GEOLOGICA CARPATHICA, FEBRUARY 2007, 58, 1, 71–87

Sedimentation and tectonics in a steep shallow-marine depositional system: stratigraphic arrangement of the Pliocene-Pleistocene Rometta Succession (NE Sicily, Italy)

AGATA DI STEFANO[1], SERGIO LONGHITANO[2] and ALESSANDRA SMEDILE[1]

[1]University of Catania, Dipartimento di Scienze Geologiche, Corso Italia 55, 95129 Catania, Italy; distefan@unict.it; asmedile@unict.it
[2]University of Basilicata, Dipartimento di Scienze Geologiche, Campus di Macchia Romana, 85100 Potenza, Italy;
longhitano@unibas.it

(Manuscript received January 5, 2006; accepted in revised form June 22, 2006)

Abstract: A 160 m thick Pliocene-Pleistocene sedimentary succession, cropping out in NE Sicily (Rometta Succession), was subdivided into three unconformity-bounded units, overlying deformed bedrock: (i) a Middle Pliocene sandy-marly R_1 unit; (ii) an Upper Pliocene-Lower Pleistocene biocalcarenitic R_2 unit; (iii) a Middle Pleistocene mudstone R_3 unit. The R_2 unit is composed of at least three sub-units, bounded by truncation surfaces, and showing aggradational patterns of strata. Each of these sub-units records a sudden seaward-shifting of the facies tract. A stratigraphic gap of ~870 kyr at the R_1/R_2 boundary, marks an abrupt change from offshore transition to shoreface environments. A second gap of ~260 kyr at the R_2/R_3 boundary corresponds to a sudden deepening of the environments, from shoreface to fully offshore. The Rometta units represent three incomplete, tectonically-enhanced depositional sequences. The R_1 unit is a HST of a lower sequence, marked at the top by a slightly angular unconformity. The R_2 unit is a HST of a younger depositional sequence, aggrading above a ravinement surface. During these relative sea level still-stands, the local tectonic uplift combined with the high-frequency eustatic oscillations, produced three forward-stepping sets of minor sequences within the R_2 HST, simulating the typical FSST stratigraphic arrangement. The top of the R_2 is bounded by an erosive surface, representing the transgressive surface of the subsequent R_3 depositional sequence. The R_3 unit is a late TST+HST of a Pliocene-Pleistocene sequence, the LST of which probably occurs basinward. The foresetted R_2 biocalcarenites are unimodal in their paleocurrents. This feature resulted from shore-directed wind stress, applied to the water surface and reflected by a steep paleocoast, generating basinward-directed bottom currents.

Key words: Pliocene–Pleistocene, NE Sicily, sedimentology, biostratigraphy and paleobathymetry, tectonics and sedimentation.

Introduction and objectives

In NE Sicily, the Peloritani Mts represent the southernmost flank of the Calabria-Peloritani Arc (Amodio-Morelli et al. 1976). In this area, the "Kabilo-Calabride" crystalline units crop out widely (Lentini et al. 1994 and references therein). They are covered by several siliciclastic sequences, Late Eocene and younger in age, each indicating a stage in the polyphasic tectonic evolution of the area (Lentini et al. 1995, 2000 and references therein).

Several authors have recently paid particular attention to the Pliocene-Pleistocene successions (Di Stefano & Lentini 1995; Lentini et al. 2000). In fact, during this time interval, the study area underwent important geodynamic events, such as the opening of the Tyrrhenian Basin (Finetti & Del Ben 1996). Thus the Plio-Pleistocene sediments were deposited in a complex geological framework, resulting from the combination of active tectonics and eustacy.

The results presented in this paper derive from a detailed stratigraphic analysis of these Plio-Pleistocene deposits, cropping out in the key area of Rometta, combining facies characteristics, biostratigraphic and paleobathymetric data, and sequence stratigraphic interpretation.

Particular attention was devoted to the analysis of a Late Pliocene-Early Pleistocene biocalcarenitic succession, very well exposed in the neighbourhood of the selected area (Fig. 1).

The Rometta biocalcarenites show some similarities with other successions described in the Mediterranean area (Barrier 1987; Colella & D'Alessandro 1988; Colella 1995; Colella & Vitale 1998; Tropeano & Sabato 2000; Pomar & Tropeano 2001; Roveri & Taviani 2003). These successions are generally interpreted as the response to particular warm/arid climatic conditions, subsequently controlled by sea-level fluctuations, tectonic activity and, on a shorter time scale, to different hydrodynamic factors as tides, waves, currents or gravity.

The sedimentary features of the Rometta biocalcarenites allow us to propose a depositional model, strictly linked to the general geological framework.

Geological setting and stratigraphic framework of the Rometta Succession

The Plio-Pleistocene deposits of the Peloritani Mts, were illustrated in detail, from a stratigraphic and paleontological point of view, by Seguenza (1873–1877) and later by Ogniben (1960), who placed them into the so-called "Neoautoctono" Complex.

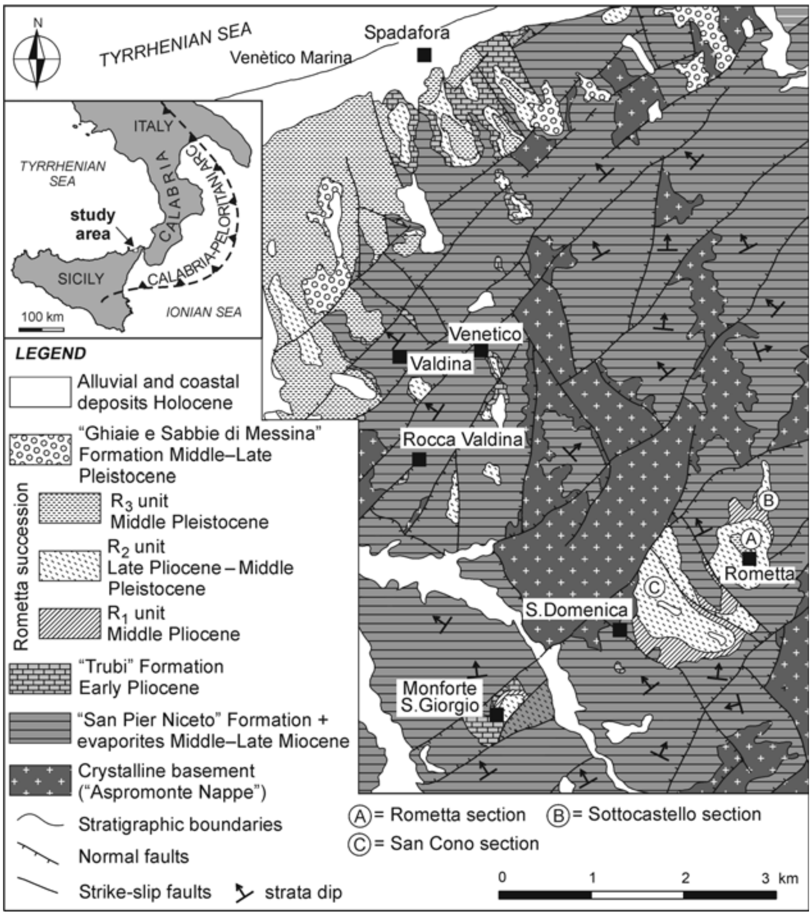


Fig. 1. Schematic geological map of the study area.

The main tectonic features of the area are represented by a NE-SW oriented normal fault system, which controls the present-day setting of this sector of the Sicilian Tyrrhenian coast (Guarnieri & Carbone 2003).

The sedimentary succession cropping out in the Rometta area, previously described by Giunta Ilaqua (1956) and Ruggieri et al. (1979), has been more recently considered as a Lower Pliocene-Lower Pleistocene succession (Violanti et al. 1987), consisting of Lower Pliocene whitish limestones (Trubi Formation), Middle Pliocene sandy marls, Upper Pliocene-Lower Pleistocene sands and biocalcarenites and Lower Pleistocene (Sicilian) marly clays.

Di Stefano & Lentini (1995) and Lentini et al. (2000) consider these sediments as deposited within a tectonically active geological context, in connection with the evolution of the southern margin of the Tyrrhenian Basin. These authors subdivided the succession into four unconformity bounded stratigraphic units, ranging in age from Early Pliocene to Middle Pleistocene. The lowermost unit, corresponds to the Early Pliocene Trubi Formation (Auct.), widespread in Sicily (Ogniben 1960). The subsequent unit (R_1 in Fig. 1) is made up of Middle Pliocene marls; it is followed by bioclastic sands and calcarenites (R_2 in Fig. 1), Late Pliocene to Early Pleistocene in age; the upper unit (R_3 in Fig. 1) is mainly represented by blue marly clays, Middle Pleistocene in age.

In the Rometta area, the Pliocene-Pleistocene sedimentary succession is mainly represented by the units R_1–R_3, and has a total thickness of 160 m. It unconformably overlies a substrate, which consists of folded crystalline rocks (Aspromonte Nappe), Middle-Upper Miocene siliciclastic rocks of the San Pier Niceto Formation (Auct.), and Messinian evaporites (Fig. 2).

Until now, the relationships among the different Plio-Pleistocene lithological units was not clarified and there was no detailed description of the different facies.

Methods

The stratigraphic framework of the Rometta Succession is based on data collected over 290 m of sedimentary logging and sampling and on the detailed mapping of the units across the studied area.

The logged sections (Sottocastello, Rometta and San Cono sections), which embrace the whole Pliocene-Pleistocene NE Sicily succession except for the Trubi Formation, are shown in Fig. 1 and summarized in Fig. 3.

A detailed facies analysis was carried out to detect the main sedimentary charac-

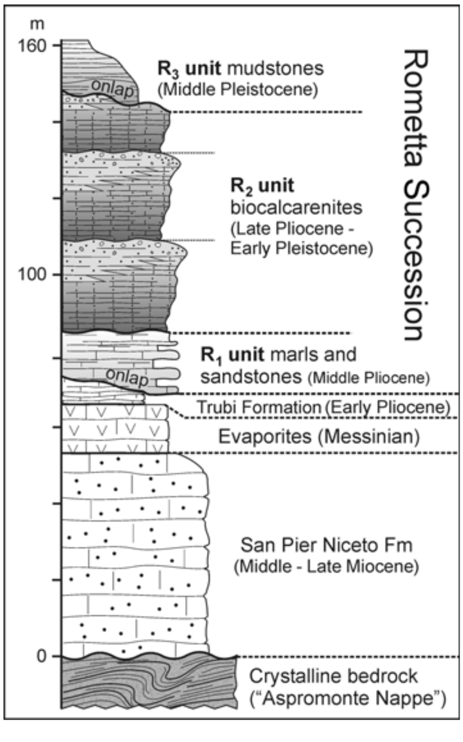


Fig. 2. Stratigraphic column of the lithological units cropping out around the study area. The R_1, R_2 and R_3 units form the Rometta Succession.

