

EASTERN MEDITERRANEAN FORAMINIFERAL PALAEOECOLOGICAL RESPONSE TO MID- LATE PLIOCENE CLIMATIC REGIME: A PRELIMINARY NOTE

Drinia H.¹, Antonarakou A.¹, Mihalakopoulos S.¹ and Tsiolakis E.²

¹*National and Kapodistrian University of Athens, Faculty of Geology and Geoenvironment,
Department of Hist. Geology - Palaeontology, cndrinia@geol.uoa.gr, aantonar@geol.uoa.gr,
archaeodiscus@gmail.com*

²*Geological Survey of Cyprus, etsiolakis@gmail.com*

Abstract

The main objective of this work is to investigate the climatic influence on the sedimentation during mid to late Pliocene in Cyprus island. For this reason, a section located in Pissouri sub-basin, southern Cyprus, was chosen to be studied. The section comprises a nearly uninterrupted succession of marine sediments, dominated by grey marls, which are cyclically alternating with yellowish silty marls. The identification of age diagnostic planktonic foraminifera suggests a mid to upper Pliocene age. The calculated faunal parameters document cyclic fluctuations consistent with shifts in such climate belts. A good age resolution of the cycles and an indication of sedimentation rate would be required in order to connect cyclicity to orbital perturbations.

Key words: *mid to late Pliocene, foraminifera, biostratigraphy, palaeoecology, climate, Cyprus.*

Περίληψη

Ο κύριος στόχος της εργασίας αυτής είναι η διερεύνηση της κλιματικής επίδρασης στην ιζηματογένεση του Μέσου –Ανώτερου Πλειοκαίνου στη νήσο Κύπρο. Για το λόγο αυτό, επιλέχθηκε να μελετηθεί μια γεωλογική τομή της υπολεκάνης του Πισσουρίου στη νότια Κύπρο. Η τομή περιλαμβάνει μια σχεδόν αδιάκοπη εναλλαγή θαλάσσιων ιζημάτων, όπου επικρατούν γκρι μάργες, οι οποίες κυκλικά εναλλάσσονται με κιτρινωπές ιλυώδεις μάργες. Η βιοστρωματογραφική ανάλυση με βάση τα πλαγκτονικά τρηματοφόρα έδειξε ηλικία Μέσο-Ανώτερο Πλειόκαινο. Οι πανιδικές παράμετροι που υπολογίστηκαν επιδεικνύουν κυκλικές διακυμάνσεις που συνάδουν με τις αλλαγές στις ζώνες του κλίματος. Υψηλής ευκρίνειας βιοστρωματογραφική ανάλυση και υπολογισμός της ταχύτητας ιζηματογένεσης απαιτούνται προκειμένου να συνδεθούν οι κυκλικές διακυμάνσεις με τις τροχιακές παραμέτρους.

Λέξεις κλειδιά: *Μέσο-Ανώτερο Πλειόκαινο, Τρηματοφόρα, Βιοστρωματογραφία, Παλαιοοικολογία, κλίμα, Κύπρος.*

1. Introduction

The Mediterranean basin is one of the most appealing natural laboratories in the world to study geodynamic and palaeoclimatic processes on different scales (e.g. Pinardi & Masetti, 2000; Krijgsman, 2002). Sediments in the Mediterranean Sea form an important archive for understanding climate and environmental conditions during the geological past. This is mainly due to its palaeo – latitudinal position in combination with its semi – enclosed, land – locked configuration (Krijgsman, 2002).

At present, the Mediterranean Sea is characterized by geographical variations in oceanographic conditions: the eastern part of the basin is characterized by warm and oligotrophic surface waters whereas in the western part the surface waters are colder and richer in nutrients (Béthoux et al., 1999; Pinardi & Masetti, 2000). This modification in the hydrological condition is mirrored in the faunal distribution (Thunell, 1978; Pujol & Vergnaud-Grazzini, 1995).

