

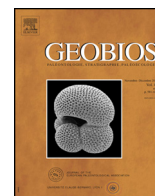


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Original article

Tortonian fish otoliths from turbiditic deposits in Northern Italy: Taxonomic and stratigraphic significance[☆]

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ABSTRACT

Fish otoliths from the fossiliferous turbiditic sand deposits outcropping at the Borelli and Moncucco localities (Piedmont, Northern Italy) are herein analyzed. The studied section is Tortonian in age and belongs to the lower portion of the Sant'Agata Fossili Formation. The study reveals the presence of at least 90 otolith-based taxa of which 78 are identified at the species level. Two of these are named and described as new species: "Gobiida" *bicornuta* and "Gobiida" *brioche*. In addition, 19 taxa, including both still living and extinct ones, are recorded for the first time in Tortonian deposits. Among them, the still living *Nansenia* aff. *oblita*, *?Sagamichthys schnakenbecki*, and *Chaunax pictus* are found as fossils for the first time. The high diversity of this well-preserved otolith assemblage improves the systematic knowledge of the Tortonian gobiids and other neritic taxa, which show a close affinity with the present-day Mediterranean fauna. Moreover, the stratigraphic distribution of both neritic and mesopelagic taxa, that were previously considered to enter the Mediterranean Basin in younger stratigraphic intervals, can now be extended back to the Tortonian.

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1. Introduction

In Northern Italy, Tortonian deposits mainly consist of hemipelagic marls, attaining more than one hundred meters of thickness at many places. At some rare sites, like Monte Gibbio, Stazzano, and the Torente Lemme section near Gavi, thin levels of turbiditic gravel and molluscs occur, but such localities are scarce. In the Tortonian of the hills of Torino, however, important masses of turbiditic sands several meters thick are known, often containing rich mollusc associations and fish otoliths. Such deposits are common in a zone extending over several kilometers from Montaldo Torinese eastward to Moncucco. They are especially well known from a small sandpit at Borelli, east of Moncucco, where they have been extensively sampled. The otolith assemblage from these turbiditic sands constitutes the object of the present paper.

In the Mediterranean Basin, open oceanic connections to the Atlantic and the Indo-Pacific realms persisted until nearly the end of the early Miocene (Rögl, 1998, 1999). After a short interruption during the late Burdigalian, the Mediterranean-Indian Ocean

connection was restored in the Langhian. From the Serravallian onwards, the passage of the Mediterranean to the Indo-Pacific gradually disappeared, and during the Tortonian, the Mediterranean only communicated with the Atlantic. Subsequently, at the beginning of the Messinian, the connection between the Mediterranean and the Atlantic was also lost due to the closure of the Rifian Corridor (Gibraltar area), which was caused by the blocking of olistostromes. This delineated the beginning of the Messinian Salinity Crisis (Hsü et al., 1977; Benson et al., 1991; Krijgsman et al., 1999; Roveri et al., 2014). During the Miocene, several connections existed between the Mediterranean and the Paratethys (Rögl, 1998, 1999). The sudden change in the ichthyofauna from the Tortonian to the middle-late Messinian has been documented on the basis of both otolith and fish-skeleton studies (Landini and Sorbini, 1992; Gaudant, 2002; Girone et al., 2010), reflecting the geologic events mentioned above. However, data on shallow marine otolith associations are still very limited for the Miocene of the Mediterranean Basin.

The faunal reconstruction presented here is based on otoliths and aims at obtaining a more complete view of the Tortonian teleostean fauna in the Mediterranean Basin, including both shallow and deep-water fishes, and integrating newly acquired data with previously published ones from northern Italy (Bassoli, 1906; Anfossi and Mosna, 1969a, b; Robba, 1970; Nolf and Steurbaut, 1983; Girone et al., 2010). Girone et al. (2010) also

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stated that, at generic level, most of the Mediterranean neritic taxa seemed to persist throughout the entire Neogene and might already have been established there as early as the Rupelian (early Oligocene) (Nolf and Girone, 2008). However, the lack of data related to shallow water fishes was a weak point in previous studies. The diverse association of otoliths from both neritic and oceanic fishes available here provides further details on faunal changes through time.

2. Material and methods

Samples were collected from exposures in the western part of the Torino-Monferrato hills. The studied localities include Borelli, Moncucco Torinese, and Montaldo Torinese (Fig. 1). All the samples are stored in the Institut royal des Sciences naturelles de Belgique, Brussels, Belgium (IRSNB). Each figured specimen has been given a specific collection number.

2.1. Moncucco Torinese, Borelli

Borelli, a hamlet of Moncucco Torinese, is located about 25 km E of Torino (Piedmont, northern Italy; Fig. 1). At this place, fossiliferous turbiditic sands are well-exposed in a small sandpit (GPS coordinates: N45.0666, E7.9422). The mollusks from this outcrop have been the object of several papers (e.g., Pavia and Robba, 1979; Pavia, 1991) which considered the deposit to be Messinian in age, based on planktonic foraminifera from the clay overlying the turbiditic sands at a site located about 500 m WNW of the Borelli sandpit. However, new sampling proved that this dating was erroneous, and a new analysis (Janssen, 2010: p. 489) indicated a Tortonian age for a sample from the same site (405, asterisk in Fig. 1(c)). In addition, in 2004, D. Nolf also submitted a sample from the clay of site 405 to E. Martini (Parkstr. 40, D-61476 Kronberg im Taunus), for which he concluded (*in litteris*) a Tortonian (biozone NN11a) age as well, on the basis of a nannoplankton analysis. In the legend of the new geological map of Italy at 1/50,000 (sheet 156, Torino E, Festa et al. (2009: p. 40) also attributed a Tortonian age to the turbiditic sands intercalated in the “Marne di S. Agata Fossili”.

The Moncucco site was first extensively sampled for otoliths by D. Nolf and E. Steurbaut in 1984, and was revisited several times in subsequent years by D. Nolf and O. Cavallo. A total of at least 500 kg of sediments has been screenwashed and examined for otoliths, with an additional otolith material provided by G. Pavia.

2.2. Moncucco Torinese, East side of the municipal road

In this site (GPS coordinates: N45.0687, S7.9748), located about 500 m E of the Borelli sandpit, similar turbiditic sands are exposed. A sample of about 100 kg was screenwashed and examined for otoliths.

2.3. Montaldo Torinese

Montaldo (GPS coordinates: N45.0694, S7.8598) is located about 5.5 km W of the Moncucco and Borelli sites. The exposed sediments consist of very sandy turbiditic deposits of Tortonian age, resembling the Borelli deposits. A sample of about 60 kg was screenwashed and examined for otoliths.

3. Systematic palaeontology

A list of taxa found in this study is presented in Table 1; most of them are illustrated in Figs. 2–7. The classification follows Nelson (2006). The abbreviation “aff.” is used when well-preserved specimens could not unequivocally be attributed, whereas “cf.” is inserted when the preservation is too poor for a conclusive identification. In the subsequent analysis, however, these identified taxa are treated in the same way as taxa without the aff. or cf. insertion. For species of uncertain generic position, the nominative singular name of the family or the higher category in quotation-marks is used, followed by the species name, e.g. “Sparida” *doderleini* (see Nolf, 2013: p. 18 for explanation).

3.1. Remarks on taxa requiring comments

3.1.1. *Nansenia aff. oblita* (Facciola, 1887)

The genus *Nansenia* is characterized by elongate and narrow otoliths, with an elongate, narrow and salient rostrum (Fig. 2(2, 3)). In the fossil assemblages, most of the collected *Nansenia* otoliths are derived from juveniles, making their identification problematic. Among our fossils there are three adult *Nansenia* otoliths, which very likely belong to the same species. They are most similar to those of the recent *N. oblita* (IRSNB collection), but in the fossils, more robust and longer rostra, and a somewhat greater thickness is observed than in the recent specimens. Previous otolith-based records of *Nansenia* in the Tortonian Mediterranean Basin include very small specimens from Rio Ossona, Northern Italy (Anfossi and Mosna, 1969b; see Nolf and Steurbaut, 1983: p. 152 for a taxonomic revision), and an incomplete specimen from Montegibbio, Northern

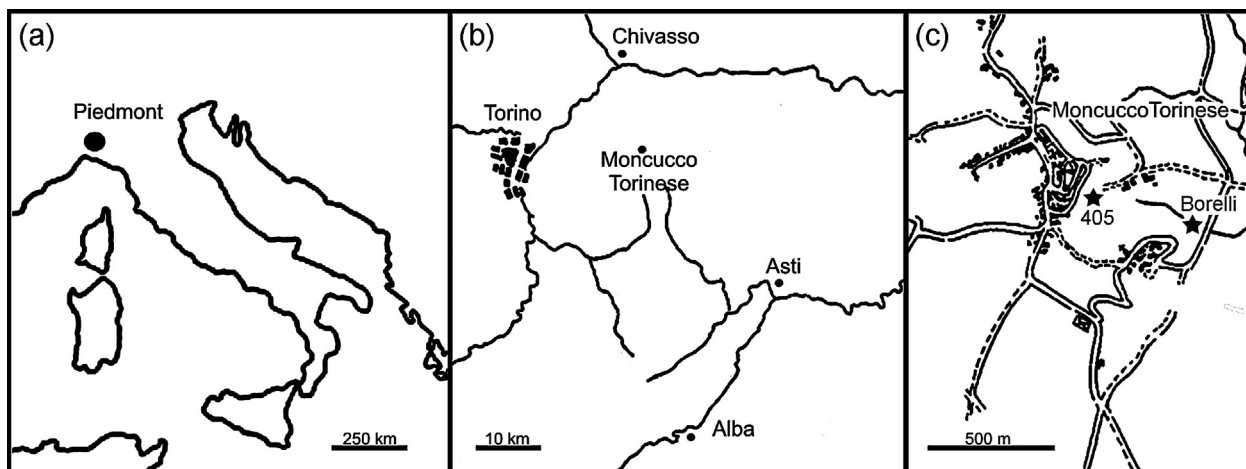


Fig. 1. Location of the study area. a: Piedmont, Northern Italy; b: Moncucco Torinese; c: detailed map showing the Borelli hamlet and 405 site (asterisks). Modified after Pavia and Robba (1979).