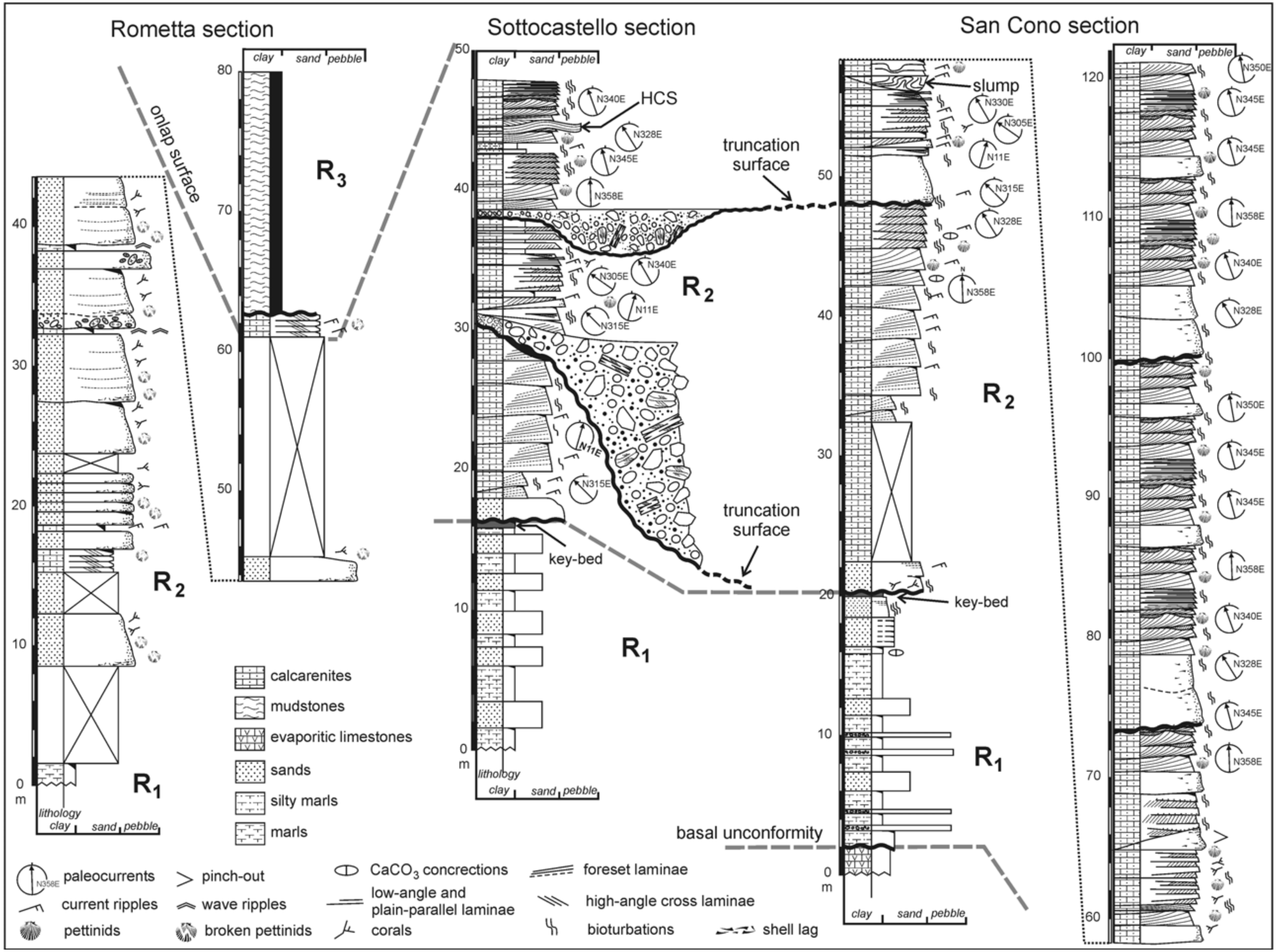


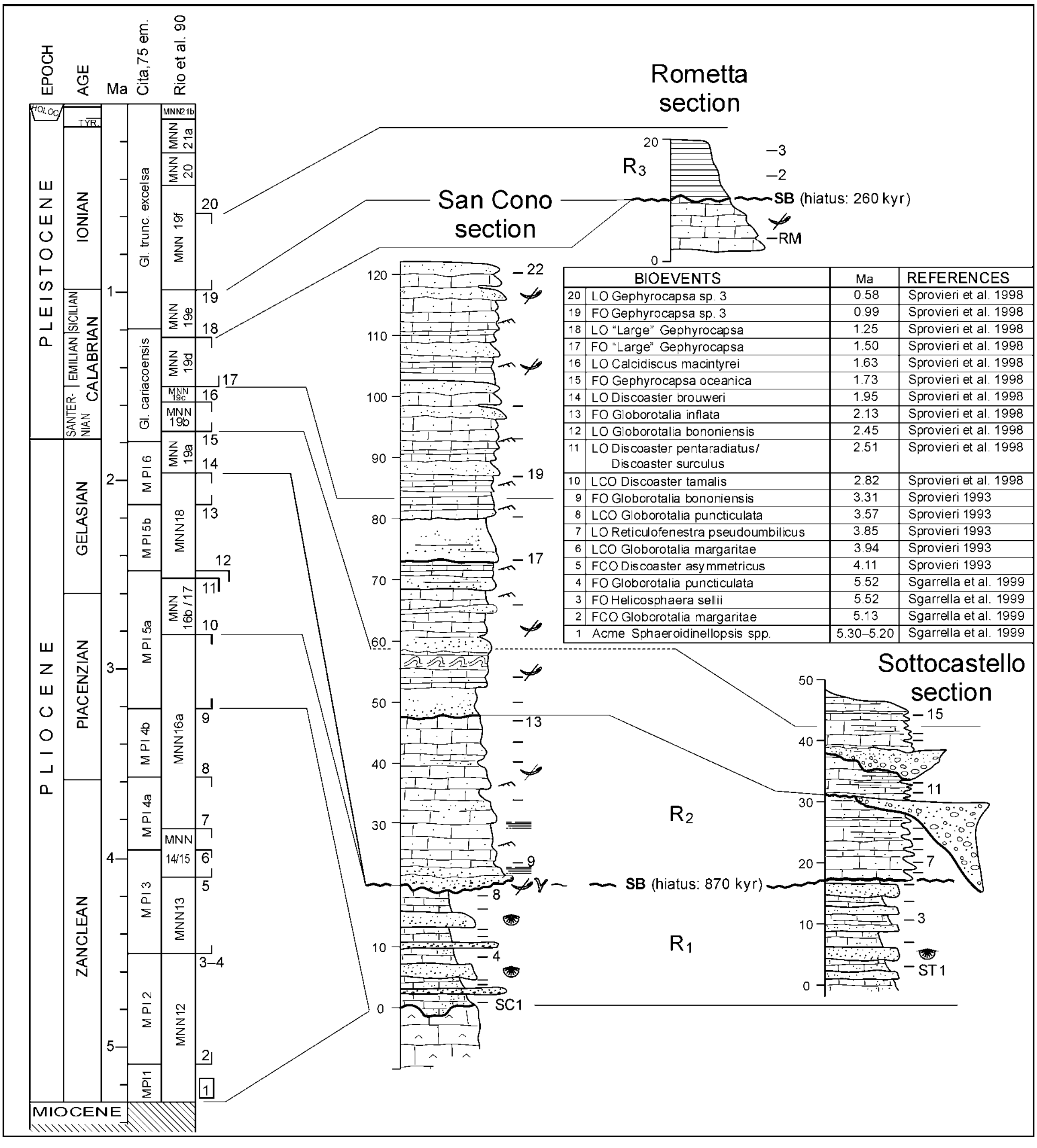
Fig. 3. Sedimentological sections measured for the Rometta area. See Fig. 1 for locations.

ters of each sequence, their vertical and lateral distribution and the depositional environments. Description of the textural and grain size features, sedimentary structures, paleocurrents and microfossil associations were obtained.

The biostratigraphic analysis is based on the study of planktonic foraminifers and calcareous nannofossils. Smear slides for nannofossil analysis were prepared following standard methodology. When possible, a quantitative analysis was carried out on selected species of the nannoplankton assemblage, in order to record the position of useful bio-horizons.

Samples for foraminiferal analysis were washed through sieves with mesh diameters of 63 and 125 μm. The > 125 μm fraction was examined for its planktonic and benthic foraminiferal content. Planktonic foraminifers were analysed qualitatively, whereas benthic foraminifers were assessed quantitatively to reconstruct the paleobathymetry of the study succession.

For this purpose, where possible, at least 200 specimens were counted in each sample. The relative frequencies of individual species were calculated in percent of the total benthic foraminiferal fauna. Paleobathymetry was estimated



	BIOEVENTS	Ma	REFERENCES
20	LO Gephyrocapsa sp. 3	0.58	Sprovieri et al. 1998
19	FO Gephyrocapsa sp. 3	0.99	Sprovieri et al. 1998
18	LO "Large" Gephyrocapsa	1.25	Sprovieri et al. 1998
17	FO "Large" Gephyrocapsa	1.50	Sprovieri et al. 1998
16	LO Calcidiscus macintyrei	1.63	Sprovieri et al. 1998
15	FO Gephyrocapsa oceanica	1.73	Sprovieri et al. 1998
14	LO Discoaster brouweri	1.95	Sprovieri et al. 1998
13	FO Globorotalia inflata	2.13	Sprovieri et al. 1998
12	LO Globorotalia bononiensis	2.45	Sprovieri et al. 1998
11	LO Discoaster pentaradiatus/ Discoaster surculus	2.51	Sprovieri et al. 1998
10	LCO Discoaster tamalis	2.82	Sprovieri et al. 1998
9	FO Globorotalia bononiensis	3.31	Sprovieri 1993
8	LCO Globorotalia puncticulata	3.57	Sprovieri 1993
7	LO Reticulofenestra pseudoumbilicus	3.85	Sprovieri 1993
6	LCO Globorotalia margaritae	3.94	Sprovieri 1993
5	FCO Discoaster asymmetricus	4.11	Sprovieri 1993
4	FO Globorotalia puncticulata	5.52	Sgarrella et al. 1999
3	FO Helicosphaera sellii	5.52	Sgarrella et al. 1999
2	FCO Globorotalia margaritae	5.13	Sgarrella et al. 1999
1	Acme Sphaeroidinellopsis spp.	5.30–5.20	Sgarrella et al. 1999

Fig. 4. Bio- and chronostratigraphic correlations of the studied sections based on planktonic foramniferal and calcareous nannofossil analysis. In the table at the right side the recognized bioevents and their related absolute ages are listed.

on the basis of benthic foraminiferal characteristics taking care to identify the displaced or reworked fauna often present in the sands and calcarenite samples. The terminology adopted for the bathymetrical zonation is *sensu* Perès & Picard (1964), simplified for the neritic and epibathyal zones by Sgarrella & Moncharmont Zei (1993).

In our study, we adopted the nannofossil zonal scheme of Rio et al. (1990) and the planktonic foraminiferal scheme of Cita (1975), emended by Sprovieri (1992) (Fig. 4). We followed the chronostratigraphic framework proposed by Cita et al. (1996) for the Pliocene, and the one proposed by the "Italian Commission on Stratigraphy" for the Early-Middle Pleistocene (Van Couvering 1997).

A total of 40 samples were collected for the micropaleontological study, located along the sections as indicated in Fig. 4.

Micropaleontology and sedimentology of the study sections

Biostratigraphy and paleobathymetry

The sandy marls of the R_1 unit, outcropping at the base of both the Sottocastello and the San Cono sections, yield abundant, well preserved planktonic foraminifers referable to the MPl5a Biozone, Middle Pliocene in age (Table1). Excellent nannofossil assemblages of the MNN16a Biozone confirm this assumption.

For micropaleontological purpose, the Sottocastello section provides the most favourable lithologies for the lowermost part of the R_2 unit. The microfaunal content has been attributed to the Upper Pliocene MPl6 Biozone. The topmost sample of the Sottocastello section yields *Neogloboquadrina pachyderma* (sx) and *Globigerina cariacoensis*, this last species marking the base of the homonymous biozone and the Pliocene/Pleistocene boundary. The nannofossil assemblage is referable to the Upper Pliocene MNN19a Biozone. The finding of *Gephyrocapsa oceanica* s.l. (*sensu* Rio et al. 1990) in the highest sample, indicates that the top of the section may be attributed to the Early Pleistocene MNN19b Biozone, thus confirming the foraminiferal data.