Cyprus with an area of 9,251 km² is the third biggest island in the Mediterranean Sea, and the biggest island in Eastern Mediterranean region. The mid- to low- latitude positioning of Cyprus within the eastern Mediterranean places the island between high latitude obliquity and mid to low latitude precessional impact. Previous studies have shown that the critical location of Cyprus within the Mediterranean semi-enclosed basin and between two major oscillatory atmospheric cells makes the area integrally sensitive to the smallest of climatic perturbations (Casford et al., 2003; Marino et al., 2007; Rohling et al., 2009).

This study constitutes a preliminary note on the mid to late Pliocene foraminiferal paleoecology in Cyprus. Mid-Pliocene is the most recent interval of sustained global warmth, which can be used to examine conditions predicted for the near future. Foraminifera are sensitive indicators of seafloor and water column ecology and therefore provide important archives of climate and ocean state interactions.

2. Geological Setting and Sedimentology

The sedimentary succession of Cyprus is affected by a complex uplift history, which is attributed to its unstable position in a fore-arc setting of the convergence zone between Africa and Eurasia (e.g. Robertson, 1998; Orszag-Sperber et al., 1989).

Four sedimentary sub-basins developed in this area during Miocene time, the Polemi, Pissouri, Limassol and Psematismenos basins (Figure 1, Orszag-Sperber et al., 1989; Robertson et al., 1995; Stow et al., 1995; Krijgsman et al., 2002).

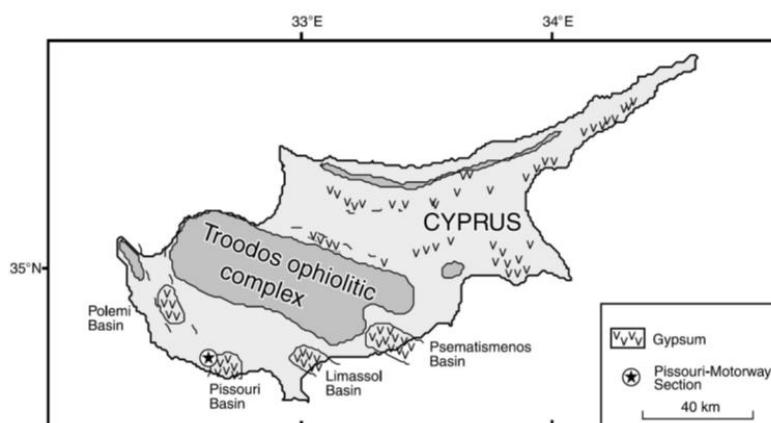


Figure 1 - Geological Sketch map of the Cyprus Island (modified after Robertson et al., 1991; Stow et al., 1995; Krijgsman et al., 2002; Kouwenhoven et al., 2006).

The Pissouri Basin contains one of the most suitable sedimentary sequences for studying the onset of the MSC in the Eastern Mediterranean (Krijgsman et al., 2002). It provides one of the most continuous sedimentary successions related to the MSC, comprising the pre-evaporitic, evaporitic and post-evaporitic deposits which cover the period from the late Tortonian up to the early Pliocene (Krijgsman et al., 2002; Orszag-Sperber et al., 2009). Palaeodepth estimations in the Pissouri Section are based on foraminifera, bivalves and gastropods (Rouchy et al. 2001; Krijgsman et al., 2002; Kouwenhoven et al. 2006). A progressive shallowing occurred from approximately 500 m in depth during the Tortonian and Early Messinian to very shallow water conditions during the late Messinian.

With the beginning of the Pliocene, deeper water conditions were re-established (Rouchy et al., 2001; Krijgsman et al., 2002). The subsequent tectonic opening of the Strait of Gibraltar in the early Pliocene (Rohling et al., 2009) and ensuing marine transgression (Rouchy et al., 2001; Soria et al., 2008) signifies the initiation of sedimentation (marine, grey clayey silts). Since this episode, a general pattern of regression is documented in the sedimentary succession of Cyprus manifested in the transition from marine clayey silts through to fan delta deposits, ultimately culminating in raised beaches and alluvial fans. The Pliocene-Pleistocene sedimentary fill of Pissouri basin is interpreted as representing a fan-delta complex with braid channels, which shows a broadly progradational sequence influenced by both sea-level fluctuation and tectonic activity (Stow et al., 1995).

