A new bathyal shark fauna from the Pleistocene sediments of Fiumefreddo (Sicily, Italy)

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ABSTRACT
A new shark fauna is described from the lower-middle Pleistocene marine sediments outcropping near the Fiumefreddo village, Southern Italy. The fossil assemblage mostly consists of teeth belonging to the bathydemersal and bathypelagic elasmobranch species *Chlamydoselachus anguineus*, *Apristurus* sp., *Galeus* cf. *melastomus*, *Etmopterus* sp., *Centroscymnus* cf. *crepidater*, *Scymnodon* cf. *ringens*, *Centrophorus* cf. *granulosus* and *C.* cf. *squamosus*, commonly recorded along the extant outer continental shelf and upper slope. From a bathymetrical point of view, the present vertical distribution of the taxa collected allows an estimate of a depth between 500 and 1000 m. The bathyal character of the fauna provides new evidence of a highly diversified and heterogeneous deep-sea Mediterranean Plio-Pleistocene marine fauna, in response to the climatic and hydrographical changes. Finally, the Fiumefreddo fauna provides new relevant data for the understanding of the processes involved in the evolution of the extant Mediterranean selachian fauna.

KEY WORDS
Elasmobranchii,
sharks,
bathyal,
teeth,
paleobiogeography,
Pleistocene,
Sicily,
Italy.

RÉSUMÉ
Une nouvelle faune de requins bathyaux des sédiments du Pléistocène de Fiumefreddo (Sicile, Italie).
Une nouvelle faune de sélaciens bathyaux est décrite des sédiments marins du Pléistocène inférieur-moyen de Fiumefreddo, Italie méridionale. L'association fossile comprend en majorité des dents attribuées à des espèces d'élasmobranches bathydémersaux et bathypélagiques *Chlamydoselachus anguineus*, *Apristurus* sp.,

Galeus cf. *melastomus*, *Etmopterus* sp., *Centroscymnus* cf. *crepidater*, *Scymnodon* cf. *ringens*, *Centrophorus* cf. *granulosus* et *C.* cf. *squamosus*, largement répartis actuellement sur le plateau continental externe et sur le talus supérieur. En ce qui concerne la bathymétrie, la distribution verticale actuelle des taxa a permis d'estimer une profondeur d'environ 500 à 1000 m. Le caractère bathyal de la faune fournit de nouvelles preuves de la mise en place d'une faune marine profonde méditerranéenne au Plio-Pléistocène fortement diversifiée et hétérogène, en réponse aux changements climatiques et hydrographiques. En conclusion, la faune de Fiumefreddo fournit de nouveaux éléments importants pour la comparaison des processus évolutifs principaux impliqués dans la mise en place de la faune actuelle méditerranéenne de sélaciens.

MOTS CLÉS
Elasmobranchii,
requins,
bathyal,
dents,
paléobiogéographie,
Pléistocène,
Sicile,
Italie.

INTRODUCTION

The Mediterranean Sea represents a semi-enclosed basin, characterized by a very impoverished bathyal fauna. This is mostly due to the restricted connection with the Atlantic Ocean, as well as to the peculiar hydrological conditions. Recently it has been demonstrated that no more than 8.6% of the total Mediterranean fauna is restricted to depths below 200 m (Bouchet & Taviani 1992). In the last decades, studies on fossil marine vertebrate and invertebrate groups have allowed to infer the main Plio-Pleistocene climatic and oceanographic changes and geological events that deeply characterized the evolutionary history of the Mediterranean Sea. In particular, many efforts have been made to define the great diversity, disparity, and heterogeneity that characterized the Plio-Pleistocene invertebrate and vertebrate fauna of the Mediterranean (see e.g., Benson 1972; Landini & Menesini 1978, 1986; Gaetani & Saccá 1984; Van Harten 1984; Raffi 1985; Sprovieri 1985; Nolf & Cappetta 1989; Barrier *et al.* 1989; Landini & Sorbini 1993, 2005a, b; Di Geronimo & La Perna 1996, 1997a; Nolf *et al.* 1998; Monegatti & Raffi 2001; Girone & Varola 2001; Di Geronimo *et al.* 2003; Girone 2003; Girone *et al.* 2006).

The elasmobranches represent an ecologically relevant group in the marine environments, because of their prominent trophodynamic. However, the studies of this predatory group have never reached a relevant role for the understanding of the main Plio-Pleistocene paleoenvironmental changes of the Mediterranean basin. The relatively poor knowledge of the Mediterranean Plio-Pleistocene shark fauna (see e.g., Landini 1977; Cigala Fulgosi & Mori 1979; Cigala Fulgosi 1984, 1988a; Cappetta & Nolf 1991; Bellocchio *et al.* 1991; Cappetta & Cavallo 2006; Carnevale *et al.* 2006; Marsili 2007) only provides some data about the diversity of some epipelagic and upper mesopelagic groups. As far as Mediterranean fossil deep-water elasmobranches are concerned, although bathyal taxa have been occasionally recorded in Pliocene sediments (see e.g., Lawley 1876; De Stefano 1911; Landini 1977; Cappetta 1987; Cappetta & Nolf 1991; Cappetta & Cavallo 2006), well developed deep-sea assemblages are rare. Cigala Fulgosi (1986, 1996), for example, described a deep-sea Mediterranean shark teeth fauna from the lower Pliocene sediments, of Sant'Andrea a Bagni (Parma district, Northern Apennines). A stratigraphic gap in the middle-upper Pliocene and the Pleistocene, characterizes the fossil record of bathyal shark species.

