

On the fossil fishes, diatoms, and foraminifera from Zanclean (Lower Pliocene) diatomitic sediments of Aegina Island (Greece): a stratigraphical and palaeoenvironmental study

JEAN GAUDANT, MARIE-DENISE COURME-RAULT & SIMONA SAINT-MARTIN

Abstract

Fossil fishes were collected in a Zanclean diatomitic marl outcropping at the foot of Aghios Thomas hill, near the village of Messagros (Aegina Island, Greece). Among them, *Spratelloides gracilis* (SCHLEGEL) is overwhelmingly dominant, like in the Pliocene diatomitic strata of the Heraklion basin (Crete). It is an epipelagic fish which suggests that the deposition of the fossiliferous level took place in neritic waters, as confirmed by the benthic and epiphytic forams and the diatoms from the same level.

Keywords: Fishes, teleosts, diatoms, foraminifera, Pliocene, Zanclean, stratigraphy, palaeoenvironment.

Zusammenfassung

Es werden fossile Fische aus einem diatomitischen Mergel (Zancleum, Unteres Pliozän) vom Fuß des Aghios Thomas-Hügels auf der griechischen Insel Ägina beschrieben. Unter diesen ist *Spratelloides gracilis* (SCHLEGEL) bei weitem überwiegend wie dies auch in den pliozänen Diatomiten des Heraklion-Beckens (Kreta) der Fall ist. Es handelt sich um einen epipelagischen Fisch, der vermuten lässt, dass der Fossilhorizont in neritischem Gewässer abgelagert worden ist. Hierauf deuten auch die benthonischen und epibenthonischen Foraminiferen und Diatomeen aus derselben Schicht hin.

Contents

1. Introduction	141
2. Geological context.....	142
3. Fishes (J. GAUDANT).....	142
3.1. Material and methods.....	142
3.2. Results.....	143
3.3. Discussion.....	144
4. Micropalaeontological study.....	145
4.1. Diatoms (S. SAINT-MARTIN)	145
4.1.1. Material and methods.....	145
4.1.2. Results	145
4.1.3. Discussion.....	145
4.2. Foraminifera (M.-D. COURME-RAULT)	145
4.2.1. Material and methods.....	145
4.2.2. Results	146
4.2.3. Discussion.....	146
5. Conclusion	146
6. References	146
Appendix 1.....	148
Appendix 2.....	149

1. Introduction

In Aegina Island (Fig. 1), the occurrence of fossil fishes was first reported by BENDA et al. (1979) from the Neogene of the Aghios Thomas section, at about 1 km southwest of Messagros village. However, no information was hitherto available concerning the composition of this fish fauna. The aim of the present paper is to compare it with that of the Piacenzian of the Heraklion basin (GAUDANT et al. 1994; GAUDANT 2001).

The material is kept in Paris, in the palaeontological collections of the National Museum of Natural History (MNHN).

Acknowledgements

The first author is indebted to Professor MICHAEL DERMITZAKIS, who suggested him to pay a visit to Messagros and to Mr. GEORGE LYRAS, who helped him when collecting material in this outcrop. The illustrations were prepared by Mr. JOËL DYON, Paris.

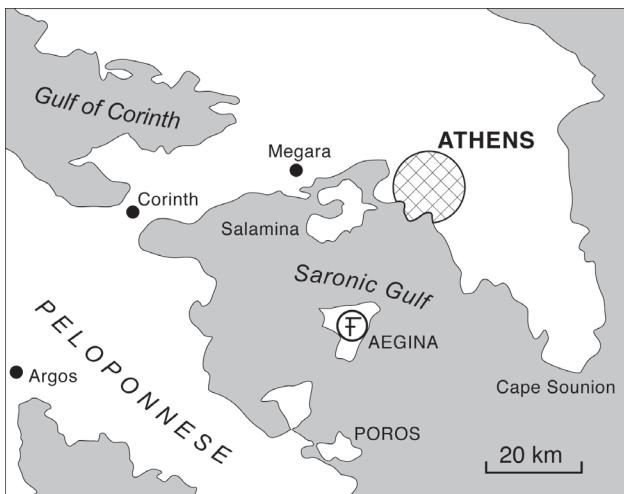


Fig. 1. Map of the Saronic Gulf showing the location of Aegina Island.

2. Geological context

Aegina is a volcanic island. It was mainly built by the Skotini volcano, which occupied the centre and the south of this island, although volcanic dacitic rocks are also present in the north-east. During the Pliocene, this volcano produced volcanoclastics and acid lava flows of andesite and dacite. Sedimentary rocks are mainly present in the northern part of the island where the Palaeozoic and Mesozoic basement is overlain by Pliocene shallow marine sediments which are themselves partly covered by Pleistocene marls and beds of "Poros" limestone.

Near Messagros, the age of the fossiliferous diatomitic levels outcropping on the southern side of Aghios Thomas hill was determined by BENDA et al. (1979), who identified *Globorotalia puncticulata*, *G. subscitula* and extremely rare *G. margaritae* in the upper part of the section, so that they attributed it to the *Globorotalia puncticulata* Zone, whereas "the co-occurrence of *Discoaster asymmetricus* and *Amaurolithus tricorniculatus* in samples from the upper part of the section points to zone NN 14 in terms of MARTINI's calcareous nannoplankton standard zonation (1970)".

Radiometric ages were also obtained by MÜLLER et al. (1979) who dated both the andesite breccia overlying the marine sequence at 3.87 ± 0.05 Ma and the andesitic tuf intercalated 6–7 m below at 4.4 ± 0.2 Ma (Fig. 2). Consequently, a good agreement already existed between the micropalaeontological and the radiometric data.