The studied section (Figure 2) is located in the centre of the Pissouri sub-basin, in southern Cyprus (Pissouri basin) and contains a relatively thick succession (thickness of ~42 m) of rhythmically bedded marls, which constitute regularly bedded, fining upward packages. Each package typically has a sharp-based fine-grained, frequently laminated sandstone/siltstone bed fining upwards into claystone. It constitutes the stratigraphic continuation of the early Pliocene Pissouri South section studied by Triantaphyllou et al. (2008, 2010).

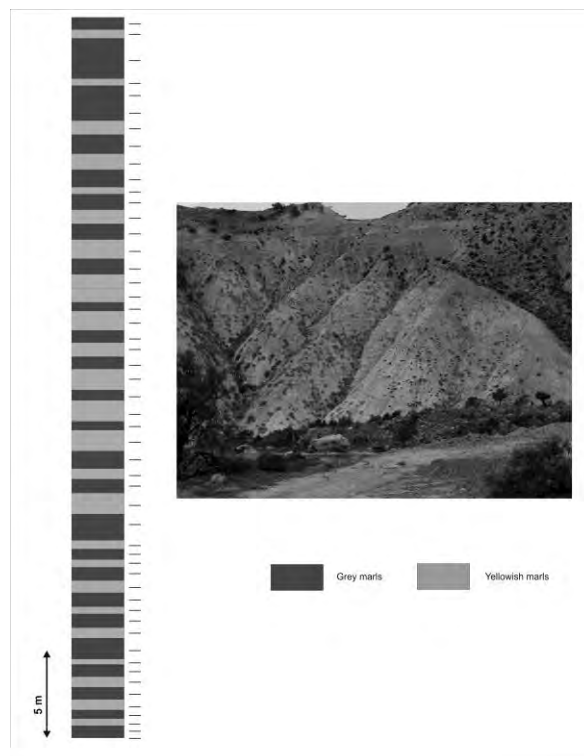


Figure 2 - Lithology and position of samples of the studied section.

3. Materials and Methods

A total of 52 samples collected at 0.5 m to 1 m intervals, were examined from the micropalaeontological point of view.

Samples were processed for foraminifera using standard separation techniques. Each sample was split into fractions, depending on sample size. A minimum of 300 complete specimens per sample were collected.

Based on the faunal counts, benthic foraminiferal numbers (BFN; number of specimens per gram dry sediment) were calculated. This number gives information on the taphonomy of the original living assemblage, the oxygen level (e.g. Ernst & Van der Zwaan, 2004), the energy level in which the sediments were deposited (high abundance in low energy), and to a minor extent the productivity or organic flux (Ernst & Van der Zwaan, 2004). The percentage of planktonic species in the total foraminiferal association (%P) was calculated as $100 \cdot P / (P+B)$, in order to reconstruct palaeodepth and track sea-level changes. To estimate the depositional depth of the sediments, the general relationship between depth and the fraction of planktonic foraminifera with respect to the total foraminiferal population (%P) (Van der Zwaan et al., 1990) was used, following sample selection and counting procedures described in Van Hinsbergen et al., (2005). If samples with evidence for downslope transport and carbonate dissolution are discarded, the relationship between %P and depth of Van der Zwaan et al. (1990) allows the estimation of the depositional depth of sediments with approximately 50 m of uncertainty at levels of a few hundreds of metres, to 150 m at depths around 1 km. Reconstruction of bottom water conditions concerning oxygen content was based on the presence of the dysoxic indicators in the assemblage. For this purpose, the percentage occurrence of the well established redox front dwelling taxa (*Bulimina exilis*, *Bulimina costata*, *Globobulimina* spp., *Bolivina spathulata/dilatata*) which according to Rogerson et al. (2006) is related to disturbance and/or environmental stress, was calculated.

4. Results and Analysis

4.1. Age Determination

Biostratigraphic analysis was performed based on the qualitative analysis of planktonic foraminifera species recognized into the faunal assemblages of the entire material.

