

Response of otolith assemblages to sea-level fluctuations at the Lower Pleistocene Montalbano Jonico Section (southern Italy)

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ABSTRACT - The study of otoliths from bulk samples collected in the lowermost sections (named *Entalina* and *Fosso Giuseppe*, early Pleistocene in age) of the *Montalbano Jonico* succession (Basilicata, southern Italy) revealed the presence of a varied deep-sea teleostean fauna. The otoliths represent at least 41 taxa including the Recent oceanic taxon *Aphanopus*, reported here for the first time in the Mediterranean realm. An integrated approach, based on the paleobathymetric method and already well known in the literature for this group, together with the paleoecological analysis on the benthic and benthopelagic elements, were performed in order to improve the knowledge on otolith assemblages as a tool to reconstruct bathymetric fluctuations. This approach, previously used on deep bathyal assemblages, appears to be useful for more detailed paleobathymetric analysis of shallower settings too. The recognized assemblages reveal, in the *Entalina* section, a bathyal homogenous environment located at about 500-600 m deep, and paleodepths ranging from the upper bathyal to shelf break environments in the *Fosso Giuseppe* section. In this section, the stratigraphic distribution of the assemblages indicates cyclic sea-level fluctuations that agree well with the cycles inferred by macrobenthic invertebrate associations.

The bathyal teleostean fauna from *Montalbano Jonico* clearly shows Atlantic or more generally oceanic affinities characterized by several taxa, which today, are not anymore known from the Mediterranean Sea, but still live in the Atlantic Ocean.

RIASSUNTO - [Risposta delle associazioni ad otoliti alle variazioni del livello del mare nella sezione di *Montalbano Jonico* (Pleistocene Inferiore, Italia meridionale)] - Lo studio degli otoliti riconosciuti dall'analisi dei campioni volumetrici raccolti lungo le sezioni *Entalina* e *Fosso Giuseppe*, riferibili al Pleistocene inferiore e affioranti nell'intervallo inferiore della sezione composta di *Montalbano Jonico* (Basilicata, Italia meridionale), ha permesso di individuare una fauna a teleostei di mare profondo ben diversificata. Gli otoliti riconosciuti rappresentano almeno 41 taxa di cui *Aphanopus*, ad affinità oceanica, è segnalata per la prima volta nel Mediterraneo. Nel presente lavoro è applicato un approccio integrato basato sul metodo paleobatimetrico, precedentemente applicato a questo gruppo fossile, e l'analisi paleoecologica condotta solo sulle associazioni bentoniche e bentonectoniche, allo scopo di migliorare le conoscenze sulle associazioni ad otoliti come strumento nelle ricostruzioni paleoambientali. Questo approccio integrato, già applicato su associazioni di mare profondo, risulta essere particolarmente risolutivo per dettagliate analisi paleobatimetriche di ambienti anche più superficiali. Le associazioni riconosciute sono indicative di un ambiente batiale collocabile a circa 500-600 metri di profondità, per la sezione *Entalina* e di profondità variabili fra il batiale superiore ed il margine di piattaforma, per la sezione *Fosso Giuseppe*. In questa sezione, la distribuzione stratigrafica delle associazioni riconosciute permettono di individuare variazioni cicliche del livello del mare che ben si confrontano con quelle dedotte dallo studio delle associazioni a macroinvertebrati bentonici.

La fauna batiale a teleostei riconosciuta lungo la sezione di *Montalbano Jonico* è chiaramente ad affinità atlantica o, più in generale, oceanica caratterizzata da diversi taxa che, sebbene scomparsi dal Mediterraneo attuale, oggi popolano l'Oceano Atlantico.

INTRODUCTION

Otoliths allow precise species-level taxonomic identifications and are precious tools for the investigation of fossil teleostean faunas since they are found in a wide spectrum of sedimentary environments and are common fossils in marine sediments. Previous studies have pointed out the contribution of otoliths to paleoenvironmental analysis. In these studies, essentially the paleobathymetric approach proposed by Nolf & Brzobohaty (1994) has been applied, considering mesopelagic, benthopelagic, and benthic fishes assemblages. In this approach, among all the various factors affecting the distribution of the fishes and the attributes of the assemblages, the depth and the taxonomic composition are the only ones taken into account.

The several applications of this method, carried out on the assemblages recognized in the Oligocene, Miocene and Pliocene sediments of various localities (Nolf & Cappetta, 1989; Nolf & Brzobohaty, 1994;

Nolf, 1995; Stringer & Miller, 2001; Stringer et al., 2001) demonstrated its usefulness for paleobathymetric interpretations of deepwater or deep neritic fish associations. Positive results have also been obtained for Pleistocene associations (Girone, 2000a, b) but, due to the high percentages of the still extant species found in the Pleistocene assemblages, more information could be obtained by applying the paleoecological approach based on a more detailed analysis of the benthic and benthopelagic associations. Recently, an integrated analysis based on the paleobathymetric method (Nolf & Brzobohaty, 1994) and the paleoecological approach has been attempted on the deep bathyal assemblages (Girone, 2003) providing more precise paleoenvironmental reconstructions. In the paleoecological approach, only the benthopelagic and benthic fishes are considered and, besides the taxonomic composition, other attributes (e.g. structure of fish populations) of the associations are analysed.

In this work, the integrated approach is carried out on several otolith assemblages recognized in the lower

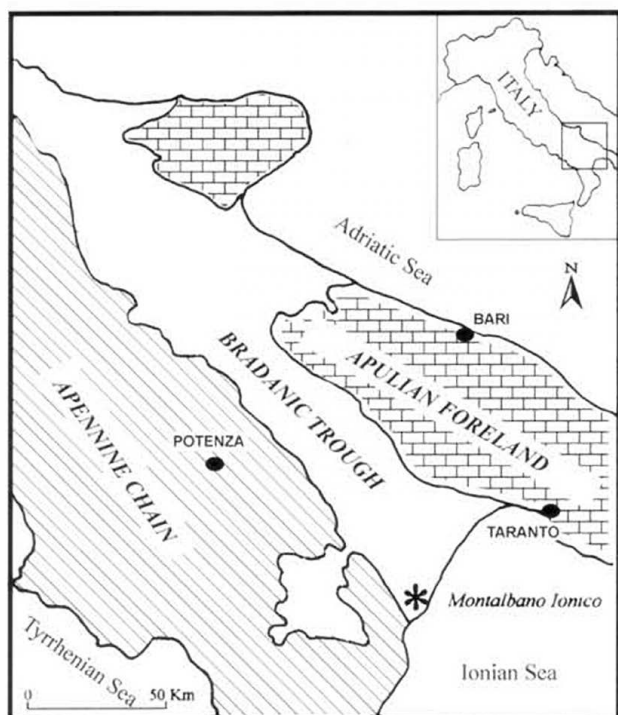


Fig. 1 - Location of the study area.

part of the Pleistocene Montalbano Jonico section cropping out along the interior border of the Southern Apennines Foredeep (Fig. 1) (Ciaranfi et al., 1997; Ciaranfi et al., 2001).