Table 1

List of otolith-based fish taxa from the turbiditic deposits in Northern Italy and their stratigraphic distribution in the Paratethys, Atlantic, and Mediterranean basins.

Family	Species	Iconography	Sample size			Stratigraphic distribution													
						Pa.						Mediterranean							
			a	b	c	Mio.	E	O	LM	MM	UM	O	LM	MM	UM	Plio.	Plei.	R	
Albulidae	<i>Pterothrissus umbonatus</i> (Koken, 1884)	Fig. 2(22)	13			Mio.	P	R/C	B	L							T		
Heterenchelyidae	<i>Panturichthys subglaber</i> (Schubert, 1906)		1			Mio.											T	Z	
Congridae	<i>Bathycongrus nagymarosyi</i> Nolf & Brzobohaty, 1994	Fig. 2(1)	4					R/C	A/B					R/C	B		T		
	<i>Rhynchoconger pantanellii</i> (Bassoli & Schubert, 1906)		6			Mio.		B	L/S				B	L/S	T		Z/P	G	
Microstomatidae	<i>Nansenia</i> aff. <i>oblita</i> (Facciola, 1887)	Fig. 2(2, 3)	4														Tfo		A/M
Platyroctidae	? <i>Sagamichthys schnakenbecki</i> (Krefft, 1953)	Fig. 2(4)	1														Tfo		A
Alepocephalidae	<i>Xenodermichthys</i> aff. <i>copei</i> (Gill, 1884)	Fig. 2(5)	1			Mio.							B				Tfo		I/A
Scopelarchidae	<i>Scopelarchus analis</i> (Brauer, 1902)	Fig. 2(6)	1														T	Z	G/C/I
Myctophidae	<i>Benthoosema fitchi</i> Brzobohaty & Schultz, 1978	Fig. 2(7, 8)	51	2	1	Mio.								B			T		I/A
	<i>Diaphus befralai</i> Brzobohaty & Nolf, 2000	Fig. 2(11)	34														S	T/M	
	<i>Diaphus cavallonis</i> Brzobohaty & Nolf, 2000		88		10												S	T/M	Z/P
	<i>Diaphus holti</i> Täning, 1918		22		1												S	T	Z
	<i>Diaphus metopoclampoides</i> Steurbaut, 1983		49	2		Mio.			B	L				B	L/S		T		G/C/I
	<i>Diaphus pedemontanus</i> (Robba, 1970)	Fig. 2(9, 10)	32											B			T/M	Z	
	<i>Diaphus rafinesquii</i> (Cocco, 1838)	Fig. 2(15)	2														S	T/M	Z/P
	<i>Diaphus</i> aff. <i>splendidus</i> (Brauer, 1904)	Fig. 2(16)	58		3												S	T/M	Z/P
	<i>Diaphus taaningi</i> Norman, 1930	Fig. 2(12, 13)			22	Mio.				L							T/M	Z/P	PI
	<i>Hygophum derthonensis</i> (Anfossi & Mosna, 1969)	Fig. 2(14)	97	1	1				A/B	L				B			T		A
	<i>Hygophum hygomii</i> (Lütken, 1892)	Fig. 2(17, 18)	58	2		Mio.			A/B	L				B	L		T/M	Z/P	PI
	<i>Lampadena</i> aff. <i>dea</i> Fraser-Brunner, 1949	Fig. 2(19, 20)	8			Mio.											T	Z	I/A
	<i>Lampadena</i> aff. <i>speculigeroides</i> B. & N., 1996	Fig. 2(21)	14			Mio.											Tfo		
	<i>Lampanyctus latesulcatus</i> Nolf & Steurbaut, 1983		15	1													T		
	<i>Lobianchia</i> aff. <i>dofleini</i> (Zugmayer, 1911)	Fig. 3(1)	5															T/M	Z/P
	<i>Lobianchia gemellari</i> (Cocco, 1838)	Fig. 3(5, 6)	8					C	A/B	L				C	B		Tfo		PI
	<i>Myctophum fitchi</i> (Schwarzshans, 1979)	Fig. 3(3, 4)	70	1													T	Z	C
	<i>Myctophum punctatum</i> Rafinesque, 1810	Fig. 3(2)	1							LM							Tfo	P	PI
	<i>Notoscopelus bolini</i> Nafpaktitis, 1975	Fig. 3(19, 20)	7														T	Z	A/M
	<i>Notoscopelus elongatus</i> (Costa, 1844)	Fig. 3(14)	3														Tfo		A/M
	<i>Notoscopelus resplendens</i> (Richardson, 1845)	Fig. 3(13)	1														T	Z/P	M
	<i>Scopelopsis pliocenicus</i> (Anfossi & Mosna, 1976)		41	2													T	Z/P	I/A
	<i>Symbolophorus meridionalis</i> Steurbaut, 1979	Fig. 3(7)	1														T	Z/P	G/C/I
Macrouridae	<i>Bathygadus novus</i> (Bassoli, 1906)	Fig. 3(8)	3			Mio.	P		A/B	L				O	A/B	L	Tfo		
	<i>Coelorinchus arthaberi</i> (Schubert, 1905)	Fig. 3(9, 10)	10			Mio.												T	Z
	<i>Coelorinchus caelorhincus</i> (Risso, 1810)	Fig. 3(11, 12)	19			Mio.									B			T	Z
	<i>Gadomus tejkali</i> (Brzobohaty & Schultz, 1978)	Fig. 3(21)	12		2	Mio.												T	G/C
	<i>Nezumia contorta</i> (Bassoli, 1906)	Fig. 4(1, 2)	6															T	A/M
	<i>Nezumia ornata</i> (Bassoli, 1906)	Fig. 3(15, 16)	16			Mio.		R	B					R	B		T	Z	
	<i>Trachyrincus scabratus</i> (Rafinesque, 1810)	Fig. 3(17, 18)	35			Mio.											T	Z/P	G/C
Moridae	<i>Physiculus</i> sp.	Fig. 4(9)	2																A/M
Melanonidae	"Melanonida" <i>vanheuckelomae</i> Nolf & Steurbaut, 1983		1															T	
	<i>Melanonus paralyconus</i> Schwarzshans, 1986	Fig. 4(5)	2															T	Z
Merlucciidae	<i>Merluccius merluccius</i> (Linnaeus, 1758)		2			Mio.											T	Z/P	C
Phycidae	<i>Phycis musicki</i> Cohen & Lavenberg, 1984	Fig. 4(7, 8)	6			Mio.			B	L				B	S		T/M	Z/P	A/M
Gadidae	<i>Gadiculus argenteus</i> Guichenot, 1850		390	2	1	Mio.			B	L							T/M	Z/P	PI
	<i>Gadiculus labiatus</i> (Schubert, 1905)	Fig. 4(3, 4)	44	1		Mio.			B	L							T/M	Z/P	G/C
	<i>Micromesistius planatus</i> (Bassoli & Schubert, 1906)	Fig. 4(13)	121	1													T		
Carapidae	<i>Echiodon</i> sp.		1																

Table 1 (Continued)