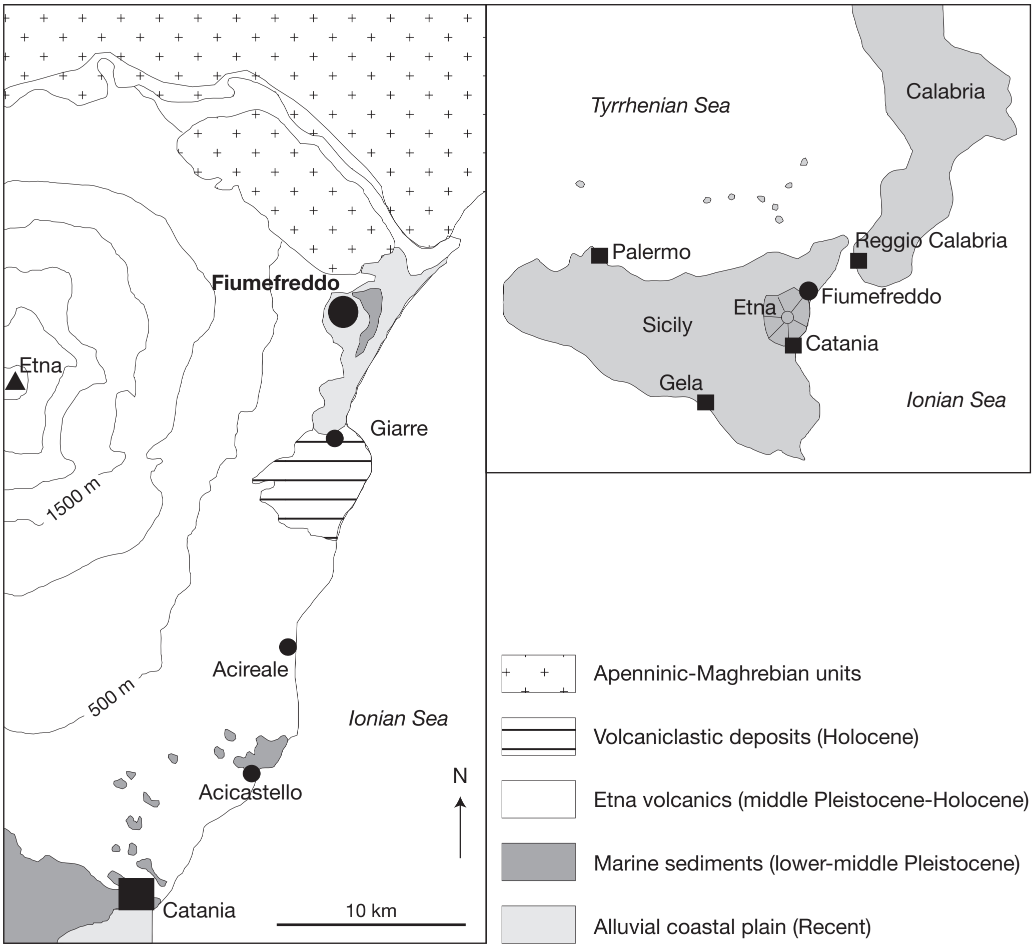


Fig. 1. — Geological sketch map of Fiumefreddo (Sicily, Italy); modified from Lanzafame *et al.* (1999) and Di Stefano & Branca (2002).

Here, a new fossil shark assemblage has been studied from the marine sediments outcropping near the Fiumefreddo village (Catania district, Sicily). This fossil assemblage improves our understanding of the relationships existing between the climatic and hydrographical changes and the development of a diversified bathyal Plio-Pleistocene fauna in the Mediterranean Sea (see e.g., Barrier *et al.* 1989; Di Geronimo & La Perna 1996, 1997a; Girone *et al.* 2006), presenting new data for understanding the evolutionary and historical processes involved in the establishment of the extant Mediterranean fish fauna (see also Landini & Sorbini 2005a, b).

MATERIALS AND METHODS

Ten fossiliferous horizons were examined. The samples (20 dm^3, routinely processed and sieved for macrofaunal studies) were collected for the study of fish otoliths fauna (see Girone *et al.* 2006), and then provided to the author for the study of the shark teeth. Thirty-four fossil teeth were extracted from eight of these fossiliferous horizons (see Table 1). About half of the teeth collected are well preserved, while the remaining material is fragmentary crowns and roots of little taxonomic interest. This sample included a number of teeth belonging to the teleostean family Trichiuridae, from several horizons (see Table 1). The specimens are deposited in the Museo di Paleontologia of the University of Catania (PMC). Morphological and tooth terminology mainly follows that of Ledoux (1970), Cappetta (1987), and Herman *et al.* (1989, 1990, 1993). Taxonomic information were derived from papers by Garrick (1956, 1959a-c), Cigala Fulgosi & Gandolfi (1983), Compagno (1984), Cigala Fulgosi (1988b, 1996) and Adnet & Cappetta (2001).

GEOLOGICAL SETTING

The northern and southern sector of the Etna Volcano are characterized by a continuous bioclastic calcarenites and marly clays succession (Lanzafame *et al.* 1999; Di Stefano & Branca 2002). In the southern sector, the calcarenites and marly clays sequence is part of a Plio-Pleistocene regressive succession that characterized the basement of the Gela-Catania foredeep (Lanzafame *et al.* 1999; Di Stefano & Branca 2002). In the north-eastern sector, such a marine succession unconformably covers the basement, represented by the inner units of the Apenninic-Maghrebian Chain (Lanzafame *et al.* 1999; Di Stefano & Branca 2002). A complex geodynamic evolution, that characterized the frontal area of the Apenninic-Maghrebian Chain, caused a more consistent uplift of the Pleistocene deposits of the northern sector, as a consequence of a buried thrust located on the northern flank of the Etna Volcano (Di Stefano & Branca 2002).

The most complete calcarenites and marly clays section crops out along the flanks of the Serra S. Biagio hill, in the northern sector of the Etna Volcano (Lombardo 1980; Lanzafame *et al.* 1997, 1999; Di Stefano & Branca 2002). The presence of the foraminiferas *Hyalinea balthica* and *Globorotalia truncatulinoides excelsa* suggested an age for these marine sediments of lower-middle Pleistocene (Lombardo 1980; Lanzafame *et al.* 1999). Recently, Di Stefano & Branca (2002), on the basis of the nannoplancton calcareous content, referred the lower part of this section to the "Small" *Gephyrocapsa* Zone of Rio *et al.* (1990), and the uppermost part to the *Pseudoemiliana lacunose* Zone of Rio *et al.* (1990).

The fossil material documented in this paper has been collected from a section located near the Fiumefreddo village (Catania district, Sicily), along the northern flank of the Serra S. Biagio hill (Fig. 1). The succession is represented by about 4.5 m of silty clays conformably covered by about 5 m of blue marly clays (Angela Girone pers. comm.). The shark teeth described herein were extracted from seven silty clays horizons (Fiumefreddo Nord 2-8), belonging to the "Small" *Gephyrocapsa* Zone, and one marly clays horizon (Fiumefreddo Cava 2) referred to the *Pseudoemiliana lacunose* Zone (Girone *et al.* 2006).