More recently, VAN HINSBERGEN et al. (2004) studied the geological evolution of the island and distinguished two units in the sedimentary succession exposed around Aghios Thomas. Their Unit 2, which has 70 metres in thickness, ends just below the andesite breccia. It is interesting

to remark that it includes three diatomitic intercalations: the fossiliferous layer that we have studied in the present paper a few metres below the andesite breccia and two other ones respectively situated about 12 metres and 22 metres underneath.

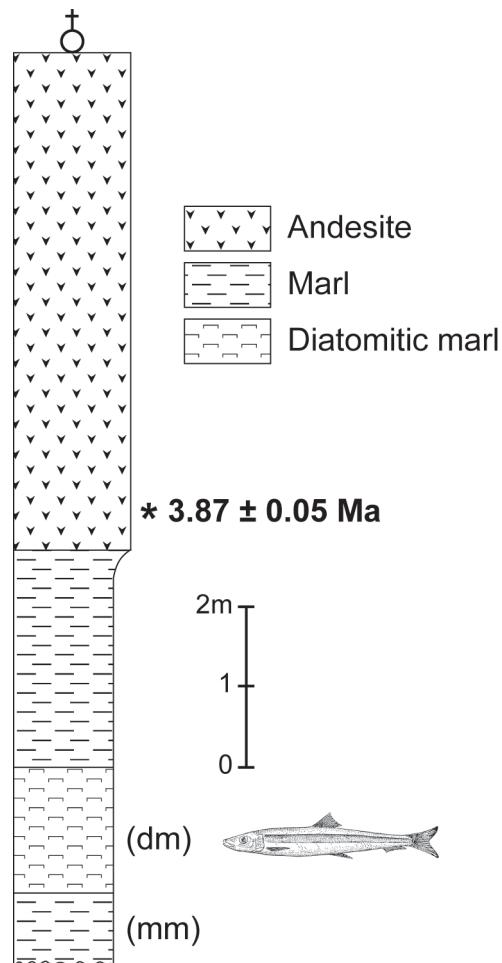


Fig. 2. Upper part of the Aghios Thomas section, Aegina (Modified from BENDA et al. 1979). – dm = diatomitic marl, mm = massive marl.

3. Fishes (J. GAUDANT)

3.1. Material and methods

The studied material was collected on the southern slope of Aghios Thomas hill, in the diatomitic marl (Fig. 2: dm) situated a few metres below the andesite breccia capping the hill. It is limited to 16 more or less complete specimens belonging to one dominant species, *Spratelloides gracilis* (SCHLEGEL), whereas a second species (Serranidae indet.) has only one representative.



Fig. 3. *Spratelloides gracilis* (SCHLEGEL). General view of specimen M NHNP PTE 480.

3.2. Results

Family Clupeidae CUVIER, 1817
Subfamily Dussumieriinae WHITEHEAD, 1963
Genus *Spratelloides* BLEEKER, 1852

Spratelloides cf. *gracilis* (SCHLEGEL, 1846)
Fig. 3

The representatives of this species have a standard length (measured or estimated) ranging from 36 to 83 mm. They are either juveniles or young adults as WHITEHEAD (1963) studied a population of recent fishes, the length of which ranges between 59 and 93 mm.

The body is elongated: its maximum height equals 13 to 18 % of standard length. The head is large: it constitutes about $\frac{1}{4}$ of standard length. The vertebral column includes 43 vertebrae; 15 of them are postabdominal. The pleural ribs are long: their distal end reaches the ventral edge of the abdominal cavity. Several isolated heads were also collected.

It should be emphasized that the anatomy of these fishes looks very similar to that of the fishes from the Messinian of Oran (Algeria) described by ARAMBOURG (1927) as *Spratelloides lemoinei* ARAMBOURG, a species which was considered by SORBINI (1988) as a synonym of *Spratelloides gracilis* (SCHLEGEL).

R e m a r k : Although they are either imperfectly preserved or incomplete, the fossil *Spratelloides* collected at Aghios Thomas are similar to those from the Piacenzian of Prassas and Amnissos (Heraklion basin, Crete) described by GAUDANT et al. (1994) and GAUDANT (2001). However, their standard length (measured or estimated) ranges from 36 to 85 mm, compared to those from Amnissos which can sometimes exceed 100 mm.

Family Serranidae

Serranidae indet.
Figs. 4–5

The only representative of the Serranids is a small fish, the standard length of which equals 27 mm. It has a rather sticky body, the maximum height of which exceeds $\frac{1}{3}$ of standard length. The head is bulky: its height equals 90 % of its length. The mouth is moderate: its length is approximately half of head length. The orbit is middle-sized as its diameter is included about three times in head length. A rather long spine is present on the postero-ventral angle of the preoperculum. The operculum was apparently ornamented by three posterior spines, as indicated by the occurrence of one spine below the main opercular spine. Its surface is covered with cycloid scales.