Family	Species	Iconography	Sample size			Stratigraphic distribution												
						Pa.						Mediterranean						
			a	b	c	Mio.	E	O	LM	MM	UM	O	LM	MM	UM	Plio.	Plei.	R
Ophidiidae	<i>Hoplobrotula</i> sp.	Fig. 4(16)	2															
Bythitidae	<i>Grammonus bassolii</i> (Nolf, 1980)	Fig. 4(14, 15)	9	1										T				
	aff. <i>Ogilbia</i> aff. <i>heinzeli</i> Lanckneus & Nolf, 1979	Fig. 4(10)	5											T	Z			
Chaunacidae	<i>Chaunax lobatus</i> (Bassoli, 1906)	Fig. 4(11, 12)	7											T				
	<i>Chaunax pictus</i> Lowe, 1846	Fig. 4(6)	2											Tfo				A/M
Mugilidae	Mugilidae indet.		9															
Atherinidae	<i>Atherina</i> sp.	Fig. 5(1)	1															
Trachichthyidae	<i>Hoplostethus praemediterraneus</i> Schubert, 1905		27											T				
Berycidae	<i>Centroberyx</i> sp.		1															
Zeniontidae	<i>Zenion hololepis</i> (Goode & Bean, 1896)	Fig. 4(17)	2											T	Z			I/A
Scorpaenidae	Scorpaenidae indet.		1															
Triglidae	Triglidae indet.	Fig. 5(6)	1															
Agonidae	Agonidae indet.	Fig. 5(7)	1															
Acropomatidae	<i>Parascombrops mutinensis</i> (Bassoli, 1906)	Fig. 5(2, 3)	12	1					L				B		T/M	Z/P	G/C	
Epigonidae	<i>Epigonus constanciae</i> (Giglioli, 1880)	Fig. 5(4)	4		1										T	Z	G/C	A/M
	<i>Epigonus denticulatus</i> Dieuzeide, 1950	Fig. 5(10, 11)	17												T	Z		I/A/M
Carangidae	Carangidae indet.		2		1													
Haemulidae	" <i>Haemulida</i> " <i>Lucida</i> (Bassoli, 1906)	Figs. 5(8, 9), 6(1–5)	12			Mio.			B	L/S				S	T			
	<i>Pomadasy incisus</i> (Bowdich, 1825)		1			Mio.			A/B	L					T/M	Z		A/M
Sparidae	<i>Dentex macrophthalmus</i> (Bloch, 1791)	Fig. 5(5)	6			Mio.								L	T/M	Z		A/M
	<i>Dentex</i> aff. <i>maroccanus</i> Valenciennes, 1830	Fig. 5(12, 13)	7			Mio.		R/C	B	L			R/C	B	L	T/M	Z	C
	<i>Diplodus karrerae</i> Nolf & Steurbaut, 1979	Fig. 5(21)	2			Mio.									S	Tfo		
	<i>Pagellus acarne</i> (Risso, 1827)	Fig. 5(14, 15)	5			Mio.										T	Z	A/M
	" <i>Sparida</i> " <i>doderleini</i> (Bassoli & Schubert, 1906)	Fig. 5(19, 20)	3			Mio.										T		
Cepolidae	<i>Cepola macrophthalma</i> (Linnaeus, 1758)	Fig. 5(16)	2			Mio.		C	A/B	L			C	B	L/S	T/M	Z/P	G/C
	<i>Owstonia neogenica</i> (Nolf & Cappelletta, 1989)	Fig. 5(17)	4													T	Z/P	
Percophidae	<i>Bembrops vandeveldae</i> Steurbaut, 1979	Fig. 5(22)	1						B	L						Tfo		
Trachinidae	<i>Trachinus draco</i> Linnaeus, 1758		6			Mio.			A/B							T/M	Z	A/M
Gobiidae	<i>Deltentosteus</i> aff. <i>quadrimaculatus</i> (V., 1837)	Fig. 7(3, 4)	55	2												Tfo	Z/P	C/I
	<i>Gobius</i> aff. <i>guerini</i> Chaine & Duvergier, 1931	Fig. 7(5)	1													Tfo	Z	A/M
	<i>Gobius</i> aff. <i>paganellus</i> Linnaeus, 1758	Fig. 7(8, 9)	10													Tfo		A/M
	<i>Lesueurigobius</i> aff. <i>friesii</i> (Malm, 1874)	Fig. 7(13–15)	29	4												Tfo	Z/P	C
	<i>Lesueurigobius</i> aff. <i>suertii</i> (Risso, 1810)	Fig. 7(10, 11)	15											S		Tfo	Z/P	C
	? <i>Mesogobius</i> sp.	Fig. 7(12)	5															
	" <i>Gobiida</i> " <i>bicornuta</i> nov. sp.	Fig. 7(6)	2													Tfo/M		
	" <i>Gobiida</i> " <i>bricoche</i> nov. sp.	Fig. 7(16–20)	12	2												Tfo	Z	
Gempylidae	<i>Promethichthys prometheus</i> (Cuvier, 1832)	Fig. 7(1)	1													T	Z	I/A
Trichiuridae	<i>Lepidopus</i> cf. <i>caudatus</i> (Euphrasen, 1788)	Fig. 4(18)	1						B	L						Tfo/M	Z	I/A/M
Caproidae	<i>Antigonia capros</i> Lowe, 1843	Fig. 5(18)	2						B	L			B	L		T		I/A
Citharidae	<i>Citharus linguatula</i> (Linnaeus, 1758)	Fig. 5(24)	2					R	B	L			R		L	T	Z	A/M
Pleuronectidae	Pleuronectidae indet.	Fig. 7(2)		1														
Bothidae	<i>Arnoglossus kokeni</i> (Bassoli & Schubert, 1906)	Fig. 5(23)	1											L	T	Z/P	C	
Soleidae	<i>Microchirus</i> aff. <i>variegatus</i> (Donovan, 1808)	Fig. 7(7)		1		Mio.										T	Z/P	C

Sample from Borelli (a), Moncucco (b), and Montaldo Torinese (c). **Pa.**: Paratethys; **Mio.**: Miocene; **E.**: Eocene, **P.**: Priabonian; **O.**: Oligocene, **R.**: Rupelian, **C.**: Chattian; **LM**: Lower Miocene, **A.**: Aquitanian, **B.**: Burdigalian; **MM**: Middle Miocene, **L.**: Langhian; **S.**: Serravallian; **UM**: Upper Miocene, **T.**: Tortonian, **Tfo**: Tortonian first occurrence, **M.**: early Messinian; **P.**: Pliocene, **Z.**: Zanclean, **P.**: Piacenzian; **PI**: Pleistocene, **G.**: Gelasian, **C.**: Calabrian, **I.**: Ionian; **R.**: Recent, **I.**: Indo-Pacific, **A.**: Atlantic, **M.**: Mediterranean.