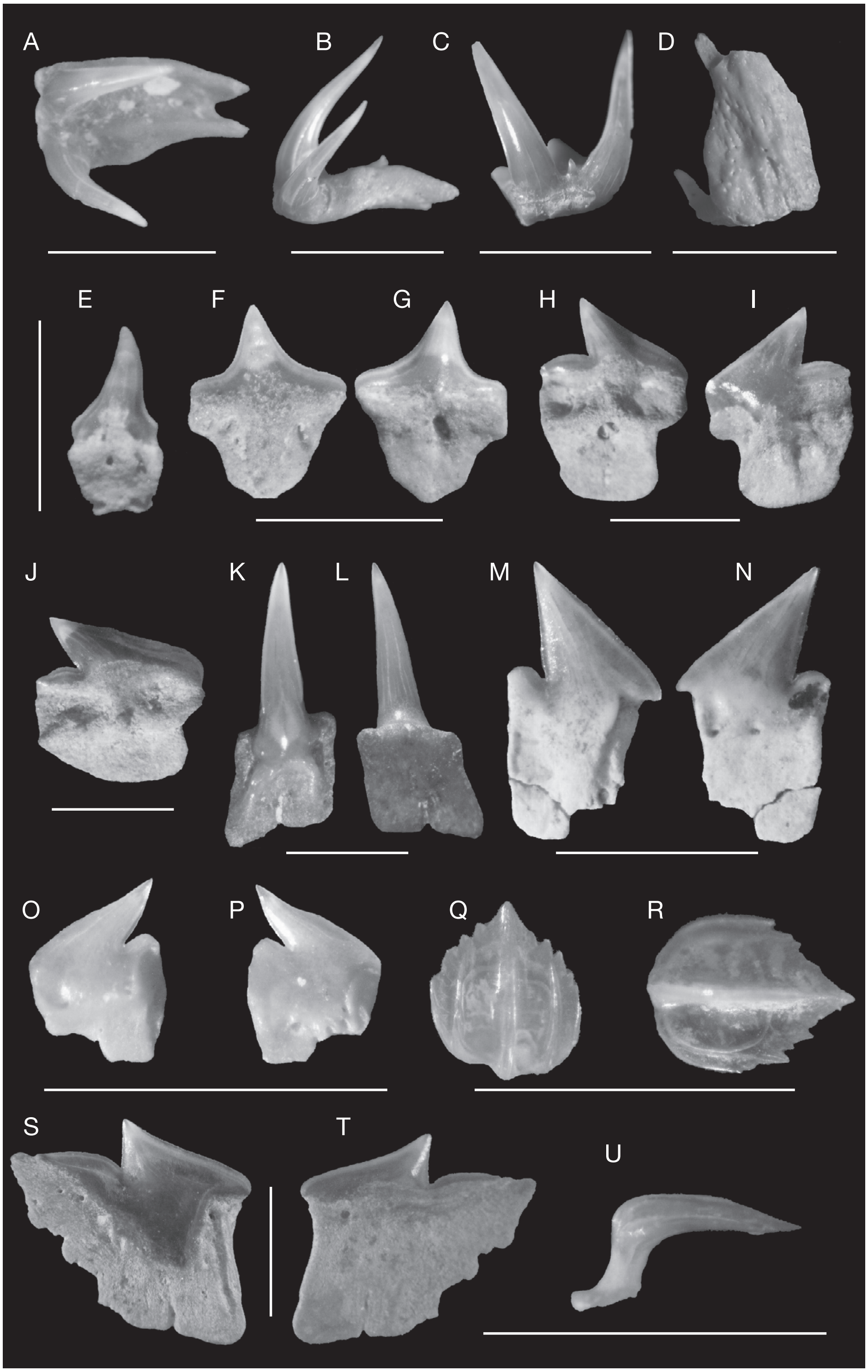
SYSTEMATICS

Order HEXANCHIFORMES Buen, 1926
Family CHLAMYDOSELACHIDAE Garman, 1884
Genus *Chlamydoselachus* Garman, 1884

Chlamydoselachus anguineus Garman, 1884
(Fig. 2A-D)

MATERIAL EXAMINED. — One incomplete tooth and one eroded root (PMC Fiumefreddo 1996. I. Pl. Sel. 1, 2).

FIG. 2. — **A**-**D**, *Chlamydoselachus anguineus* Garman, 1884, anterior-lateral tooth (PMC Fiumefreddo 1996. I. Pl. Sel. 1); **A**, lingual view; **B**, lateral view; **C**, labial view; **D**, basal view; **E**-**J**, *Centrophorus* cf. *granulosus* (Bloch & Schneider, 1801); **E**, upper anterior tooth, lingual view (PMC Fiumefreddo 1996. I. Pl. Sel. 12); **F**, **G**, upper anterior-lateral tooth (PMC Fiumefreddo 1996. I. Pl. Sel. 13); **F**, labial view; **G**, lingual view; **H**, **I**, lower anterior-lateral tooth (PMC Fiumefreddo 1996. I. Pl. Sel. 14); **H**, lingual view; **I**, labial view; **J**, lower anterior-lateral tooth, lingual view (PMC Fiumefreddo 1996. I. Pl. Sel. 15); **K**-**N**, *Scymnodon* cf. *ringens* Bocage & Capello, 1864; **K**, **L**, upper anterior-lateral tooth (PMC Fiumefreddo 1996. I. Pl. Sel. 10); **K**, labial view; **L**, lingual view; **M**, **N**, lower anterior-lateral tooth (PMC Fiumefreddo 1996. I. Pl. Sel. 11); **M**, labial view; **N**, lingual view; **O**, **P**, *Etmopterus* sp., lower anterior-lateral tooth (PMC Fiumefreddo 1996. I. Pl. Sel. 8); **O**, lingual view; **P**, labial view; **Q**, **R**, **U**, *Centrophorus* cf. *squamosus* (Bonnaterre, 1788); **Q**, **R**, dermal scale, ventral view; **Q**, PMC Fiumefreddo 1996. I. Pl. Sel. 16; **R**, PMC Fiumefreddo 1996. I. Pl. Sel. 17; **U**, dermal scale, lateral view (PMC Fiumefreddo 1996. I. Pl. Sel. 17); **S**, **T**, *Centroscymnus* cf. *crepidater* (Bocage & Capello, 1864), lower commissural tooth (PMC Fiumefreddo 1996. I. Pl. Sel. 9); **S**, labial view; **T**, lingual view. Scale bars: 3 mm.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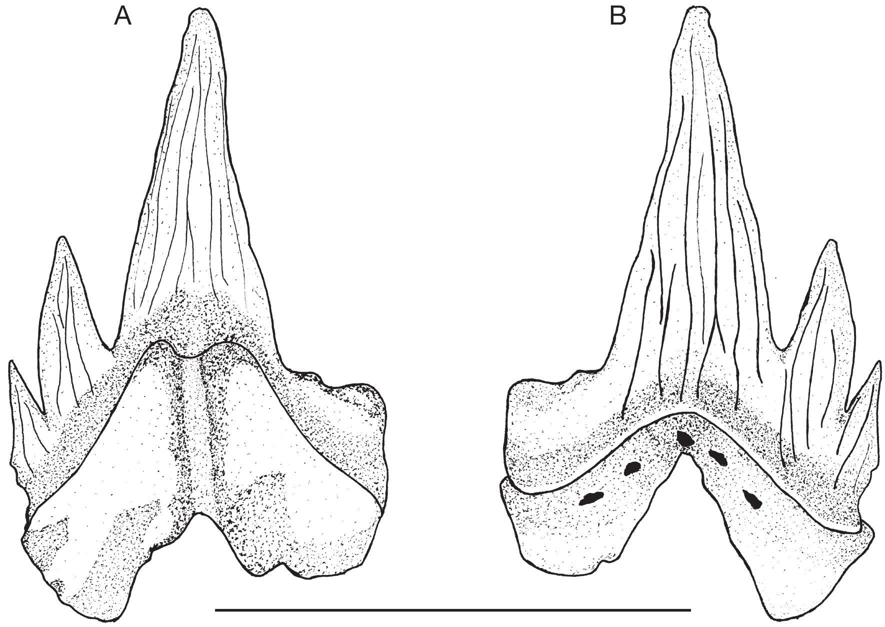

Fig. 3. — *Apristurus* aff. *laurussoni* (Saemundsson, 1922), lower anterior tooth (PMC Fiumefreddo 1996. I. Pl. Sel. 3): **A**, lingual view; **B**, labial view. Scale bar: 1 mm.