Thin sandy layers in the middle part of the San Cono section are clearly referable to the Early Pleistocene (Santernian) (MNN19b/c Biozones) due to the presence of *Gephyrocapsa oceanica* s.l.

Samples of the topmost part of the section have been attributed to the MNN19d Biozone, characterized by the presence of *Gephyrocapsa* "large" (*sensu* Rio et al. 1990), indicating an Early Pleistocene (Emilian) age. The planktonic foraminiferal content in this section is not indicative.

The nannofossil content of the R_3 unit is characterized by the occurrence of *Gephyrocapsa* sp. 3 (Rio et al. 1990), which defines the Middle Pleistocene MNN19f Biozone. The foraminiferal assemblage is typical for a Pleistocene age (*G. truncatulinoides excelsa* Biozone), but does not add further constraints to the age defined on the basis of the nannofossils.

The biostratigraphic analysis allowed us to detect two significant stratigraphic gaps within the studied successions. Their temporal duration is inferred on the basis of the age assigned to the recognized bioevents (Fig. 4). The first gap is recorded at the R_1/R_2 boundary and is constrained by the last common occurrence of *Discoaster tamalis* (2.82 Ma; Sprovieri et al. 1998) and the last occurrence of *Discoaster brouweri* (1.95 Ma; Sprovieri et al. 1998), thus its minimum value is 870 ka. The second gap, at the R_2/R_3 boundary, is estimated to span a minimum of 260 kyr, which corresponds to the duration of MNN19e Biozone.

The results of the quantitative study on benthic foraminifers are reported in Fig. 5 and Table 2.

The benthic content of the R_1 unit is characterized by consistent percentages of *Cibicides lobatulus, C. refulgens, Asterigerinata planorbis*, *Elphidium* spp., *Hanzawaia rhodiensis* and *Angulogerina angulosa* (Fig. 5, samples SC3 and SC8) which define an upper circa-littoral environment (inferred paleobathymetry 50–100 m; Table 2). The presence of specimens indicative of a much deeper environment, such as *Planulina ariminensis*, *Cassidulina carinata*, *Oridorsalis umbonatus*, *Cibicidoides kullembergi*, is recorded within almost all the examined samples. Such species may derive from the erosion of the Trubi Formation, for which an epibathyal environment has been inferred (Violanti et al. 1987).

The benthic association of the R_2 unit differs from the previously described for the lower abundance and specific diversity, and for the worse degree of preservation. Shallow water species such as *Elphidium crispum* and *Ammonia* spp. defines an infra-littoral environment (inferred paleobathymetry 0–50 m; Table 2) (Fig. 5, samples SC9 and SC22). The benthic assemblages of the R_2 unit at Sottocastello (Fig. 5, samples ST11 and ST15) suggest a slightly deeper environment, due to the scarcity of the *Ammonia* group.

The benthic foraminifers of the R_3 unit is composed of common *Cassidulina carinata*, *C. crassa* and *Globocassidulina subglobosa* and subordinate *Melonis* spp., *Uvigerina peregrina* and *Sphaeroidina bulloides* (Fig. 5, sample RM3). Sporadic specimens of *Planulina ariminensis*, *Hoeglundina elegans* and *Hyalinea baltica* are also recorded. This assemblage defines a lower circa-littoral–upper epibathyal environment (Table 2). According to Sgarrella & Moncharmont Zei (1993) such an association, with abundant *Cassidulina* spp. and *Globocassidulina subglobosa* is referable to a depth interval between 120 and 350 m. Shallow-water forms are considered to be displaced from the older substratum or from coeval marginal areas.

Sedimentology of the Rometta Succession

The facies association was subdivided into seven sedimentary types (Table 3), characterized by different lateral/vertical distributions.

The R_1 unit

The Middle Pliocene R_1 unit, up to 20 m thick, consists of alternating grey silty marls and sandstones (see Sot-

Table 1: List of planktonic foraminifers and calcareous nannofossils identified in the Plio-Pleistocene units of the Rometta Succession. Biostratigraphic and chronostratigraphic attribution.

Unit	Planktonic Foraminifera	Biozone (Cita 1975 em.)	Calcareous Nannofossils	Biozone (Rio et al. 1990)	Age
R_1	*Globorotalia bononiensis* *G. crassaformis* *Globigerina bulloides* *G. falconensis* *G. foliata* *Globigerinoides gomitulus* *G. elongatus* *G. ruber* *Globigerinita glutinata* *Neogloboquadrina pachyderma* (dx)	MPl 5a	*Helicosphaera carteri* *H. sellii* *Calcidiscus leptoporus* *C. macintyrei* *Discoaster asymmetricus* *D. brouweri* *D. pentaradiatus* *D. surculus* *D. tamalis* *D. variabilis* *Pseudoemiliania lacunosa*	MNN16a	MIDDLE PLIOCENE
	LOWER PART *Globigerina bulloides* *G. falconensis* *Turborotalia quinqueloba* *Globorotalia inflata* *Sphaeroidinella dehiscens* *Neogloboquadrina pachyderma* (dx) *Globigerinoides conglobatus* *G. elongatus* *G. gomitulus* *G. ruber* *G. trilobus*	MPl 6	LOWER PART *Helicosphaera carteri* *H. sellii* *Pseudoemiliania lacunosa* *Calcidiscus leptoporus* *C. macintyrei* *Dictyococcites* spp. *Reticulofenestra* spp. *Gephyrocapsa* "small" (*sensu* Rio et al. 1990)	MNN19a	LATE PLIOCENE I I I I I I I I I I
R_2	INTERMEDIATE and UPPER PART *Globigerina cariacoensis* *Globorotalia inflata* *Globigerina bulloides* *Globigerinoides conglobatus* *G. elongatus* *G. gomitulus* *G. ruber* *Neogloboquadrina pachyderma* (sx)	*G. cariacoensis*	INTERMEDIATE PART *Helicosphaera carteri* *H. sellii* *Pseudoemiliania lacunosa* *Calcidiscus leptoporus* *Gephyrocapsa* "small" *Gephyrocapsa oceanica* s.l. (*sensu* Rio et al. 1990)	MNN19b/c	EARLY PLEISTOCENE (Santernian) I I I I I
			UPPER PART *Helicosphaera carteri* *H. sellii* *Pseudoemiliania lacunosa* *Calcidiscus leptoporus* *Gephyrocapsa* "small" (*Gephyrocapsa oceanica* s.l. *Gephyrocapsa* "large" (*sensu* Rio et al. 1990)	MNN19d	EARLY PLEISTOCENE (Emilian)
R_3	*Globorotalia inflata* *Globigerina cariacoensis* *G. calabra* *G. bulloides* *Globigerinoides tenellus* *G. ruber* *G. quadrilobatus* *Globigerinita quinqueloba* *Negloboquadrina pachyderma* (sx)	*G. truncat. excelsa*	*Helicosphaera carteri* *Pseudoemiliania lacunosa* *Gephyrocapsa* "small" *Gephyrocapsa* sp. 3 (Rio et al. 1990) *Calcidiscus leptoporus* *Gephyrocapsa oceanica* s.l.	MNN19f	MIDDLE PLEISTOCENE

tocastello section). It is bounded at the base by an erosional unconformity, cutting the bedrock down to the Messinian evaporites (Fig. 6A).

The R_1 unit crops out N of Rometta (Sottocastello section) and E of Pizzo Motta area (San Cono section).

The sediments consist of fine- to medium-grained sand beds interbedded with massive, bioturbated and sparsely fossiliferous silty clays (facies R1a, see Fig. 6B). Sand beds are characterized by a gently undulating low-angle, current ripples cross-lamination. They are up to 30–40 cm thick, have sharp bases and may pass upward into silty to very fine-grained silty sands.

The top of the unit is characterized by a 20–30 cm thick key bed (Fig. 6C) of massive reddish silts, which can be traced through all the studied localities.

This unit is interpreted as storm-dominated offshore sediments deposited below the storm wave base in an open marine setting. The claystones represent the distal deposi-

Table 2: Depth-ranges of the main benthic foraminifers identified in the Plio-Pleistocene units of the Rometta Succession and inferred paleobathymetry for each unit.

Unit	Benthic Foraminifera	Depth Range	References	Inferred Paleobathymetry
R_1	*Cibicides lobatulus* *Cibicides refulgens*	infra-littoral – lower circa-littoral (0–200 m)	Parker 1958 Sgarrella & Moncharmont Zei 1993	upper circa-littoral (50–100 m)
	Asterigerinata planorbis	infra-littoral – upper circa-littoral (0–100 m)	Murray 1991	
	Elphidium crispum	infra-littoral – upper circa-littoral (0–90 m)	Sgarrella & Moncharmont Zei 1993	
	Elphidium macellum	infra-littoral – upper circa-littoral (0–100 m)	Sgarrella & Moncharmont Zei 1993	
	Hanzawaia rhodiensis	infra-littoral – upper circa-littoral (0–100 m)	Jorissen 1987 Sgarrella & Moncharmont Zei 1993	
	Angulogerina angulosa	infra-littoral – bathyal (common at 20–120 m)	Sgarrella & Moncharmont Zei 1993	
R_2	*Ammonia* spp.	infra-littoral (0–50 m)	Murray 1991	infra-littoral – upper circa-littoral (0–50 m)
	Elphidium crispum	infra-littoral – upper circa-littoral (0–90 m)	Sgarrella & Moncharmont Zei 1993	
	Cibicides lobatulus	infra-littoral – upper circa-littoral (0–100 m)	Sgarrella & Moncharmont Zei 1993	
	Asterigerinata planorbis	infra-littoral – upper circa-littoral (0–100 m)	Murray 1991	
	discorbids	infra-littoral – upper circa-littoral (0–100 m)	Murray 1991	
R_3	*Cassidulina carinata*	upper circa-littoral – bathyal (optimum at 70–700 m)	Sgarrella & Moncharmont Zei 1993	lower circa-littoral – upper epibathyal (120–350m)
	Cassidulina crassa	circa-littoral – bathyal (optimum at 120–650 m)	Sgarrella & Moncharmont Zei 1993	
	Globocassidulina subglobosa	upper circa-littoral – bathyal	Sgarrella & Moncharmont Zei 1993	
	Melonis barleeanum	circa-littoral – bathyal (abundant at 200–600 m)	Wright 1978	

tion of suspended fines, while the planar- and rippled-laminated sandy horizons correspond to the record of frequent storm-fair weather sequences described in offshore environments by Johnson & Baldwin (1986).

The R_2 unit

The Upper Pliocene-Lower Pleistocene R_2 unit, from 30 to 120 m thick (see San Cono, Sottocastello and Rometta sections in Figs. 3 and 4), represents the main volume of the studied succession. In the Rometta area this unit shows its maximum thickness and overlies the R_1 unit and the oldest substratum above a sligthly angular unconformity. In outcrop, the unit dips at 10º–20º toward the NNE.

Several facies have been distinguished on the basis of sedimentological characteristics.

The facies R2a consists of siliciclastic normal graded, poorly sorted and matrix supported granules, organized into 1–2 m thick tabular beds, related to massive grain-flows deposits. This facies, cropping out mainly in the southernmost zone of the study area, occurs alternating with the other facies along the stratigraphic succession (Sottocastello section, Fig. 6D,E).

