/B) - subsections. On the right side, the simplified stratigraphic log of the Miocene succession (from Giannelli & Salvatorini 1975).

composite section (Tremiti Islands) (Lirer et al. 2002). We have selected the uppermost Langhian-lower Serravallian Ras il-Pellegrin section, sampled in the Blue Clay Formation of the Malta island, to extend downward the astrochronological study.

Geological framework

Malta is the largest island of the Maltese Arcipelago (Fig. 1) which is located about 100 km South of Sicily, near the actual boundary between the Malta Platform and the Pantelleria or Strait of Sicily Rift (Finetti 1982). The arcipelago consists of two major islands, Malta and Gozo, and other small islands. The geology of the arcipelago was studied by several authors (Hyde 1955; Felix 1973; Pedley et al. 1976, 1978, among the others). All the outcropping sediments of the islands are carbonatic and Oligocene-Miocene in age.

Four formations were recognized in the arcipelago (Debono et al. 1993) (Fig. 1). They are from bottom to top:

1) Lower Coralline Limestone Fm. It consists of carbonate mudstones, wackestones and packstones with abundant fossil remains mainly composed of coralline algae. The formation is divided into four members and the total thickness is more than 100 m. The age is Oligocene (Chattian).

2) Globigerina Limestone Fm. It is formed by well stratified yellow- whitish planktonic foraminiferal limestones. The formation is divided into three members (Lower, Middle and Upper) by unconformable boundaries characterised by hardgrounds with phosphorite clast beds (see also Jacob et al. 1996). The maximum thickness of the formation is about 100 m. The age is Miocene (Aquitanian - Langhian).

3) Blue Clay Fm. It consists of foraminiferal-bearing blue-grey pelagic marls with pale bands (light grey or whitish). This unit conformably overlies the Globigerina Limestone Fm. The maximum thickness is about 70 m. The deposition of these sediments occurred during the Miocene (Langhian - Tortonian).

4) Upper Coralline Limestone Fm. This unit

unconformably covers the Blue Clay Fm. and is divided into four members which together reach a maximum thickness of about 50 m. It predominantly consists of limestones, wackestone and packstone with a rich macrofossils content. Coralline algae are the most common organic remains. According to Debono et al. (1993) the Upper Coralline Limestone includes also the Green Sand Fm. (a few meters thick) of the previous literature, which forms part of the lowermost member. The green colour is due to the relatively high content of glauconite grains. The age of this formation is Late Miocene (Messinian).

Quaternary deposits are also present in the Maltese Arcipelago. They mainly consist of sands and conglomerates with intercalated paleosoils and remains of continental malacofauna.

The Maltese Arcipelago is a part of a graben system which has been formed by two groups of faults: one with a NW-SE direction and the other with an ENE-WSW trend. This graben system lies within the African plate, in the foreland of the Sicilian Apennine-Maghrebian fold and thrust belt. During the Miocene-Pliocene this graben system represented the most northern portion of the Pantelleria rift zone.

Two main hypotheses explaining the Pantelleria rift evolution are found in the literature. According to the first hypothesis, pull-apart basins formed as consequence of the development of dextral transfer faults with an E-W direction (Cello et al. 1984; Finetti 1984; Cello 1987; Robertson & Grasso 1995). In the second hypothesis the rift is due to the development of normal extensional faults (Dart et al. 1993), which are causally related to back arc extension in the Tyrrhenian Sea and compression in the Apennine-Maghrebian thrust (Argnani 1990). The kinematic evolution of the structures has been considered to occur during one (Dart et al. 1993) or more phases (Illies 1981; Reuther & Eisbacher 1985).

Therefore, some authors consider the rifting to start from Early-Middle Miocene (Finetti 1982; Dart et al. 1993), others from Late Miocene-Early Pliocene (Cello et al. 1984; Finetti 1984; Cello 1987; Boccaletti et al. 1988; Robertson & Grasso 1995). Dart et al. (1993) recognised in the Neogene-Quaternary succession of the arcipelago and its surrounding area four sedimentary phases: 1) the Lower Coralline Limestone and the Lower Globigerina Limestone Fm. formed during the pre-rift phase (>21 Ma); 2) the Middle and Upper Globigerina Limestone Fm. Blue Clay Fm. and Upper Coralline Limestone Fm., (p.p.) were deposited during the early syn-rift phase (21-6 Ma); 3) the Upper Coralline Limestone Fm. (p.p.) and the Pliocene-Quaternary succession formed during the late syn-rift phase (< 5 Ma); 4) the infilling of the basins happened during the post-rift phase (probably < 1.5 Ma). The third phase was the most active and characterized by the highest sedimentation rate.

The studied section

The Ras il-Pellegrin section has been selected for its excellent exposure and its well known biostratigra-

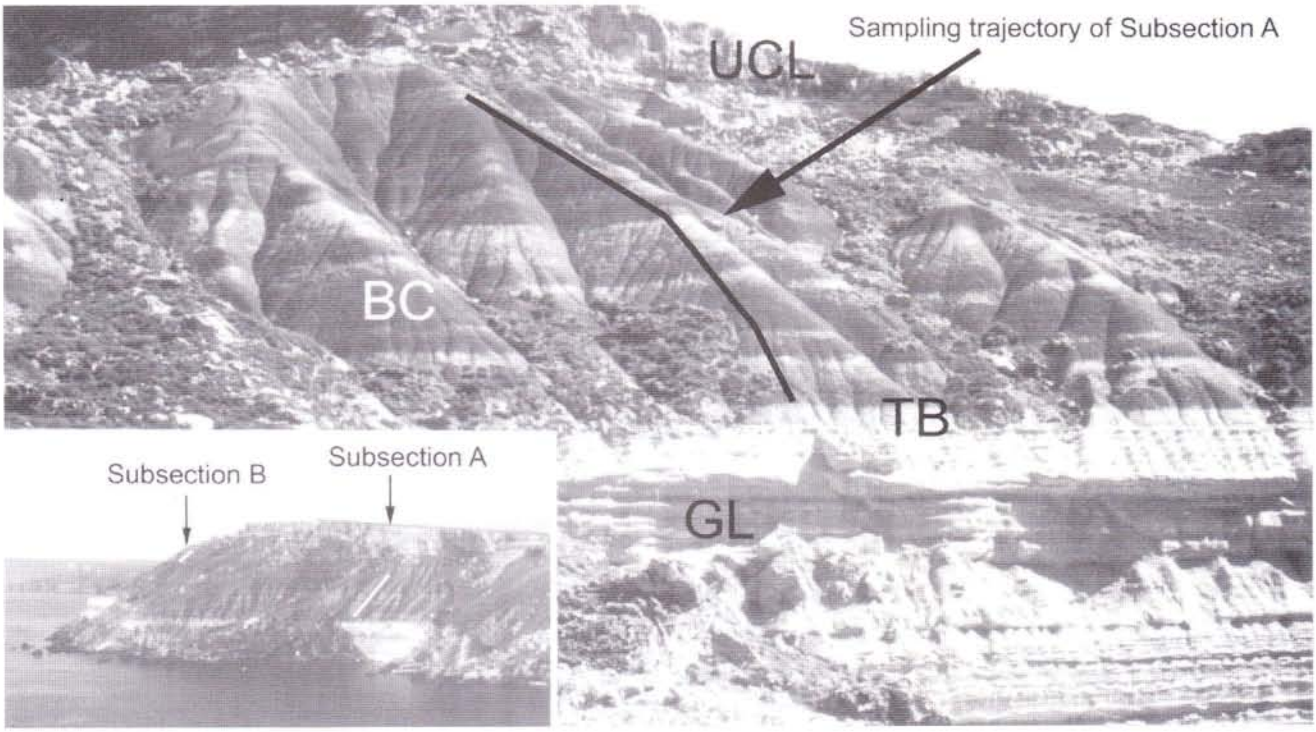


Fig. 2 - Sampling trajectories of the Ras il-Pellegrin section. GL: Globigerina Limestone, BC: Blue Clay, UCL: Upper Coralline Limestone, TB: transition bed from GL to BC. No photo is available for the B subsection.