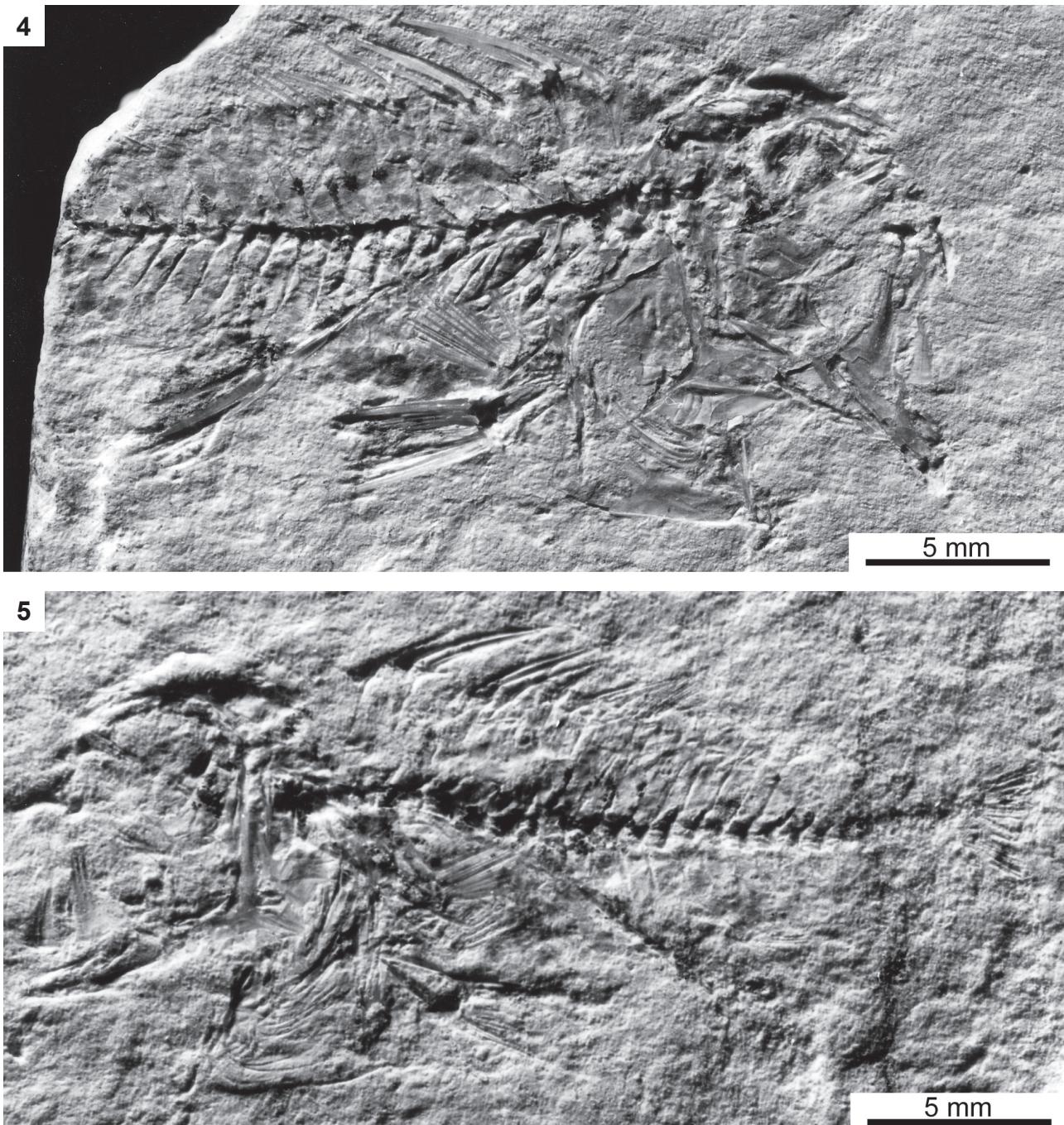
There are ten vertebrae in the abdominal region of the vertebral column, whereas the number of postabdominal vertebrae is unknown. The caudal fin is incompletely preserved. There is only one dorsal fin which has nine relatively short spines. The longest of them is the third or the fourth one. Its length is only 15 % of standard length. The number of dorsal rays is unknown.

The anal fin has three spines. The second one is the longest and the most robust. Its length equals that of the longest spine of the dorsal fin. The number of anal fin rays is unknown.

The pectoral fin consists of 14 rays.

The pelvic fins are situated below the pectorals. They have a spine which is longer than that of the longest spine of the unpaired fins.

The body is covered with ctenoid scales.



Figs. 4–5. Serranidae indet. General view of specimen MNHN PTE 488 (part and counterpart).

3.3. Discussion

The oligospecific character of the fish fauna collected in the diatomitic marl outcropping at Aghios Thomas is not surprising, partly because of the rather small amount of specimens. Additionally, a rather similar situation is known in the Piacenzian of the Heraklion basin

where two species make up together approximately 90 % or even more of the fish association collected at Voutes (88.9 %), Prassas (94.4 %) and in the lower diatomitic bed of Gournes (95.8 %). There, *Spratelloides gracilis* (SCHLEGEL) is remarkably dominant in the lower diatomitic bed of Gournes with 85.4 % of the collected material ($N=48$). In these three localities, the second most abundant

species is *Bregmaceros albyi* (SAUVAGE), with only 10.4% at Gournes, but 38.9% at Voutes ($N=54$) and even 42.2% at Prassas ($N=90$).

The fact that no specimen of *Bregmaceros albyi* (SAUVAGE) was found in the uppermost diatomitic bed of Aghios Thomas during our field work looked rather surprising in comparison with the Piacenzian diatomitic fish localities of the Heraklion basin. This impression was recently confirmed by the find near Aghios Thomas of a new outcrop in which *Bregmaceros albyi* (SAUVAGE) is present together with *Spatelloides gracilis* (ARGYRIOU 2010).

4. Micropalaeontological study

4.1. Diatoms (S. SAINT-MARTIN)

4.1.1. Material and methods

Samples were processed according to the preparation method described by SCHRADER & GERSONDE (1978). 10 g of sediments were treated with hydrogen peroxide (10%) and then with hydrochloric acid (30%). Successive decantations were repeated at about 1.5 hour interval to remove the detritic fraction. Then the solution was put in suspension and a drop of solution was placed on a slide. When dry, the slide was mounted with Canada balsam under a coverslip. The relative abundance was calculated after having counted 400 diatoms. The main ecological data were drawn from several papers: PERAGALLO & PERAGALLO (1897–1908), HUSTEDT (1930–1966), HENDEY (1964), JOUSÉ (1957), JOUSÉ et al. (1971), BARRON (1973, 1992), MAYNARD (1976), RICARD (1977), GUILLARD & KILHAM (1978), SANCETTA (1979, 1982), GERSONDE (1980), HARTLEY (1986), SANCETTA & SILVESTRI (1986), NOËL (1982, 1984), BARRON (1985), ROUND et al. (1990), SANCETTA et al. (1992), RINCÉ (1993).