The facies R2b is the most common and was subdivided into four subfacies ($R2b_{1-4}$). Cross-laminated (current ripples) and cross-stratified (dunes) biocalcarenites form the subfacies $R2b_1$ and $R2b_2$, respectively (Fig. 6E,F). The dunes are sharp-based and composed of stacked tabular cross-sets up to 1 m thick, with foresets inclined up to 30º and dipping towards N10–20 and N340–360. Upper phase plane beds of laminated granules and pebbles form the subfacies $R2b_3$, interbedded with subfacies $R2b_1$ and $R2b_2$ in the northern area (see Sottocastello section), and with facies R2a in the southern area (San Cono section). Locally, isotropic HCS (Hummocky Cross-Stratification *sensu* Midtgaard 1996) of bioclastic sands and granules (subfacies $R2b_4$) occur with crests parallel to the paleo-shoreline (Sottocastello section, Fig. 7A). In the down-current flank of the HCS, scour-and-fill backset cross-laminae occur (Fig. 8A). The facies R2c is represented by slump deposits, 1.5 m thick and 10–15 m wide, occurring SW of Rometta within the facies R2b deposits; this facies is made up of deformed laminae of bioclastic sands and granules showing a direction of gravitative translation toward NNE, obtained from the axis inclination of the crests (Fig. 7B).

The facies R2d, consisting of 10–12 m thick debris-flow channel fills comprised within the subfacies $R2b_2$ and $R2b_3$, occurs in the Sottocastello area. Such deposits show a concave/planar geometry, and are made of chaotic and matrix-supported bioclastic cobbles and boulders, massive and poorly sorted. Each block contains traces of cross-lamination, indicating a provenance from the R2b deposits (Fig. 8B). The channel axes have a NNE-orientation (Fig. 8C) and are base-marked by erosional surfaces that truncate the underlying facies.

Table 3: Sedimentary facies association of the Rometta Succession. R_1, R_2, R_3 are the recognized unconformity bounded units.

Unit	Facies	Sub-facies	Lithology	Sedimentary structures and bioturbation	Fossils	Environments and processes	Paleodepth
R_1	R1a	–	Marls, silts and fine- to medium-grained sandstones	Plain-parallel and rippled lamination. Vertical burrows	Brachiopods	Offshore transition sediments and lag of condensed deposits	Circa-littoral (50–100 m)
R_2	R2a	–	Normal-graded siliciclastic sandstones.	Absent.	Absent.	Grain-flow deposits shed from a cliffed lateral margin.	Infra-littoral (0–50 m)
	R2b	$R2b_1$	Bioclastic medium-coarse sands, granules and subordinate pebbles.	Small- to medium-scale tangential-based cross-sets (0.2 to 1 m thick). Frequent bioturbation.	Pectinids, cardids, venerids, gastropods.	Unimodal, NNE(offshore)-directed, tractive currents flowing along the inner- to outer-ramp (lower shoreface).	
		$R2b_2$		Upper phase planar sets.			
		$R2b_3$		Isotropic hummocky (HSC) cross-stratification.	Absent.	Lower shoreface, high-energy 'resonant' storm waves.	
		$R2b_4$		Set of deformed laminae (2–3 m thick).			
	R2c	–	Bioclastic sands and granules.		Absent.	Slump deposits moving along a steep paleobottom.	
	R2d	–	Chaotic, matrix-supported bioclastic cobbles and boulders.	Concave/planar bodies.	Fossils in fragments.	Channel fill deposits NNE-oriented.	
	R2e	$R2e_1$	Normal-graded bioclastic coarse sands and granules, with scattered pebbles and cobbles of intrusive rocks.	Absent.	Pectinids, cardids, venerids, gastropods, corals.	Proximal grain-flow deposits.	
		$R2e_2$	Medium-fine bioclastic sands.	Small-scale symmetrical cross-sets (2–10 cm thick).		Beachface wave-reworked deposits.	
R_3	R3a	–	Brown and grey mudstones.	Absent.	Absent.	Open offshore.	Epibathyal (120–350 m)

At the south-western extremity of Rometta village (Rometta section), the facies R2b merges landwards into normal-graded, up to 4 m thick bioclastic grain-flow deposits, containing intrusive-rock cobbles and fossil fragments (facies $R2e_1$, Fig. 8D); these beds alternate with thin wave-rippled beds (facies $R2e_2$, Fig. 8E). The paleocurrent measurements develop towards the NE. These facies correlate basinwards with the facies R2d, following a basal truncation surface.

The facies association of the R_2 unit describes a facies tract belonging to a ramp-type shelf, where a beachface (facies $R2e_1$ and $R2e_2$) rapidly passes into a lower shoreface, where sedimentation takes place below the fair-weather wave base. In this setting, storm-generated HCS and frequent gravitative debris- and grain-flow occur.

The R_3 unit

The Middle Pleistocene R_3 unit forms the relief of the highest Rometta Hills (up to 563 m a.s.l.) and represents part of the town's substrate. The unit consists of 15–20 m of brown and grey mudstones, and onlaps onto the R_2 unit, above an erosive surface. The rare outcrops of this unit and the intense vegetation cover do not allow its facies description in detail (see Rometta section in Fig. 3).

These deposits are referable to an open offshore environment.

Depositional architecture and sequence stratigraphic interpretation

The surfaces bounding the R_2 unit are two unconformities, marking abrupt changes in the sedimentary facies and in the micropaleontological content.

The first lower slightly angular unconformity (inclined 2°–4°), separates the lower unit (R_1) from the intermediate unit (R_2), recording a stratigraphic gap quantified into at least 870 kyr. The top of the R_1 unit is marked by a bed of reddish sandstone, which is abruptly truncated by the first unconformity.

The upper unconformity separates the intermediate unit R_2 from the uppermost unit R_3, and marks a gap of at least 260 kyr; above this irregular surface, the offshore mudstones of the upper R_3 unit develop.

The R_2 biocalcarenitic unit is composed of a set of at least three high-frequency sequences, characterized by identical facies tracts and bounded by truncation boundaries. Along these surfaces, a basinward shifting of the facies is evident.

Each high-frequency sequence shows an aggradational-to-progradational type architecture and indicates that the sedimentation developed during a relative rise and still-stand of the sea level. The occurrence of erosional surfaces of marine regression bounding each high-frequency sequence indicate a relative sea-level fall.

Therefore, the stratigraphic arrangement of the composed R_2 unit may suggest that the sedimentation occurred during a falling stage of the relative sea level, but

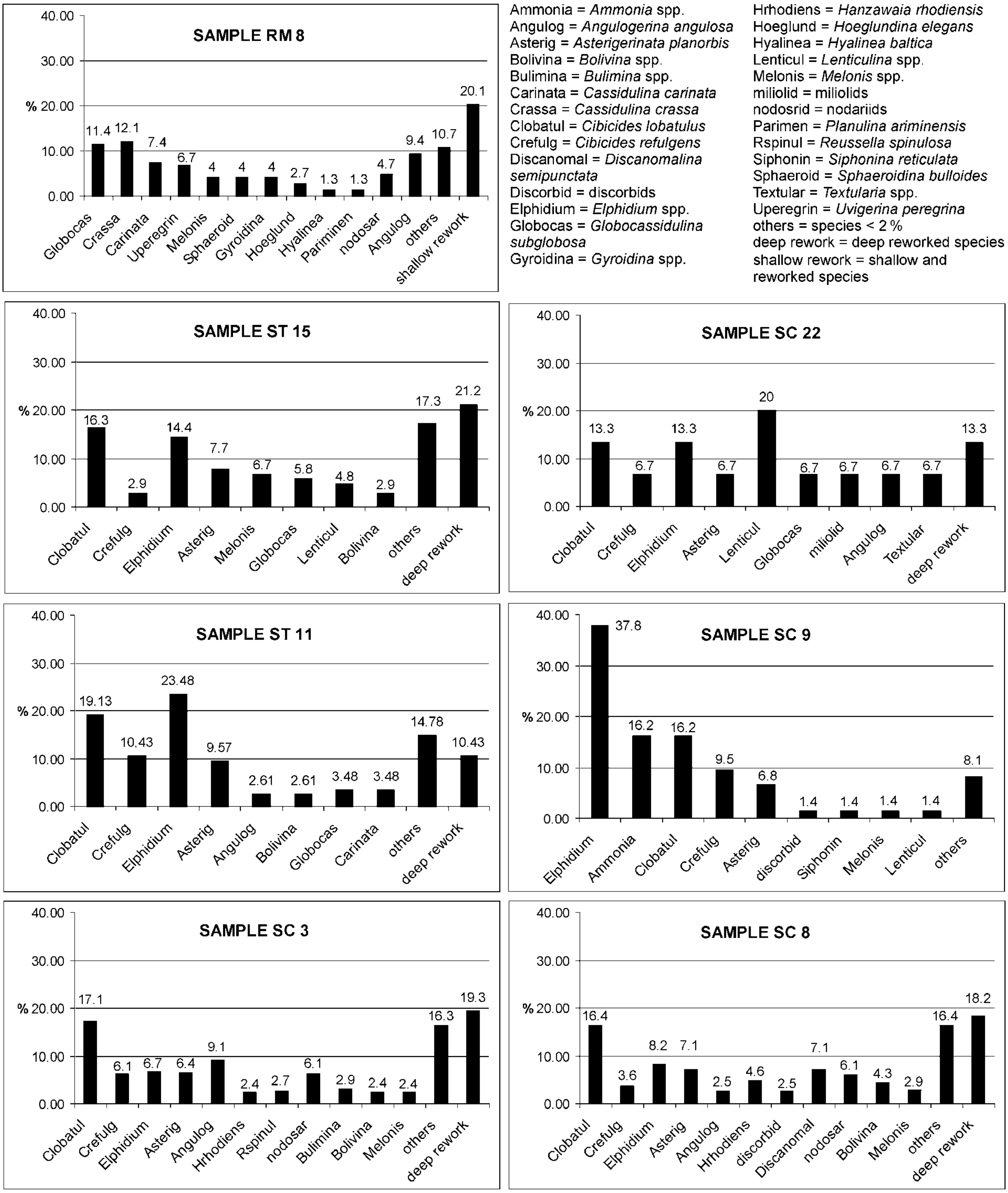


Fig. 5. Histograms indicating the percentages of the different species within the benthic foraminiferal association in selected samples.

the relationship between the lower and upper units does not confirm this hypothesis.

Forced regressive deposits are characterized by downward-stepping depositional architectures and by a relative stratigraphic continuity with the lowermost highstand deposits, according to the segment of the relative sea-level curve to which it refers. After the beginning of the sea-level drop, the definitive fall produces a sequence boundary, marking the top of the FSST (Falling Stage Systems Tract of Plint & Nummedal 2000; Posamentier & Morris 2000).