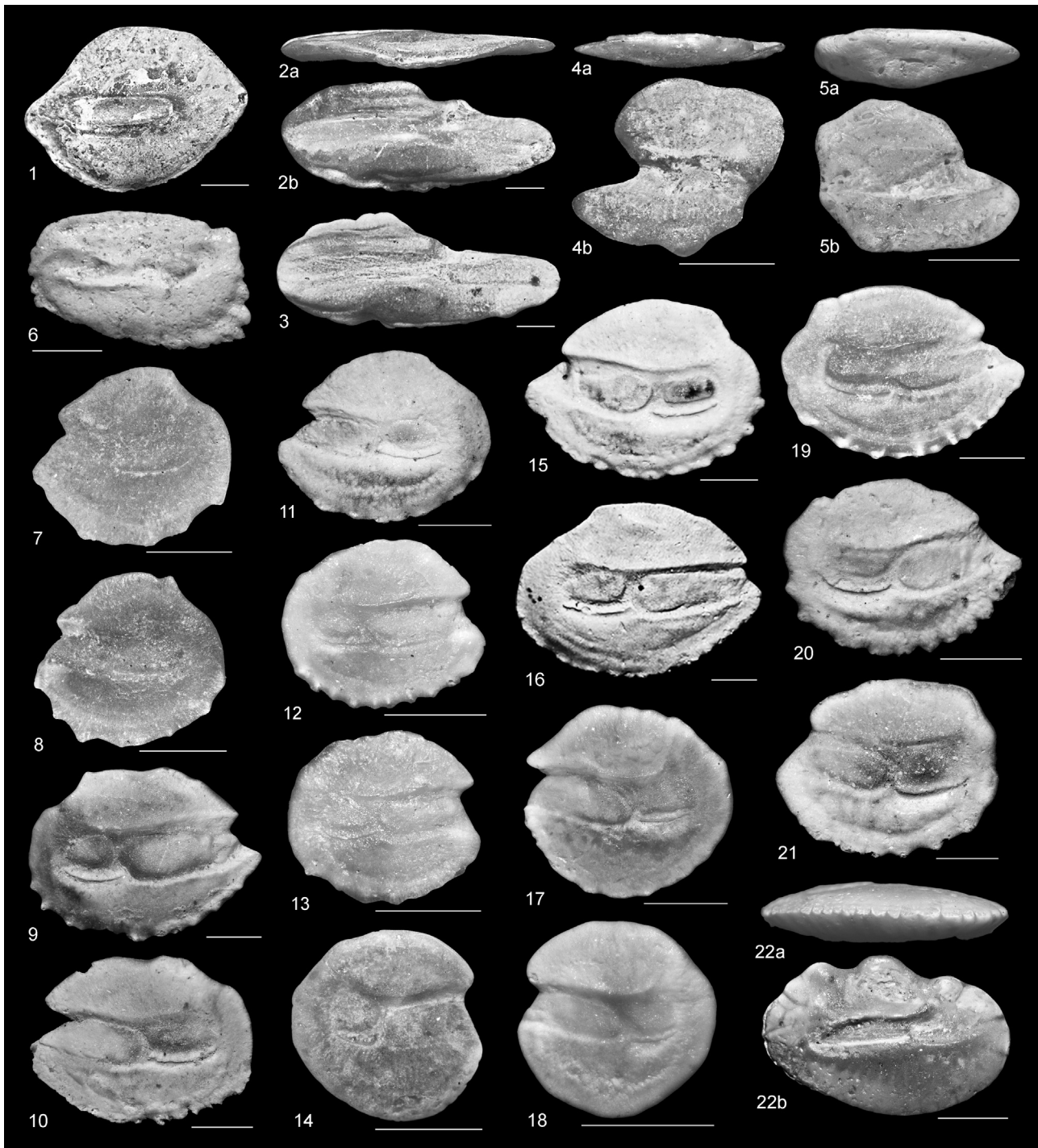


Fig. 2. Tortonian fish otoliths from turbiditic deposits in Northern Italy. **1.** *Bathycongrus nagymarosyi* Nolf and Brzobohaty, 1994, P 9338. **2, 3.** *Nansenia* aff. *oblita* (Facciola, 1887), P 9339–9340. **4.** ?*Sagamichthys schnakenbecki* (Krefft, 1953), P 9341. **5.** *Xenodermichthys* aff. *copei* (Gill, 1884), P 9342. **6.** *Scopelarchus analis* (Brauer, 1902), P 9343. **7, 8.** *Benthoosema fitchi* Brzobohaty and Schultz, 1978, P 9344–9345. **9, 10.** *Diaphus pedemontanus* (Robba, 1970), P 9347–9348. **11.** *Diaphus befralai* Brzobohaty and Nolf, 2000, P 9346. **12, 13.** *Diaphus taaningi* Norman, 1930, P 9351–9352. **14.** *Hygophum derthonensis* (Anfossi and Mosna, 1969), P 9353. **15.** *Diaphus rafinesquii* (Cocco, 1838), P 9349. **16.** *Diaphus* aff. *splendidus* (Brauer, 1904), P 9350. **17, 18.** *Hygophum hygomii* (Lütken, 1892), P 9354–9355. **19, 20.** *Lampadena* aff. *dea* Fraser-Brunner, 1949, P 9356–9357. **21.** *Lampadena* aff. *speculigeroides* Brzobohaty and Nolf, 1996, P 9358. **22.** *Pterothrissus umbonatus* (Koken, 1884), P 9337. All materials are from the turbiditic Tortonian sands at Moncucco, Borelli, except 12 and 13 which are from the turbiditic Tortonian sands at Montaldo Torinese. a: ventral view; b: inner view. Scale bars: 1 mm.

Italy (Nolf and Steurbaut, 1983). Consequently, a comparison with the studied material is not pertinent.

3.1.2. ?*Sagamichthys schnakenbecki* (Krefft, 1953)

One otolith was identified as *S. schnakenbecki*, based on the very typical outline, the characteristic large dorsal area, and the robust antirostrum, which is exactly the same as the recent one illustrated

by Smale et al. (1995: pl. 10, fig. I1) (Fig. 2(4)). Note that Smale et al. (1995: pl. 10, fig. H1) may represent a different species, presented under the same name, which makes its evaluation difficult. However, the available comparative material of the recent Alepocephalid otoliths in the IRSNB collection shows that they exhibit a considerable intra-specific variability and, therefore, it cannot be excluded that the two otoliths illustrated by Smale et al. (1995)

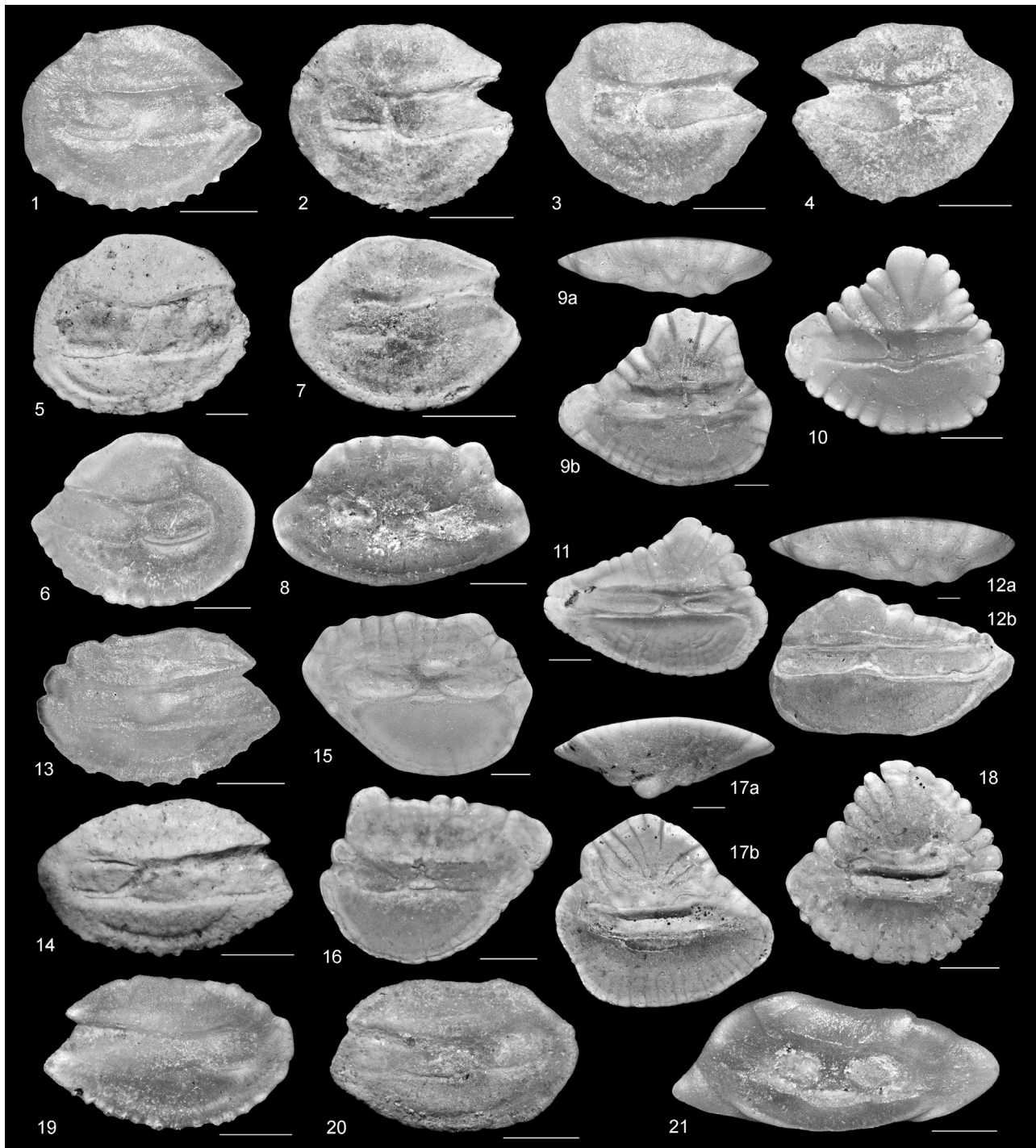


Fig. 3. Tortonian fish otoliths from turbiditic deposits in Northern Italy. **1.** *Lobianchia* aff. *dofleini* (Zugmayer, 1911), P 9359. **2.** *Myctophum punctatum* Rafinesque, 1810, P 9364. **3, 4.** *Myctophum fitchi* (Schwarzahns, 1979), P 9362–9363. **5, 6.** *Lobianchia gemellari* (Cocco, 1838), P 9360–9361. **7.** *Symbolophorus meridionalis* Steurbaut, 1979, P 9369. **8.** *Bathygadus novus* (Bassoli, 1906), P 9370. **9, 10.** *Coelorinchus arthaberi* (Schubert, 1905), P 9371–9372. **11, 12.** *Coelorinchus caelorhincus* (Risso, 1810), P 9373–9374. **13.** *Notoscopelus resplendens* (Richardson, 1845), P 9368. **14.** *Notoscopelus elongatus* (Costa, 1844), P 9367. **15, 16.** *Nezumia ornata* (Bassoli, 1906), P 9378–9379. **17, 18.** *Trachyrincus scabrus* (Rafinesque, 1810), P 9380–9381. **19, 20.** *Notoscopelus bolini* Nafpaktitis, 1975, P 9365–9366. **21.** *Gadomus tejkali* (Brzobohaty and Schultz, 1978), P 9375. All materials are from the turbiditic Tortonian sands at Moncucco, Borelli. a: ventral view; b: inner view. Scale bars: 1 mm.

belong to the same species. Because no more recent comparative specimens are available, a tentative “?” mark is used here.