4.1.2. Results

The diatomitic flora of the diatomitic marl includes 30 genera of diatoms (16 centric and 14 pennate) represented by 55 species: 30 species of centric and 25 of pinnate (Appendix 1). Among the centric genera, *Coscinodiscus* and *Thalassiosira* are the most diversified, whereas the pinnate genus, *Diploneis* is represented by the greatest number of species.

The planktonic taxa *Thalassionema nitzschiooides* is by far the most abundant with 31.2%, whereas *Rhizosolenia hebetata* reaches 12.2% and *Chaetoceros* spores 6.8%.

As many of the identified species are present in the modern diatom microflora, they support palaeoecological interpretations. From a bathymetrical point of view, the neritic-oceanic species are dominant, with 66% of the total assemblage. They are mainly represented by *Thalassionema nitzschiooides*, *Rhizosolenia hebetata*, *Coscinodiscus asteromphalus*, *Coscinodiscus oculus-iridis*,

Thalassiosira lineata, *Thalassiosira cf. lineata* 1, *Thalassiosira cf. lineata* 2 and *Thalassiosira symbolophora*.

Typical oceanic species like *Thalassiosira convexa* reach 11%, whereas neritic-meroplanktic species such as *Actinocyclus ehrenbergii* var. *tenella*, *Actinoptychus senarius*, *Coscinodiscus argus*, *Coscinodiscus granii*, *Paralia sulcata*, *Stephanopyxis turris* are less abundant (7%). Benthic taxa which are very common (27%) are mainly represented by different species of *Grammatophora* (*G. oceanica*, *G. undulata*, *G. angulosa*) and by *Coccconeis scutellum*, *Diploneis lineata*, *D. smithii*, *Mastogloia splendida*, *Navicula lyra*, *N. praetexta*, *Rhabdonema adriaticum*, *Rhopalodia gibberula*.

Concerning the water temperature, cosmopolitan species (*Thalassionema nitzschiooides*, *Rhizosolenia hebetata*, *Actinocyclus ehrenbergii* var. *tenella*, *Actinoptychus senarius*, *Coscinodiscus granii*, *C. obscurus*) make up the major part of the total assemblage (82%). They are mixed with warm water species (15%) *Coscinodiscus argus*, *C. asteromphalus*, *C. radiatus*, *Thalassiosira convexa*, *T. eccentrica*, *T. lineata*, *Thalassiosira cf. lineata*, *T. symbolophora* and also with cold water species (3%) like *Thalassiothrix longissima* and *Coscinodiscus decrescens*.

Consequently, the diatom assemblage from Aghios Thomas characterizes a neritic open shelf environment. The dominant *Thalassionema nitzschiooides* suggests a possible occurrence of upwellings, as this species is frequently found in upwelling areas where it is often accompanied by *Chaetoceros* spores (SCHUETTE & SCHRADER 1981; ROMERO & HEBBELN 2003).

4.1.3. Discussion

Most of the taxa observed in the Aghios Thomas diatom assemblage are recorded in other Pliocene assemblages described in the Mediterranean area (FRYDAS 1999), in California (BARRON 1975; BARRON & BALDAUF 1986), as well as in the Pacific realm (BARRON 1980).

The diatom assemblage from Aghios Thomas suggests a neritic open shelf environment. The dominance of *Thalassionema nitzschiooides* (GRUNOW) VAN HEURCK may indicate the occurrence of upwellings because this species is generally observed in the recent upwellings in which it is frequently accompanied by *Chaetoceros* spores (SCHUETTE & SCHRADER 1981; ROMERO & HEBBELN 2003).

4.2. Foraminifera (M.-D. COURME-RAULT)

4.2.1. Material and methods

The sediments were washed with water in which a small amount of hydrogen peroxide had been added. Then, they were sifted with sifters having meshes of 0.500, 0.250 and 0.125 mm. The microfossils were finally examined under a binocular microscope.

4.2.2. Results

Two facies were studied, both intercalated between the andesitic tuff and the andesite breccia. The first one is a massive marl (Fig. 2: mm) which takes place above the andesitic tuff and is overlaid by the diatomitic marl (Fig. 2: dm) in which the fossil fishes are preserved. The composition of the foraminiferid fauna from these two facies is given in the Appendix 2.

Diatomitic marl. – Although *Globorotalia puncticulata* is absent, the occurrence of *G. margaritae* is indicative of the Lower Pliocene age (pars N18–pars N19; Zanclean). The planktonic and benthic foraminifera from the diatomitic marl are rather unfrequent and generally smaller than those from the massive marl. Among the benthic ones, epiphytes are predominant: especially *Ammonia* spp., *Biasterigerina*, *Cibicides lobatulus*, *Elphidium* spp. However, other species are adapted to stressful conditions, especially to suboxic waters (with the exception of *Gyroidinoides* which thrives in low salinity waters). The microfauna from this level indicates bathymetric conditions ranging from the external neritic (circalittoral) to the epibathyal zones.