Sample N.	meters	Sample N.	meters	Sample N.	meters	Sample N.	meters	Sample N.	meters	Sample N.	meters
ML-1	0,00	ML-77	11,60	ML-153	23,25	ML-229	34,89	ML-305	46,53	ML-522	58,02
ML-2	0,11	ML-78	11,76	ML-154	23,40	ML-230	35,04	ML-306	46,69	ML-523	58,18
ML-3	0,27	ML-79	11,91	ML-155	23,55	ML-231	35,20	ML-307	46,84	ML-524	58,33
ML-4	0,42	ML-80	12,06	ML-156	23,71	ML-232	35,35	ML-308	46,99	ML-525	58,48
ML-5	0,57	ML-81	12,22	ML-157	23,86	ML-233	35,50	ML-309	47,15	ML-526	58,64
ML-6	0,73	ML-82	12,37	ML-158	24,01	ML-234	35,66	ML-310	47,30	ML-527	58,79
ML-7	0,88	ML-83	12,52	ML-159	24,17	ML-235	35,81	ML-311	47,45	ML-528	58,94
ML-8	1,03	ML-84	12,68	ML-160	24,32	ML-236	35,96	ML-312	47,61	ML-529	59,10
ML-9	1,19	ML-85	12,83	ML-161	24,47	ML-237	36,12	ML-313	47,76	ML-530	59,25
ML-10	1,34	ML-86	12,98	ML-162	24,63	ML-238	36,27	ML-314	47,91	ML-531	59,40
ML-11	1,49	ML-87	13,14	ML-163	24,78	ML-239	36,42	ML-315	48,07	ML-532	59,56
ML-12	1,65	ML-88	13,29	ML-164	24,93	ML-240	36,58	ML-316	48,22	ML-533	59,71
ML-13	1,80	ML-89	13,44	ML-165	25,09	ML-241	36,73	ML-317	48,37	ML-534	59,86
ML-14	1,95	ML-90	13,60	ML-166	25,24	ML-242	36,88	ML-318	48,53	ML-535	60,02
ML-15	2,11	ML-91	13,75	ML-167	25,39	ML-243	37,04	ML-319	48,68	ML-536	60,17
ML-16	2,26	ML-92	13,90	ML-168	25,55	ML-244	37,19	ML-320	48,83	ML-537	60,32
ML-17	2,41	ML-93	14,06	ML-169	25,70	ML-245	37,34	ML-321	48,99	ML-538	60,48
ML-18	2,57	ML-94	14,21	ML-170	25,85	ML-246	37,50	ML-322	49,14	ML-539	60,63
ML-19	2,72	ML-95	14,36	ML-171	26,01	ML-247	37,65	ML-323	49,29	ML-540	60,78
ML-20	2,87	ML-96	14,52	ML-172	26,16	ML-248	37,80	ML-324	49,45	ML-541	60,94
ML-21	3,03	ML-97	14,67	ML-173	26,31	ML-249	37,96	ML-325	49,60	ML-542	61,09
ML-22	3,18	ML-98	14,82	ML-174	26,47	ML-250	38,11	ML-326	49,75	ML-543	61,24
ML-23	3,33	ML-99	14,98	ML-175	26,62	ML-251	38,26	ML-327	49,90	ML-544	61,39
ML-24	3,49	ML-100	15,13	ML-176	26,77	ML-252	38,41	ML-328	50,06	ML-545	61,55
ML-25	3,64	ML-101	15,28	ML-177	26,92	ML-253	38,57	ML-329	50,21	ML-546	61,70
ML-26	3,79	ML-102	15,43	ML-178	27,08	ML-254	38,72	ML-330	50,36	ML-547	61,85
ML-27	3,94	ML-103	15,59	ML-179	27,23	ML-255	38,87	ML-331	50,52	ML-548	62,01
ML-28	4,10	ML-104	15,74	ML-180	27,38	ML-256	39,03	ML-332	50,67	ML-549	62,16
ML-29	4,25	ML-105	15,89	ML-181	27,54	ML-257	39,18	ML-333	50,82	ML-550	62,31
ML-30	4,40	ML-106	16,05	ML-182	27,69	ML-258	39,33	ML-334	50,98	ML-551	62,47
ML-31	4,56	ML-107	16,20	ML-183	27,84	ML-259	39,49	ML-335	51,13	ML-552	62,62
ML-32	4,71	ML-108	16,35	ML-184	28,00	ML-260	39,64	ML-336	51,28	ML-553	62,77
ML-33	4,86	ML-109	16,51	ML-185	28,15	ML-261	39,79	ML-337	51,44	ML-554	62,93
ML-34	5,02	ML-110	16,66	ML-186	28,30	ML-262	39,95	ML-338	51,59	ML-555	63,08
ML-35	5,17	ML-111	16,81	ML-187	28,46	ML-263	40,10	ML-339	51,74	ML-556	63,23
ML-36	5,32	ML-112	16,97	ML-188	28,61	ML-264	40,25	ML-340	51,90	ML-557	63,39
ML-37	5,48	ML-113	17,12	ML-189	28,76	ML-265	40,41	ML-341	52,05	ML-558	63,54
ML-38	5,63	ML-114	17,27	ML-190	28,92	ML-266	40,56	ML-342	52,20	ML-559	63,69
ML-39	5,78	ML-115	17,43	ML-191	29,07	ML-267	40,71	ML-343	52,36	ML-560	63,85
ML-40	5,94	ML-116	17,58	ML-192	29,22	ML-268	40,87	ML-344	52,51	ML-561	64,00
ML-41	6,09	ML-117	17,73	ML-193	29,38	ML-269	41,02	ML-345	52,66	ML-562	64,15
ML-42	6,24	ML-118	17,89	ML-194	29,53	ML-270	41,17	ML-346	52,82	ML-563	64,31
ML-43	6,40	ML-119	18,04	ML-195	29,68	ML-271	41,33	ML-347	52,97	ML-564	64,46
ML-44	6,55	ML-120	18,19	ML-196	29,84	ML-272	41,48	ML-348	53,12	ML-565	64,61
ML-45	6,70	ML-121	18,35	ML-197	29,99	ML-273	41,63	ML-349	53,28	ML-566	64,77
ML-46	6,86	ML-122	18,50	ML-198	30,14	ML-274	41,79	ML-350	53,43	ML-567	64,92
ML-47	7,01	ML-123	18,65	ML-199	30,30	ML-275	41,94	ML-351	53,58	ML-568	65,07
ML-48	7,16	ML-124	18,81	ML-200	30,45	ML-276	42,09	ML-352	53,73	ML-569	65,22
ML-49	7,32	ML-125	18,96	ML-201	30,60	ML-277	42,24	ML-353	53,89	ML-570	65,38
ML-50	7,47	ML-126	19,11	ML-202	30,75	ML-278	42,40	ML-354	54,04	ML-571	65,53
ML-51	7,62	ML-127	19,26	ML-203	30,91	ML-279	42,55	ML-355	54,19	ML-572	65,68
ML-52.	7,77	ML-128	19,42	ML-204	31,06	ML-280	42,70	ML-356	54,35	ML-573	65,84
ML-53	7,93	ML-129	19,57	ML-205	31,21	ML-281	42,86	ML-357	54,50	ML-574	65,99
ML-54	8,08	ML-130	19,72	ML-206	31,37	ML-282	43,01	ML-358	54,65	ML-575	66,14
ML-55	8,23	ML-131	19,88	ML-207	31,52	ML-283	43,16	ML-500	54,62	ML-576	66,30
ML-56	8,39	ML-132	20,03	ML-208	31,67	ML-284	43,32	ML-501	54,81	ML-577	66,45
ML-57	8,54	ML-133	20,18	ML-209	31,83	ML-285	43,47	ML-502	54,96	ML-578	66,60
ML-58	8,69	ML-134	20,34	ML-210	31,98	ML-286	43,62	ML-503	55,11	ML-579	66,76
ML-59	8,85	ML-135	20,49	ML-211	32,13	ML-287	43,78	ML-504	55,27	ML-580	66,91
ML-60	9,00	ML-136	20,64	ML-212	32,29	ML-288	43,93	ML-505	55,42	ML-581	67,06
ML-61	9,15	ML-137	20,80	ML-213	32,44	ML-289	44,08	ML-506	55,57	ML-582	67,22
ML-62	9,31	ML-138	20,95	ML-214	32,59	ML-290	44,24	ML-507	55,73	ML-583	67,37
ML-63	9,46	ML-139	21,10	ML-215	32,75	ML-291	44,39	ML-508	55,88	ML-584	67,52
ML-64	9,61	ML-140	21,26	ML-216	32,90	ML-292	44,54	ML-509	56,03	ML-585	67,68
ML-65	9,77	ML-141	21,41	ML-217	33,05	ML-293	44,70	ML-510	56,19	ML-586	67,83
ML-66	9,92	ML-142	21,56	ML-218	33,21	ML-294	44,85	ML-511	56,34	ML-587	67,98
ML-67	10,07	ML-143	21,72	ML-219	33,36	ML-295	45,00	ML-512	56,49	ML-588	68,14
ML-68	10,23	ML-144	21,87	ML-220	33,51	ML-296	45,16	ML-513	56,65	ML-589	68,29
ML-69	10,38	ML-145	22,02	ML-221	33,67	ML-297	45,31	ML-514	56,80	ML-590	68,44
ML-70	10,53	ML-146	22,18	ML-222	33,82	ML-298	45,46	ML-515	56,95	ML-591	68,60
ML-71	10,69	ML-147	22,33	ML-223	33,97	ML-299	45,62	ML-516	57,11	ML-592	68,75
ML-72	10,84	ML-148	22,48	ML-224	34,13	ML-300	45,77	ML-517	57,26		
ML-73	10,99	ML-149	22,64	ML-225	34,28	ML-301	45,92	ML-518	57,41		
ML-74	11,15	ML-150	22,79	ML-226	34,43	ML-302	46,07	ML-519	57,56		
ML-75	11,30	ML-151	22,94	ML-227	34,58	ML-303	46,23	ML-520	57,72		
ML-76	11,45	ML-152	23,09	ML-228	34,74	ML-304	46,38	ML-521	57,87		