Description

The incomplete tooth lacks the distal lateral cusp and part of the root. The median and mesial lateral cusps are thin, slender and sigmoid, with a few short basal folds. The mesial lateral cusp is more sigmoid than the median one and laterally divergent. The labial face of the cusps is flat to slightly convex, while the lingual face is completely convex. The lateral mesial and distal cutting edges of the cusps are smooth. There is a very short intermediate cusplet between the median and mesial lateral cusps.

The root is perpendicular to the cusps. The labial face of the root is short with a well developed basal mesial depression. The basal face of the root is broad, flat, and labio-lingually elongated with two lobe-like extensions directed lingually, that provided a transversal interlocking with the labial mesial depressions of the root of the previous tooth of the same row. A mesial depression characterized the basal face of the root, in which is presents a large central oval-shape foramen. A great number of small foramina are randomly scattered all over the root base. The lingual face of the root is divided into three distinct regions by two high, thick crests. The central concave to slightly flat region is characterized by a large central foramen. The distal and mesial regions are flat and slightly sloped, with few small foramina randomly scattered. Two or three small foramina are present on the inner end of the lingual crests.

Remarks

The characters described, the very peculiar shape, as well as its strict morphological affinity with the extant teeth published by Bass *et al.* (1975a: pl. 6) and Herman *et al.* (1993: pls 1, 2) support the assignment of the specimens to the Recent *C. anguineus*. Lawley (1876: pl. 1, fig. 1-1b) first described fossil teeth of *Chlamydoselachus*, later on assigned by Davis (1887) to the fossil taxon *C. lawleyi* Davis, 1887. Since no teeth of living or fossil species were known to Lawley (1876), he only provided a brief description of the specimens, without any taxonomic assignment. The extant species was described only few years later by Garman (1884a, b, 1885). The diagnosis proposed by Davis (1887) was based on an indirect comparison between the fossil tooth drawn by Lawley (1876) and a single extant specimen of *C. anguineus*. Davis (1887: 544) remarked that the fossil teeth was twice the diameter of the anterior teeth of the extant specimens. Unfortunately, the holotype of *C. lawleyi* has been lost, so that the taxonomic validity of the morphometric characters used by Davis cannot be stated definitively. Moreover, *C. lawleyi* differs from *C. anguineus* because of the absence of the intermediate cusplets and it may have been omitted by Lawley himself (Richter & Ward 1990). The uncertainty of the characters used to define *C. lawleyi* and its morphological affinities with the teeth of living species suggests that the fossil taxon might be conspecific with *C. anguineus* (Richter & Ward 1990).

Order CARCHARHINIFORMES
Compagno, 1973
Family Scyliorhinidae Gill, 1862
Genus *Apristurus* Garman, 1913

Apristurus sp.
(Fig. 3)

Material examined. — One incomplete lower anterior tooth and one mostly incomplete lower lateral tooth (PMC Fiumefreddo 1996. I. Pl. Sel. 3, 4).

Description

The anterior teeth are characterized by a narrow and elongated principal cusp and by two mesial and distal lateral cusplets. The specimens studied preserve only the mesial lateral cusplets, of which the closest reaches half the height of the principal cusp. The lateral tooth is incomplete and presents three mesial lateral cusplets of which the closest reaches almost the height of the bent principal cusp. The lingual faces of the principal cusp and cusplets are convex, and present some folds, more evident along the basal region of the face than near the apex. The labial face of the principal cusp is flat to slightly convex in the basal region, and completely convex in the upper region, characterized by 6 or 7 linear to sigmoid folds, much more evident than those present on the lingual face of the cusp. The more central labial folds run from the crown base towards the tip of the cusp. A few folds (1 or 3), continuous from the crown base towards the apex, are also present on the labial face of cusplets.

The root is high, with a well pronounced torus characterized by a large central lingual foramen, from which a deep basal central transverse groove originates. A few small lingual foramina (3-4) are present on the lingual face of the root lobes. The basal face of the root is flat and labio-lingually elongated, divided by the basal central transverse groove into two distinct lobes. A large number of small basal foramina are randomly scattered on the basal surface of the root lobes. The labial face of the root is low and partially eroded, with a longitudinal central depression characterized by five large labial foramina. The more central labial foramina are merged in the anterior tooth.

Remarks

The presence of few linear to sigmoid folds on the labial face of the narrow and elongated principal cusp, continuous from the crown base toward the apex, as well as the presence of a deep central transverse groove on the basal face of the root (Herman *et al.* 1990) justify the assignment of the studied samples to the genus *Apristurus*. Moreover, *Apristurus* sp. shares a close tooth morphology with the teeth of the living *A. laurussoni* (Saemundsson, 1922) described by Herman *et al.* (1990: pls 1-4). However, the taxonomic problems concerning this genus (see Iglésias & Nakaya 2004), as well as the poor extant comparative materials do not allow a specific assignment of the specimens studied.

Genus *Galeus* Rafinesque, 1810

Galeus cf. ***melastomus*** Rafinesque, 1810
(Fig. 4)

Galeus cf. *melastomus* – Cigala Fulgosi 1986: 135.

Material examined. — Two lower anterior-lateral teeth and one lower lateral tooth (PMC Fiumefreddo 1996. I. Pl. Sel. 5, 6, 7).

Description

The anterior tooth is characterized by a narrow and elongated principal cusp, and by two mesial

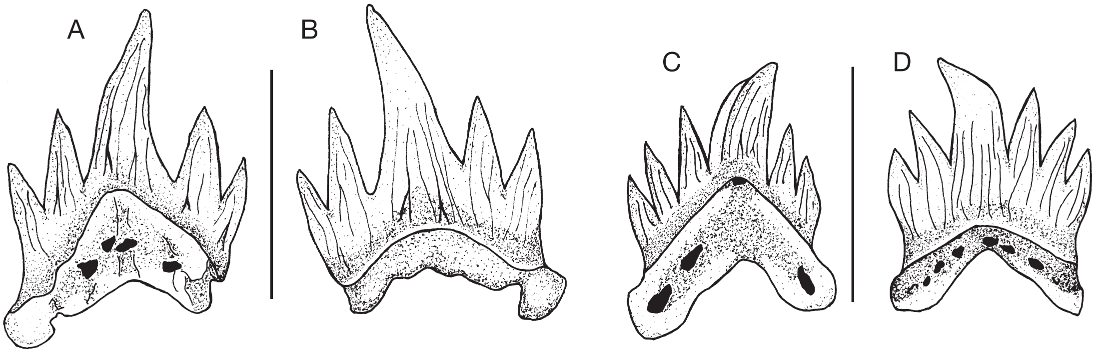

FIG. 4. — *Galeus melastomus* Rafinesque, 1810: **A**, **B**, lower anterior tooth (PMC Fiumefreddo 1996. I. Pl. Sel. 5); **A**, lingual view; **B**, labial view; **C**, **D**, lower anterior-lateral tooth (PMC Fiumefreddo 1996. I. Pl. Sel. 6); **C**, lingual view; **D**, labial view. Scale bars: 1 mm.