The primary purpose of this study is to test the integrated approach in different environmental settings and its sensitiveness to record the sea-level fluctuations. Previous data, available for the Montalbano Jonico section, allowed a continuous comparison with data obtained in this work.

MATERIALS AND METHODS

The studied sections, located in the basal part of the Montalbano Jonico section, are named the Entalina section (x: 631.600; y: 4463.380) and Fosso Giuseppe section (x: 632.410; y: 4463.430). The first section, 12 m thick, refers to the "large" *Gephyrocapsa* Zone (Marino, pers. com.; Ciaranfi et al., 2001); the Fosso Giuseppe section, about 110 m thick, belongs to the "small" *Gephyrocapsa* Zone (Marino, 1996; Ciaranfi et al., 2001) and is topped by a volcanoclastic layer (V1) which is used as a guide-horizon in the area (Fig. 2).

Three bulk-samples have been collected along the Entalina section and thirteen along the Fosso Giuseppe section (Fig. 2), each measuring about 100 dm³. They have been routinely processed for macrofaunistic studies, and the residues sieved through a 425 µm mesh. The fraction was entirely sorted and quantitatively analysed.

In the Fosso Giuseppe section, four samples (FGQE, FGQF, FGQN and FGQP) provided an insignificant number of otoliths for the quantitative

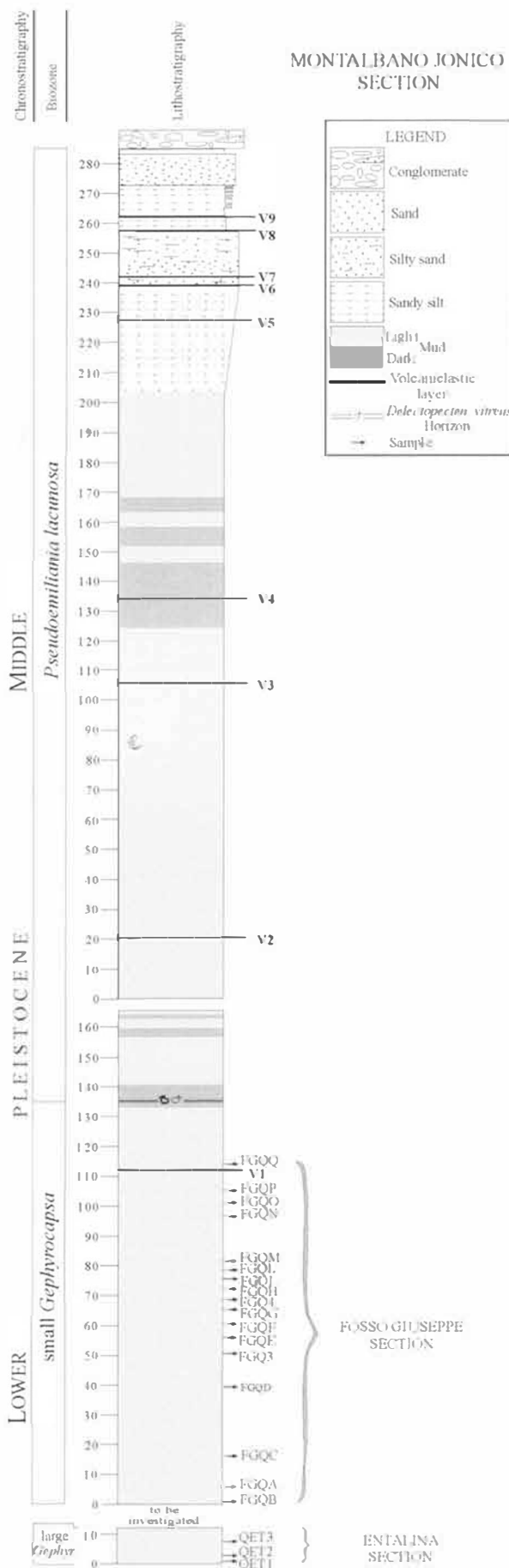


Fig. 2 - The Montalbano Jonico section.

analysis. Moreover, the screenwashing of the samples FGQA, FGQC, FGQO, FGQ3 and FGQ4 yielded no invertebrates and vertebrates specimens.

For each sample, the abundance and the dominance of the single taxa have been calculated following the criterion suggested for bivalve groups by Di Geronimo & Robba (1976).

The paleoecological analysis has been integrated with *continuum* taphonomic observations along the entire sections in order to infer the main depositional patterns (i.e., background versus event depositions). These observations allowed to better evaluate the allochthonous-autochthonous origin of the analysed assemblages. The field detailed observations allowed to define the stratigraphic interval better suitable for the collection of the bulk samples.

The paleobathymetric method proposed for fish otoliths by Nolf & Brzobohaty (1994) has been integrated with the paleoecological approach based on benthic and benthopelagic taxa.

Various ecological conditions other than bathymetry, the only factor taken into account in the paleobathymetric method, are responsible for the composition of otolith associations, in particular in the littoral environment (Nolf, 1995). It is obvious that the communities of an exposed beach differ from those of an estuarine environment just as a kelp-associated fauna is different from that of an area devoid of any seaweed. Consequently, sediments from all these environments have their own typical otolith associations, which must be interpreted with a background knowledge of fish ecology.

The study of the Recent associations, both in the composition and the structure, allow a definition and interpretation of the fossil associations. Similar environmental settings are characterized by fish associations with similar ecological features, according to the geographic position of the concerned locality (Nolf, 1995) and so in agreement with the concept of "parallel communities" (Thorson, 1957).

It worth noting that some attributes of the structure of the fish populations are linked to depth-size stratification and the bigger-deeper phenomenon (Polloni et al., 1979). Fish may change life habits or bathymetric distribution during their growth: some of them, pelagic in juvenile stage, show benthopelagic habits in the adult stage and therefore have a different ecological meaning. These changes are highlighted in the fossil assemblages. The analysis of the structure of fish populations, besides taxonomic composition, is a good tool for the interpretation of deep benthic and benthopelagic associations.

Consequently, several observations have been carried out on the otolith assemblages. With regards to the paleoecological approach, only the benthic and benthopelagic elements have been considered. The percentages of the dominance for the single taxon, belonging to these two groups, have been calculated (Tab. 1). It is worth noting that in the paleobathymetric method, the taxonomic composition of the whole assemblage is the only attribute taken into account; the abundance and the relative dominance do not influence the analysis.

RESULTS

The bulk samples collected along the Entalina and Fosso Giuseppe sections contain otoliths referable to 41 teleost taxa (Tab. 1) of which 26 still live in the Mediterranean, beside Atlantic or more generally oceanic taxa (for further taxonomic comments of peculiar taxa, see Nolf & Girone, 2000; Girone & Varola, 2001; Girone & Nolf, 2002; Girone et al., in press). In particular, *Bentho-sema suborbitale* and *Diaphus taaningi* are Atlantic species (Nafpaktitis et al., 1977); the genus *Aphanopus* (here represented by *Aphanopus* aff. *carbo*) is reported only from outside the Mediterranean: many localities in the Atlantic, Indian and Pacific oceans (Whitehead et al., 1986).