3.1.3. *Lampadena* aff. *dea* Fraser-Brunner, 1949

Eight otoliths show a reasonable similarity with those of the recent species *L. dea*, which is also known as fossil in the Tortonian Mediterranean Basin (Girone et al., 2010) (Fig. 2(19, 20)). However, the nearly vertical posterior margin (which is more curved in the

recent otoliths) and the less prominent postero-dorsal angle do not allow an unequivocal determination.

3.1.4. *Lampadena* aff. *speculigeroides* Brzobohaty and Nolf, 1996

Otoliths of *Lampadena* are relatively scarce in the studied localities (Fig. 2(21)). Fourteen specimens show enough features to allow comparison with those of *L. speculigeroides*, which occurs in the Badenian (Langhian) of the Paratethys. However, larger

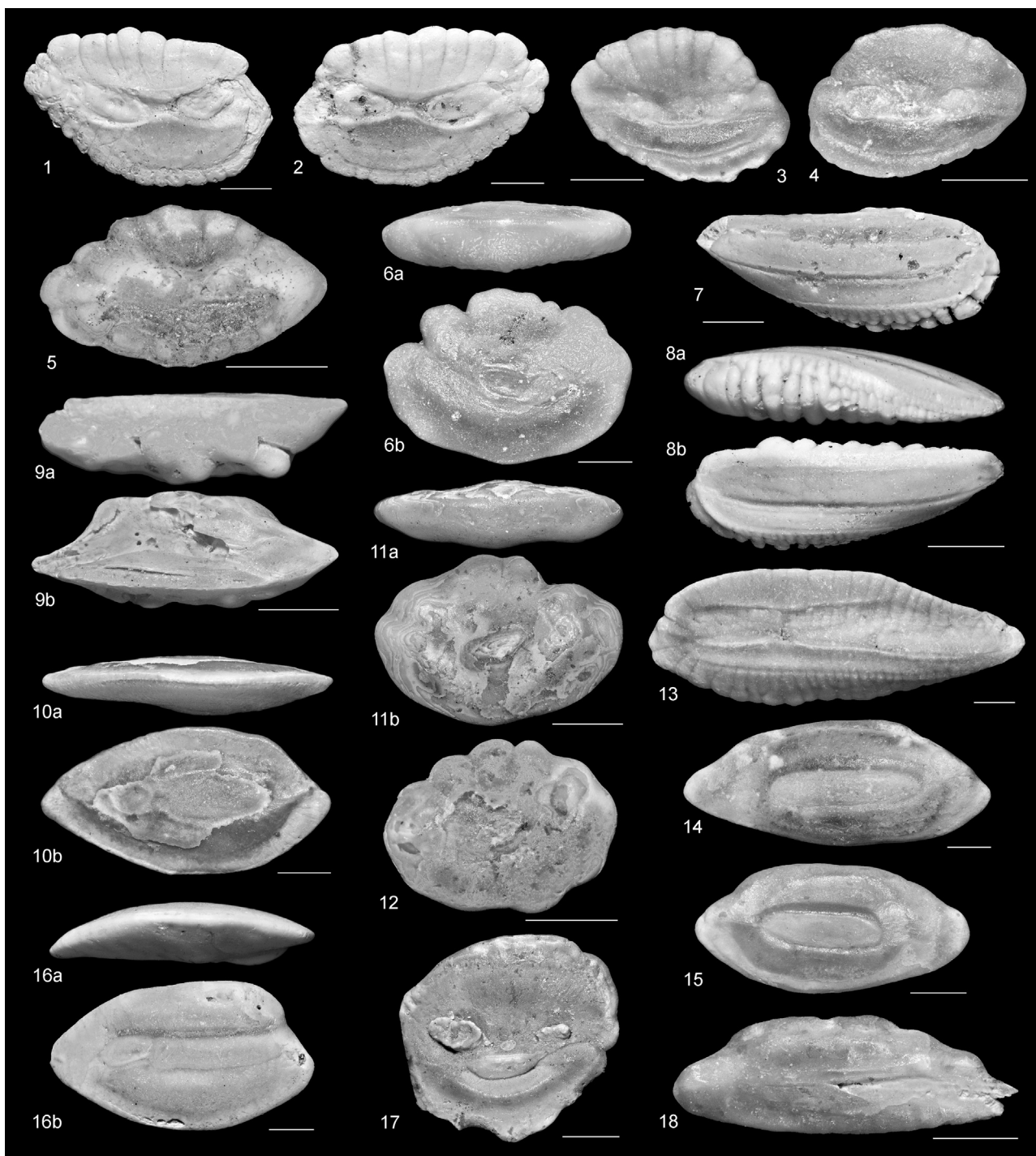


Fig. 4. Tortonian fish otoliths from turbiditic deposits in Northern Italy. **1, 2.** *Nezumia contorta* (Bassoli, 1906), P 9376–9377. **3, 4.** *Gadiculus labiatus* (Schubert, 1905), P 9386–9387. **5.** *Melanonus paralyconus* Schwarzhans, 1986, P 9383. **6.** *Chaunax pictus* Lowe, 1846, P 9395. **7, 8.** *Phycis musicki* Cohen and Lavenberg, 1984, P 9384–9385. **9.** *Physiculus* sp. P 9382. **10.** *Ogilbia* aff. *heinzeli* Lanckneus and Nolf, 1979, P 9392. **11, 12.** *Chaunax lobatus* (Bassoli, 1906), P 9393–9394. **13.** *Micromesistius planatus* (Bassoli and Schubert, 1906), P 9388. **14, 15.** *Grammonus bassolii* (Nolf, 1980), P 9390–9391. **16.** *Hoplobrotula* sp., P 9389. **17.** *Zenion holelepis* (Goode and Bean, 1896), P 9397. **18.** *Lepidopus* cf. *caudatus* (Euphrasen, 1788), P 9436. All materials are from the turbiditic Tortonian sands at Moncucco, Borelli. a, ventral view; b, inner view. Scale bars: 1 mm.

specimens among the Tortonian otoliths are slightly higher and shorter along the horizontal axis than those from the Badenian, which are more slender in shape (Brzobohaty and Nolf, 1996: pl. 4, fig. 16). Based on these differences, we prefer to identify the Tortonian otoliths as *L. aff. speculigeroides*.

3.1.5. *Myctophum punctatum* Rafinesque, 1810

An otolith of *M. punctatum* was easily distinguished from those of the extinct *M. fitchi* (Schwarzhans, 1979), which is very abundant in

the material studied here (Fig. 3(2)). This single specimen shows features of the recent *M. punctatum*. It is characterized by a more rounded shape than the fossil species and by ventral and dorsal areas almost equal in size (Girone et al., 2010: fig. 10). The first occurrence of *M. punctatum* in the Mediterranean in the Piacenzian (upper Pliocene; Girone, 2007), but Nolf and Aguilera (1998) reported three *M. cf. punctatum* otoliths in the early Miocene of Venezuela (Western Atlantic), which suggests that this species might also have occurred in the Miocene Mediterranean.