and distal lateral cusplets, of which the closest reach half the height of the principal cusp, while the distal ones reach half the height of the closest cusplets. The lateral tooth is characterized by two distal and three mesial lateral cusplets, of which the closest reach almost the height of the strongly bent principal cusp. The lingual faces of the cusp and cusplets are convex, and present a few folds, more evident along the basal region of the face than near the apex. The labial face of the principal cusp is flat to slightly convex, and characterized by 6 or 7 folds that run from the crown base toward half the height of the labial face of the cusp, never reaching the tip of the cusp. By contrast, a few continuous folds (1 or 3) are present on the labial face of the cusplets.

The root is high, with a well pronounced torus, characterized by a large central lingual foramen. A few small lingual foramina (3 or 4) are present on the lingual face of the root lobes. The basal face of the root is flat and labio-lingually elongated, with a large number of small randomly scattered basal foramina. The basal central deep transverse groove is completely absent. The labial face of the root is low, with a longitudinal central depression characterized by 5 or 6 large labial foramen. The more central labial foramina are merged in the anterior tooth.

REMARKS

According to Herman *et al.* (1990), the characters described justify the assignment of the specimens to the living *Galeus* cf. *melastomus*. This deep-water shark shares a very close tooth morphology with *Apristurus*. However the presence of obvious folds on the labial face of the principal cusp that never reach the crown apex (Herman *et al.* 1990), as well as the absence of a basal deep central transverse groove (Cappetta 1987; Herman *et al.* 1990) are the main characters to separate *G.* cf. *melastomus* from *Apristurus* sp.

Fossils of the genus *Galeus* have been found in the Burdigalian and Langhian bathyal deposits of France (Cappetta 1987), and the living species was firstly recorded in the lower Pliocene deposit of the Northern Apennines (Cigala Fulgosi 1986). The presence of *G.* cf. *melastomus* in the Pleistocene sediments has been recently confirmed also in the Italian section of Archi and Vallone Catrica, in the Reggio Calabria district (unpublished data).

Order SQUALIFORMES Goodrich, 1909
Suborder DALATIOIDEI
sensu De Carvalho 1996
Family DALATIIDAE Gray, 1851
Genus *Etmopterus* Rafinesque, 1810

Etmopterus sp.
(Fig. 2O, P)

MATERIAL EXAMINED. — One complete lower anterior-lateral tooth (PMC Fiumefreddo 1996. I. Pl. Sel. 8).

Description

The tooth is labio-lingually compressed. The cusp is strongly inclined and narrow, with the tip slightly turned upward. The mesial cutting edge is wavy and completely smooth. The distal cutting edge is short and convex, separated by a deep notch from a distal smooth enamel blade, convex in the outline. The apron is rectangular and wide, and it completely covers the upper central and distal region of the labial face of the root. The uvula is rectangular and wide, and it completely covers the upper central and mesial region of the lingual face of the root.

The root is rectangular and incomplete. The lingual face of the root is flat, with a deep strong distal depression, resulting from interlocking of the teeth. A thick longitudinal ridge is present just below the basal margin of the uvula. Three lingual foramina are present along the uvula-root junction, of which the mesial one is much larger than the central and distal foramina. A small lingual central foramen characterized also the lower region of the lingual face of the root. The labial face of the root is flat, with a strong mesial depression, resulting from interlocking of the teeth. Two labial foramina are present between the basal margin of the apron and the root, while two other labial foramina are present between the mesial margin of the apron and the distal margin of the mesial depression of the root. A small incomplete central labial foramen is also present in the lower region of the labial face.

Remarks

The presence of uvula and apron that cover the whole upper region of the root (Ledoux 1970; Herman *et al.* 1989) supports the assignment of the specimens to the genus *Etmopterus*. The lower tooth collected in the Fiumefreddo section differs from the Recent *E. spinax* (Linnaeus, 1758) because of a narrower and slightly more erected cusp, with a tip turned upward, and for a lower number of labial foramina along the apron-root junction (see Herman *et al.* 1989). The Miocene *Etmopterus* sp. reported by Ledoux (1972) differs from the Fiumefreddo specimens in having a shorter cusp and a much higher root. The scant knowledge about the dental variation of the Mediterranean specie *E. spinax*, as well as of the eastern Atlantic species *E. princeps* Collet, 1904 or *E. pusillus* Lowe, 1839 does not allow a specific assignment of the material studied.

The presence of *Etmopterus* sp. in the Pleistocene Italian sediments has been recently confirmed also in the Archi section, in the Reggio Calabria district (unpublished data).

Genus *Centroscymnus* Bocage & Capello, 1864

Centroscymnus* cf. *crepidater
(Bocage & Capello, 1864)
(Fig. 2S, T)

Centroscymnus cf. *crepidater* – Cigala Fulgosi 1986: 134.

Material examined. — One complete lower commissural tooth (PMC Fiumefreddo 1996. I. Pl. Sel. 9).

Description

The tooth is labio-lingually compressed, with a short and inclined cusp. The mesial cutting edge is sigmoid and completely smooth. The distal cutting edge is perpendicular, short and completely smooth, separated by a deep notch from a long distal enamel blade. The apron is rectangular, projected downward, reaching half the height of the labial face of the root. The uvula is completely absent.

The root is rectangular, and mesio-distally elongated, characterized by an irregular and oblique distal basal margin. The lingual face of the root is flat, characterized by a longitudinal ridge near the crown-root junction, on which a large mesial and central foramen is present. The lingual axial groove is absent. The labial face of the root is flat, characterized by a hardly mesial depression, resulting from interlocking of the teeth. Three large labial foramina, vertically stacked, are present along the mesial margin of the apron. Few small labial foramina are all around the distal margin of the apron and the crown-root junction. A shallow and short axial groove characterized the lower region of the root.

Remarks

The absence of a lingual axial groove on the lingual face of the root (Herman *et al.* 1989) and the strong morphological affinity with the teeth of *C. crepidater* published by Ledoux (1970) and Herman *et al.* (1989) support the assignment of the studied material to this bathydemersal shark species. Because of the general morphology of the root, the specimens studied can be considered a commissural tooth (see e.g., Ledoux 1970: fig. 17Ad). A less erected cusp in the lower teeth and the absence of a lingual axial groove on the lingual face of the tooth distinguish *C. crepidater* from *Scymnodon ringens* Bocage & Capello, 1864 (Ledoux 1970; Herman *et al.* 1989; Adnet & Cappetta 2001). *Centroscymnus crepidater* differs from the Mediterranean specie *C. coelolepis* Bocage & Capello, 1864 and from *C. cryptacantus* (Bocage & Capello, 1864) in having a shorter root and apron (Ledoux 1970; Herman *et al.* 1989). The same characters might be used also to separate *C. crepidater* from the species *C. owstoni* Garman, 1906 and *C. plunketi* (Waite, 1900) (Garrick 1959b, c), but more detailed and exhaustive studies are necessary.