Tab. 1 - List of the investigated samples.

phy (sections 5 and 5 bis of Giannelli & Salvatorini 1975; section 5 of Mazzei 1985; section Karabba of Fornaciari et al. 1996). The section is located at the northern side of the Fomm ir-Rih Bay (Fig. 1) where the Middle and Upper Globigerina Limestone, Blue Clay and Upper Coralline Limestone Formations crop out. The investigated stratigraphic interval belongs to the Blue Clay Fm. The marly lithological sequence includes some whitish, more carbonatic beds, a few decimetres thick. They were visually identified in the lower and upper part of the section, where they are grouped in more or less evident clusters. The base of the section is just above the transition bed referred to the *Globigerina* Limestone by Giannelli & Salvatorini (1975). The section ends just below the first level of fossiliferous (*Amussium* and *Flabellipecten*) glauconite sand which is intercalated in the uppermost part of the Blue Clay Fm. (Giannelli & Salvatorini 1975).

The section is composed of two subsections. Subsection A covers the interval from the base to level 54.65 m; subsection B covers the interval from this level to the top. Correlation between the subsections is based on the recognition of the same cluster of four whitish beds in the upper part of segment A and in the lower part of segment B (Fig. 2). The whole thickness of the composite section is about 70 m. A total of 451 samples (Tab. 1) have been collected at an average spacing of about 15-20 cm.

A hiatus is recorded in the upper part of the Blue Clay, just at the base of the first level of glauconite sand (Fig. 1), by Giannelli & Salvatorini (1975) and Mazzei (1985), but it is not reported by Fornaciari et al. (1996). The investigated interval ends just below the hiatus recognized by Giannelli & Salvatorini (1975).