In the case of the R_2 unit, this fundamental stratigraphic condition is not respected. The lowermost R_1 unit is composed of sediments of open marine environments, but are bounded at the top by an erosional, gently angular unconformity, that signs a deep stratigraphic gap with the overlying R_2 unit. Nevertheless the abrupt transition at the R_1/R_2

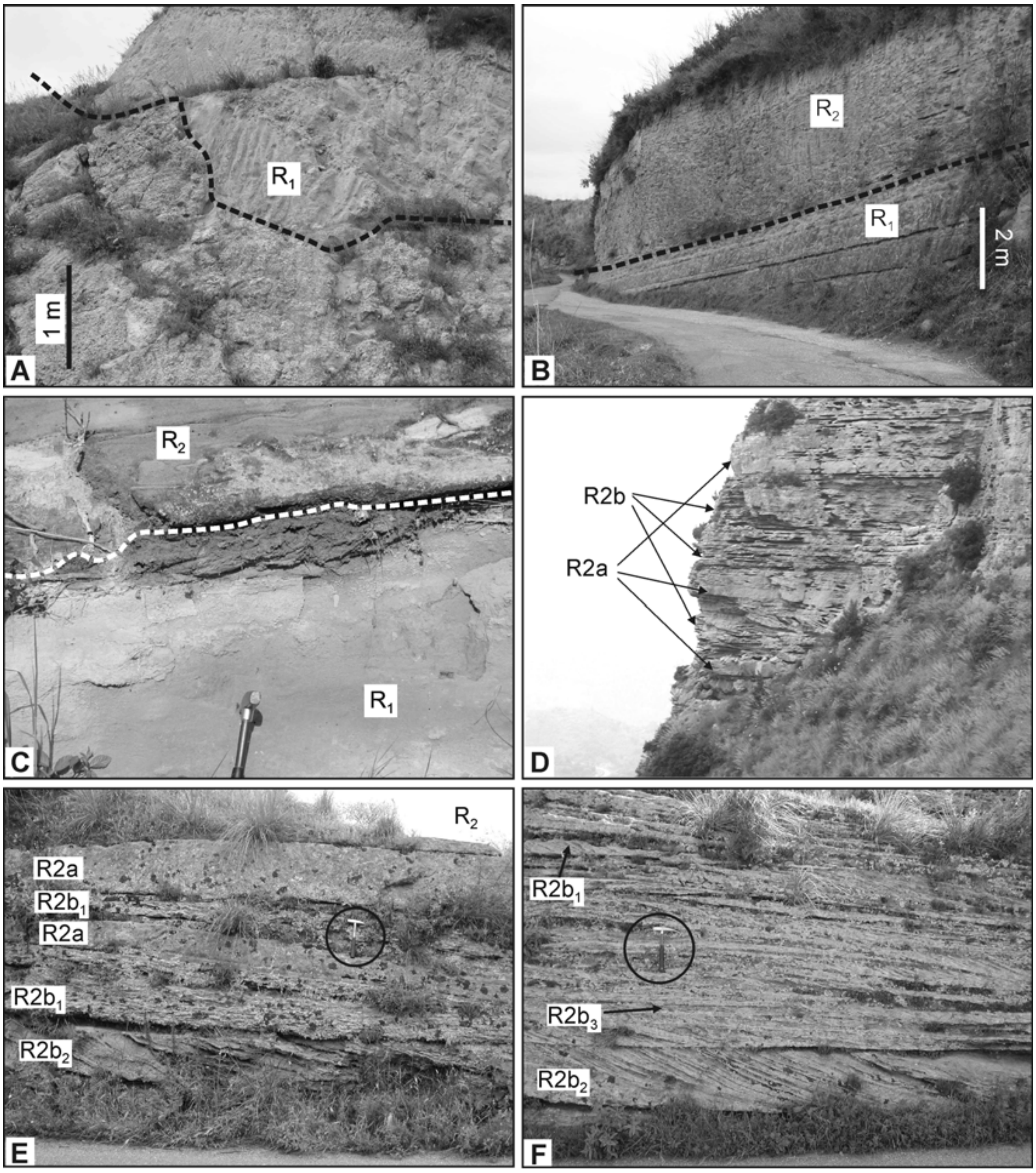


Fig. 6. Outcrop photographs of the R_1 and R_2 units near Rometta. **A** — Erosion along the lower surface of the R_1 unit, lying above the Messinian evaporites. **B** — Surface bounding the Middle Pliocene R_1 unit and the Plio-Pleistocene R_2 unit; note the low-angle angular unconformity (Sottocastello section). **C** — Detail of B; note the bed occurring on top of the R_1 unit, used as key bed for stratigraphic correlations. **D** — Massive siliciclastic beds (R2a facies) alternating with cross-stratified beds (R2b facies, San Cono section). **E** — Massive siliciclastic beds (R2a facies) alternating with ripple- and dune-bedded biocalcarenitic beds ($R2b_1$ and $R2b_2$ facies respectively), belonging to R_2 unit (San Cono section). **F** — Alternating $R2b_1$, $R2b_2$, $R2b_3$ facies (San Cono section); note the uni-modal direction (N-trending) of foresets.

boundary shows a shallowing, regressive trend of the sedimentary facies (from offshore transition to shoreface), the hiatus between these two adjacent environments represents a sequence boundary that can be interpreted as the effect of a transgression rather than a regression.

Consequently, the R_2 unit must be interpreted in a different way.

To justify the stratigraphic organization of the Rometta Succession, with special emphasis on the R_2 unit, a new relative curve of the sea-level changes must be reconstructed, considering that the sedimentation probably occurred during a stage of late sea-level rise and consequent highstand, combining the high-frequency eustatic oscillations with the effect of a tectonic uplift of the area.

In fact, if a strong linear uplift trendline is superimposed to the medium-frequency eustatic curve during a still-stand, the resulting tendency (relative curve) is a falling line that expresses a relative fall of the sea level. If we consider that the sea-level highstand was probably characterized by high-frequency sea-level oscillations, the resulting

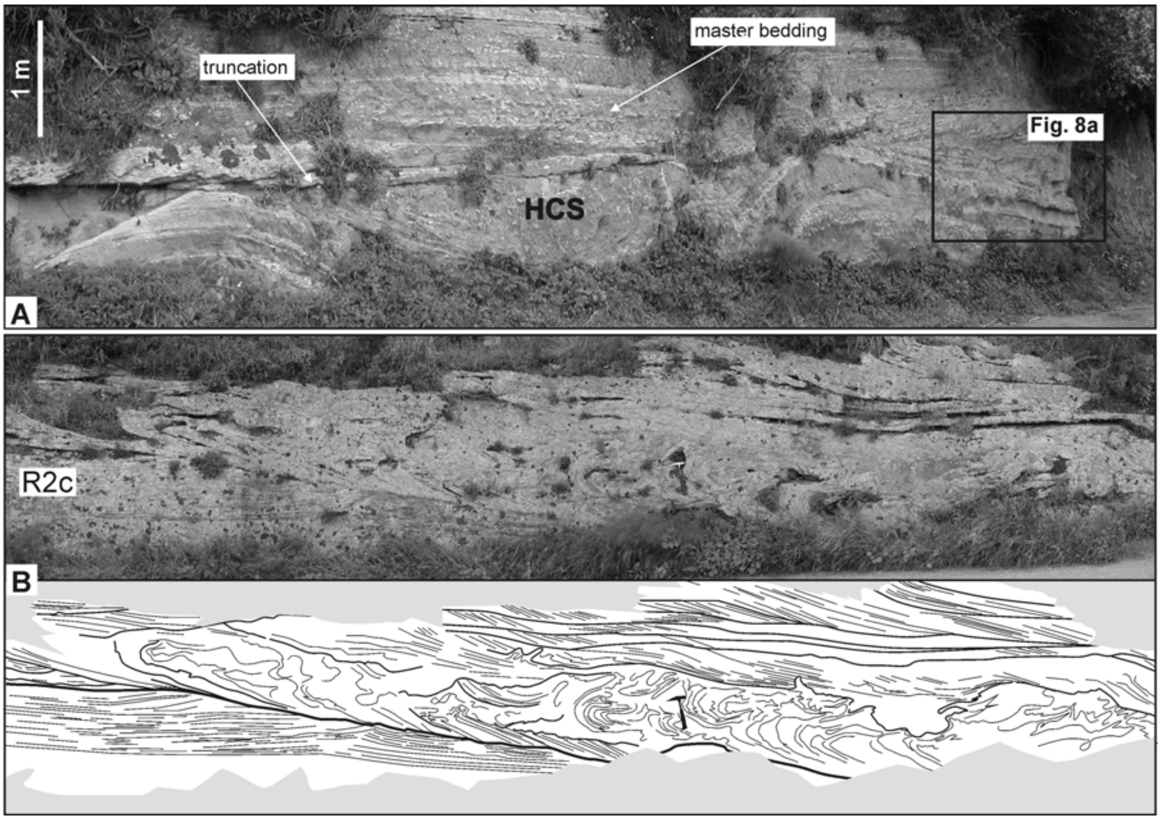


Fig. 7. Road-cut along the Sottocastello section. **A** — Example of isotropic hummocky cross-stratified (HCS) bed within the R_2 unit; the direction of the paleo-flow is from left to the right. The crests of HCS are parallel to the paleo-shoreline. See detail in the box in figure 8A. **B** — Interval of the San Cono section showing spectacular slump deposits. The crests of the deformed laminae indicate the direction of gravitative movement (paleo-dip).

effect is a composite falling curve of the relative sea level (Fig. 9, inset).

During the sedimentation of the R_2 biocalcarenites, a tectonic uplift of the coastal sector may have occurred contemporaneously to high-frequency eustatic oscillations. The combined effect of the tectonics and eustatism may have produced abrupt basinward-shifting of the facies, simulating an apparent fall of the sea-level. During the high-frequency oscillations, the relative sea-level fall, constrained the entire system to sweep basinwards. In this situation, mass-movement processes were favoured (Posamentier & Morris 2000), resulting in the formation of channel complexes along the regressive surfaces (Fig. 9).

The occurrence of syndepositional unconformities bounding the minor R_2 sequences and the progressive basinward shifting of the facies tract provides evidence that uplift was active at least from the Late Pliocene. Considering the late Gelasian-Emilian age of the R_2 unit (about 700 ka) and the topographic heights at which it is preserved near Rometta (about 500 m a.s.l), an average uplift rate on the order of 0.7 $mm \cdot kyr^{-1}$ can be estimated for this part of the Tyrrhenian paleocoast since late Late Pliocene.

At the end of the deposition of the R_2 unit (relative sea-level highstand), the subsequent sea-level drop produced a truncation surface, representing the base of a younger sequence (sequence boundary). The absence of any traces of continental deposits does not confirm the exposure of the unit during the sea-level fall.

Thus, the R_1–R_3 units represents three incomplete depositional sequences, deposited within a very active geological setting, where the tectonics played a fundamental role in the control of sedimentation.

The lower R_1 unit represents the highstand systems tract (HST) of the oldest depositional sequence. The intermediate R_2 unit is the HST of a new depositional sequence, which developed during a period of tectonic uplift. The TST (Transgressive Systems Tract) is probably recorded only by the ravinement surface marking the top of the R_1 unit. The set of minor sequences forming the HST (R_2 unit), represents the sedimentary record of the sum of the tectonic uplift and the sea-level high-frequency oscillations during a phase of stillstands (Fig. 9, inset).

The influence of uplift in controlling small-scale sequence development is also recognizable in the volumetric development of individual systems tracts and in the control exercised on the sequence arrangement. This characteristic is also very frequent near continental margins, where the tectonics were strongly active during sedimentation, imposing its influence on the smaller time scale high-frequency eustatic oscillations (e.g. Cantalamessa & Di Celma 2004).