Genus *Scymnodon* Bocage & Capello, 1864

Scymnodon cf. ***ringens*** Bocage & Capello, 1864
(Fig. 2K-N)

Scymnus lichia – De Stefano 1911: 398, pl. 10, figs 27, 28.

Scymnodon cf. *ringens* – Cigala Fulgosi 1986: 135.

Scymnodon ringens – Cigala Fulgosi 1996: 314, pl. 5, fig. 9, pl. 6, fig. 6.

Material examined. — One upper anterior-lateral tooth and one lower anterior-lateral tooth (PMC Fiumefreddo 1996. I. Pl. Sel. 10, 11).

Description

The upper anterior-lateral tooth is characterized by a conical narrow, sigmoid and elongated cusp. The lateral cutting edges are smoothed and incomplete. The lingual face of the cusp is convex. The uvula is absent. The labial face of the crown is flat, with a deep basal depression bordered by a thick mesial and distal vertical ridge, characterized by a few costules.

The root is quadrangular. The lingual face of the root is flat, and forms an angle with the cusp. A very small lingual central foramen is present along the root-crown junction, while a narrow and deep lingual axial groove characterizes the basal region of the lingual face. The labial face of the root is characterized by a deep central depression, in which a narrow and deep labial axial groove is present, and by a mesial and distal depression, in which few foramina are randomly scattered.

The lower anterior-lateral tooth is labio-lingually compressed, with a triangular erected cusp distally inclined. The mesial and distal cutting edges are completely smooth. The mesial cutting edge is straight to slightly sigmoid. The distal cutting edge is straight, and separated by a deep notch from a distal enamel blade. The uvula is absent. The apron is rectangular, narrow and not so much elongated.

The root is rectangular. The lingual face of the root is flat, characterized by low longitudinal ridge along the crow-root junction, on which a mesial and central lingual foramen is present. A shallow incomplete lingual axial groove is present on the basal region of the lingual face of the root. The labial face of the root is flat, with a well developed mesial depression, resulting from interlocking of the teeth. Several small labial foramina, vertically arranged, are present along the mesial and distal margins of the apron, of which the upper are larger than the lower ones.

Remarks

Scymnodon ringens shares a close tooth similarity with the bathyal shark of the genus *Zameus* (*sensu* Cigala Fulgosi 1996), *Centroscymnus* and *Scymnodalatias* Garrick, 1956. An upper anterior-lateral tooth with a bilobate root (Garrick 1956; Herman *et al.* 1989; Cigala Fulgosi 1996) separated *Scymnodalatias* from *S. ringens*. *Centroscymnus* differs from *Scymnodon* in having upper teeth with one or two large foramina on the lingual face of the root (Herman *et al.* 1989), and a bilobate root (see *C. colelolepis* in Ledoux 1970; Herman *et al.* 1989). Finally, *S. ringens* differs from *Zameus squamulosus* (Günther, 1877) in having a quadrangular root in the upper anterior-lateral teeth and a shorter root and apron in the lower teeth (Herman *et al.* 1993).

TABLE 1. — Systematic list of sharks from Fiumefreddo (Sicily, Italy) with relative total amount of specimens per sample.

		Fiumefreddo Nord 2	Fiumefreddo Nord 3	Fiumefreddo Nord 4	Fiumefreddo Nord 5	Fiumefreddo Nord 6	Fiumefreddo Nord 7	Fiumefreddo Nord 8	Fiumefreddo Cava 2
Chlamydoselachidae	*Chlamydoselachus anguineus*		1				1		
Scyliorhinidae	*Apristurus* sp.	1	1						
	Galeus cf. *melastomus*		1				2		
Dalatiidae	*Etmopterus* sp.			1					
	Centroscymnus cf. *crepidater*			1					
	Scymnodon cf. *ringes*			1					1
Centrophoridae	*Centrophorus* cf. *granulosus*					3	1		
	Centrophorus cf. *squamosus*		1				2		
Fragmentary shark teeth		1	2		5		4	2	2
Teeth of teleostean family Trichiuridae		1		1			41		2

The upper lateral-anterior tooth is the only recorded in the middle Pleistocene sediments of the Fiumefreddo section, and in particular it has been collected from the "Fiumefreddo Cava 2" horizon (Table 1), located in the upper part of the section. This tooth also represents the first middle Pleistocene record of the bathyal shark *S. ringens*.

Family CENTROPHORIDAE Bleeker, 1859
Genus *Centrophorus* Müller & Henle, 1837

Centrophorus* cf. *granulosus
(Bloch & Schneider, 1801)
(Fig. 2E-J)

Acanthias major Lawley, 1876: 40, pl. 1, fig. 19a, b.

Acanthias vulgaris – De Stefano 1910: 594, pl. 17, figs 23, 24.

Centrophorus granulosus – Ledoux 1972: 145, fig. 5. — Landini 1977: 119, fig. 4.

Centrophorus cf. *granulosus* – Cigala Fulgosi 1986: 134.

Centrophorus aff. *granulosus* – Cappetta & Nolf 1991: 52, pl. 2, figs 1-4. — Cappetta & Cavallo 2006: 36, pl. 1, fig. 2.

MATERIAL EXAMINED. — One upper anterior tooth; one upper anterior-lateral tooth; two lower anterior-lateral teeth (PMC Fiumefreddo 1996. I. Pl. Sel. 12, 13, 14, 15).

DESCRIPTION

The upper anterior tooth is higher than wide, characterized by a more or less symmetrical cusp. The mesial lateral cutting edge is convex and smooth, while the distal one is concave and smooth. The upper anterior-lateral tooth is almost as high as wide. The mesial lateral cutting edge is concave and smooth, while the distal one is slightly concave and smooth. Laterally to the cusp, a smoothed mesial and distal enamel blades are present. The upper teeth are characterized by a narrow and elongated apron, that reaches the basal margin of the labial face of the root. A short smoothed uvula is also present.

The lower anterior-lateral teeth exhibit a very distally inclined cusp. The mesial lateral cutting edge is slightly convex and poorly serrated. The distal cutting edge is short and straight, separated by a deep notch from a distal enamel blade. The apron is narrow and elongated, stopping just before the basal margin of the labial face of the root. In one specimen the basal margin of the apron is branched. A short smoothed uvula is present.