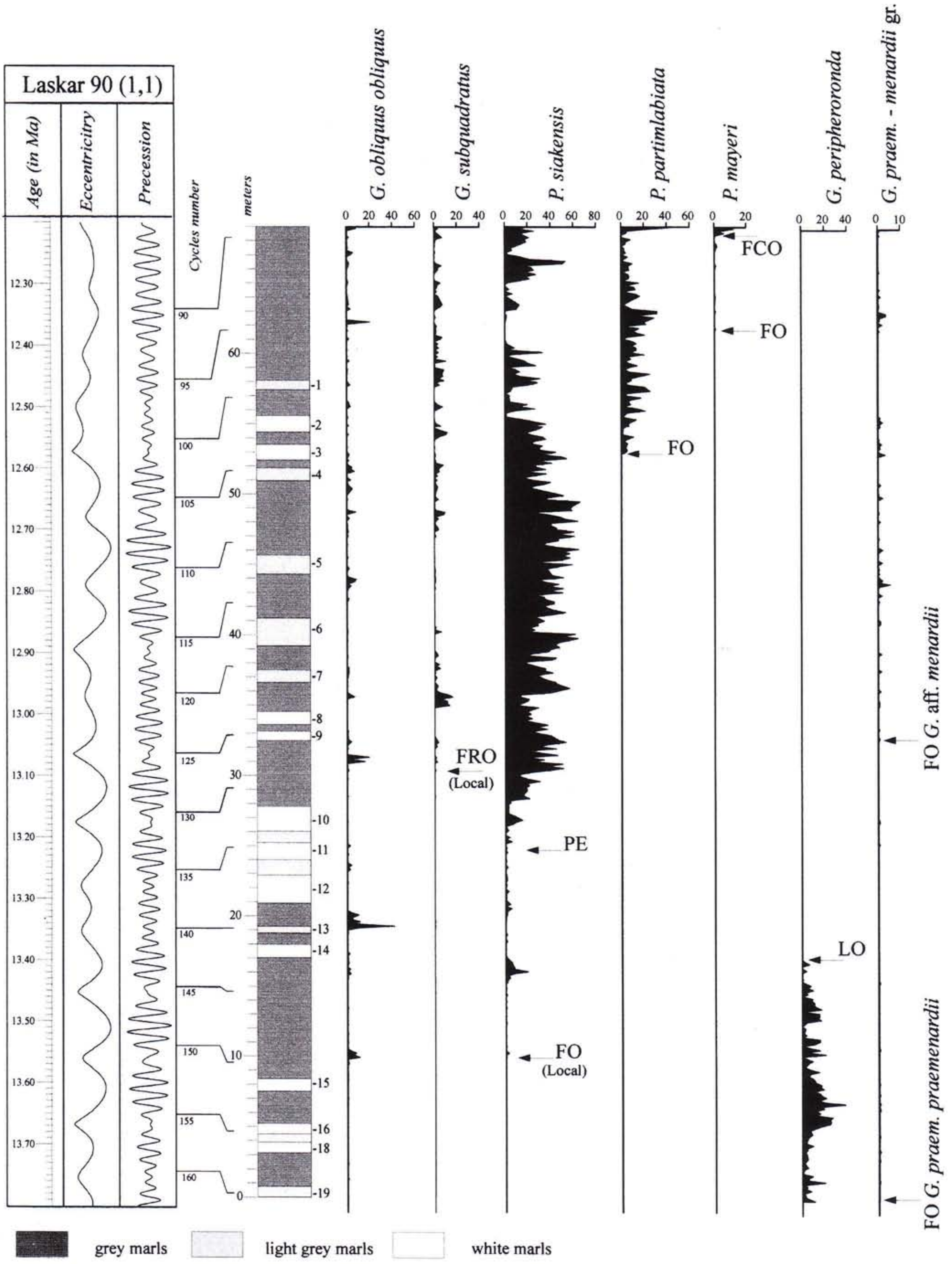
The Ras il-Pellegrin section has been astronomically calibrated by Sprovieri M. et al. (2002) assuming a quasi-constant sedimentation rate and using two tie points recognized in the upper part of the section. They are the *Paragloborotalia mayeri* FCO and the *Calcidiscus macintyrei* FO that, in the S. Nicola composite section, have an estimated age of 12.34 Ma and 12.57 Ma respectively (Lirer et al. 2002). The astronomical calibration of the section allowed us to estimate the astronomical age of the calcareous plankton events and the most prominent abundance fluctuations of several species.

Biostratigraphy and biochronology

Planktonic foraminifera

Preservation is generally good but it slightly decrease in the white limestone layers.

Fifty grams of dry sediments were washed through a 63 µm sieve for the foraminiferal analyses. Quantitative data are based on counting of 300 specimens from the > 125 µm size fraction of the 451 sam-



FO: First Occurrence; **FCO**: First Common Occurrence; **FRO**: First Regular Occurrence; **LO**: Last Occurrence; **PE**: Paracme End

Fig. 3 - Quantitative distribution pattern of some relevant planktonic foraminifera.

ples. The relative abundance of the taxa is expressed as percentage of the total fauna. The abundance fluctuations of the most important taxonomic units, related to the astronomical tuning, are reported in Fig. 3. The qualitative analysis has been performed each meter, on the fractions between 63 and 150 µm and greater than 150 µm. Here below the distribution and taxonomic notes of some relevant species are reported.

Globigerinoides subquadratus Brönnimann (Pl. 2, figs. 20, 21)

Bolli & Saunders (1985) report this taxon as an junior synonym of *Globigerinoides ruber (*d'Orbigny). We consider *G. subquadratus* and *G. ruber* as two different species. The first species is a Miocene taxon and the second species is present in Pliocene sediments only (see also Bossio et al. 1998).

G. subquadratus shows a very scattered distribution from the base of the study section up to 30.3 m (dated at 13.14 Ma) where its first regular occurrence (FRO) is identified. A short paracme interval occurs between 40.56 m and 46.68 m.

Globigerinoides obliquus obliquus (Bolli) (Pl. 2, figs. 18, 19)

This taxon, recorded from the base of the section, has a scattered distribution and low percentages throughout. Only in four levels does it show percentages higher than 10%: at about 10 m (at 13.53 Ma), at about 20 m (at 13.32 Ma), at about 31 m (at 13.12 Ma) and at about 62 m (at 12.5 Ma). The first specimens of *G. obliquus obliquus* are recorded by several authors (e.g. Blow 1969; Salvatorini & Cita 1979; Kennett & Srinivasan 1983; Spezzaferri 1994) from Lower Miocene sediments, but the regular and common distribution pattern is recorded only in the Upper Miocene (Foresi et al. 2002, Foresi et al. in press). The lower Serravallian specimens of *G. obliquus obliquus* differ from the upper Serravallian specimens for the primary aperture and the last chamber which are less compressed.

Globorotalia praemenardii-menardii gr.

We recognized two taxa belonging to this group: *Globorotalia praemenardii praemenardii* Cushman & Stainforth and *Globorotalia* aff. *menardii*. The two taxa have been separated only through the qualitative analysis. This group has a very scattered distribution and percentages lower than 4% (see Foresi et al. 2000 and Foresi et al. in press, for a detailed description of these forms).

The occurrence of *G. praemenardi praemenardi* from the base of the Blue Clay succession possibly corresponds to the FO (at 13.75 Ma) of the species, because it has not been found in the Upper Globigerina Limestone (Giannelli & Salvatorini, 1975), below the Blue Clay. *G.* aff. *menardii* first occurs at 32.5 m (at 13.09 Ma). The two taxa are present up to the top of the section.

Paragloborotalia siakensis (Le Roy) (Pl. 2, figs. 1-12)

Typical forms of *P. siakensis* are commonly associated to juvenile specimens, which show 4-5 chambers in the last whorl, a more narrow umbilicus and a lower aperture. *P. siakensis* is absent in the lower part of the section and the first specimens of the species occur at 9. 92 m; the taxon is then rare and scattered up to 26.42, from where it becomes common (base of the acme interval: AB). Lower and more scattered percentages, and scattered distribution of the taxon are also recorded in the upper part of the section (from 55. 5 m). This interval coincides with the common presence of *P. partimlabiata*. These data suggest that the two species may be vicariant, as in the Tremiti succession (Foresi et al. 2002).

Paragloborotalia partimlabiata (Ruggieri & Sprovieri) (Pl. 2, figs. 13-17)

P. partimlabiata is usually smaller than the other species belonging to the *Paragloborotalia* group. It also differs from the other species for its oblique and curved sutures on the spiral side, and for the size of the last chamber which is 1/3 of the test; additionally, the last chamber is clearly inflated and protru-ding on the umbilical side in axial view.