In most of the samples, the macrofaunal remains, both invertebrate and vertebrate, are rather rare and for a large part decalcified. Contrasting with the poorly fossiliferous samples, QET1 and FGQH show the highest species diversity and abundance whereas the samples FGQL and FGQM are only characterized by a high diversity. The sample FGQG is relatively less rich both in species and specimens.

The assemblages show low percentages of the benthic and benthopelagic components with respect to the pelagic group (Fig. 3), which is mainly represented by mesopelagic fishes (myctophids). With the exception of QET1 and FGQD, in which the percentages are lower than 5%, the benthic and benthopelagic group shows values mostly ranging from about 10% up to

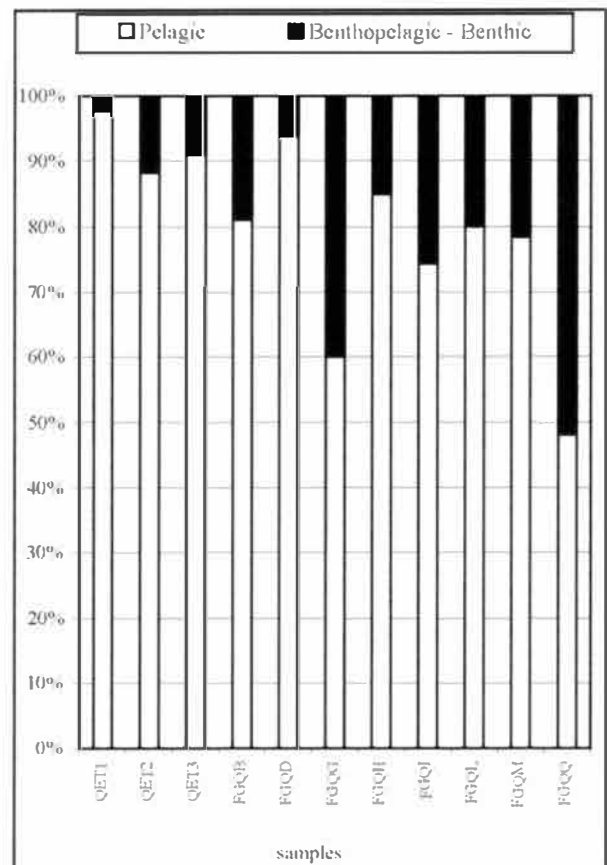


Fig. 3 - Benthopelagic-benthic/mesopelagic ratio in the otolith assemblages from Entalina and Fosso Giuseppe sections.

SYSTEMATIC LIST OF THE TAXA FROM ENTALINA AND FOSSO GIUSEPPE SECTIONS		QET1	QET2	QET3	FGQB	FGQB	FGQG	FGQH	FGQI	FGQL	FGQM	FGQQ
taxa in bold = Recent Atlantic taxa disappeared from Mediterranean												
* = extinct species												
PELAGIC												
STERNOPTHYCHIDAE	<i>Manrolucus muelleri</i> (Gmelin, 1789)	0.4			9.1	11.8	16.7		7.1	2.8	1.4	
	<i>Valenciennellus tripunctulatus</i> (Esmark, 1871)	0.4									1.4	
PHOSICHTHYIDAE	<i>Vinciguerrus powertae</i> (Cocco, 1838)	1.5				2.9						
MYCTOPHIDAE	<i>Benthosemi glaciale</i> (Reinhardt, 1837)	0.4	23.5	2.8		11.8		24.3	3.6	2.8	4.3	25
	<i>Benthosemi suborbitale</i> (Gilbert, 1913)	0.8										
	<i>Ceratoscopelus maderensis</i> (Lowe, 1939)	22.6	29.4	18.3	12.1	8.8	66.7	21.3	28.6	8.3	34.8	41.7
	<i>Diaphus</i> cf. <i>holi</i> Taaning, 1918										5.8	
	<i>Diaphus rafinesquii</i> (Cocco, 1838)	1.9		1.4			16.7	2.6	10.7	2.8	1.4	
	<i>Diaphus taaningi</i> Norman, 1930	13.8		23.9	33.3	44.1				13.9	11.6	
	<i>Diaphus</i> sp. 1	0.8										
	<i>Electrona rissoi</i> (Cocco, 1829)	0.8	11.8	8.5								
	<i>Hygophum benoitii</i> (Cocco, 1838)	9.6	5.9	18.3	27.3	5.9		26.0	25	13.9	18.8	16.7
	<i>Hygophum hygomi</i> (Lutken, 1892)	8.4	5.9		3					11.1	10.1	
	<i>Lampanyctus crocodilus</i> (Risso, 1810)					5.9		7		2.8	2.9	
	* <i>Lampadena</i> sp.	5.4										
	* <i>Lampadena ionica</i> Girone & Nolf, 2002			4.2								
	<i>Lobianchia dosleui</i> (Zugmayer, 1911)				6.1	5.9		0.9	10.7	13.9	5.8	8.3
	<i>Myctophum punctatum</i> Rafinesque, 1810	4.6	5.9	15.5	9.1			10.4	10.7	16.7		8.3
	<i>Nothoscopus elongatus</i> (Costa, 1844)	4.6	5.9	7		2.9		4.3	3.6	11.1	1.4	
	* <i>Scopelopsis phaeocemus</i> (Anf. & Mosna, 1976)	24.1										
total pelagic specimens		261	17	71	33	34	6	115	28	36	69	12
BENTHOPELAGIC												
	<i>Lampanyctus crocodilus</i> (Risso, 1810)	66.7	100	86								
GADIDAE	<i>Gadidulus argenteus</i> Guichenot, 1850				70		50	22.2	60	40	73.7	42.8
	<i>Atheromestis pouassou</i> (Risso, 1826)					33.3	25	22.2	20	20	5.3	21.4
	<i>Phycis blennoides</i> (Brunnich, 1768)				10	33.3	25	11.1				7.1
	<i>Merluccius merluccius</i> (Linneo, 1758)										10.5	
	<i>Gaidropsarus biscaienensis</i> (Collet, 1890)									10		7.1
MACROURIDAE	<i>Coelornichus coelornichus</i> (Risso, 1810)				10							
	* <i>Coelornichus stellaris</i> Nolf & Girone 2000									10		
	* <i>Coryphaenoides sicilianus</i> Schwarzhan, 1986	16.7										
	<i>Nezumia sclerorhynchus</i> (Valenciennes, 1838)			14								
CARANGIDAE	<i>Trachurus trachurus</i> (Linneo, 1758)							5.6				
	<i>Trachurus</i> ind.								10			
TRICHIURIDAE	<i>Aphanopus</i> aff. <i>carbo</i> Lowe, 1839	16.7										
BENTHIC												
BYTHIIDAE	<i>Bellottia</i> cf. <i>apoda</i> Giglioli, 1883							5.6				
	Bythidae ind.							11.1				
CEPOLIDAE	<i>Cepola rubescens</i> Linnaeus, 1766											7.1
GOBIIDAE	<i>Gobius</i> sp. 1							11.1	10		10.5	
	Gobiidae ind.					33.3						
	<i>Dehentosteus quadrimaculatus</i> (V., 1837)							5.6				
	<i>Lesueurigobius friesi</i> (Malm, 1874)							16.7		10		14.3
BOTIIDAE	<i>Arnoglossus</i> sp.				10							
SOLEIDAE	<i>Microchirus</i> ind.									10		
total benthic and benthopelagic specimens		6	2	7	10	3	4	20	10	10	19	14