Massive marl. – The occurrence of *Globorotalia puncticulata* indicates a Lower Pliocene age (pars N19, Zanclean) for this layer. For every species (except for *Globigerina quinqueloba*, *Globorotalia* gr. *scitula* and *G. puncticulata*), the abundance of planktonic foraminifera is higher than that of benthic ones which show an important specific diversity. Among them, *Lenticulina nitida*, *L. calcar*, *L. rotulata*, *Bulimina aculeata* and *Brizalina dilatata* are the most abundant. Additionally to the typical open marine benthic foraminifera (*U. peregrina*, *Sarcenaria*, *Neoponides*, *Heterolepa*, *Lenticulina*), there are foraminifera which are adapted to slight increases of salinity (*Bigenerina*, *Bolivina scalprata miocenica*, *Gyroidinoides*, *Pullenia*). Epiphytes (*Ammonia* and *Biasterigerina*) are rather scarce. *Bulimina*, *Cassidulina* and *Hopkinsina*, which are adapted to stressful conditions, are indicative of a muddy substratum. *Bulimina exilis* is generally considered as being indicative of sediments deposited in anoxic conditions, whereas *Hopkinsina* suggests the occurrence of water stagnation. Additionally, *Globigerina bulloides* and *G. quinqueloba* are considered as suggesting stressful environments, i. e. partly closed marine areas (CITA & GARTNER 1973).

4.2.3. Discussion

The foraminifera from the Aghios Thomas section are indicative of a Zanclean age. They are also informative from a palaeoenvironmental point of view. Making reference to MURRAY (1991, 2006), it is possible to consider that

the deposition of the two studied strata took place in the circalittoral zone.

5. Conclusion

As the fossiliferous diatomitic level is outcropping in the cliff situated at the foot of Aghios Thomas chapel, SW of the village Messagros, only a small amount of fossil fishes could be collected at this place. They belong to only two different families. However, several undeterminable fragments observed in the field bear testimony of a slightly more important biodiversity. The most abundant species is *Spratelloides gracilis* (SCHLEGEL), a species which is also abundant in the Piacenzian of Crete (GAUDANT et al. 1994; GAUDANT 2001). It is an epipelagic fish which is mainly living in the neritic zone. This interpretation is fully in agreement with the palaeoenvironmental information provided by diatoms and foraminifera. The apparent lack of *Bregmaceros albyi* (SAUVAGE) in our material looks surprising when comparing the fish fauna from Aghios Thomas to that from the diatomitic Piacenzian of the Heraklion basin. However, excavations made in a nearby outcrop have recently shown that this species was also present in Aegina during the Zanclean (ARGYRIOU 2010), although the position of the fossiliferous diatomitic layer remains unknown relatively to the bed which has been studied in the present paper. Consequently, the association of *Spratelloides gracilis* (SCHLEGEL) and *Bregmaceros albyi* (SAUVAGE) has apparently played a significant role in the Eastern Mediterranean during the Zanclean, the Piacenzian (RÖGL & MÜLLER in GAUDANT 2001) and possibly the Gelasian (BIZON, TRIANTAPHYLLOU & FOURTANIER in GAUDANT et al. 1994).

6. References

- ARAMBOURG, C. (1927): Les poissons fossiles d'Oran. Matériaux pour la Carte géologique d'Algérie, 1re série: Paléontologie, **6**: 1–298 + Atlas.
- ARGYRIOU, T. (2010): Study of the petrified fish fauna from the Upper Pliocene of Aegina Island (Greece). 101 pp.; unpublished thesis, Athens University [In Greek].
- BARRON, J. (1973): Late Miocene-Early Pliocene paleotemperatures for California from marine diatom evidence. – Palaeogeography, Palaeoclimatology, Palaeoecology, **14**: 277–291.
- BARRON, J. A. (1975): Late Miocene-Early Pliocene marine diatoms from southern California. – Palaeontographica, Abteilung B, **151** (4–6): 97–170.
- BARRON, J. A. (1980): Upper Pliocene and Quaternary diatom biostratigraphy of D.S.D.P leg 54, tropical eastern Pacific. – In: ROSENTHAL, B. R., HEKINIAN, R. et al. (eds.): Initial Reports of DSDP, **54**: 455–486; Washington (US. Govt. Printing Office).
- BARRON, J. A. (1985): Miocene to Holocene planktic diatoms. – In: BOLLI H., SAUNDERS J. & PERCH-NIELSEN K. (eds.): Plankton Stratigraphy: 763–793; Cambridge (Cambridge University Press).