The stratigraphic gap of at least 870 kyr recognized at the R_1/R_2 sequence boundary is therefore interpreted as

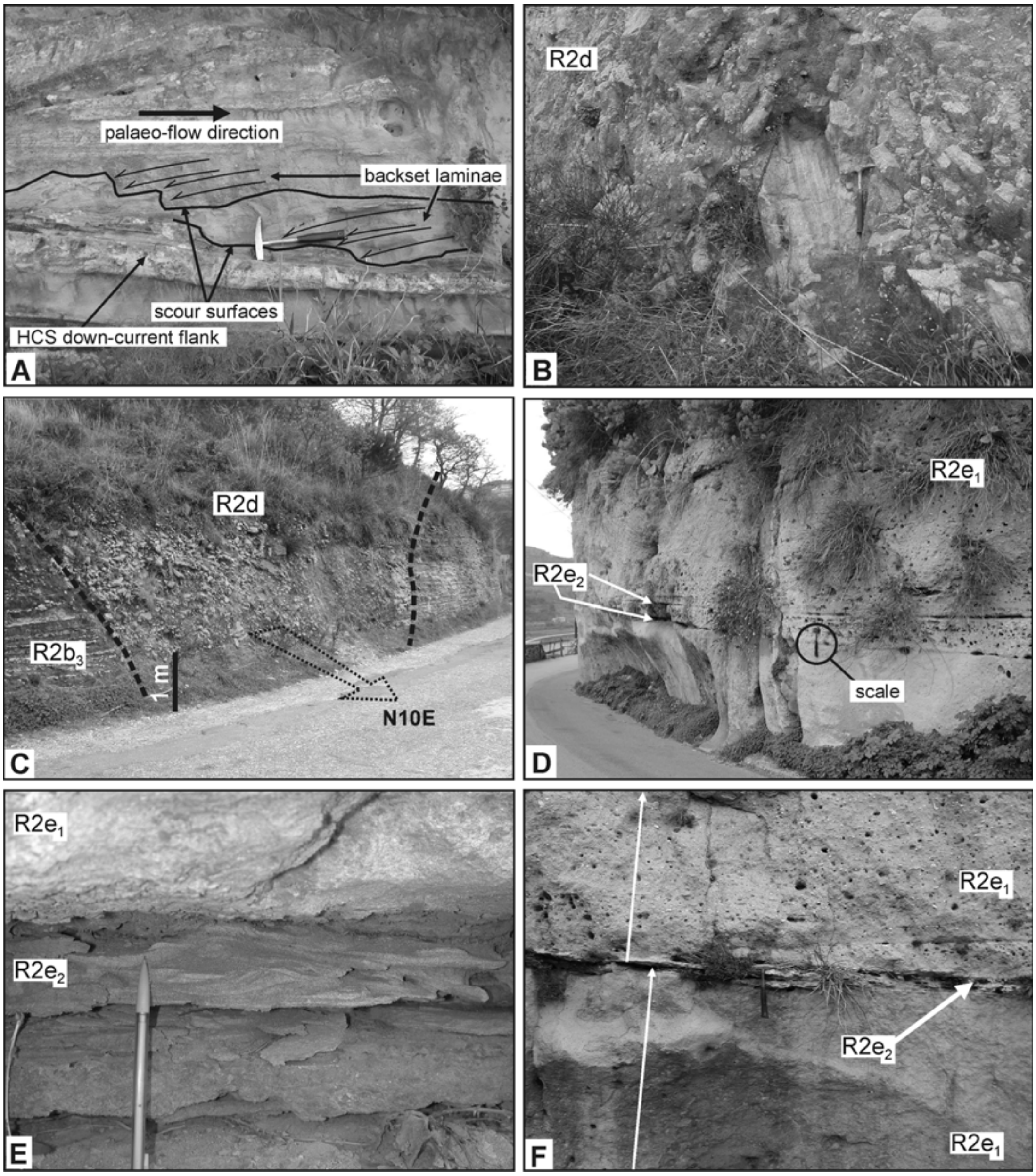


Fig. 8. Outcrop photographs of the R_2 and R_3 units. **A** — Detail of the figure 7A; here the down-current flank of the HCS is partially scoured and filled by backset laminae; this process is related to supercritical flows, producing vortex migrating up-current. **B** — Detail of the channel fill deposits (R2d facies); note the tabular lamination within the block in the centre of the picture (Sottocastello section). **C** — Roadcut showing a transversal section of a channelfill deposits (R2d facies); the dotted arrow indicates the translation direction (Sottocastello section). **D** — Proximal coarse-grained facies of the R_2 unit; each single bed, 1–2 m thick, is made of normal-graded massive biocalcarenites (R2e_1) alternating with wave rippled thin beds (R2e_2 facies, Rometta section). **E** — Wave ripples of the R2e_2 facies. **F** — Massive and normal-graded (arrows) biocalcarenites of the R2e_1 facies, intercalated with the thin horizons of the R2e_2 facies; note the abundance of bioclasts in the upper bed.

the result of an Early–Middle Pliocene phase of tectonic uplift; the reddish fine level occurring on top of the R_1 unit can be regarded as a condensed level, deposited during the sea-level stillstand that preceded the beginning of the first sea-level drop.

The absence of any traces of subaerial exposure, that may form during the sea-level lowstand and usually characterizes the top of a HST, may be related to erosion during the subsequent sea-level rise and identifies such a surface as a transgressive erosion surface (Walker & Plint 1992; Hunt & Tucker 1995). The hypothetical lowstand systems tract deposits of the depositional sequence and the subsequent early TST have to be searched basinwards (i.e. to the north), in a presently down-faulted area partially covered by the Holocene coastal plain sediments of the Tyrrhenian shoreline.

The main part of the R_3 depositional sequence (TST) developed in a sector far from the study area, near the coastal areas; in fact, NW of Rometta, the Middle Pleistocene "Argille di Spadafora" Formation (Auct.) represents the early TST of the sequence and is referable to the R_3 unit

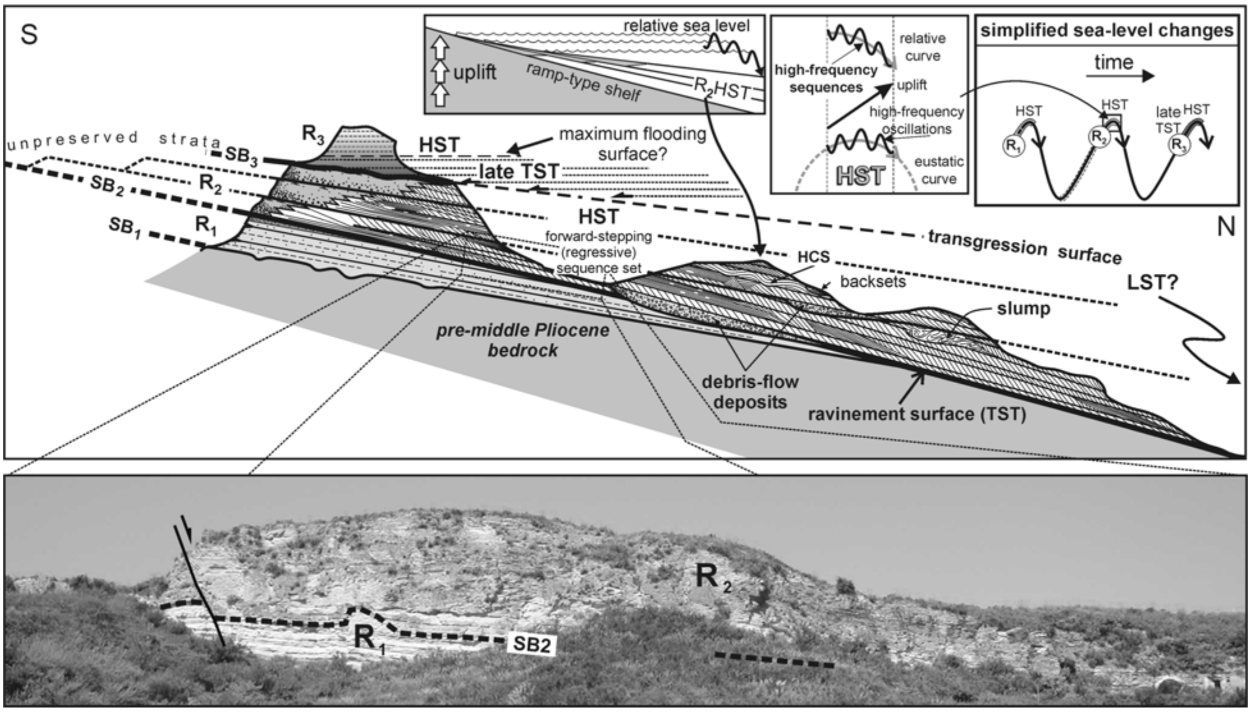


Fig. 9. Bi-dimensional reconstructed section across the Rometta Succession. The whole succession is the result of the superimposition of three, third-order depositional sequences. The R_1 unit is the top of a HST belonging to the oldest sequence. The top of the R_1 unit, represents a ravinement surface, on which the HST of the R_2 unit aggrades. The R_2 unit is composed of a set of simple high-frequency sequences, bounded by regressive surfaces of marine erosion. The LST may be deposited in a position too far to be recognized in the study area (basinward). The subsequent relative sea-level rise forms a late TST, onlapping onto a new transgression surface (top of the R_2 unit). The R_3 unit occurring on top of the section and forming the highest Rometta Hill, can be interpreted as the whole TST+HST, in which the occurrence of a maximum flooding surface can be supposed. The combined influence of the high-frequency eustatism and the tectonic uplift produces the sedimentation of simple sequences within the R_2 unit, simulating a regressive stratigraphic arrangement of the facies (inset; see text for further details).

cropping out at Rometta. The R_3 unit is here interpreted as the late TST+HST; our stratigraphic resolution of the R_3 unit does not allow us to identify the maximum flooding surface separating these two systems tracts (Fig. 9). The deposition of the offshore mudstones of the R_3 unit records a strong and sudden tectonic subsidence, responsible for the deepening of the sedimentary basin.

Above this sequence, not recognizable in the outcrop near Rometta but occurring elsewhere in NE Sicily, a younger prograding regressive-system develops (Middle–Late Pleistocene "Ghiaie di Messina" Formation (Auct.) (see coastal areas in Fig. 1).

Depositional and paleogeographical setting of R_2 unit

The depositional architecture of the R_2 unit, does not show a 'traditional' progradational geometry (i.e. clinoforms or basal downlapping surfaces at outcrop-scale of observation). The absence of prograding architectures is typical of depositional settings characterized by a sea-floor gradient too steep to provide a stable substrate for prograding deposits (e.g. ramp-type inner shelf, e.g. Plint & Norris 1991 and references therein).

The main component of the R_2 unit consists of bioclasts represented by skeletal remains of mainly epifaunal organisms (pectinids, ostreids and corals). The benthic foraminiferal association and the sedimentary facies association indicate that deposition took place on the inner-middle ramp-type shelf, not deeper than 50–80 m.

Observing the S-to-N-longitudinal facies tract of the R_2 unit (Fig. 10), the system rapidly evolves seaward from beachface coarse-grained facies ($R2e_{1-2}$, estimated paleobathymetry: 1–5 m), to lower shoreface cross-bedded biocalcarenites (R2a–d, estimated paleobathymetry: from 30 to 50 m), suggesting a reflective-type high-gradient paleobottom-profile (Orton & Reading 1993), characterized by a 'resonant domain' of a steep beach face zone, in which the oscillatory wave motion reworks the sediment.

These features, recognizable in each single point where the succession was studied, suggest that deposition occurred on a ramp-type depositional system (Plint & Norris 1991), characterized by the quick deepening of the sea-floor below the fair-weather wave base.