Tab. 1 - Systematic list of teleost taxa from Entalina and Fosso Giuseppe sections. Relative abundance of each species and total number of specimens per sample. The populations of *L. crocodilus* have been included in the benthopelagic associations in the Entalina section and in the pelagic assemblages in the Fosso Giuseppe section due to age and size-related differences (see the text) fish. To provide a homogenised view of the relative abundance of each taxon percentage values are used. Although many of those percentages are not statistically significant (see total numbers of specimens used), they at least provide a homogenised picture that allows to compare trends that differentiate the successive samples.

20%. FGQG and FGQQ are the only assemblages with values of the benthic and benthopelagic group between 40% and 50%. In all the samples from the examined sections, the benthopelagic taxa are by far the most abundant with respect to the benthic fishes. This group is only well represented in the Fosso Giuseppe section (Tab. 1).

The different structure displayed by the myctophid *Lampanyctus crocodilus* populations permits to include it in the benthopelagic or mesopelagic group in the Entalina and Fosso Giuseppe assemblages respectively (Tab. 1), in relationship with the different life habit showed by the fish during the growth: from mesopelagic, in the juvenile stage, to benthopelagic later on (Stefanescu & Cartes, 1992). In the Entalina assemblages, mostly adult specimens compose the populations of *L. crocodilus* (Fig. 4a), while in the Fosso Giuseppe section, juvenile specimens and rarely sub-adult individuals are included (Fig. 4b). The structure of *L. crocodilus* populations in the Entalina assemblages is closely related to that from other Pleistocene deep bathyal assemblages (Girone, 2003); juvenile specimens coming from the shallower layer of column water, and adult specimens living close to the bottom. Conversely, juvenile individuals compose the *L. crocodilus* populations from deep shelf and very shallow bathyal assemblages from other Pleistocene sites (Girone, 2000b; Di Geronimo et al., 2003). Furthermore, the frequent occurrence of this myctophid at depths greater than 400 m on the sea floor of the Recent Mediterranean Sea and, in particular, the notable meaning in the deep-sea benthopelagic associations on the slope 400-800 m deep have been also addressed by Maurin (1968), Bombace & Li Greci (1970), Stefanescu et al. (1994) and D'Onghia et al. (1998).

The recognized macrourids can be divided into two groups according to their different ecological meaning: the deeper bathyal species found in the Entalina section and the shallower bathyal species only recognized in the Fosso Giuseppe assemblages (Tab. 1). In both sections, the abundance of these taxa could be increased if the numerous specimens, picked up in the outcrop, were also considered.

The first group includes *Nezumia sclerorhynchus*, reported as a characteristic species of continental slope at depths between 400-500 m and 800 m in the Recent Mediterranean Sea (Maurin, 1968; Ungaro et al., 1995; D'Onghia et al., 1998; D'Onghia et al., 2000), and *Coryphaenoides sicilianus*. The extinct species *C. sicilianus* has mainly been reported, in the bathyal assemblages of the Pliocene (Schwarzhan, 1986; Nolf & Cappetta, 1988) associated with the deep macrourid *Nezumia sclerorhynchus* and *Trachyrincus*. Today, the genus *Coryphaenoides* is known at depths greater than 400 m (Whitehead et al., 1986; Cohen et al., 1990) mainly in oceanic areas. One Recent species, *C. guentheri* is also known in the Mediterranean at depths greater than 1000 m (Stefanescu et al., 1994) but in the Atlantic with depths greater than 800 m (Cohen et al., 1990).

In QET 1, this macrourid is associated with the extra-Mediterranean species *Aphanopus* aff. *carbo*. *A. carbo* shows a wide bathymetric range (200-1600 m) on the

continental slope (Whitehead et al., 1986). Along the Portuguese coast, the depth distribution of this fish is more restricted (1000-1600 m) whereas in the Madeira area *A. carbo* occurs between 700 and 1300 m in waters characterised by low values of dissolved oxygen (ca. 6.0 mg/l), very small salinity gradients (35.6-36.0‰), a temperature of 8.5-10.5°C, and high nutrient values (Morales-Nin & Sena-Carvalho, 1996).

Medium size otoliths of the extant *C. coelorhincus* (sample FGQB), and of the extinct *C. stellaris* (sample FGQL) represent the second ecologic group. In the

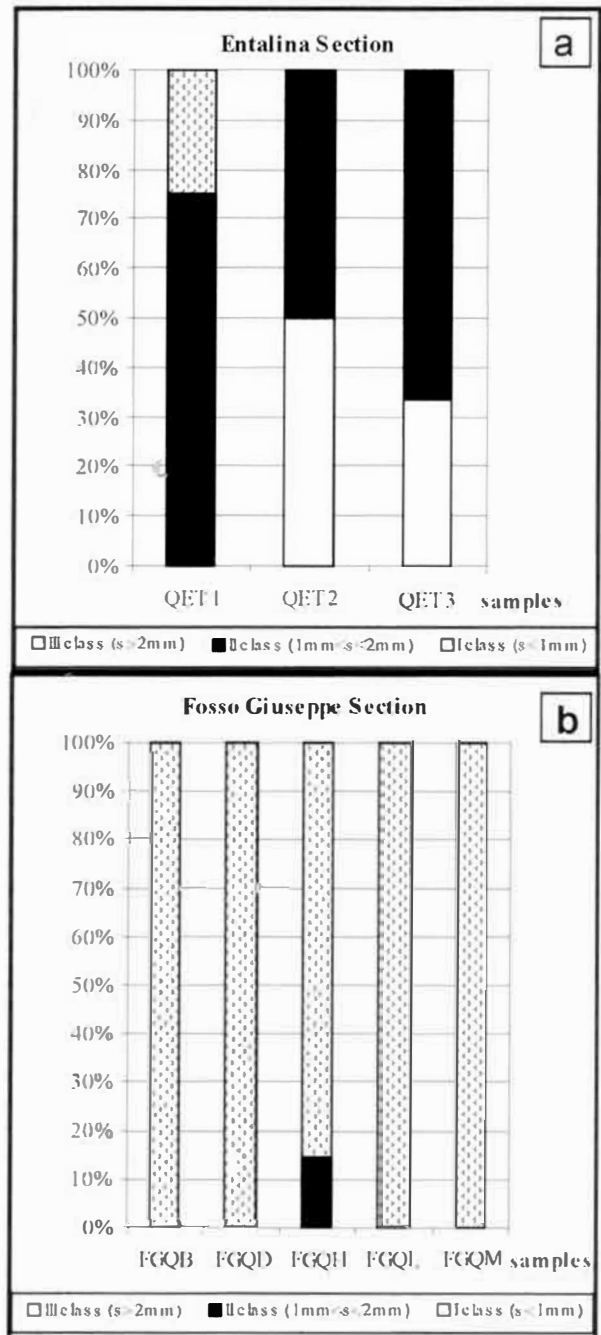


Fig. 4 - Size distribution of otoliths in *Lampanyctus crocodilus* populations. a) Size distribution in the populations from Entalina section. b) Size distribution in the populations from Fosso Giuseppe section.