- BARRON, J. A. (1992): Pliocene paleoclimatic interpretation of DSDP Site 580 (NW Pacific) using diatoms. – *Marine Micropaleontology*, **20**: 23–44.
- BARRON, J. A. & BALDAUF, J. G. (1986): Diatom stratigraphy of the lower Pliocene part of the Sisquoc Formation, Harris Grade section, California. – *Micropaleontology*, **32** (4): 357–371.
- BENDA, L., JONKERS, H. A., MEULENKAMP, J. E. & STEFFENS, P. (1979): Biostratigraphic correlations in the Eastern Mediterranean Neogene. 4. Marine microfossils, sporomorphs and radiometric data from the Lower Pliocene of Ag. Thomas, Aegina, Greece. – *Newletters on Stratigraphy*, **8** (1): 61–69.
- CITA, M. B. & GARTNER, S. (1973): Studi sul Pliocene e sugli strati di passaggio dal Miocene al Pliocene. IV. The stratotype Zanclean foraminiferal and nannofossil stratigraphy. – *Rivista italiana di Paleontologia e Stratigrafia*, **79**: 503–558.
- FRYDAS, D. (1999): Paleoecology, stratigraphy and taxonomy of the Pliocene marine diatoms from central Crete (Greece). – *Revue de Micropaléontologie*, **42** (4): 269–300.
- GAUDANT, J. (2001): Amnissos: un gisement clé pour la connaissance de l'ichthyofaune du Pliocène supérieur de Crète. – *Annalen des Naturhistorischen Museums in Wien*, **102A**: 131–187.
- GAUDANT, J., DELRIEU, B., DERMITZAKIS, M. D. & SYMEONIDIS, N. K. (1994): Découverte d'une ichthyofaune dans le Pliocène supérieur (Plaisancien) des environs d'Héraklion (Crète centrale). – *Comptes Rendus de l'Académie des Sciences, Paris*, **319** (II): 589–596.
- GERSONDE, R. (1980): Paläoökologische und biostratigraphische Auswertung von Diatomeen-Assoziationen aus dem Messinium des Caltanissetta-Beckens (Sizilien) und einiger Vergleichsprofile in SO-Spanien, NW-Algerien und auf Kreta. 393 pp.; Dissertation, Universität Kiel.
- GUILLARD, R. R. L. & KILHAM, P. (1978): Ecology of marine planktonic diatoms. – In: WERNER, D. (ed.): *The biology of diatoms*. – Botanical Monographs, **13**: 470–483; Berkeley (University of California Press).
- HARTLEY, B. (1986): A check-list of the freshwater, brackish and marine diatoms of the British Isles and adjoining coastal waters. – *Journal of the Marine Biological Association of the U.K.*, **66**: 531–610.
- HENDEY, N. I. (1964): An introductory account of the smaller algae of the British coastal waters. Part V: Bacillariophyceae (Diatoms). 317 pp.; Fishery investigations, series 4, London (Her Majesty's Stationery Office).
- HINSGERGEN, D. J. J. VAN, SNEL, E., GARSTMAN, S. A., MARUNTE-ANU, M., LANGEREIS, C. G., WORTEL, M. J. R. & MEULENKAMP, J. E. (2004): Vertical motions in the Aegean arc: evidence for rapid subsidence preceding volcanic activity on Milos and Aegina. – *Marine Geology*, **209**: 329–345.
- HUSTEDT, F. (1930–1966): Die Kieselalgen Deutschlands, Österreichs und der Schweiz. – In: RABENHORST, L. (ed.): *Kryptogamen-Flora*, **7**, Die Kieselalgen, 1 (1930): 920 pp., 2 (1959): 845 pp., 3 (1961–1966): 816 pp.; Leipzig (Akademie Verlag).
- JOUSÉ, A. P. (1957): Diatoms in the surface layer of the sediments in the Sea of Okhotsk. – *Trudy Instituta Okeanologii Akademii Nauk SSSR*, **22**: 1–164 [In Russian].
- JOUSÉ, A. P., KOSLOVA, O. G. & MUKHINA, V. V. (1971): Distribution of diatoms in the surface layer of sediment from Pacific Ocean. – In: FUNNEL, B. M. & RIEDEL, W. R. (eds.): *The Micropaleontology of Oceans*: 263–269; Cambridge (Cambridge University Press).
- MAYNARD, N. G. (1976): Relationship between diatom in surface sediments of the Atlantic Ocean and the biological and physical oceanography of overlying waters. – *Paleobiology*, **2**: 99–121.
- MÜLLER, P., KREUZER, H., LENZ, H. & HARRE W. (1979): Radio-metric dating of two extrusives from a Lower Pliocene marine section on Aegina Island, Greece. – *Newletters on Stratigraphy*, **8** (1): 70–78.
- MURRAY, J. W. (2006): *Ecology and applications of benthic Foraminifera*. 438 pp.; Cambridge (Cambridge University Press).
- NOËL, D. (1982): Les diatomées des saumures des marais salants de Salin-de-Giraud (Sud de la France). – *Géologie Méditerranéenne*, **9** (4): 413–446.
- NOËL, D. (1984): Les diatomées des saumures et des sédiments de surface du Salin de Bras del Port (Santa Pola, province d'Alicante, Espagne). – *Revista de Investigaciones geológicas*, **38/39**: 79–107.
- PERAGALLO, H. & PERAGALLO, M. (1897–1908): *Diatomées marines de France et des districts maritimes voisins*, 491 pp.; Grez-sur-Loing (Micrographe-Editeur LK).
- RICARD, M. (1977): Les peuplements de diatomées des lagons de l'Archipel de la Société (Polynésie Française): floristique, écologie, structure des peuplements et contribution à la production primaire. – *Revue Algologique*, (N. S.), **12** (3–4): 1–336.
- RINCÉ, Y. (1993): Les diatomées marines de la région de Basse-Loire: inventaire, distribution spatio-temporelle et devenir expérimental des peuplements naturels d'écosystème ostréicoles. 489 pp.; Thèse de Doctorat d'Etat, Université de Nantes.
- ROMERO, O. & HEBBEN, D. (2003): Biogenic silica and diatom thanatozoenosis in surface sediments below Peru-Chile current: controlling mechanisms and relationship with productivity of surface waters. – *Marine Micropaleontology*, **48**: 71–90.
- ROUND, F. E., CRAWFORD, R. M. & MANN, D. G. (1990): *The diatoms. Biology and morphology of the genera*. 747 pp.; Cambridge (Cambridge University Press).
- SANCETTA, C. (1979): Oceanography of the North Pacific during the last 18.000 years; evidence from fossil diatoms. – *Marine Micropaleontology*, **4**: 103–123.
- SANCETTA, C. (1982): Distribution of the diatom species in surface sediments of the Bering and Ohotsk seas. – *Micropalaeontology*, **28** (3): 221–257.
- SANCETTA, C. & SILVESTRI, S. (1986): High-resolution biostratigraphy and oceanographic events in the late Pliocene and Pleistocene North Pacific. – *Paleoceanography*, **1** (2): 163–180.
- SANCETTA, C., HEUSER, L. & HALL, M. A. (1992): Late Pliocene climate in the Southeast Atlantic: preliminary results from a multidisciplinary study of D.S.D.P. site 532. – *Marine Micropaleontology*, **20**: 59–75.
- SCHRADER, H. J. & GERSONDE, R. (1978): Diatoms and silicoflagellates. – In: ZACHARIASSE, W. J., RIEDEL, W. R., SANFILIPPO, A., SCHMIDT, R. R., BROLSMA, M. J., SCHRADER, H. J., GERSONDE, R., DROOGER, M. M. & BROEKMAN, J. A. (eds.): *Micropaleontological counting methods and techniques – an exercise on an eight metres section of the lower Pliocene of Capo Rosso, Sicily*. – Utrecht Micropaleontological Bulletin, **17**: 129–176.
- SCHUETTE, G. & SCHRADER, H. J. (1981): Diatoms in surface sediments: A reflection of coastal upwelling. – In: RICHARDS, F. A. (ed.): *Coastal and estuarine Sciences. I. Coastal Upwelling*: 372–380; Washington, D.C. (American Geophysical Union).
- SORBINI, L. (1988): Biogeography and climatology of Pliocene and Messinian fossil fish of Eastern-Central Italy. – *Bollettino del Museo civico di Storia naturale di Verona*, **14** (1987): 1–85.
- WHITEHEAD, P. J. P. (1963): A revision of the recent round herrings (Pisces: Dussumieriidae). – *Bulletin of the British Museum (Natural History), Zoology*, **10**: 305–380.