The root is quadrangular in the upper anterior tooth, and becomes sub-rectangular in the upper anterior-lateral and in the lower anterior-lateral teeth. The lingual face of the root is characterized by a depressed crown-root junction, below which a thick longitudinal ridge divided the lingual surface into an upper and lower region. A large lingual foramen, located mesially beside the uvula, is present on the longitudinal ridge. A shallow infundibulum, that originates from the lingual foramen, is scarcely developed, because of the eroded root of the teeth. A deep distal depression, resulting from interlocking of the teeth, is present in the upper region of the lingual face of the root. Few small foramina are randomly scattered on the upper distal and mesial region of the lingual face of the root. The labial face of the root is flat, with a deep mesial depression, resulting from interlocking of the teeth. In the upper anterior teeth, one large mesial and one distal foramina are present laterally to the apron. Several small foramina are also present along the crown-root junction. In the lower teeth, along the crown-root junction, one or two large labial foramina, and several small labial foramina are present in the upper mesial region of the labial face of the root. Two or three large labial foramina, and several small labial foramina are also present on the upper distal region of the labial face.

REMARKS

The presence of a large lingual foramen located mesially beside the uvula, and of an infundibulum that originates from the lingual foramen, support the assignment of the specimens to the genus *Centrophorus*. The species of this genus are characterized by a very similar tooth morphology (Cigala Fulgosi 1986; Cappetta & Nolf 1991). The strong morphological affinity with the teeth of *C. granulosus* published by Ledoux (1970) and Herman *et al.* (1989) supports the assignment of the studied material to this bathydemersal shark species. An uvula without ornamentations (Ledoux 1970) separates *C. granulosus* from *C. squamosus* (Bonnaterre, 1788), while a larger apron and uvula (Cappetta & Nolf 1991) separates this shark from *C. lusitanicus* Bocage & Capello, 1864. The teeth of the genus *Deania* Jordan & Snyder, 1902 share a close morphology with *Centrophorus*, except that in *Deania* the infundibulum is absent and two large axial foramina are present (Ledoux 1970, 1972; Cappetta & Nolf 1991; Adnet & Cappetta 2001). The teeth of *Somniosus rostratus* (Risso, 1826) differ from those of *Centrophorus* because they are higher than wide, by the much wider and shorter apron and uvula, and by the presence of larger foramina on the labial and lingual faces of the root (Cigala Fulgosi & Gandolfi 1983; Cigala Fulgosi 1988b; Herman *et al.* 1989).

The presence of *C. granulosus* in the Pleistocene sediments has been recently confirmed also in the Italian section of Grammichele, in the Catania district (unpublished data).

Centrophorus cf. *squamosus*
(Bonnaterre, 1788)
(Fig. 2Q, R, U)

Centrophorus squamosus – Keyes 1984: 206, figs 8-20. — Cigala Fulgosi 1986: 134.

MATERIAL EXAMINED. — Three dermal scales (PMC Fiumefreddo 1996. I. Pl. Sel. 16, 17, 18).

DESCRIPTION

The dermal scales are characterized by a slender and elongated peduncle, that sustained a rhomboidal and leaf-like crown. The basal region of the peduncle is widen, and adorned by few small crests. The crown is characterized by arched and thick anterior-lateral margins, and by straight and serrated posterior-lateral margins. The serrations of the posterior-lateral margins are characterized by a posterior central strong main cusp and by 3 or 4 small lateral cusplets. A thick central longitudinal ridge is present on the ventral face of the crown, and runs from the anterior region of the crown to the tip of the posterior central main cusp. Two small lateral ridges run along the anterior-lateral margins of the crown, parallel to the central longitudinal ridge, and stop at the midpoint of the ventral face of the crown. These lateral ridges can be forked in two parallel branches. No ornamentations are present on the ventral face of the crown.

REMARKS

Centrophorus squamulosus is known in the Pleistocene sediments of Fiumefreddo section only by the presence of rare dermal scales.

The presence of a slender and elongated peduncle sustaining a rhomboidal and leaf-like crown,

TABLE 2. — Present status and paleoecological preferences of the shark taxa from Fiumefreddo (Sicily, Italy).

Taxa	Present status	Environment		Depth range (m)
Chlamydoselachus anguineus	Extra-Mediterranean	Bathydemersal	Outer shelf-upper slope	0-1570
Apristurus sp.	Extra-Mediterranean	Bathydemersal	Upper slope	560-1462
Galeus cf. *melastomus*	Mediterranean	Bathydemersal	Outer shelf-upper slope	0-1873
Etmopterus sp.	Mediterranean	Bathydemersal	Outer shelf-upper slope	0-2490
Centroscymnus cf. *crepidater*	Extra-Mediterranean	Bathydemersal	Upper slope	230-1500
Scymnodon cf. *ringes*	Extra-Mediterranean	Bathypelagic	Slope	200-1600
Centrophorus cf. *granulosus*	Mediterranean	Bathydemersal	Outer shelf-upper slope	100-1200
Centrophorus cf. *squamosus*	Extra-Mediterranean	Bathypelagic	Slope	145-2400

and of a crown characterized by a posterior-lateral margins with three or four lateral cusplets and a posterior main cusp (Garrick 1959a; Hulley 1971; Bass *et al.* 1975b; Compagno 1984), supports the assignment of the specimens to the Recent leaf-scale gulper shark *C. squamosus*. All the other species of the genus *Centrophorus* differ from *C. squamosus* by the absence of a slender peduncle and a different physiognomy of the crown (Compagno 1984). A rounded to ovoid or elongated crown with two or three posterior main cusps distinguishes *Centroscymnus*, *Scymnodalatias* and *Scymnodon ringens* from *C. squamosus* (Bigelow & Schroeder 1957; Garrick 1956, 1959b, c; Compagno 1984). Moreover, the absence of cross-ridges on the ventral surface of the crown excludes the possible assignment to *Zameus squamulosus*.

DISCUSSION

The Fiumefreddo shark fauna provides new knowledge of the Mediterranean Plio-Pleistocene bathyal elasmobranch distribution, disparity and diversity. This fossil shark fauna represents the first deep-sea tooth assemblage recorded in the lower Pleistocene sediments of the Mediterranean basin. In particular, the tooth assigned to *Chlamydoselachus anguineus* represents the first fossil record of this species. Moreover, the teeth assigned to *Apristurus* sp. fill in part the fossil record of the genus *Apristurus*, recorded for the first time in the middle Eocene deposits of Landes, in the South-West of France (Adnet 2006). Finally, the only shark tooth collected in the fossiliferous horizon "Fiumefreddo Cava 2" (Table 1) represents the first middle Pleistocene record of *Scymnodon* cf. *ringens*.