Recent Mediterranean Sea, *C. coelorhincus* shows a marked abundance in the bathymetric interval between 300 and 500 m (Massuti et al., 1995) although, in the eastern and central Mediterranean, the highest densities of the small-medium size specimens have been observed in the uppermost 400-500 m (Maurin, 1968; D'Onghia et al., 2000). At depths greater than 400-500 m the abundance of *C. coelorhincus* decreases and, being subjected to the bigger-deeper phenomenon (Polloni et al., 1979), only the larger specimens occur at greater depths.

As elsewhere stressed (Girone, 2000b; Nolf & Girone, 2000; Girone, 2003), the extinct *C. stellaris* seems to have a similar life habit; common occurrence of medium-large specimens in the upper bathyal assemblages, and only very large individuals in deeper bathyal settings.

The gadids are found in all samples from the Fosso Giuseppe section (Tab. 1); in the Entalina section only larger specimens of *Micromesistius poutassou* have been recognized in the outcrop, but not in screenwashed samples.

In the Fosso Giuseppe section, *G. argenteus* and *M. poutassou*, represented by medium-large size specimens, are dominant with respect to other species. Moreover, numerous specimens were also collected from the surface of the outcrop. These fishes, in adult stage, live on the upper continental slope with a maximum abundance in the bathymetric range between 200 and 400 m, both in the Mediterranean and in the Atlantic (Maurin, 1968; Bombace, 1972; Arena & Li Greci, 1973; Cohen et al., 1990); only the larger individuals seems to move at greater depth. In the Ionian Sea, *M. poutassou* is reported as characteristic species of the upper slope (200-400 m deep), just like *Merluccius merluccius* (D'Onghia et al., 1998) found in the sample FGQM and the bothid *Arnoglossus* recognized in the sample FGQB.

The benthic group includes five shelf species with *Lesueurigobius friesii* and *Gobius* sp. 1 more frequent as well as the eurytopic taxa, *Bellottia* cf. *apoda* and *Arnoglossus* (Tab. 1). In the samples FGQ1, FGQ2, and FGQM, benthic taxa are reduced to just one species representing only 10% of the association while in the samples FGQH and FGQQ, they are more abundant in number and species and represent over 21% of the benthic and bathypelagic associations.

L. friesii, a cryptobenthic fish (burrowing in muddy sand and mud), is generally known at depths between 10 and 130 m and is often associated with the decapod *Nephrops* (Tortonese, 1975; Whitehead et al., 1986). According to various authors (Maurin, 1968; Arena & Bombace, 1970) it can inhabit muddy substrate and, preferably, the deeper part of its bathymetric range or

at greater depths (Matarrese et al., 1996) moving in the transitional-to-slope zone. In the Fosso Giuseppe section, *L. friesii* is associated with the outer shelf - shelf margin fish (Arena & Bombace, 1970) *Cepola rubescens* (sample FGQQ) and with *Deltentosteus*

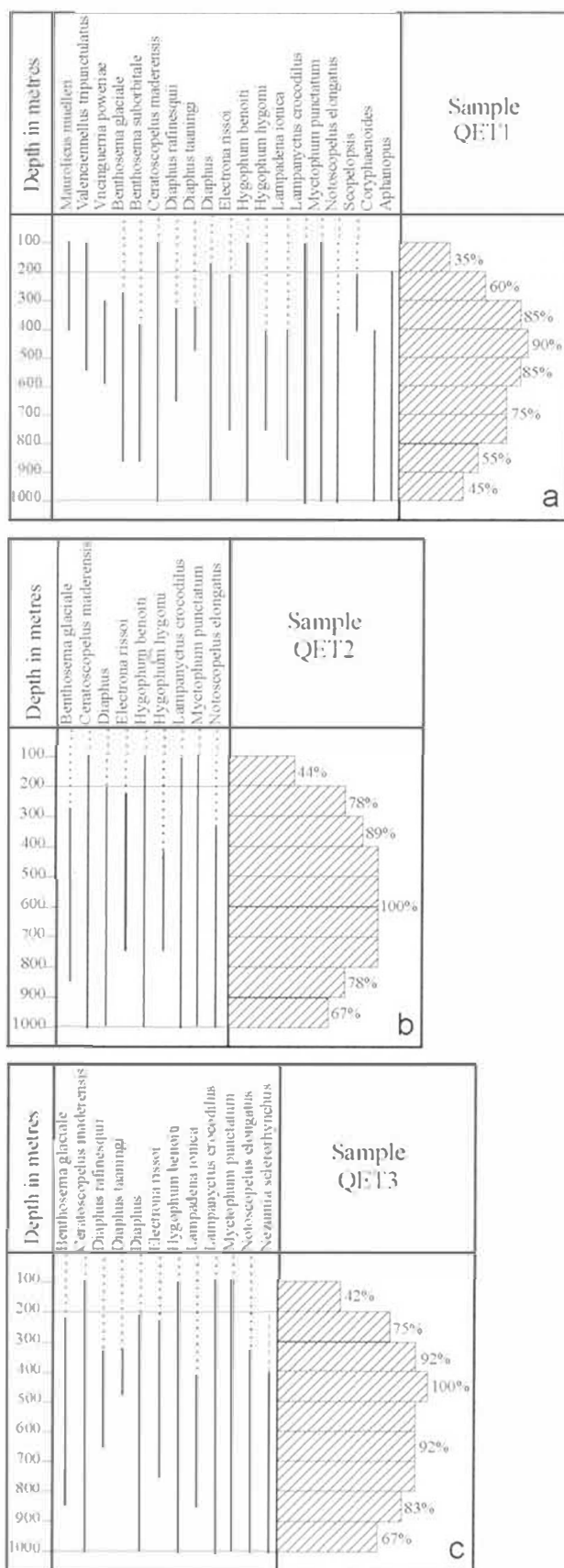


Fig. 5 - a) Recent bathymetric distribution of teleost taxa represented in QET1; b) in QET2; and c) QET3 assemblages from Entalina section. For each 100 m bathymetric interval, the graph shows the potential presence, expressed as a percentage of the total number of taxa utilized in the analysis. The dotted lines indicate nightly presence of mesopelagic species at the surface; for a more detailed discussion of the methodology, see Nolf & Brzobohaty (1994).