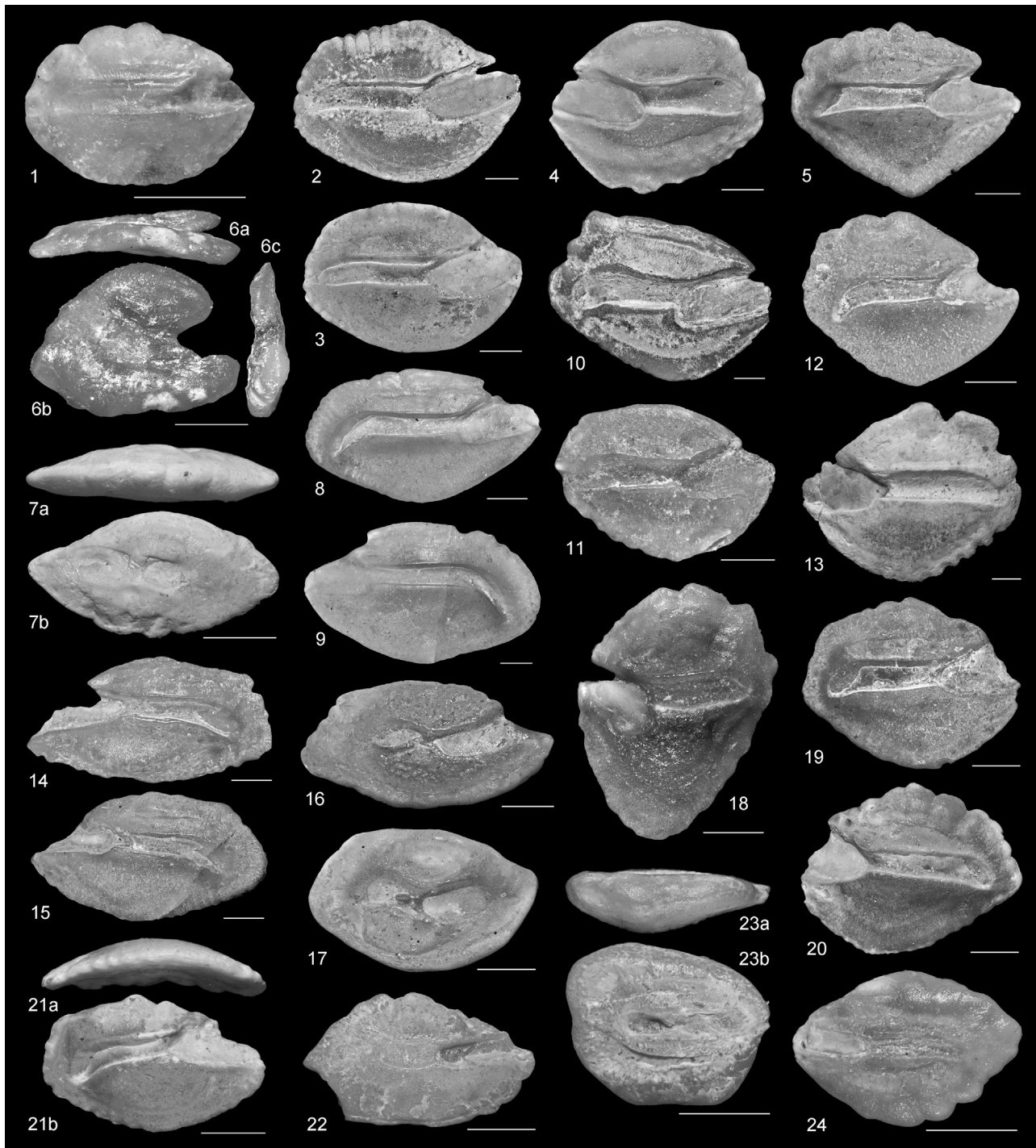


Fig. 5. Tortonian fish otoliths from turbiditic deposits in Northern Italy. **1.** *Atherina* sp., P 9396. **2, 3.** *Parascombrops mutinensis* (Bassoli, 1906), P 9400–9401. **4.** *Epigonus constanciae* (Giglioli, 1880), P 9402. **5.** *Dentex macrophthalmus* (Bloch, 1791), P 9407. **6.** Triglidae indet., P 9398. **7.** Agonidae ind., P 9399. **8, 9.** “*Haemulida*” *lucida* (Bassoli, 1906), P 9405–9406. **10, 11.** *Epigonus denticulatus* Dieuzeide, 1950, P 9403–9404. **12, 13.** *Dentex* aff. *maroccanus* Valenciennes, 1830, P 9408–9409. **14, 15.** *Pagellus acarne* (Risso, 1827), P 9411–9412. **16.** *Cepola macrophthalma* (Linnaeus, 1758), P 9415. **17.** *Owstonia neogenica* (Nolf and Cappetta, 1989), P 9416. **18.** *Antigonia capros* Lowe, 1843, P 9437. **19, 20.** “*Sparida*” *doderleini* (Bassoli and Schubert, 1906), P 9413–9414. **21.** *Diplodus karrerae* Nolf and Steurbaut, 1979, P 9410. **22.** *Bembrops vandeveldeae* Steurbaut, 1979, P 9417. **23.** *Arnoglossus kokeni* (Bassoli and Schubert, 1906), P 9440. **24.** *Citharus linguatula* (Linnaeus, 1758), P 9438. All materials are from the turbiditic Tortonian sands at Moncucco, Borelli. a, ventral view; b, inner view; c, anterior view. Scale bars: 1 mm.

3.1.6. *Notoscopelus*

Eleven specimens can be referred to the genus *Notoscopelus*, characterized by oval to elongate-ovate otoliths. Following the criteria adopted by Brzobohaty and Nolf (1996), it was possible to distinguish three species at Borelli: *N. bolini* Nafpaktitis, 1975 (Fig. 3(19, 20)), *N. elongatus* (Costa, 1844) (Fig. 3(14)), and *N. resplendens* (Richardson, 1845) (Fig. 3(13)). On the one hand,

the otoliths of *N. resplendens* are easily recognizable by a more marked postero-dorsal angle and by a shorter and higher shape, which distinguish them from the other two species. On the other hand, the otoliths of *N. bolini* and *N. elongatus* are difficult to separate from each other, because only the adult specimens show the main diagnostic features. Nevertheless, *N. bolini* shows a longer and less rounded dorsal rim than *N. elongatus*. Moreover,

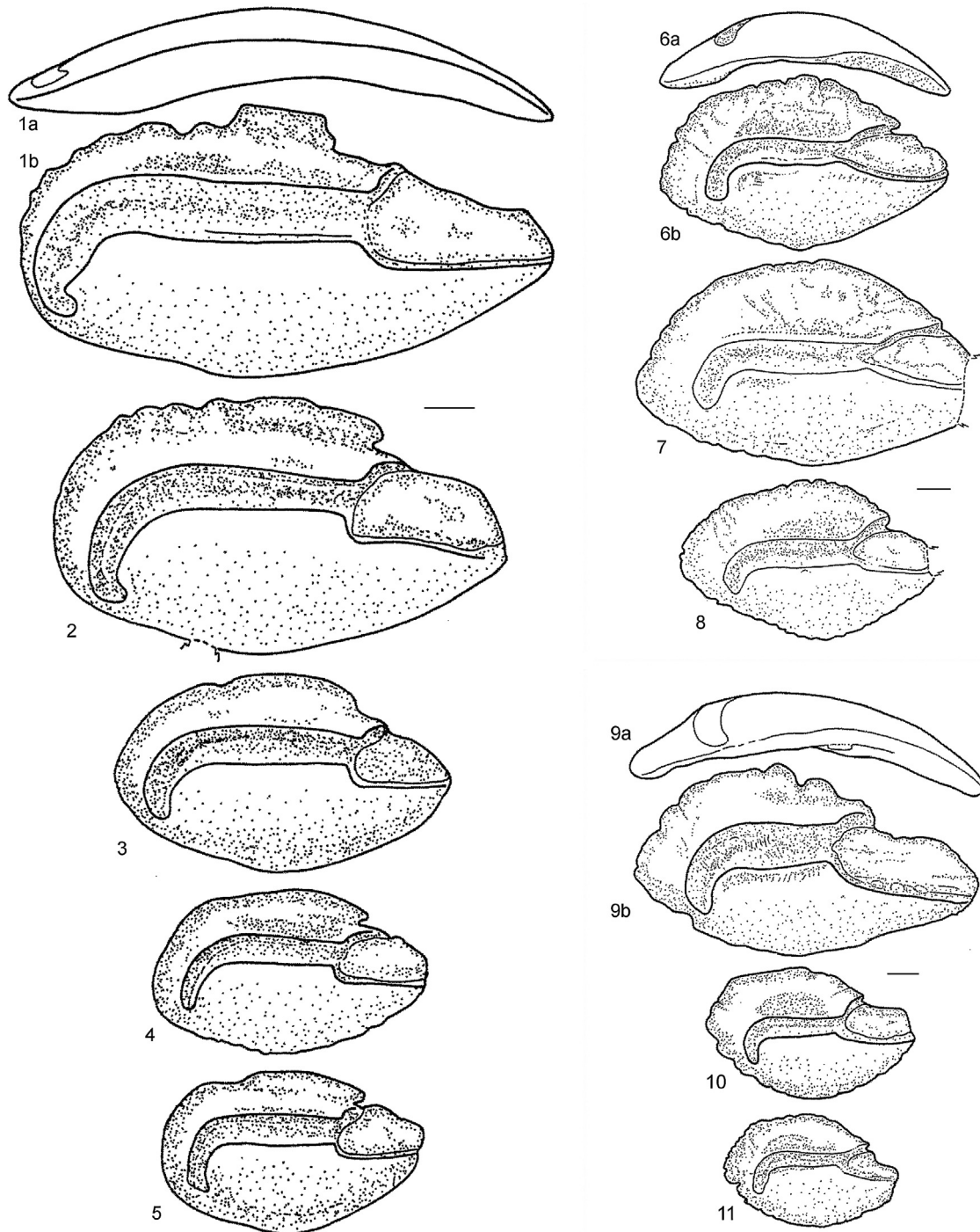


Fig. 6. 1–5. Fossil “*Haemulida*” *lucida* growth series from the Serravallian from Sallespisse (Carré, Aquitaine Basin, SW France) (IRSNB P 9442–P 9446). 6–11. recent *Parapristipoma* species: *P. octolineatum* from Tenerife (6, 7) and from Senegal (8), 29.4 cm fish total length (TL); *P. trilineatum* from Choshi city, Japan (9), from Hong Kong (10) and from Taiwan (11), 14.4 cm TL. a, ventral view; b, inner view. Scale bars: 1 mm (1–5, 6–8, and 9–11).

well-preserved specimens of *N. bolini* show an ornate ventral margin with 9–12 well-developed and sharper denticles. The earliest *N. elongatus* fossil otolith was recorded from the lower Miocene of the North Sea Basin (Huyghebaert and Nolf, 1979; Brzobohaty and Nolf, 1996).

3.1.7. *Triglidae* indet.