This character is documented by three main features: (i) the total absence of wave-influenced transitional beachface-to-shoreface facies, typical instead of a slow-shoaling dissipative coastal domain, (ii) the occurrence of several mass-flow deposits (slumps and debris-filled channel complexes), associated with a high-gradient bottom profile, and (iii) the presence of shore-normal oriented HCS-bedded horizons, associated with sedimentary structures (backset laminae)

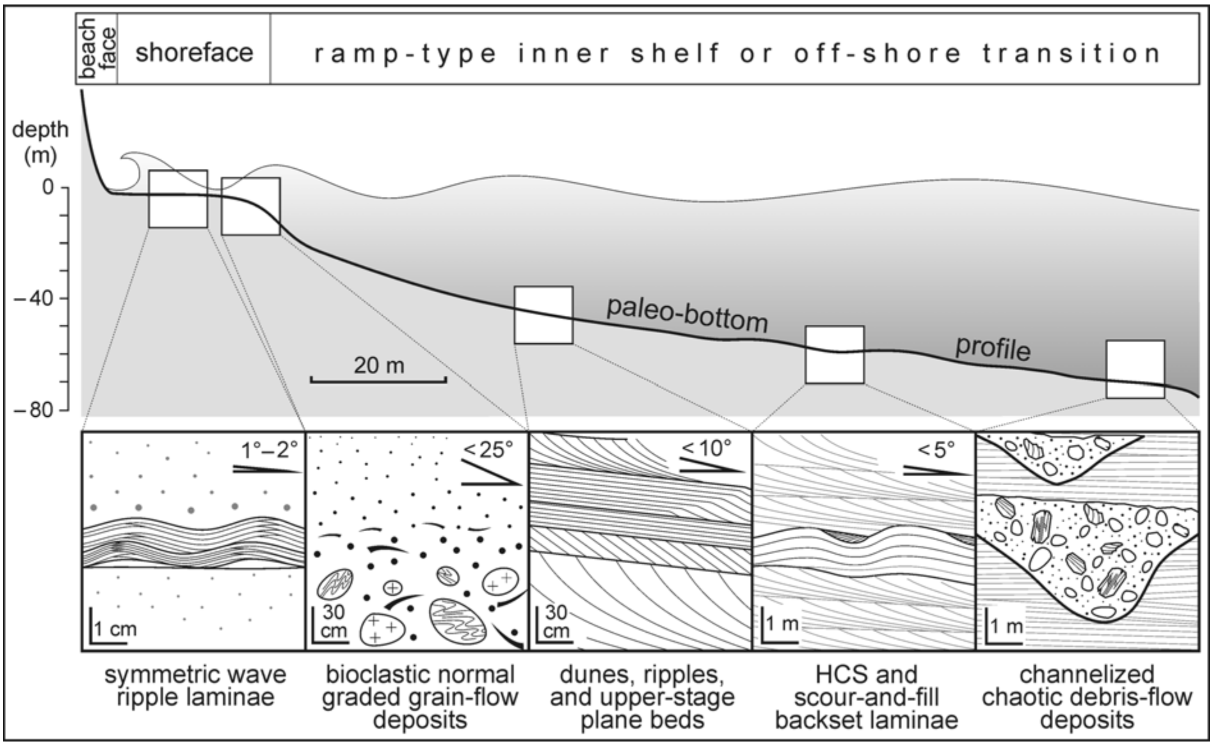


Fig. 10. Facies tract obtained from the longitudinal correlation of sedimentary types recognized within the R_2 unit. This typical facies distribution suggests a ramp-type inner shelf depositional setting, where the high-gradient paleo-bottom profile inhibits a shoreface development that abruptly merges into the deepest deposits.

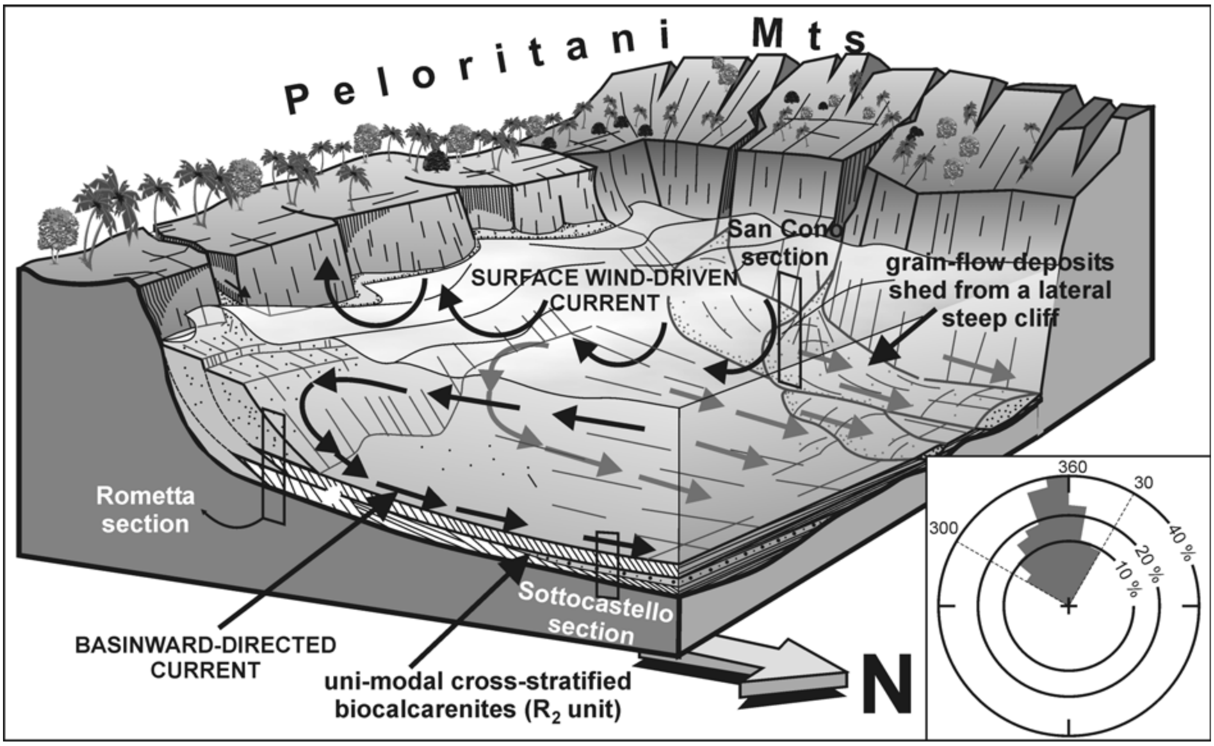


Fig. 11. Paleogeographical reconstruction during the time of deposition of the R_2 unit. The uni-modal N-directed cross-bedded biocalcarenites (see rose diagram) are interpreted as the result of the action of seaward-directed tractive currents, favoured by the dynamic action of wind-driven surficial currents, impacting against a steep coastal cliff, and generating a basinward-directed circulation. The occurrence of siliciclastic deposits merging laterally with the biocalcarenites is, in contrast, the product of grain-flows shed from a cliffed-lateral western margin.

that imply quick increasing of the flow-velocity, localized at a paleodepth of 50–70 m.

These sedimentary structures were commonly associated with steep-slope environments (e.g. delta slope, see Massari 1996; Colella & Vitale 1998) where flow acceleration produces simultaneous excavation and filling of scours by landward-dipping laminae under supercritical flow. In our setting, these structures indicate a local steepening of the paleo-bottom profile, due to the increasing of the dip-angle along the HCS down-current flank.

The present-day dip displayed by the R_2 unit in the outcrop has to be considered as the sum of an original depositional inclination, increased by subsequent local uplift. Considering that the original depositional dip of these facies can be estimated at up to 5° (Fig. 10), and that the present-day strata dip is of 10°–20°, the amount of tectonic tilt can be quantified as 5°–15°.

The paleocurrent directions measured on the cross-bedded strata and the axis trend of the gravitative flows show a common NNE-trending orientation.

This uncommon environmental setting is inferred to be connected to wind-driven surficial currents (*sensu* Swift et al. 1983), impacting against a steep bottom profile and reflected to form basinward-directed bottom currents (Duke et al. 1991). These currents occur both in normal and in high-energy phases of wave motion, producing different-in-velocity offshore-migrating tractive-flows. During the very-high energy stages (storms), the wave motion may interrupt the formation of the orbital motion of currents, producing only reflective/resonant oscillatory long-movement, which justifies the origin of HCS (Harms et al. 1982; Walker et al. 1983; Duke 1990) in the inner shelf.

Such a coastal setting can be compared to the present Tyrrhenian coast of NE Sicily, characterized by analogous morphological conditions (Gamberi & Marani 2006); furthermore, the lateral extension of the biocalcarenitic unit and the occurrence of the interfingered siliciclastic grain-flow deposits deriving from a western (lateral) margin of the area, suggest the paleogeographical setting of a 'semi-enclosed gulf' or embayment (Fig. 11).

Conclusion

A detailed stratigraphic analysis was performed on the NE Sicily Pliceneo-Pleistocene succession, cropping out in the key area of Rometta, which provided sedimentological, biostratigraphic and paleobathymetric data.

Three sedimentary units (R_1, R_2 and R_3) form the succession, respectively Middle Pliocene, Late Pliocene-Early Pleistocene and Middle Pleistocene in age. They are separated by two main angular unconformities, which mark important changes in lithological characters, biogenic content, depositional environments (from offshore transition to shoreface to open offshore again), and are accompanied by two main sedimentary gaps spanning at least 870 and 260 kyr respectively.

A sequence stratigraphy interpretation suggest that the Rometta Succession is composed by the superimposition of three incomplete, tectonically-enhanced, third-order depositional sequences. The lower R_1 unit forms the topmost of a late TST+HST of a Middle Pliocene depositional sequence, deeply eroded by a subsequent first sea-level drop. During the subsequent transgression, a younger depositional sequence evolves, onlapping the R_2 unit sediments onto a ravinement surface (top of the R_1 unit) and forming a HST in the Rometta area. The internal organization of the R_2 HST simulates a Falling Stage Systems Tract (Hart & Long 1996; Plint & Nummedal 2000), since it is composed by a set of high-frequency minor sequences, separated by erosive surfaces showing a basinward shift of the facies tract.

The set of minor sequences record the interaction between high-frequency oscillations of the sea level under the influence of the coastal tectonic uplift, during which the coastal systems prograded along a steep sea floor.

The mudstone of the R_3 unit, onlapping the topmost bounding surface of the HST belonging to the R_2 unit, has to be interpreted as the whole late TST+HST of the youngest sequence, closing a new cycle of relative sea-level change.

The R_2 unit does not show prograding surfaces, commonly associated with various examples of coastal systems developing during relative sea-level still-stands; the absence of prograding architectures is typical of depositional settings characterized by a very steep sea-floor gradient, where clinoforms cannot develop.

In this framework the R_2 unit represents the HST of a NNE-developing depositional sequence, whose distal counterpart (LST+TST) has been down-dropped by recent normal faults and is presently covered by the Holocene coastal sediments of the northern Sicilian shoreline.

The lithofacies of the R_2 unit, represented by shoreface beds and cross-stratified ramp-type shelf deposits, identifies a reflective-type high-gradient coastal domain. The steep gradient favoured the generation of mass-flow deposits, translating basinward. The ramp-type cross-stratified deposits form a set of strata in which a variety of tractive structures occur, denoting the action of medium to high velocity uni-directional basinward-directed flows. The latter may derive from the influence of wind-driven surficial water movements that, directed and impacting against a steep sea-cliff, generated basinward-directed backflows.

Acknowledgments: We are grateful to Prof. Diego Puglisi (University of Catania), Prof. Luisa Sabato (University of Bari) and Assoc. Prof. Jozef Michalík for the accuracy in revising the manuscript. Discussions with Dr. Pierpaolo Guarnieri (University of Catania) on regional geology were very productive. We are also grateful to Dr. Marcello Tropeano (University of Bari) for the precious suggestions on sequence stratigraphy interpretations. This research was supported by "Ateneo Grants (ex 60 %-2003-/2005)" to Agata Di Stefano and Fabio Lentini.

References

Amodio Morelli L., Bonardi G., Colonna V., Dietrich D., Giunta G., Ippolito F., Liguori V., Lorenzoni S., Paglionico A., Perrone V., Piccarreta G., Russo M., Scandone P., Zanettin Lorenzoni E. & Zuppetta A. 1976: The Calabria-Peloritani Arc within the Apenninian-Maghrebian orogen. *Mem. Soc. Geol. Ital.* 17, 1–60 (in Italian).