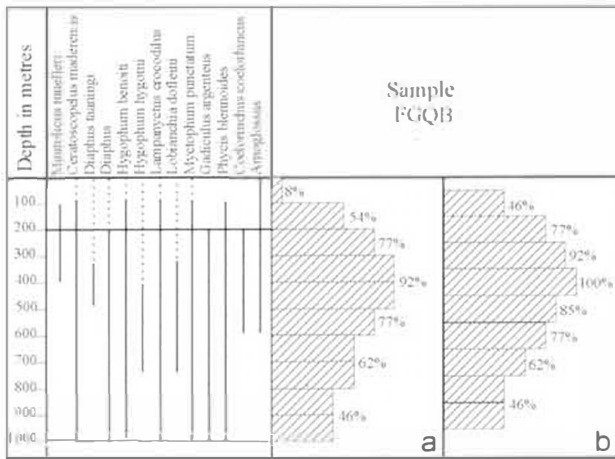


Fig. 6 - a) Recent bathymetric distribution of teleost taxa represented in FGQB assemblage from Fosso Giuseppe section; see Fig. 6 for the explanation. b) Revised graph obtained changing the limits of the 100 m intervals: 50-150 m, 150-250 m, etc. instead of 0-100 m, 100-200 m, etc.; for a more detailed discussion of the methodology, see Nolf & Brzobohaty (1994).

quadrifasciatus (sample FGQH) that is reported as typical species in the Recent outer shelf associations by Arena & Bombace (1970). The fossil taxon *Gobius* sp. 1 has been reported, up to now, in Pleistocene outer shelf associations (Girone, 2000a, b).

The pelagic group mainly includes mesopelagic fishes belonging to the Family Myctophidae (Tab. 1) as well as the sternopterygids *Maurollicus muelleri* and *Valenciennellus tripunctulatus*. The latter two are both present in the Recent Mediterranean and in the Atlantic; *M. muelleri* is more common in the Mediterranean and lives in a bathymetric range between 100 and 400 m while *V. tripunctulatus* is more common in the Recent Atlantic and is reported at depths between 100 and 550 m.

Among the myctophids, *Ceratoscopelus maderensis* occurs in all the samples and shows high values of dominance. *Benthosema glaciale*, *Hygophum benoitii*, *Myctophum punctatum*, and *Notoscopelus elongatus* have also been frequently found (Tab. 1). The deep myctophid *Electrona rissoi* has only been recognized in samples of the Entalina section while *Lobianchia dofleini* occurs only in the Fosso Giuseppe section. The Atlantic *Diaphus taaningi*, occurring in the all examined sections, is a species associated with land environments and land-orientated food chains (Hulley, 1981). In the Fosso Giuseppe section, it occurs only in some samples but in these it always shows high values of dominance (Tab. 1).

The analysis of the whole assemblages (pelagic, benthopelagic and benthic) from the Entalina section by means of the paleobathymetric method suggests a depth interval of 400-500 m for the assemblages QET1 and QET3 (Figs. 5a, c) and a wider interval ranging between 400-800 m for the QET2 assemblage (Fig. 5b).

In the Fosso Giuseppe section, the graph of the basal assemblage FGQB indicates a wide depth interval ranging between 300 and 500 m (Fig. 6a). By changing

the limits of the 100 m intervals (50-150 m, 150-250 m, etc. instead of 0-100 m, 100-200 m, etc.) (Nolf & Brzobohaty, 1994) the resulting graph indicates a depth ranging between 350 and 450 m (Fig. 6b).

The graph of the FGQH assemblage as well as the graph of the FGQQ assemblage (Figs. 7a-b), both of which are composed of heterogeneous benthic and benthopelagic associations, indicates a wider depth interval probably ranging between 300 and 500 m. The revised graphs again show a wide peak, corresponding to bathymetric interval between 250 and 450 m (Figs. 7a1-b1); the diagrams are flattened and the values of the peaks are very homogenous in the whole bathymetric interval.

The graphs of the FGQD and FGQG assemblages show a clear peak between 300 and 400 m (Figs. 8a-b), reaching 100% values; in this interval, all taxa can be present. The same bathymetric interval is indicated for the assemblages FGQI, FGQL, and FGQM (Figs. 8c-e), but in these cases the peaks show lower values and a clear difference between the peaks of 100 till 200 m and the deeper intervals. This point is well highlighted by comparing the graphs of the FGQI, FGQL, and FGQM with the Entalina assemblages, which clearly indicate a bathyal environment.

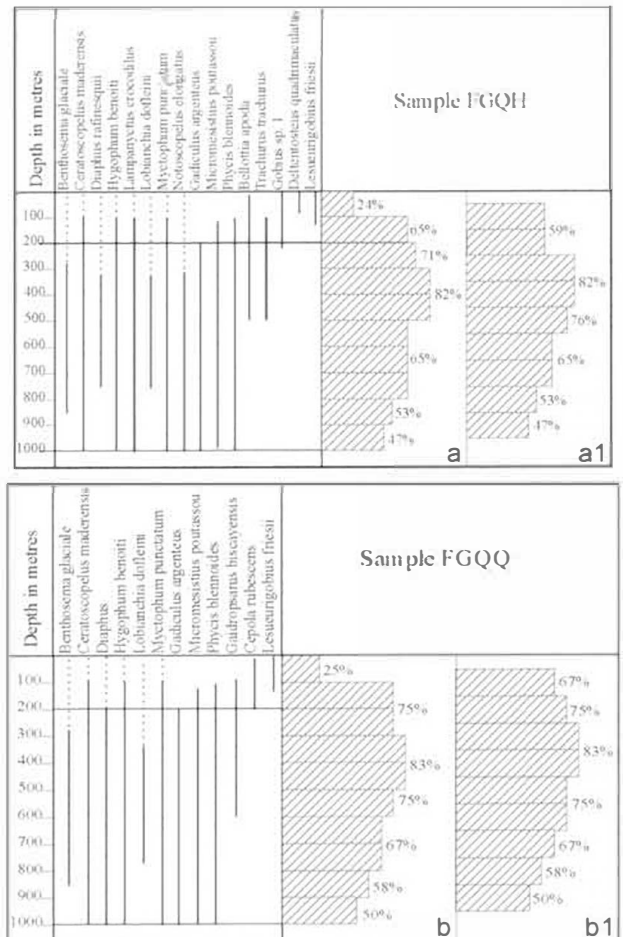


Fig. 7 - a) Recent bathymetric distribution of teleost taxa represented in FGQH; and b) in FGQQ assemblages from Fosso Giuseppe section. a1) Revised graph of FGQH assemblage. b1) Revised graph of FGQQ assemblage; see Fig. 5 and Fig. 6 for the explanation.