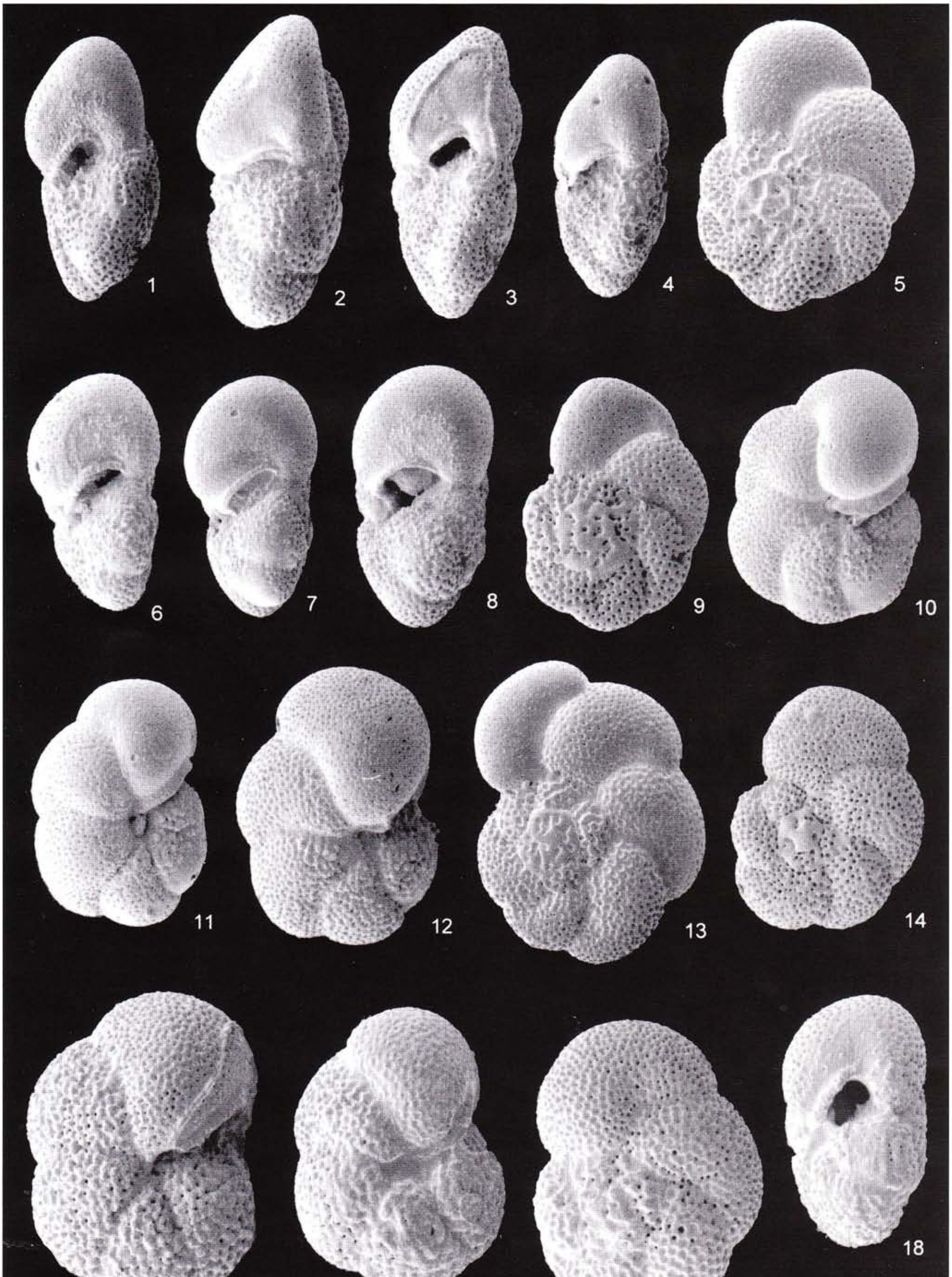
The *P. partimlabiata* FO is recorded in the upper part of the section at 52.82 m (dated at 12.62 Ma) and rapidly increases in abundance (generally >10 %, with a maximum of about 30%).

G. peripheroronda Blow & Banner (Pl. 1, figs 6-8, 11-14)

Globorotalia peripheroronda is present from the base of the section and disappears at 16.97 m, at 13.39

PLATE 1

Fig. 1, 4, 10 - *Globorotalia* cf. *peripheroacuta*, ML-46; Fig. 2-3, 5 - *Globorotalia* cf. *peripheroacuta*, ML-36; Fig. 6 - *Globorotalia peripheroronda*, ML-21; Fig. 7 , 12, 14 - *Globorotalia peripheroronda*, ML-26; Fig. 8, 13 - *Globorotalia peripheroronda*, ML-61; Fig. 9 - *Globorotalia* cf. *peripheroacuta*, ML-26; Fig. 11- *Globorotalia* cf. *peripheroronda*, ML-21; Fig. 15- 18 - *Paragloborotalia mayeri*, ML-590.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100 μm

Ma. Specimens showing the last chamber with a more subacute peripheral margin (*Globorotalia* cf. *peripheroacuta*, Pl. 1, figs 1-5, 9-10) are recorded in association with the typical forms. These forms occur from 1 m below the base of the studied section (in the transition bed between the Upper Globigerina Limestone and Blue Clay Fms.) up to the extinction level of the taxon. They resemble *G. peripheroacuta*, but they do not show all the distinctive characters of the type species (the peripheral margin is not completely acute). Comparison of these forms with specimens of the *Globorotalia fohsi* lineage from the Ceara Rise sequence, shows a strong resemblance with *Globorotalia "peripheroacuta"* of Turco et al. (in press).

Paragloborotalia mayeri (Cushman & Ellisor) (Pl. 1, figs. 15-18).

Bolli & Saunders (1982, 1985) do not distinguish *P. mayeri* from *P. siakensis* and include both species in *P. mayeri*. Nevertheless, the concept of Blow (1969) and Iaccarino (1985), who consider *P. mayeri* and *P. siakensis* as two distinct taxa, is followed here. The specimens of *P. mayeri* have a low trochospiral test, a sligthly lobate and ovate equatorial peripheral margin and a rounded axial margin; the aperture, interiomarginal, extraumbilical-umbilical, is a high arch with a distinct rim; 5-6 subspherical chambers are present in the last whorl; the sutures on the spiral side are oblique and gently curved. In addition, *P. mayeri* differs from *P. siakensis* for the wall texture. Apart from the last two chambers, the wall texture of *P. mayeri* is characterized by euhedral calcite overgrowth, which gives to the wall a granular aspect. A more detailed discussion about the problem *mayeri-siakensis* is given in Bolli & Saunders (1982 and 1985), Iaccarino (1985) and Foresi et al. (in press).

P. mayeri is present only in the uppermost part of the sampled section. Its FO is recorded at 61.55 m, with an age of 12.46 Ma. In the lower part of its range, this species has a discontinuous distribution pattern. Only in the uppermost part of the section its abundance increases, with a maximum of 6,2 %. The FCO of this taxon occurs at 68,29 m (12.34 Ma).

Calcareous nannofossils

Smear slides were prepared from unprocessed sediments following standard techniques. To obtain the distribution patterns of selected calcareous nannofossil taxa, light microscope analyses were performed (transmitted light and crossed nicols) at about 1000X magnification. Abundance data were collected using methodology described by Backman & Shackleton (1983), Rio et al. (1990) and extensively used in Mediterranean and extra-Mediterranean quantitative biostratigraphic studies of Neogene marine records (ODP sequences and land sections; (Raffi & Flores 1995; Raffi et al. 1995; Fornaciari et al. 1996; Backman & Raffi 1997; Di Stefano 1998; Hilgen et al. 2000).

The following counting methods were used:

1) Index species versus a prefixed number of taxonomically related forms;

2) Number of specimens of an index species or genus in a prefixed area of the slide (4.52 mm^2).

Method 1 was adopted to detect abundance patterns of *Sphenolithus heteromorphus* (within 30 to 50 *Sphenolithus*), *Cyclicargolithus floridanus* (within 100 reticulofenestrids), *Reticulofenestra pseudoumbilicus* (within 100 reticulofenestrids), *Calcidiscus premacintyrei* and *C. macintyrei* (within 30 to 50 *Calcidiscus*), *Coccolithus miopelagicus* (within 100 *Coccolithus*), *Helicosphaera walbersdorfensis* (within 100 helicoliths).