Planktonic foraminiferal assemblages are dominated by high abundances of *G. ruber*, *G. obliquus*, *G. extremus*, *G. apertura*, *G. trilobus-sacculifer* and *O. universa*. High abundances are also recorded for *Neogloboquadrina* sp. dextral coiled specimens, whereas presence and/or absence of the species *Sphaeroidinellopsis*, *G. puncticulata*, and *G. crassaformis* is used to detect the biostratigraphic framework of the section following the zonation of Cita (1973, 1975), emended by Sprovieri (1993).

Six planktonic foraminiferal bioevents were recognized: (1) appearance of *Globorotalia crassaformis*, (2) appearance of *Globorotalia bononiensis*, (3) LO of *Sphaeroidinellopsis* s.l., (4) FO of *Neogloboquadrina atlantica*, (5) LO of *Neogloboquadrina atlantica* and (6) LO of *G. bononiensis*.

From the biostratigraphic point of view the studied interval lies above the Pissouri section of Triantaphyllou et al. (2008, 2010). The quantitative analysis of planktonic foraminiferal assemblages of the studied section revealed that up to 14.4 m *Sphaeroidinellopsis* s.l. is present in all the samples. *Globorotalia crassaformis* appears in our data at 10 m, corresponding to the *G. crassaformis* reappearance bioevent (3.35 Ma, Lourens et al., 1996; 2004). This event predates the appearance of *G. bononiensis* (at 10.5 m), dated at 3.31 Ma (Lourens et al., 1996; 2004). These bioevents constitute the typical association of MPL4b biozone. The last occurrence of *Sphaeroidinellopsis* is recorded some cm above this level, at 14.4 m, dated at 3.19 Ma (Lourens et al., 2004) and notes the transition to MPL5a subzone. *Neogloboquadrina atlantica atlantica* first

occurs at 20.5 m and it is commonly present up to 37.4 m. The occurrence of this species in the Mediterranean Pliocene has been dated from 2.72 Ma to 2.41 Ma (Lourens et al., 2004). At the same level of the studied interval, the last occurrence of *G. bononiensis* is recorded, dating the top of the section at 2.41 Ma, (Lourens et al., 2004). Consequently, the section falls into the Piacenzian-early Gelasian Stages, ending in MPL5a subzone.

4.2. Faunal Parameters

Benthic and planktonic foraminifera are present in all samples and show highly variable temporal changes in assemblage composition, relative abundance and preservation. Moreover, the common occurrence of planktonic foraminifera, throughout the succession, suggests open marine connection to a rather oceanic realm. The taxonomic concept of each individual species is beyond the scope of this study but it will be discussed in detail in Drinia et al. (in prep.).

BFN remains relatively stable exhibiting low values apart from the stratigraphic level of 11 m, where BFN shows an abrupt increase (up to 80,000, Figure 3). This horizon also contains other shallow-water debris, such as echinoid spines and gastropods and is interpreted as a turbidite sourced from a shallower water environment. Another reason for this abrupt increase in the abundance of benthic foraminifera could have a secondary, taphonomic origin, which would imply that the original benthic foraminiferal assemblage is best preserved in this level and that the remainder of the section does suffer from preferential dissolution. However, the actual assemblage quality (in situ fauna) is identical to other levels, and there is no evidence that dissolution-sensitive species are better preserved in this level.

Well-established redox front dwelling taxa S% dominate throughout the succession, strongly fluctuating in the range of 0.94–96.54%. These taxa practice an opportunistic life strategy, and are able to tolerate periodic reductions in dissolved oxygen contents by modifying their microhabitat from infaunal to epifaunal (Jorissen et al., 1992; Kaiho, 1994). In particular and according to Van der Zwaan (1982), Verhallen (1991), Jorissen et al. (1992), Kaiho (1994) and Loubère (1996, 1997), this group of species tends to increase in abundance when the influx of terrigenous organic matter dominates the environment. It shows opportunistic behaviour and a tolerance to dysoxia, but also to elevated bottom water salinity. The highly shifting abundances of redox fauna species, observed in the lower part of the record (Figure 3) may reflect cyclic changes in sediment input and/or circulation.