An adult otolith with a triangular outline, a salient rostrum, a pointed posterior rim and a slightly convex inner face is assigned to the family Triglidae (Fig. 5(6)). This specimen resembles otoliths of the recent *Chelidonichthys lastoviza* (Bonnaterre, 1788),

which were already cited by Hoedemakers (1997) and Schwarzhans (2010: pl. 68, figs. 8, 9) from the Miocene of northern Germany. However, our specimen shows an upward-directed sulcus, especially in the cauda, a feature that was not observed in other triglid otoliths. Therefore, this single otolith was only assigned at the family level.

3.1.8. “*Haemulida*” *lucida* (Bassoli, 1906)

This fossil species is known from the middle Miocene of the Mediterranean and the lower to middle Miocene of the Aquitaine Basin (Figs. 5(8, 9), 6(1–5)). The otoliths are very thin and

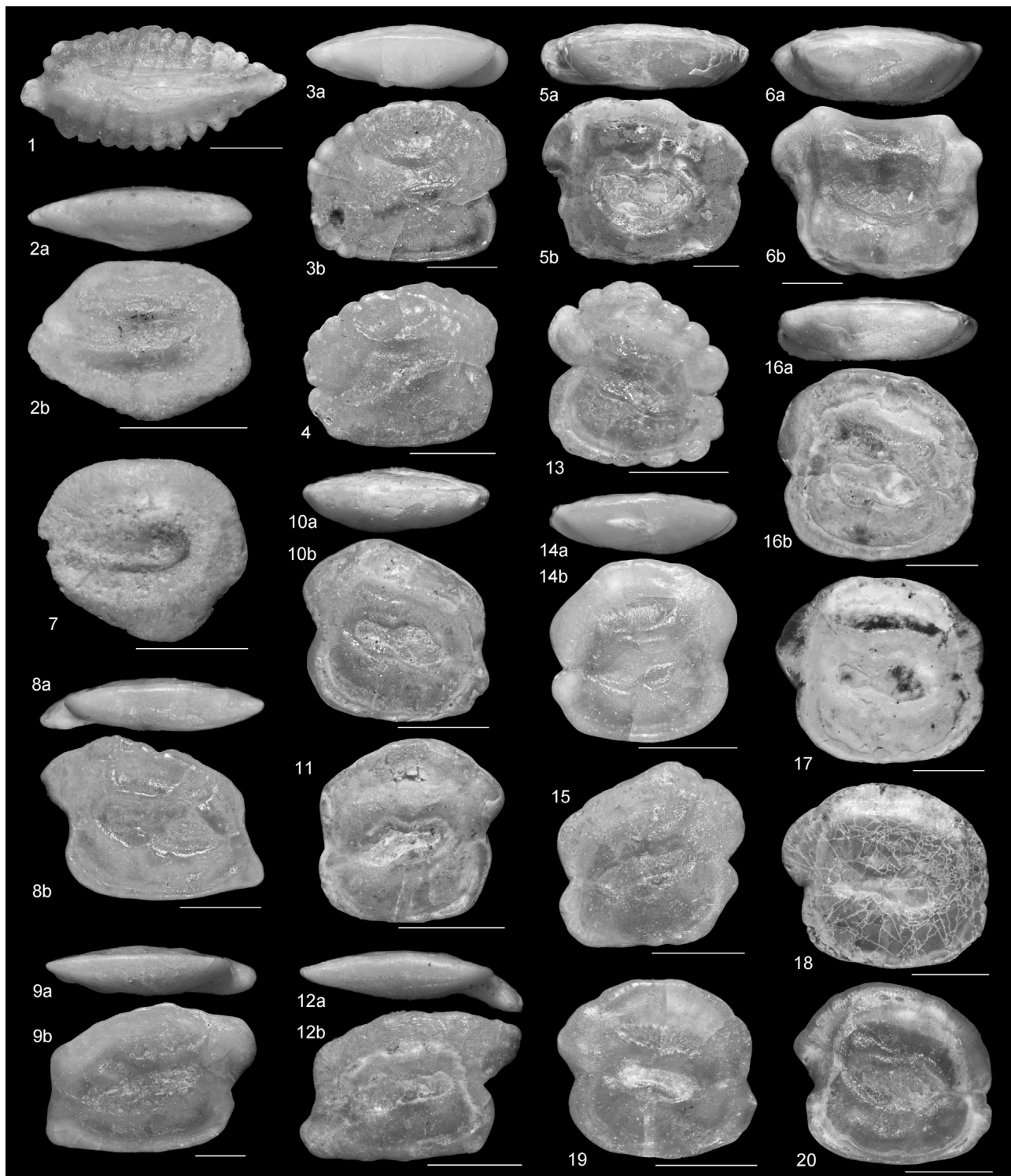


Fig. 7. Tortonian fish otoliths from turbiditic deposits in Northern Italy. **1.** *Promethichthys prometheus* (Cuvier, 1832), P 9435. **2.** Pleuronectidae ind., P 9439. **3, 4.** *Deltentosteus* aff. *quadrimaculatus* (Valenciennes, 1837), P 9418–9419. **5.** *Gobius* aff. *guerini* Chaine and Duvergier, 1931, P 9420. **6.** “Gobiida” *bicornuta* nov. sp., P 9429 (holotype). **7.** *Microchirus* aff. *variegatus* (Donovan, 1808), P 9441. **8, 9.** *Gobius* aff. *paganellus* Linnaeus, 1758, P 9421–9422. **10, 11.** *Lesueurigobius* aff. *suarii* (Risso, 1810), P 9426–9427. **12.** ?*Mesogobius* sp., P 9428. **13–15.** *Lesueurigobius* aff. *friesii* (Malm, 1874), P 9423–9425. **16–20.** “Gobiida” *brioche* nov. sp., P 9430 (holotype), P 9431–P 9434 (paratypes). All materials are from the turbiditic Tortonian sands at Moncucco, Borelli, except 2 and 7, which are from the turbiditic Tortonian sands at Montaldo Torinese. a: ventral view; b: inner view. Scale bars: 1 mm.

characterized by a very concave outer face, with some lobes in smaller specimens, but smooth in larger specimens. The inner face is very convex and characterized by a sulcus with a wide ostium and a long and straight cauda that is largely curved towards the ventral margin in the posterior end. The attribution of this species

to the genus *Parapristipoma* was suggested by Schwarzahns (2014), who stated that the elongate otolith shape is typical of this genus, but unfortunately without naming any recent species, and on the basis of three rather worn otoliths from the Serravallian of the Karaman Basin (Turkey).

Two recent *Parapristipoma* otoliths are figured for the first time here: *P. octolineatum* and *P. trilineatum* (Fig. 6(6–11)); the caudal end of their sulcus is curved differently than in the fossil species. The caudal characters of the Tortonian fossil species are rather more similar to those of the genus *Plectorhynchus* (see Nolf and Steurbaut, 2002: pl. 4, figs. 1–5; Lin and Chang, 2012: pl. 106), whose caudal end curves forward. But similarly, the fossil specimens do not show sufficient similarity to be allocated to the genus *Plectorhynchus*. Therefore, it should be better to maintain this species in open nomenclature at the family level, following the suggestion in Nolf (2013: p. 102) and other previous articles. To provide a better look at the morphology of “Haemulida” *lucida* otoliths, a growth series of the species is illustrated in Fig. 6(1–5), based on materials from the Serravallian from Sallespisse (Carré, Aquitaine Basin, SW France).

3.1.9. Gobiidae

Gobiid otoliths are very common in many neritic Neogene sediments. Despite their abundant record, the systematic knowledge of fossil gobiid otoliths is chaotic, because it is often based on doubtful morphological features and because of the still poor knowledge of recent gobiid otoliths. Nolf (2013) stated that fossil species should preferably be left in open nomenclature, at least at the generic level, when they cannot be directly compared with recent species. Abundant gobiid otoliths were recovered from the studied localities. Most of them represent juvenile specimens lacking diagnostic features at specific and generic level. However, the systematic assignment of otoliths in this group is less rigorous because of the subtle inter-specific differences and the considerable intra-specific variability of the concerned taxa.

Many otoliths could be referred to the recent Mediterranean *Deltentosteus* aff. *quadrimaculatus* (Valenciennes, 1837) (Fig. 7(3, 4)). Their features resemble specimens described from the lower Pleistocene of Northern Italy (Nolf and Girone, 2000), which all have more rounded antero-ventral angles compared to the sharp angles of the recent *D. quadrimaculatus*.

One large and thickset specimen (5.5 mm in length) can be compared with *Gobius guerini* Chaîne et Duverger, 1931 (Fig. 7(5)) because of the large expansion of the postero-dorsal portion and the short ventral rim. However, the sulcus of our otolith is slightly wider than that of the *G. guerini* specimens from the Zanclean of Catalonia (Nolf, 2013: pl. 320), and therefore, it is assigned to *G. aff. guerini*.

A group of ten specimens is identified as *Gobius* aff. *paganellus* Linnaeus, 1758 (Fig. 7(8, 9)), but the sulcus of the Tortonian otoliths is shallower than that of the recent ones.