Method 2 was adopted to detect the abundance patterns in the genus *Discoaster* and of some selected *Discoaster* species.

Calcareous nannofossils are generally abundant, well diversified and well preserved. Only in some rare samples specimens of *Discoasters* exhibit slight dissolution and/or overgrowth hampering their identification at specific level. Large to medium size placoliths of the genera *Calcidiscus, Coccolithus, Cyclicargolithus, Dicthyococcites* and *Reticulofenestra* are common to abundant in the nannofloras. Helicoliths are generally common and mainly represented by *Helicosphaera carteri, H. walbersdorfensis* and, in the upper part, *H. orientalis*.

Taxonomic concepts of Perch-Nielsen (1985), Theodoridis (1984), and Fornaciari et al. (1996) is followed and the biostratigraphic scheme proposed by Fornaciari et al. (1996) is followed here.

The abundance data of the most common and biostratigraphic relevant species are plotted in Fig. 4. The following bio-events (First Occurrence [FO], First Common Occurrence [FCO], Last Occurrence [LO], Last Common Occurrence [LCO]) recognized in the section are listed below from bottom to top:

LO of *Sphenolithus heteromorphus* (Deflandre);

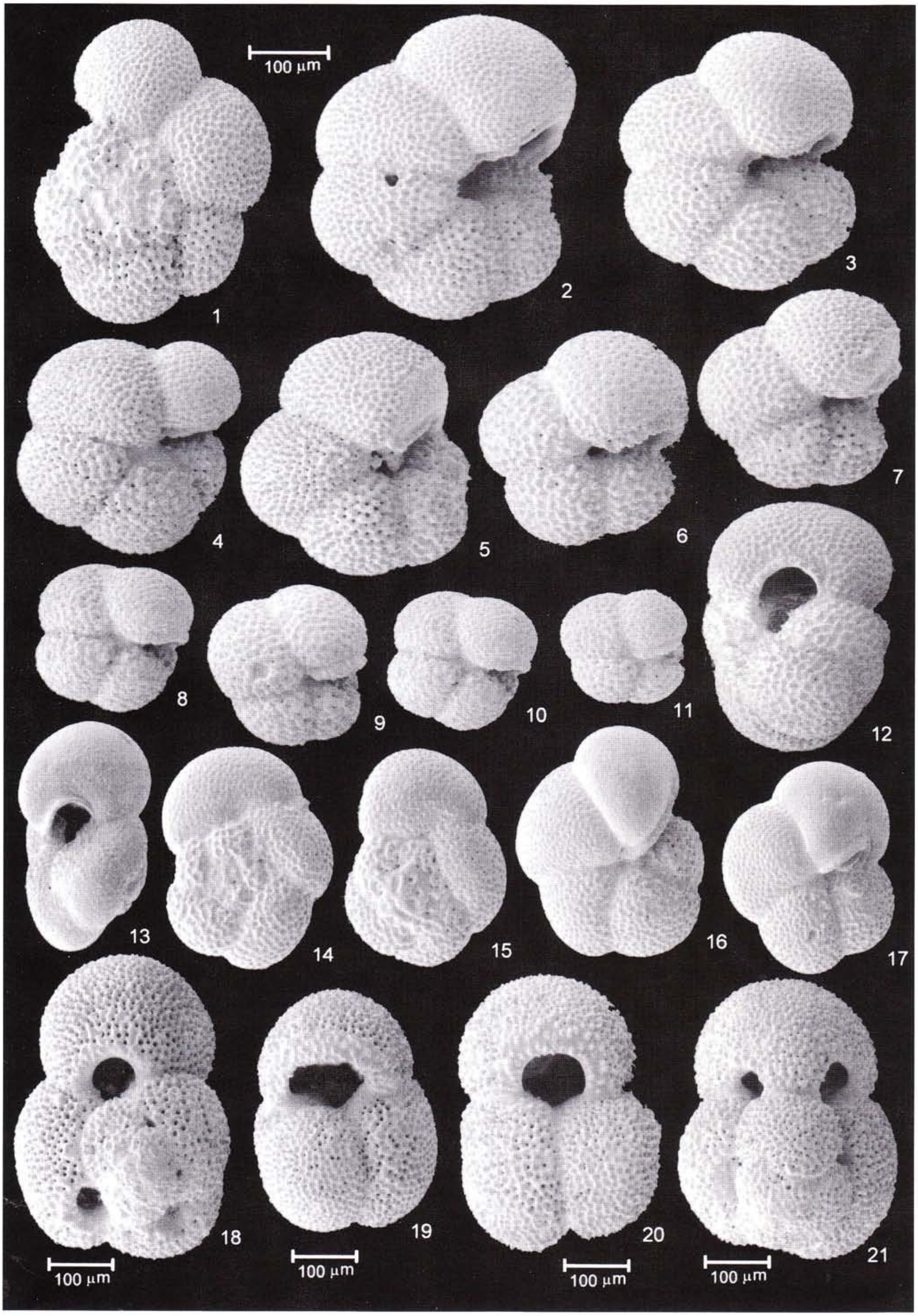
LCO of *Cyclicargolithus floridanus* (Bukry);

FCO of *Reticulofenestra pseudoumbilicus* (Gartner) ≥7 μm;

FO of *Calcidiscus macintyrei* (Loeblich & Tappan);

PLATE 2

Figs. 1-12 - *Paragloborotalia siakensis*, ML-231; Figs. 13, 16-17 - *Paragloborotalia partimlabiata*, ML-545; Fig. 14 -15 - *Paragloborotalia partimlabiata*, ML-535; Fig. 18-19 - *Globigerinoides obliquus obliquus*, ML-131; Fig. 20 -21 - *Globigerinoides subquadratus*, ML-231.


100 µm
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LCO of *Calcidiscus premacintyrei* (Theodoridis) >11 μm

LO *Sphenolithus heteromorphus*

As generally reported in the literature, the LO of *Sphenolithus heteromorphus* can be considered one of the most easily recognisable bio-horizons in the Miocene marine record both in the Mediterranean (Fornaciari et al. 1996) and in the oceans (Olafsson 1991, Raffi et al. 1995; Backman & Raffi 1997). This event was calibrated at 13.523 ± 0.011 Ma in the low-latitude Atlantic ocean, ODP Site 926 (Backman & Raffi 1997) and at 13.57 Ma in the Equatorial Pacific Ocean, ODP Leg 138, (Shackleton et al. 1995). If the re-evaluation of the age of the extinction level of *Discoaster kugleri* in the Ceara Rise sequence reported by Hilgen et al. (2000) can be extended also to the extinction level of *S. heteromorphus*, the age of this event in the Ceara Rise sequence is about 13.57 Ma.

Our data show that the quantitative distribution pattern of *S. heteromorphus* is well defined and agrees with its distribution in different regions (oceanic ODP sequences and Mediterranean land sections). In our plot the uppermost part of its range shows high abundance values just below its final sharp abundance decrease at the top of which a very clear LO bio-horizon can be identified (Fig. 4). The rare specimens of *S. heteromorphus* observed in younger samples together with reworked taxa (*S. distentus* and *S. belemnos*) are considered to be reworked. Our astronomical age for the LO of *S. heteromorphus* at 13.59 Ma is in good agreement with the previous estimates obtained for the same event in the extra-Mediterranean record (Backman & Raffi 1997). Therefore it may be considered virtually synchronous in the Middle Miocene global record.