Barrier P. 1987: Stratigraphie des depôts pliocènes et quaternaires du Detroit de Messine (Italie). *Doc et Trav IGAL* 11, 59–81.

Cantalamessa G. & Di Celma C. 2004: Sequence response to syndepositional regional uplift: insights from high-resolution sequence stratigraphy of late Early Pleistocene strata, Periadriatic Basin, central Italy. *Sed. Geol.* 164, 283–309.

Cita M.B. 1975: Planktic foraminiferal biozonation of the mediterranean Pliocene deep sea record: a revision. *Riv. Ital. Paleont. Stratigr.* 81, 527–544.

Cita M.B., Rio D., Hilgen F., Castratori D., Lourens L. & Vergerio P.P. 1996: Proposal of the global boundary stratotype section and point (GSSP) of the Piacenzian stage (Middle Pliocene). *International Union of Geological Sciences*, International Commission on Stratigraphy (Subcommission on Neogene Stratigraphy), 1–14.

Colella A. 1995: Sedimentation, deformational events and eustacy in the Perityrrhenian Amantea Basin: preliminary synthesis. *Giornale di Geologia* 57, 179–193.

Colella A. & D'Alessandro A. 1988: Sand waves, *Echinocardium* traces and their bathyal depositional setting (Monte Torre Paleostrait, Plio-Pleistocene, southern Italy). *Sedimentology* 35, 219–237.

Colella A. & Vitale F.P. 1998: Eustacy, tectonics and their controls on the depositional patterns of clinostratified shoreface carbonates (late Pliocene, Sicily). In: Colella A. (Ed.): Society of economic paleontologists and mineralogists research Conference, strata and sequence on shelves and slopes, Catania, Italy. *Excursion Guidebook,* 27–69.

Di Stefano A. & Lentini R. 1995: Stratigraphic reconstruction and paleotectonic significance of the Plio-Pleistocene deposits of the Tyrrhenian margin between Villafranca Tirrena and Faro villages (NE Sicily). *Studi Geologici Camerti*, *Spec. Vol.* 2, 219–237 (in Italian).

Duke W.L. 1990: Geostrophic circulation on shallow marine turbidity currents? The dilemma of palaeoflow patterns in storm-influenced prograding shoreline systems. *J. Sed. Petrology*, 60, 870–883.

Duke W.L., Arnott R.W.C. & Cheel R.J. 1991: Shelf sandstones and hummocky cross-stratification: new insights on a stormy debate. *Geology* 19, 625–628.

Finetti I. & Del Ben A. 1996: Geophysical study of the Tyrrhenian opening. *Bollettino di Geofisica Teorica e Applicata* 28, 110, 75–156.

Gamberi F. & Marani M. 2006: Interland geology and continental margingrowth: the case of Gioia Basin (southeastern Tyrrhenian Sea). In: Moratti G. & Chalouan A. (Eds.): Tectonics of the Western Mediterranean and North Africa. *Geol. Soc. Spec. Publ.* 262, 349–364.

Giunta Ilaqua M. 1956: Calabrian Foraminifera of Rometta (Messina). *Riv. Ital. Paleont. Stratigr.* 62, 4, 224–237 (in Italian).

Guarnieri P. & Carbone S. 2003: Geologic arrangement and morpho-structural lineages of the Plio-Quaternary sedimentary basins of southern Tyrrhenian. *Boll. Soc. Geol. Ital.* 122, 377–386 (in Italian).

Harms J.C., Southard J.B. & Walker R.G. 1982: Structures and sequences in clastic rocks. *Soc. Econ. Paleont. and Mineralogists*, *Short Course* 9.

Hunt D. & Tucker M.E. 1995: Stranded parasequences and the forced regressive wedge systems tract: deposition during base-level fall-reply. *Sed. Geol.* 95, 147–160.

Jorissen F.J. 1987: The distribution of benthic Foraminifera in the Adriatic Sea. *Mar. Micropal.* 12, 21–48.

Johnson H.D. & Baldwin C.T. 1986: Shallow siliciclastic seas. *Sed. Environments and Facies*, 2nd edition, 229–282.

Lentini F., Carbone S. & Catalano S. 1994: Main structural domains of the central Mediterranean region and their tectonic evolution. *Bollettino di Geofisica Teorica e Applicata*, 36, 141–144, 103–125.

Lentini F., Carbone S., Catalano S., Di Stefano A., Gargano C., Romeo M., Strazzulla S. & Vinci G. 1995: Sedimentary evolution of basins in mobile belts: examples from tertiary terrigenous sequences of the Peloritani Mts (NE Sicily). *Terra Nova* 7, 2, 161–170.

Lentini F., Catalano S. & Carbone S. 2000: Geological map of Messina province (NE Sicily) 1:50,000, S.El.Ca., Florence.

Massari F. 1996: Upper-flow-regime stratification types on steep-face, coarse-grained, Gilbert-type progradational wedges (Pleistocene, southern Italy). *J. Sed. Res.* 66, 364–375.

Midtgaard H.H. 1996: Inner shelf to lower-shoreface hummocky sandstones bodies with evidence for geostrophic influenced combined flow, lower Cretaceous, west Greenland. *J. Sed. Res.* 66, 2, 343–353.

Murray J.W. 1991: Ecology and palaeoecology of benthic foraminifera. *Longman Scientific & Technical, Longman,* Harlow, 1–397.

Ogniben L. 1960: Explicative notes of the Geological scheme of NE Sicily. *Riv. Mineraria Siciliana* 64–65, 183–212 (in Italian).

Orton G.J. & Reading H.G. 1993: Variability of deltaic processes in terms of sediment supply, with particular emphasis on grain size. *Sedimentology* 40, 475–512.

Parker F.L. 1958: Eastern Mediterranean Foraminifera. *Reports of the Swedish Deep Sea Expedition* 8, 2, 4, 217–283.

Perès J.M. & Picard J. 1964: Nouveau manuel de Bionomie benthique de la mer Mediterranée. *Rec. Trav. Station Marine d'Endoume* 31, 47, 1–137.

Plint A.G. & Norris B. 1991: Anatomy of a ramp margin sequence: Facies successions, paleogeography and sediment dispersal patterns in the Muskiki and Marshy bank formation, Alberta Foreland Basin. *Bull. Canad. Petrol. Geol.* 39, 18–42.

Plint A.G. & Nummedal D. 2000: The falling stage systems tract: recognition and importance in sequence stratigraphic analysis. In: Hunt D. & Gawthorpe R. (Eds.): Sedimentary response to forced regression. *Geol. Soc., Spec. Publ.* 172, 1–17.

Pomar L. & Tropeano M. 2001: The Calcarenite di Gravina Formation in Matera (southern Italy): New insights for coarse-grained, large-scale, cross-bedded bodies encased in offshore deposits. *AAPG Bullettin* 85, 4, 661–689.

Posamentier H.W. & Morris W.R. 2000: Aspects of stratal architecture of forced regressive deposits. In: Hunt D. & Gawthorpe R. (Eds.): Sedimentary response to forced regression. *Geol. Soc., Spec. Publ.* 172, 19–46.

Rio D., Raffi I. & Villa G. 1990: Pliocene-Pleistocene nannofossil distribution patterns in the Western Mediterranenan. In: Kastens K.A., Mascle J. et al. (Eds.): Proceedings of the Ocean Drilling Project, Scientific Results, Vol. 107. *Ocean Drilling Project, College Station*, TX, 513–533.

Roveri M. & Taviani M. 2003: Calcarenite and sapropel deposition in the Mediterranean Pliocene: shallow- and deep-water record of astronomically driven climatic events. *Terra Nova* 15, 279–286.

Ruggieri G., Sprovieri R. & Unti M. 1979: The Emilian transgression of NE Sicily. *Boll. Soc. Geol. Ital.* 98, 475–482 (in Italian).

Seguenza G. 1873–1877: Stratigraphic study on the Pliocene formation of southern Italy. *Boll. Regio Comitato Geologico*, s. I, 4–7 (in Italian).

Sgarrella F. & Moncharmont Zei M. 1993: Benthic Foraminifera of Gulf of Napples (Italy): systematics and autoecology. *Boll. Soc. Paleont. Ital.* 32, 2, 145–264.

Sgarrella F., Sprovieri R., Di Stefano E., Caruso A., Sprovieri M. & Bonaduce G. 1999: The Capo Rossello bore-hole (Agrigento, Sicily): cyclostratigraphic and paleoceanographic reconstructions from quantitative analyses of the Zanclean foraminiferal assemblages. *Riv. Ital. Paleont. Stratigr.* 105, 2, 303–322.

Sprovieri R. 1992: Mediterranean Pliocene biochronology: an high resolution record based on quantitative planktic foraminifera distribution. *Riv. Ital. Paleont. Stratigr.* 98, 1, 61–100.

Sprovieri R. 1993: Pliocene-early Pleistocene astronomically forced planktic foraminifera abundance fluctuation and chronology of Mediterranean calcareous plankton bio-events. *Riv. Ital. Paleont. Stratigr.* 99, 3, 371–414.

Sprovieri R., Di Stefano E., Howell M., Sakamoto T., Di Stefano A. & Marino M. 1998: Integrated calcareous plankton biostratigraphy and cyclostratigraphy at site 964. In: Robertson A.H.F., Emeis K.C., Richter C. & Camerlenghi A. (Eds.): Proceedings of the Ocean Driling Program, Scientific Result, Vol. 160. *Ocean Drilling Project, College Station*, TX, 155–165.

Swift D.J.P., Figueiredo A.G.J., Freeland G.L. & Oertel G.F. 1983: Hummocky cross-stratification and megaripples: a geological double standard? *J. Sed. Petrology* 53, 1295–1317.

Tropeano M. & Sabato L. 2000: Response of Plio-Pleistocene mixed bioclastic-lithoclastic temperate-water carbonate systems to forced regressions: the Calcarenite di Gravina Formation, Puglia, SE Italy. In: Hunt D. & Gawthorpe R.L. (Eds.): Sedimentary responses to forced regressions. *Geol. Soc. London, Spec. Publ.* 172, 217–243.

Van Couvering J.A. 1997: Preface: the new Pleistocene. In: Van Couvering J.A. (Ed.): The Pleistocene boundary and the beginning of the Quaternary. *Cambridge University Press*, xi–xvii.

Van Morkhoven F.P.C.M., Berggren W.A. & Edwards A.S. 1986: Cenozoic cosmopolitan deep-water benthic foraminifera. *Bulletin des Centres de Recherches Exploration-Production Elf-Aquitaine, Mém.* 11, 1–421.

Violanti D., Bonfiglio L. & Saccà D. 1987: Pleistocene Foraminifera and paleoenvironmental interpretation of Plio-Pleistocene deposits outcropping in NE Sicily (Rometta, Messina). *Riv. Ital. Paleont. Stratigr.* 93, 2, 251–286 (in Italian).

Walker R.G., Duke W.L. & Leckie D.A. 1983: Hummocky cross-stratification: significance of its variable bedding sequences: discussion. *Geol. Soc. Amer. Bull.* 94, 1245–1251.

Walker R.G. & Plint A.G. 1992: Wave- and storm-dominated shallow marine systems. In: Walker R.G. & James N.P. (Eds.): Facies models: responses to sea level changes. *Geol. Assoc. Canad.*, Toronto, 219–238.

Wright R. 1978: Neogene paleobathymetry of the Mediterranean based on benthic foraminifers from DSDP leg 42A. In: Kidd R.B., Worstell P.J., et al. (Eds.): Initial Reports of the deep sea drilling project, Vol. 42, *U.S. Governments Printing Office,* Washington, 837–846.