The assemblage is characterized by temperate to subtropical bathydemersal and bathypelagic shark species, that commonly inhabit the deep waters of the outer continental shelves and/or upper slope (Compagno 1984) (Table 2). The taxa identified show the high bathyal shark diversity of the section, in contrast with the present Mediterranean Sea condition, characterized by a very impoverished deep-water fauna (Bouchet & Taviani 1992; Sion *et al.* 2004). Several Atlantic taxa now absent in the Mediterranean are represented in this Pleistocene assemblage, including *C. anguineus*, *S.* cf. *ringens*, *Centroscymnus* cf. *crepidater*, *Centrophorus* cf. *squamosus* and *Apristurus* sp. The genus *Apristurus* included a lot of species with a more or less restricted extra-Mediterranean geographic distribution (see Compagno 1984). In particular, *A. laurussoni*, characterized by a tooth morphology near to Fiumefreddo specimens, is a North Atlantic species, characterized by a discontinuous distribution along the Massachusetts and Delaware coasts, in the Gulf of Mexico, along the south of Ireland and in the Canary and Madeira islands (Compagno 1984; Iglésias & Nakaya 2004). *S. ringens* is the only extra-Mediterranean species of Fiumefreddo section distributed only in the eastern Atlantic Ocean, from Scotland to Senegalese coasts (Compagno 1984). By contrast, *C. anguineus*, *C. squamosus* and *C. crepidater* are characterized by wider geographical distribution, recorded both in the Atlantic, Pacific and Indian oceans (Bass *et al.* 1975a, b; Nakaya & Bass 1978; Compagno 1984). *Etmopterus* sp., *Centrophorus* cf. *granulosus* and *Galeus* cf. *melastomus* instead represent some of the rare bathyal sharks characteristic of the present deep Mediterranean fauna (Sion *et al.* 2004).

Concerning the paleobathymetry (see Compagno 1984), all the shark species collected along the Fiumefreddo horizons occur today at depths below 150-200 m. *Apristurus laurussoni* is characterized by a bathymetric range of 560 m to 1462 m. *C. anguineus*, *C. crepidater* and *C. granulosus* are characterized by a deeper bathymetric limit that ranges in depth from 1000 to 1200 m. *S. ringens* may reach at least about 1600 m depth. *C. squamosus* is a rare shark above 1000 m depth in the eastern Atlantic, and, likewise *Etmopterus* sp. and *G. melastomus*, has a lower bathymetric limit placed at around 2000 m. Today, in the Mediterranean deep waters, *Etmopterus spinax*, *C. granulosus* and *G. melastomus* have been recently recorded at depths that range from about 600 to about 1500 m, and, in the eastern Ionian Sea, *E. spinax* has been captured at about 2200 m depth (Sion *et al.* 2004). Therefore, the Fiumefreddo shark fauna supports a depositional environment with a depth between about 500 and 1000 m. This bathymetric range is in agreement with the large number of Trichiurid teeth (Table 1), as well as with the previous study on the otoliths fish fauna from the same section of Fiumefreddo (Girone *et al.* 2006).

Most of the Atlantic bathyal taxa collected in the studied section appeared in the Mediterranean Sea during the early Pliocene (Cigala Fulgosi 1986, 1996; Cappetta & Nolf 1991). Their occurrence was favoured by the peculiar deep-water hydrographical conditions that during the lower Pliocene characterized this basin, due to the establishment of an estuarine type water circulation, as well as to the presence of a lower sill in the Gibraltar area (see e.g., Benson 1975; Thunnel *et al.* 1987; McKenzie *et al.* 1990; Iaccarino *et al.* 1999). Cigala Fulgosi (1996) related the disappearance of many of these Atlantic bathyal taxa, just at the end of the Zanclean, to a rapid normalization of the Mediterranean water circulation (estuarine type model circulation, deep homothermy, nutrients depletion), that led to a strong impoverishment of the deep-water Mediterranean fauna. The Fiumefreddo assemblage disagrees with a rapid disappearance of bathyal sharks from the Mediterranean, suggesting a continuity in deep-water shark diversity and disparity until the lower Pleistocene. Moreover, the occurrence of several bathyal shark teeth (see also Marsili & Tabanelli in press), as well as of other invertebrate groups (see e.g., Monegatti & Pantoli 1987; Tabanelli 1993; Vaiani & Venezia 1999; Monni & Tabanelli 2006; Monni 2006) from the middle-upper Pliocene of Romagna, confirms the persistence of a more Atlantic deep-water fauna also during these periods in the Mediterranean.

The strong oceanization and biodiversity of the Pleistocene bathyal shark fauna from Fiumefreddo agrees with a more upper Pliocene-lower Pleistocene general Mediterranean faunistic trend, characterized by a large and progressive entrance of both Atlantic deep-water invertebrate and vertebrate marine group in the basin (see e.g., Gaetani & Saccá 1984; Barrier *et al.* 1989; Di Geronimo & La Perna 1996, 1997a, b; Di Geronimo *et al.* 1997, 2003; Rosso & Di Geronimo 1998; Corselli 2001; Girone & Varola 2001; Girone 2003; Girone *et al.* 2006). The Plio-Pleistocene global climatic cool trend and the subsequent lowering of the median annual sea surface temperature (Dowsett & Poore 1990; Dowsett *et al.* 1994; Herbert & Schuffert 1998), permitted the entrance of boreal and/or arctic cold stenothermic taxa, such as the ostracod *Cytheropteron testudo* (Bonaduce & Sprovieri 1985), or the molluscs *Arctica islandica* (Raffi 1985; Malatesta & Zarlenga 1986) and *Homalopoma emulum* (Di Geronimo & La Perna 1997b). A similar trend can be observed also for some teleostean fishes such as *Nansenia groenlandica*, *Bathylagus euryops*, *Coryphaenoides rupestris* or *Aphanopus carbo* (Girone *et al.* 2006). Moreover, a deeper connection between the Atlantic Ocean and the Mediterranean Sea, characterized by the absence of a real threshold at Gibraltar, favoured the persistence of these cold stenothermic taxa in this basin (Barrier *et al.* 1989; Di Geronimo & La Perna 1996, 1997a).

None of the Atlantic bathydemersal and bathypelagic shark species collected in the studied section are characterized by an exclusive boreal or arctic geographic distribution, as well as a stenothermic character. However, their presence in the Fiumefreddo section confirms that different hydrographic conditions of the Mediterranean deep waters existed during the lower Pleistocene, as well as a major connection with the near Atlantic Ocean (Barrier *et al.* 1989; Di Geronimo & La Perna 1996, 1997a). Moreover, such an organized elasmobranch fauna supports the establishment of a basin system characterized by a decreasing temperature, a good deep nutrient supply and a better deep-water circulation, similar to the near eastern Atlantic, that favoured the development of a rich deep ecosystem in the Mediterranean, supported by a well structured trophic system, where sharks played an important role. The present Mediterranean hydrographical conditions (see e.g., Bouchet & Taviani 1992), due to a different circulation model (Thunell *et al.* 1987) and to a reached "threshold basin condition" in the Gibraltar region (Di Geronimo & La Perna 1996, 1997a), caused the disappearance of many cold stenothermic taxa from the Mediterranean Sea, representing today also the main extant physical and biological barrier to the penetration in the basin of many Recent deep-water Atlantic species.

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