LCO *Cyclicargolithus floridanus*

. The distribution pattern of this taxon in its final range has been recently observed in low-and mid-latitude oceanic and Mediterranean sediments (Olafsson 1989, 1991; Fornaciari et al. 1990; Fornaciari et al. 1993; Fornaciari et al. 1996; Raffi et al. 1995). The authors point out that the LO of this species varies considerably with latitude; it occurs earlier at low-latitude sites (just after the LO of *S. heteromorphus* and close the *Reticulofenestra pseudoumbilicus* increase in abundance) than in mid-latitudes, where the taxon survived longer. The marked drop in abundance (LCO) is here correlated with its LO at low-latitudes (Olafsson 1991). In the Mediterranean of *C. floridanus* in its final range slightly precedes the *R. pseudoumbilicus increase* (FCO), in agreement with low-latitude data. Above this level the sporadic occurrences are questionable in terms of autocthonous or reworked specimens (Fornaciari et al. 1996). In our samples *C. floridanus* varies in abundance and is continuously present up to 17 m, above the *S. heteromorphus* LO and below the *R. pseudoumbilicus* FCO. Above this level it is very rare and scattered. We identify the LCO of this taxon at 17 m. Its cyclostratigraphically estimated age is 13.39 Ma. Shackleton et al. (1995) dated the *C. floridanus* top-range at 13.19 Ma in the low-latitude equatorial ODP Pacific Leg 138.

FCO *Reticulofenestra pseudoumbilicus* (≥7μm)

We followed the taxonomic concept adopted by Fornaciari et al. (1996) who used the FCO of this taxon as zonal boundary. Our high resolution data point out that *R. pseudoumbilicus* occurs discontinuously, with very low abundance values, from the base of the studied section, and is common and continuously present (FCO) from a level (20.34 m) well above the *S. heteromorphus* LO and slightly above the LCO of *C. floridanus* (Fig. 4). These data agree with previous distribution patterns reported within the Miocene Mediterranean record and confirm that this event is reliable and can be considered an important and well correlatable horizon in this region. Its estimated age in our section is 13.32 Ma. Shackleton et al. (1995) dated the base of the *R. pseudoumbilicus* range at 13.95 Ma in low-latitude equatorial Pacific ODP Leg 138. We could not recognize the entry level of this taxon because it is present from to the basal sample and we can only speculate that its Mediterranean FO cannot be younger than 13.76 Ma, age at which the base of the studied section has been calibrated.

FO *Calcidiscus macintyrei* ≥11 μm

We ascribe to *C. macintyrei* specimens larger than 11 μm following the same taxonomic concept adopted by Backman & Shackleton (1983) and Fornaciari et al. (1990, 1996). According to Raffi et al. (1995), who report very detailed distributional extra Mediterranean patterns of this taxon, the FO of *C. macintyrei* is probably biogeographically controlled and must be considered a poor reliable bio-horizon. In the Mediterranean sediments Fornaciari et al. (1996) recognized this event slightly below the LCO of *C. premacintyrei*. The latter is preferred as a zonal boundary event because *C. macintyrei* is very rare and scattered with respect to the other *Calcidiscus* species in the lower part of its range. Its appearance level, if identified in a closely spaced set of samples, can, however, be used to identify a short interval below the LCO horizon of *C. premacintyrei*. We suggest that, in the Mediterranean, this event can be used to improve the stratigraphic resolution in the topmost part of the MNN6b Subzone of Fornaciari et al. (1996). The time interval covered by the co-occurrence of *C. macintyrei* and *C. premacintyrei* covers three precession cycles both in the Malta and in the well correlatable Tremiti section (Lirer et al. 2002). The cyclostratigraphically estimated age obtained for the FO of *C. macintyrei* in our section is 12.57 Ma. This Mediterranean age cannot

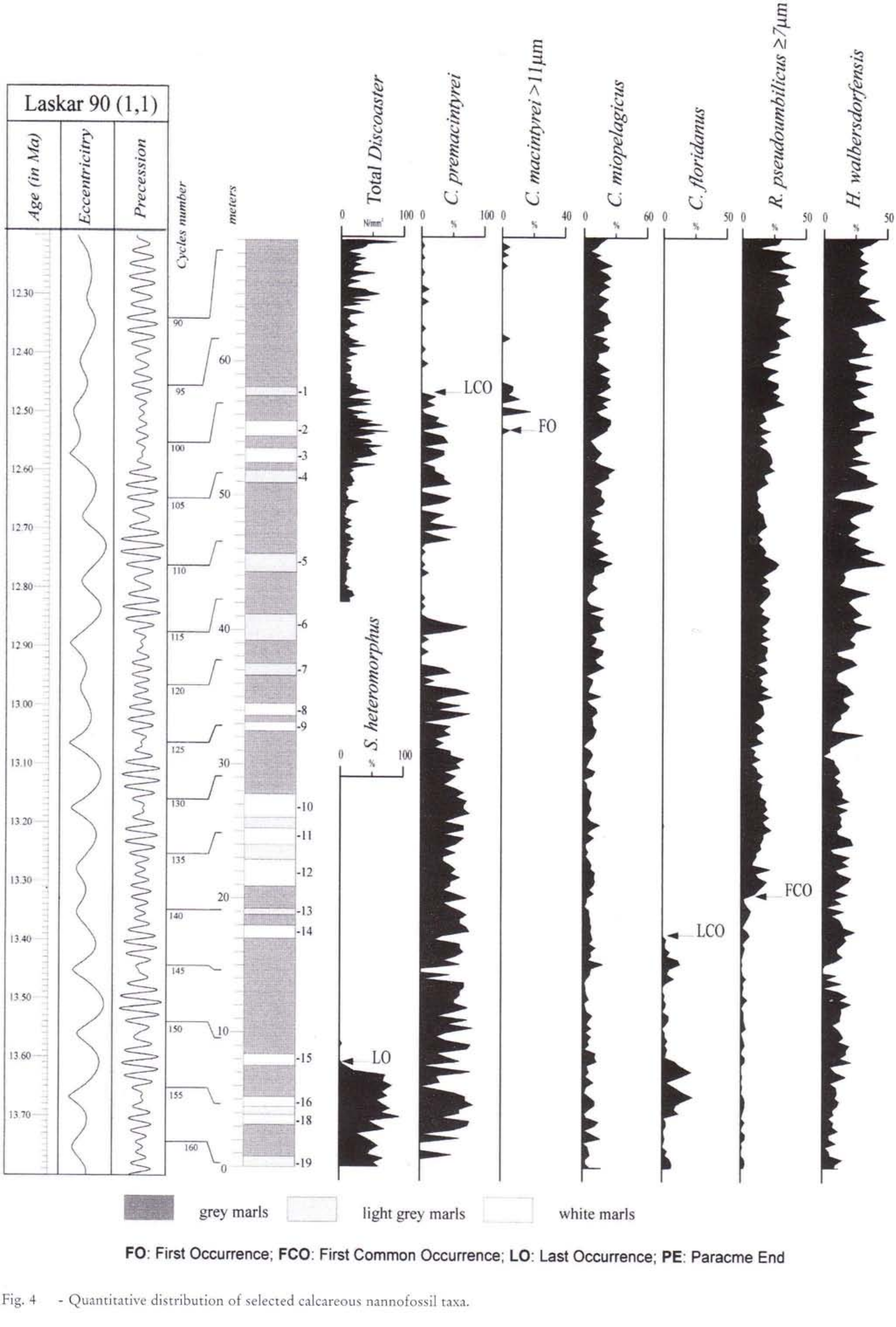

Fig. 4 - Quantitative distribution of selected calcareous nannofossil taxa.

be compared with the age of 12.14 Ma (Shackleton et al. 1995) reported for the *C. macintyrei* appearance level in the low latitude equatorial Pacific ocean and indicate diachroneity for this event.