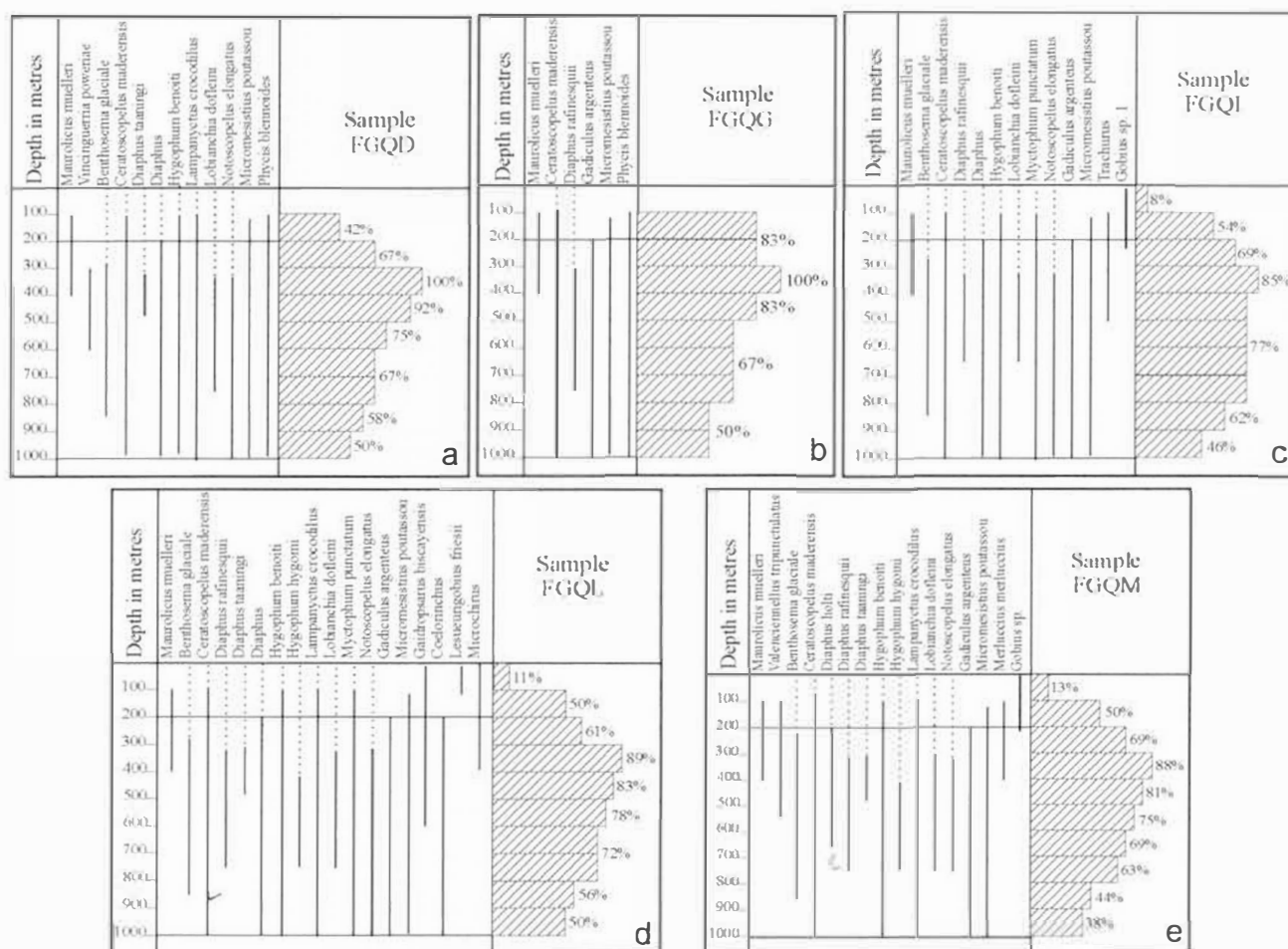


Fig. 8 - a) Recent bathymetric distribution of teleost taxa represented in FGQD; b) in FGQG; c) in FGQI; d) in FGQL; and e) in FGQM assemblages from Fosso Giuseppe section; see Fig. 6 for the explanation.

DISCUSSION AND CONCLUDING REMARKS

The studied benthic and benthopelagic otolith associations are generally bathyal in nature. However, several shelf species are also present in some associations of the Fosso Giuseppe section. The benthopelagic fishes are largely represented by gadids and macrourids, whereas the benthic group is mostly composed of mud and silt-dwelling epifaunal and infaunal species.

The Entalina associations, characterized by deep water macrourids *N. sclerorhynchus* and *C. sicilianus* as well as by adult individuals of myctophid *L. crocodilus*, are referable to the upper part of the middle bathyal zone at the depth of about 500-600 m.

The benthic and benthopelagic associations recognized in the Fosso Giuseppe section clearly indicate an upper slope environment located in the shallower interval due to the common and abundant presence of species characteristic of this interval, such as the gadids *Gadiculus argenteus*, *Micromesistius poutassou*, and *Phycis blennoides*. The associations recognized in the lowermost samples FGQB, FGQD, and FGQG, which are lacking or with a low component of shelf species, indicate a deeper upper slope environment of 300-400 m. In particular, the

associations of the sample FGQB, characterized also by the presence of the macrourid *C. coelorinchus*, may be slightly deeper.

Upward, the paleoecological analyses of benthic and benthopelagic associations shows co-occurrence of upper slope benthopelagic fishes and shelf benthic fishes; the latter, in favourable conditions, prefer to inhabit the deeper part of their bathymetric range.

In the associations of the samples FGQL and FGQM, the shallow benthic fishes are reduced to single species and are largely subordinated to the upper slope group; a paleodepth probably very similar to the association recognized in the sample FGQG may be inferred. Conversely, the shelf species and in particular species characteristic of deep outer shelf (*D. quadrimaculatus*, *T. trachurus* and *C. rubescens*) show a higher abundance in the samples FGQH and FGQQ, suggesting an upper slope transitional to shelf-margin setting. In the southern Adriatic Sea, Recent benthic and benthopelagic associations very similar to the Pleistocene associations have been recognized in similar environmental setting 200-250 m deep (Ungaro et al., 1995).

The data obtained by means of the paleoecological analyses are largely in agreement with the results deduced by means of the paleobathymetric method.

The latter well distinguishes the deeper assemblages recognized in the Entalina section from the shallower slope assemblages of the Fosso Giuseppe section, even if the composition and the structure of the benthic and benthopelagic associations from the Entalina section suggest that the deeper part of the bathymetric range indicated by the bathymetric graph (Figs. 5a-c) may be more probable.

With regard to the upper slope associations of the Fosso Giuseppe section, the paleobathymetric method seems to discriminate different depth intervals into it, but provides wide and not significant bathymetric intervals for the shallower assemblages. In these cases, it is clearly evident that the mesopelagic components (which may be very abundant in the shelf and slope assemblages) may distort the real environmental meaning of the assemblage, obscuring the importance of the composition and structure of the benthic and benthopelagic associations as already stressed elsewhere for deep-sea assemblages (Girone, 2003).