Addresses of the authors:

JEAN GAUDANT, 17 rue du Docteur Magnan, 75013 Paris, France (USM 203 du Muséum national d'Histoire naturelle et UMR 7207 du CNRS)
 E-mail: jean.gaudant@orange.fr

MARIE-DENISE COURME-RAULT, 6 rue Porte vendômoise, 45190 Beaugency, France
 E-mail: mdcourme@free.fr

SIMONA SAINT-MARTIN, UMR 7207 – Centre de recherche sur la paléobiodiversité et les paléoenvironnements, Département «Histoire de la Terre», Muséum national d'Histoire de la Terre, 8 rue Buffon, 75005 Paris, France
 E-mail: simsmart@mnhn.fr

Manuscripts received: 5 November 2009, accepted: 11 October 2010.

Appendix 1. Percentages of diatom species identified in the diatomitic marl of Aghios Thomas.

Centric diatoms	%	Pennate diatoms	%
<i>Actinocyclus ehrenbergii</i> var. <i>tenella</i>	2.0	<i>Amphora intersecta</i>	0.2
<i>Actinoptychus senarius</i>	0.5	<i>Cocconeis belawani</i>	0.5
<i>Azpeitia nodulifer</i>	0.5	<i>C. debesi</i>	0.5
<i>Bacteriastrum delicatum</i>	2.9	<i>C. scutellum</i>	2.4
<i>Biddulphia pulcella</i>	0.2	<i>Cymatosira lorenziana</i>	0.5
<i>B. tuomeyi</i>	0.5	<i>Dimerogramma marinum</i>	0.2
<i>Chaetoceros</i> (spores)	6.8	<i>Diploneis bombus</i>	0.2
<i>Coscinodiscus argus</i>	0.2	<i>D. crabo</i>	0.2
<i>C. asteromphalus</i>	1.2	<i>D. lineata</i>	0.5
<i>C. decrescens</i>	0.2	<i>D. smithii</i>	0.5
<i>C. granii</i>	0.5	<i>D. suborbicularis</i>	0.2
<i>C. obscurus</i>	0.5	<i>D. subovalis</i>	0.2
<i>C. oculus-iridis</i>	1.0	<i>Grammatophora angulosa</i>	1.0
<i>C. radiatus</i>	0.2	<i>G. oceanica</i>	8.3
<i>C. sp. 1 GARDETTE</i>	0.5	<i>G. undulata</i>	2.9
<i>Lithodesmium</i> sp.	0.5	<i>Mastogloia splendida</i>	0.5
<i>Paralia sulcata</i>	0.7	<i>Navicula lyra</i>	0.5
<i>Psammodiscus nitidus</i>	0.2	<i>N. praetexta</i>	0.5
<i>Rhizosolenia hebetata</i>	12.2	<i>Rhabdonema adriaticum</i>	1.0
<i>Rossiella tatsunokuchiensis</i>	1.2	<i>Rhaphoneis nitida</i>	0.2
<i>Stephanopyxis turris</i>	1.0	<i>Rhopalodia gibberula</i>	2.9
<i>Stictodiscus parallelus</i>	0.2	<i>Surirella fastuosa</i>	0.2
<i>Thalassiosira convexa</i>	0.2	<i>Thalassionema nitzschiooides</i>	31.2
<i>T. eccentrica</i>	1.5	<i>Thalassiothrix longissima</i>	2.0
<i>T. eccentrica</i> var. <i>fasciculata</i>	0.5	<i>Trachyneis aspera</i>	0.2
<i>T. lineata</i>	1.0		
<i>T. cf. lineata</i> with central areola	2.0		
<i>T. cf. lineata</i> without central areola	1.0		
<i>T. cf. symbolophora</i>	2.0		
<i>Triceratium balearicum</i>	0.2		

Appendix 2. Abundance of foraminifera species identified at Aghios Thomas. VR: very rare; R: rare; F: few; C: common; A: abundant.