LCO *Calcidiscus premacintyrei*

The LCO horizon of *C. premacintyrei* was adopted by Fornaciari et al. (1996) in their zonal system to subdivide, in the Early Serravallian of the Mediterranean, a time interval corresponding to NN6-NN7 of Martini (1971) or CN5 of Okada and Bukry (1980). According to Raffi et al. (1995) who reported a very detailed distributional extra-Mediterranean pattern of this taxon, the LCO of *C. premacintyrei*, occurs about 0.3-0.4 My before its last occurrence. Shackleton et al. (1995) dated the *C. premacintyrei* top-range at 12.65 Ma in the low-latitude equatorial pacific ODP Leg 138.

In our section, *C. premacintyrei* is regularly present, with fluctuating abundance values, well above the FCO of *R. pseudoumbilicus*. After an interval of discontinuous and rare occurrence ("paracme"), we identify another short interval where this taxon is common before its definitive decrease in abundance. Above this horizon and up to the top of the section, *C. premacintyrei* occurs, with very low abundance values, only in some samples. It is very difficult to establish, in a dominantly terrigenous sequence, if these are autocthonous or reworked specimens and consequently where to recognize the LO event. Fornaciari et al. (1996) report a similar distribution as a tail of not reworked specimens. Following this interpretation, we consider the highest decrease in abundance of *C. premacintyrei* as its LCO horizon. Its cyclostratigraphically estimated age is 12.51 Ma. The same age was obtained for this bio-horizon in the Miocene section studied in the Tremiti islands (Lirer et al. 2002). The data reported here suggest that this bio-horizon can be considered isochronous in the investigated intervals and very important for correlations in the Mediterranean. No age evaluations for the LCO horizon of *C. premacintyrei* are reported in the literature. Shackleton et al. (1995) dated the top-range horizon of *C. premacintyrei* at 12.65 Ma in the low-latitude ODP Leg 138 (Equatorial Pacific).

Total *Discoaster* abundance.

Discoasterids are rare to common throughout. The total *Discoaster* distribution was estimated only for the middle-upper part of the section (from 42 m above the base), the interval where the occurrence of the first specimens of *Discoaster kugleri* was accurately investigated (Fig. 4). We followed a conservative approach to identify this six rayed asterolith. Specimens having similar but more sculptured central areas were identified as *D.* cf. *kugleri*.

Four discrete intervals of total *Discoaster* abundance can be distinguished as follows: 1) low values occur between 42 and 52 meters above the base of the section; 2) from the top of this segment a sharp, even fluctuating increase in its abundance was recognised up to the LCO horizon of *C. premacintyrei*; 3) above this level its abundance decreases again up to 61 m, where 4) a new increasing trend with large fluctuations up to the top of the section begins.

In the literature *Discoaster* abundance variations recognised in well preserved assemblages have been related to productivity changes (Chepstow-Lusty et al. 1989; Chepstow-Lusty et al. 1992). In particular, in the Pliocene-Miocene record of the Atlantic and Pacific oceans, low *Discoaster* abundance intervals have been related to high productivity (Chepstow-Lusty et al. 1989, 1992; Raffi & Flores 1995). Consequently, the changes in abundance in the considered stratigraphic interval may reflect repeated productivity variations.

The Langhian-Serravallian boundary

The Langhian and Serravallian stages were erected in the same year by Pareto (1865). The reference section for the Langhian was chosen several years later, in the Tertiary Piedmont Basin (BTP), in the Cessole-Bricco della Croce section, near the Village of Cessole, by Cita & Premoli Silva (1960). The *Orbulina universa* FO and *Helicosphaera walbersdorfensis* FCO occur about 10 m below and just above the top of the type section respectively (Fornaciari et al. 1997). In the Serravallian stratotype defined by Vervloet (1966) in the Serravalle Sandstone, the extinction level of *S. heteromorphus* occurs about 10 m above the base of the section, with the *Ciclocargolithus floridanus* LCO and the *Reticulofenestra pseudoumbilicus* (≥7 μm) FCO occurring just above the extinction level of *S. heteromorphus* (Fornaciari et al. 1996). Consequently, Fornaciari et al. (1996) indicated the LO of *S. heteromorphus* as an excellent biostratigraphic marker for world-wide recognition of the Langhian-Serravallian boundary. Our results confirm the fairly synchronous occurrence of the LO of *S. heteromorphus* in the Mediterranean and the Atlantic and Pacific Oceans (Backman & Raffi 1997). Therefore, we suggest that a lithological level near or coincident with this event may be suitable for the definition of the GSSP of the Serravallian chronostratigraphic unit and that the Ras il-Pellegrin section is a good candidate for this definition.

Conclusions

The integrated calcareous nannofossil and planktonic foraminifera biostratigraphic and cyclostratigraphic study of the Ras il-Pellegrin section (Fomm ir-Rih Bay, Malta) allowed us to recognize several bio-events

	Event	Cycle	Position (m)	Age (Ma)
Top of the Section		90	68.8	12.33
Base of the Section		161	0	13.76
Planktonic foraminifera				
Paragloborotalia mayeri	FCO	90	68.29	12.34
Paragloborotalia mayeri	FO	96	61.55	12.47
Paragloborotalia partimlabiata	FO	104	52.82	12.62
Globorotalia aff. *menardii*	FO	127	32.5	13.09
Globigerinoides subquadratus	FRO local	129	30.3	13.14
Paragloborotalia siakensis	PE	133	26.47	13.20
Globorotalia peripheroronda	LO	142/143	16.97	13.39
Paragloborotalia siakensis	FO local	150	9.92	13.53
Globorotalia praem. praemenardii	FO	161	0	13.76
Calcareous nannofossils				
Calcidiscus premacintyrei	LCO	98/99	57.71	12.52
Calcidiscus macintyrei	FO	101	52.66	12.56
Reticulofenestra pseudoumbilicus	FCO	139	20.34	13.33
Cyclicargolithus floridanus	LCO	142/143	17.42	13.39
Sphenolithus heteromorphus	LO	152	7.77	13.59

Tab. 2 - Stratigraphic position and astronomical ages of calcareous plankton events.

important for the early Serravallian stratigraphic interval in the Mediterranean.

The age of the bio-events is provided and reported in Tab. 2, with reference to Sprovieri M. et al. (2002). Quantitative analysis allowed to identify acme and paracme intervals for some of the identified taxa. They may be used to increase the biostratigraphic resolution of this stratigraphic interval in the Mediterranean.

The obtained ages for these Mediterranean bio-events have been compared with the same events from the oceanic record (Shackleton et al. 1995; Backman & Raffi 1997).

We suggest the Ras il-Pellegrin section as potential for the definition of the GSSP of the Serravallian chronostratigraphic unit.

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