The bathymetric range of the associations recognized in the Entalina section indicate a homogenous environment located at the upper interval of the middle bathyal zone (500-600 m) while the distribution of the associations recognized in the Fosso Giuseppe section indicates cyclic changes of depth ranging from 350-450 m up to 200-250 m (Fig. 9a). The first shallowing phase occurs at about 75 m from the bottom of the section. Upward the associations indicate again a clearly epibathyal environment; a new shallowing phase occurs a few metres above the volcanoclastic layer V1 (Fig. 9a).

The cycles recognized with the otoliths are in good agreement with the cycles inferred by macrobenthic invertebrate (Ciaranfi et al., 2001; D'Alessandro et al., 2003) for the same stratigraphic interval. The shallowing phase at about 30 m from the bottom of the section (Fig. 9b) indicated by the invertebrate associations is not registered in this study because of the scarcity of otoliths and their unreliable ecological meaning. In the middle-upper part (above the gap in Fig. 9c) of the Montalbano Jonico, the paleobathymetric analysis based on otolith assemblages showed a higher order cycle comparable with the envelope of the minor cycles obtained by means of the macrobenthic invertebrate associations. In this interval, only the paleobathymetric method proposed by Nolf & Brzobohaty (1994) has been applied (Girone, 2000a).

However, the otolith associations indicate a general regressive trend from upper slope to shoreface environments, in agreement with the data obtained by means of the invertebrate associations (macrobenthic and microbenthic) (Ciaranfi et al., 1997; Ciaranfi et al., 2001; Stefanelli, 2003) and taphofacies analysis (Soldani, 2000).

As noted earlier, the teleostean fauna from the lower Pleistocene of the Montalbano Jonico is characterized by the presence of Atlantic, or more generally oceanic taxa (Tab. 1). They also include the tropical-subtropical mesopelagic fish *Benthoosema suborbitale* already known in the Mediterranean Sea from the early Pliocene (Nolf et al., 1998), and that seems to survive until the early Pleistocene (large *Gephyrocapsa* nanofossil

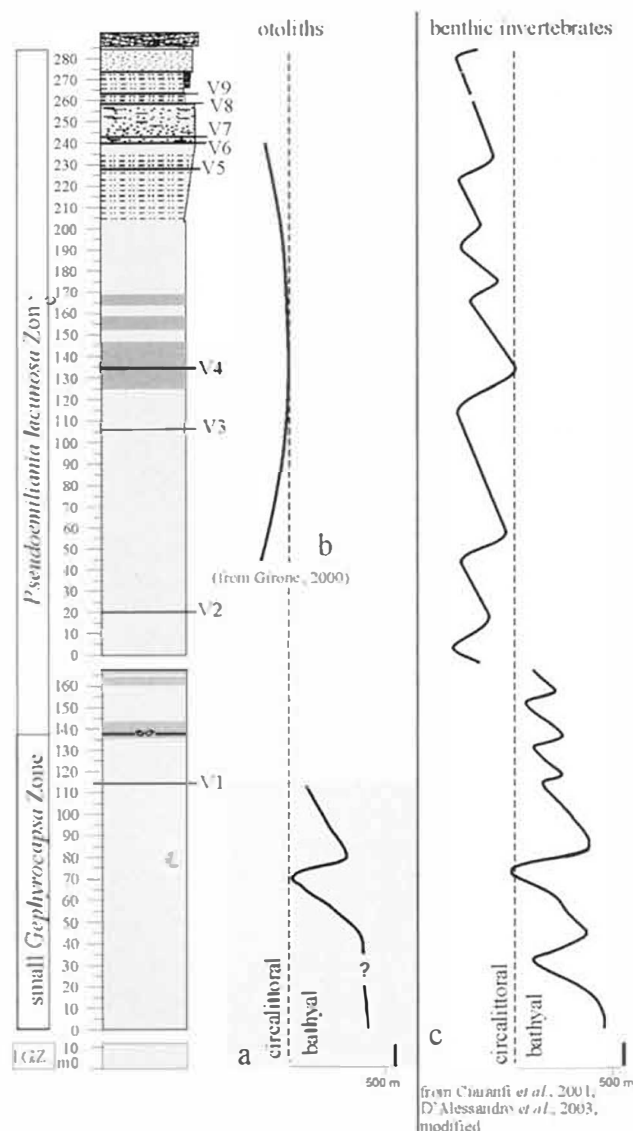


Fig. 9 - Paleobathymetric curves for the Montalbano Jonico section based on different approaches. a) and b) otoliths; c) benthic invertebrates (from Ciaranfi et al., 2001; D'Alessandro et al., 2003). The curve of Fig. 9a is based on the data from the present work; the curve of Fig. 9b is from Girone (2000a). For the legend, see Fig. 2.

biozone). According to the available data, this species is lacking in all younger Pleistocene otolith assemblages. Other taxa, with oceanic or Atlantic affinity, have been discussed elsewhere (Nolf & Girone, 2000; Girone, 2000b; Girone & Nolf, 2002; Girone, 2003), and include the pelagic fossil species *Scopelopsis pliocenicus* and *Lampadena ionica* and the fossil benthopelagic *Coelorinchus stellaris*. In addition to known taxa, the Montalbano teleostean fauna includes the Recent *Aphanopus* aff. *carbo*, recently recognized in coeval deposits from Sicily associated with other deep-sea Atlantic taxa (Girone, unpublished data). Off the Recent North Atlantic coast, it seems closely related to cold deep-sea water (Morales-Nin & Sena-Carvalho, 1996).

The occurrence of these taxa is a further proof of the marked Atlantic or generally oceanic affinity of the Pleistocene teleostean deep-sea fauna of the

Mediterranean. This marked Atlantic affinity, persisting from the Pliocene (Nolf et al., 1998; Girone, 2000b), seems to be linked, alongside global climate changes, to the different paleoceanographic settings in the Mediterranean Sea during the Plio-Pleistocene. However, the Montalbano Jonico deep-sea fauna appears to lack many of the Recent North Atlantic deep-sea taxa that regularly are collected from coeval sediments in southern Italy (southern Calabria and Sicily) (Girone, 2003; Girone, unpublished data). These other Pleistocene assemblages are referable to similar depths registered for the Entalina section, the shallower depths of the Montalbano Jonico assemblages, and/or geographic position may be responsible for a different faunistic composition. The Montalbano Jonico sections were located in the interior border of Apennine Foredeep, may be less exposed to influence of Atlantic water than the other investigated sections in southern Italy. However, no other definitive paleontological data are available to support this hypothesis, and more data on the otolith fauna are required.

Conversely, the presence of the Recent Atlantic species *Bonapartia pedaliota* and *Polyipnus polli* in the outer shelf assemblages from the upper part of the Montalbano Jonico succession (middle Pleistocene in age) (Girone & Varola, 2001) seems more related to climate than paleoceanographic setting. They occur in a stratigraphic interval which, according to micropaleontological data, corresponds to interglacial phases and, consequently, to a relative "warmer" period.

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