Diatomitic marl (dm)		Massive marl (mm)	
Planktonic foraminifera		Planktonic foraminifera	
<i>Orbulina universa</i> d'ORBIGNY	A	<i>Globigerinoides ruber</i> (d'ORBIGNY)	A
<i>Globigerina bulloides</i> d'ORBIGNY	C	<i>G. obliquus extremus</i> (BOLLI & BERMUDEZ)	C
<i>G. quinqueloba</i> NATLAND	R	<i>Globigerina bulloides</i> d'ORBIGNY	A
<i>Globorotalia humerosa</i> TAKAY & SAITO	F	<i>G. apertura</i> CUSHMAN	A
<i>G. acostaensis</i> acostaensis BLOW	A	<i>G. quinqueloba</i> NATLAND	R
<i>G. margaritae</i> margaritae BOLLI & BERMUDEZ	VR	<i>G. foliata</i> BOLLI	R
<i>G. obesa</i> BOLLI	R	<i>Globorotalia humerosa</i> TAKAY & SAITO	F
<i>G. gr. scitula</i>	VR	<i>G. acostaensis</i> acostaensis BLOW	F
<i>Globigerinita glutinata</i> (JENKINS)	VR	<i>G. obesa</i> BOLLI	R
		<i>G. gr. scitula</i>	VR
		<i>Hastigerina siphonofera</i> (d'ORBIGNY)	A
Benthic foraminifera		Benthic foraminifera	
<i>Ammonia tepida</i> (CUSHMAN)	R	<i>Ammonia beccarii</i> (LINNAEUS)	R
<i>Asterigina mamilla</i> (WILLIAMS)	R	<i>Amphicoryna scalaris</i> (BATSCH)	F
<i>Biasterigerina planorbis</i> (d'ORBIGNY)	F	<i>Baggina totomiensis</i> MAKIYAMA	R
<i>Bolivina subexcavata</i> (CUSHMAN & WICKENSON)	F	<i>Biasterigerina planorbis</i> (d'ORBIGNY)	F
<i>Brizalina dilatata</i> (REUSS)	F	<i>Bigenerina nodosaria</i> d'ORBIGNY	F
<i>B. catanensis</i> (SEGUENZA)	F	<i>Bolivina scalprata miocenica</i> MACFADYEN	F
<i>B. cf. aenariensis</i> (COSTA)	F	<i>Brizalina dilatata</i> (REUSS)	A
<i>Bulimina exilis</i> BRADY	C	<i>B. arta</i> MACFADYEN	A
<i>B. aculeata</i> d'ORBIGNY	A	<i>B. spathulata</i> (WILLIAMS)	F
<i>Cancris oblongus</i> (WILLIAMSON)	F	<i>B. alata</i> (SEGUENZA)	A
<i>Cassidulina neocarinata</i> (THALMANN)	F	<i>Bulimina costata</i> d'ORBIGNY	A
<i>Cassidulinoides bardyi</i> (NORMAN)	F	<i>B. aculeata</i> d'ORBIGNY	A
<i>Cibicides lobatulus</i> (WALKER & JACOB)	F	<i>Cancris auriculus</i> (FICHTEL & MOLL)	F
<i>Elphidium fichtelianum</i> (d'ORBIGNY)	C	<i>Cassidulina neocarinata</i> (THALMANN)	F
<i>E. flexuosum</i> (d'ORBIGNY)	F	<i>C. laevigata</i> d'ORBIGNY	F
<i>E. macellum</i> (FICHTEL & MOLL)	F	<i>Dorothia gibbosa</i> (d'ORBIGNY)	C
<i>E. aff. excavatum</i> (TERQUEM)	R	<i>Eponides umbonatus</i> (REUSS)	F
<i>Florilus boueanum</i> (d'ORBIGNY)	F	<i>Florinus boueanum</i> (d'ORBIGNY)	C
<i>Furkenkoina</i> sp.	VR	<i>Globocassidulina subglobosa</i> (BRADY)	C
<i>Globocassidulina subglobosa</i> (BRADY)	F	<i>Gyroidinoides girardanus</i> (REUSS)	C
<i>Gyroidinoides parvus</i> CUSHMAN & RENZ	R	<i>Hanzawaia boueana</i> (d'ORBIGNY)	C
<i>Hopkinsina bononiensis parkeri</i> (FORNASINI)	C	<i>Heterolepa ungeriana</i> (d'ORBIGNY)	A
<i>H. bononiensis compressa</i> CUSHMAN	F	<i>Hopkinsina bononiensis parkeri</i> (FORNASINI)	F
<i>Praeglobulima affinis</i> (d'ORBIGNY)	C	<i>Lenticulina nitida</i> REUSS	F
<i>Siphogenerinoides gaudryinoides arquat.</i> PAPP	C	<i>L. calcar</i> (LINNAEUS)	A
<i>Trifarina bradyi</i> CUSHMAN	F	<i>L. rotulata</i> (LAMARCK)	C
		<i>L. crassa</i> (d'ORBIGNY)	F
		<i>Martinotella communis</i> (d'ORBIGNY)	C
		<i>Melonis padanum</i> (PERCONIG)	F
		<i>Neponides schreibersii</i> (d'ORBIGNY)	C
		<i>Planulina ariminensis</i> d'ORBIGNY	F
		<i>Pullenia bulloides</i> (d'ORBIGNY)	C
		<i>P. quinqueloba</i> (REUSS)	F
		<i>Quinqueloculina horrida</i> CUSHMAN	R
		<i>Rectuvigerina siphogenerinoides</i> (LIPPARINI)	F
		<i>Saracenaria italica</i> DEFRENCE	F
		<i>Sigmoilopsis</i> sp.	VR
		<i>Svatikina perlata</i> (ANDRAEAE)	F
		<i>Uvigerina pygmaea</i> d'ORBIGNY	F
		<i>Valvulinaria bardiana</i> (FORNASINI)	F
		<i>Vulvulina pennatula</i> (BATSCH)	F