Our material also includes two different morphological groups referable to *Lesueurigobius* aff. *friesii* (Malm, 1874) (Fig. 7(13–15)) and *L. aff. suerii* (Risso, 1810) (Fig. 7(10, 11)). The specimens assigned to these species compare well with the recent ones (Nolf and Girone, 2000: pl. 2, figs. 1–3, and figs. 7–9 for recent specimens), except for the swollen collicular crest, which is less pronounced or even absent in the fossil otoliths.

Five otoliths show general features of the recent genus *Mesogobius*, but the fossil otoliths have less clear sulcus margins. In addition, our specimens, particularly smaller otoliths, are more elongate than the recent ones. However, these Tortonian specimens (Fig. 7(12)) are very close to the pre-evaporitic Messinian specimens which were identified as ?*Mesogobius* sp. by Girone et al. (2010: fig. 10d).

3.1.10. *Lepidopus* cf. *caudatus* (Euphrasen, 1788)

One otolith shows general features very similar to those of the recent *L. caudatus* (Fig. 4(18)). However, the state of preservation at the anterior portion of the otolith does not permit a confident assignment to the recent species.

3.2. Description of new species

Order PERCIFORMES Bleeker, 1859

Family GOBIIDAE Cuvier, 1816

Gobiidae *incertae sedis*

“Gobiida” *bicornuta* nov. sp.

Fig. 7(6)

2010. “Gobiidarum” sp. 1 – Girone et al., p. 409, fig. 10j1-5.

Derivation of the name: *bicornuta* = bearing two horns; refers to the two large horn-shaped angles on each side of the dorsal rim.

Holotype: left otolith IRSNB P 9429 (Fig. 7(6)).

Type locality and horizon: Turbiditic Tortonian sands at Moncucco, Borelli.

Measurements of the holotype: length = 3.55 mm, height = 2.80 mm, and thickness = 1.25 mm.

Diagnosis: Very thickset otoliths with large expansions on both the antero- and postero-dorsal angles, and a shallow sulcus without clear division in ostial and caudal portion, and without manifesting any swelling of the collicular crest.

Description: This species is characterized by very thickset otoliths. The inner face is more or less flat; the outer face is slightly convex. The outline is trapezoid, with largely expanded antero- and postero-dorsal angles. These angles are slightly pointed and their lobed tips give a somewhat Y-shape structure to both expansions. The posterior expansion is particularly salient. The margins of the otoliths are smooth. A marked concavity is observed in the middle of the dorsal rim; the ventral rim is straight to slightly convex. The antero- and postero-ventral angles are rounded. The sulcus is rather shallow and the cristae are poorly developed. The sulcus is not clearly divided into ostium and cauda, but these structures are marked by a subtle constriction in the middle. There is no markedly swollen collicular crest in the Tortonian specimens, but the structure is well-developed in several of the Messinian specimens.

Remarks: “Gobiida” *bicornuta* is very rare in the studied Tortonian localities (only a single specimen) but the species is relatively abundant in the pre-evaporitic Messinian localities described by Girone et al. (2010). The Tortonian record indicates that this species existed at least from the Tortonian to the early Messinian in the central Mediterranean.

“Gobiida” *brioche* nov. sp.

Fig. 7(16–20)

1998. “Gobiidarum” sp. 2 – Nolf et al., pl. 7, figs. 1–3.

Derivation of the name: *brioche* = named for a kind of bread in the French and Italian languages; refers to the outline, especially the dorsal rim, of the otoliths that resembles the cross sectional view of the bread.

Holotype: left otolith IRSNB P 9430 (Fig. 7(16)).

Paratypes: Four specimens IRSNB P 9431–P 9434 (Fig. 7(17–20)).

Type locality and horizon: Turbiditic Tortonian sands at Moncucco, Borelli.

Measurements of the holotype: length = 2.85 mm, height = 2.65 mm, and thickness = 0.90 mm.

Diagnosis: Otoliths with rounded dorsal rim and less expanded postero-dorsal angle, and a deep, well-divided sulcus without a clear swollen collicular crest.

Description: This species is characterized by moderately thickset, more or less square otoliths with a well-marked constriction in both their anterior and posterior rims. The inner face is nearly flat to slightly convex in the antero-posterior direction; the outer face is clearly convex. The margins are smooth. The dorsal rim is rounded with a slightly expanded posterior part. The expansion is followed by a conspicuous constriction in the middle of the posterior rim. The ventral rim is moderately rounded and the antero-ventral expansion is not very pronounced but

always present. There is a deep and large depression in the dorsal portion of the inner face. The sulcus is deep and well-divided into ostium and cauda, with both cristae that are constricted. There is no marked swollen collicular crest.

Remarks: At the generic level, otoliths of this species show some similarities to those of *Lesueurigobius*, but our fossils have the thickest part of the otolith at about the center of the outer face, whereas it is more ventrally-located in *Lesueurigobius*. Furthermore, their dorsal rim is rounded and approximately symmetric in shape, in contrast to the slight posterior expansion of the dorsal rim in *Lesueurigobius*. At the species level, this species resembles “Gobiida” *bolligeri* Reichenbacher, 1993 from the late Burdigalian in Switzerland (Reichenbacher, 1993: pl. 9, figs. 129–131), especially in the sulcus morphology. However, the Tortonian specimens have more rounded dorsal rim than those of the Burdigalian ones.

4. Discussion and concluding remarks

The otolith-based reconstruction of the ichthyofauna resulting from the present study provides new data concerning both the composition and the distribution of the fishes in the Mediterranean realm during the Tortonian. The data reveal an association of at least 90 taxa of which 78 can be identified at the species level. They belong to 42 families and, when excluding most of the juvenile specimens, 19 taxa are reported for the first time from the Tortonian of the Mediterranean Basin. Most otoliths are well-preserved; and therefore, most of them show quite distinct features to allow identification at specific or generic level. As can be expected in turbiditic sediments, the assemblages contain taxa from various environments, including inhabitants of nearshore shallow water to deep sea. The most diversified and abundant groups are those of the myctophids and the gadiforms; equally remarkable and perhaps more intriguing are the sparids and the gobiids. These four groups make 56.6% (51 out of 90) of the total number of taxa. Some otoliths could only be identified to the family level (such as Mugilidae, Triglidae, Agonidae, Carangidae, and Pleuronectidae) due to their state of preservation and/or small size. The most common species in the association are *Gadiculus argenteus* and *Micromesistius planatus* (Table 1).

Nineteen of the species are here recorded for the first time, including still living and extinct ones (Table 1). Among the surviving species, *Nansenia* aff. *oblita*, *Sagamichthys schnakenbecki*, and *Chaunax pictus* are found as fossils for the first time, whereas *Gobius* aff. *paganellus* and *Xenodermichthys* aff. *copei* are recorded for the first time in the Mediterranean. The latter two species are known as fossils from the Piacenzian of the Atlantic realm (Nolf and Marques da Silva, 1997) and from the middle Miocene of the Paratethys (Brzobohaty, 1986), respectively.

Data from the studied localities suggest that *Delontosteus* aff. *quadrimaculatus*, *Gobius* aff. *guerini*, *Gobius* aff. *paganellus*, and *Lesueurigobius* aff. *friesii* occur in the Mediterranean since the Tortonian, which is earlier than the previously published records (from the Zanclean to the recent; Girone et al., 2006). The occurrence of these gobiids and other Tortonian neritic taxa such as *Chaunax pictus*, several sparids, *Citharus linguatula*, and *Microchirus* aff. *variegatus*, appears to support the hypothesis that the fossil neritic assemblages become increasingly similar to the present-day Mediterranean neritic fauna at the generic level throughout the Neogene (Girone et al., 2010). Indeed, this similarity increases in the Tortonian assemblage as comparing with the Rupelian (early Oligocene; Nolf and Girone, 2008) and Aquitanian (early Miocene; Reichenbacher and Cappetta, 1999) Mediterranean assemblages.

An interesting fact is the occurrence of *Notoscopelus elongatus* and *Myctophum punctatum*. *Notoscopelus elongatus* is a modern species distributed in the Mediterranean and the Atlantic

(Nafpaktitis et al., 1977) and has previously been reported in the Mediterranean as fossils from the lower Pleistocene (Gelasian) (Girone, 2005; Girone et al., 2006; Agiadi et al., 2011). According to Girone et al. (2006), *N. elongatus* entered the Mediterranean and replaced the congeneric *N. resplendens* as a response to the Pleistocene global climate deterioration. A similar meaning has been attributed to the entry of *M. punctatum* into the Mediterranean Basin during the Piacenzian (Girone et al., 2006). The occurrence of these species in the Tortonian sediments testifies that the entry into the Mediterranean of these temperate-subpolar Atlantic taxa started before the Plio-Pleistocene, which is probably linked to the palaeoceanographic changes occurring in the basin during the Tortonian. However, we retain here that more data are needed to better understand the stratigraphic distribution of these species that, on the basis of the present data, appears to be very scattered.

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