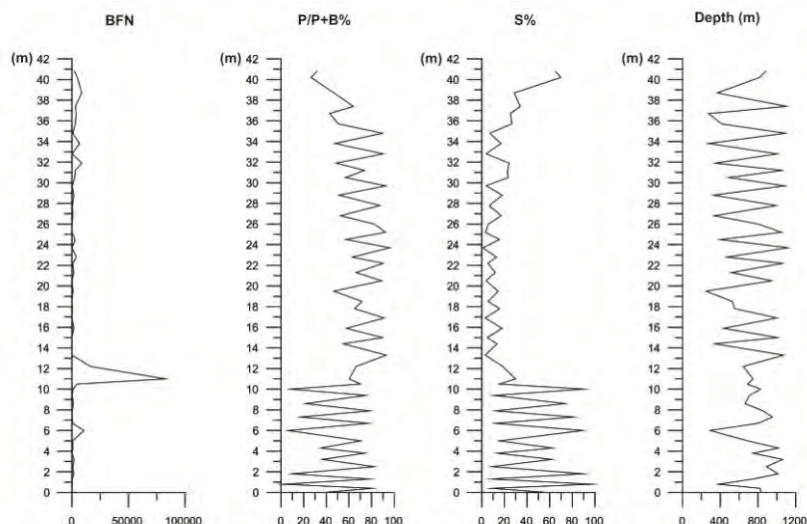


Figure 3 - Calculated benthic foraminiferal faunal parameters of the studied section together with palaeobathymetry.

The percentage (%) of planktonic foraminifera is one of the most consistent proxies to assess palaeo-water depths. It has been known for a long time that the percentage of planktonic foraminifera in modern sediments increases with water depth (e.g. Boltovskoy & Wright, 1976; Gibson, 1989; Van der Zwaan et al., 1990, 1999). Van der Zwaan et al. (1990, 1999) and Leckie et al. (1998) emphasized the significance of nutrients for the P/B ratio, in particular for benthic foraminifera. Because the density of planktonic and benthic foraminifera depends on the organic flux, and the amount of organic matter reaching the sea floor decreases with increasing water depth because of oxidation, the P/B ratio as anticipated has to increase with depth (Van der Zwaan et al., 1999). Other parameters such as temperature, salinity, substrate-type or circulation patterns may play a minor role.

In our record, the benthic and planktonic foraminifera relative abundance (P/B-ratio, Figure 3) ranges between 2.3 to 96.24%. A simple interpretation of this ratio using modern analogies (e.g. Gibson, 1989) points to very rapid changes in water-depth between middle shelf and lower bathyal, which is very unlikely and not supported by any other evidence. Hence, the ecologic reason for these enormous differences cannot be water-depth alone.

High fluctuations in the P/B ratio are interpreted as unstable conditions in the upper water layers. However, an increasing oceanic influence is implied by the increasing content of planktonic foraminifera. As bottom-water stress is developing, the P/B ratios are no longer reliable palaeodepth-indicators, since declining benthic faunas could erroneously suggest apparent deepening (Van der Zwaan et al., 1999).

Moreover, the high %P (>90%), observed in a number of samples does not seem realistic when compared with the benthic assemblages, which suggest that the palaeodepth of the succession studied was rather stable at around 300–500 m.

On the other hand, the abrupt declining of the P/B ratio in some intervals of the record may merely reflect periodic dilution of the autochthonous deep-water fauna with transported shallower faunas (e.g. Robertson, 1998). It is likely that, in these beds, some degree of faunal reworking has occurred, displacing shallow water taxa into deeper water faunas.

5. Discussion

As seen in Figure 3, the calculated foraminiferal parameters of mid-Pliocene Pissouri section document cyclic but irregular fluctuations. Numerous studies across the Mediterranean postulate a climatic control on cyclical alternations in marine and terrestrial successions, invoking a linkage with the changeable variations in the Earth's orbital parameters (e.g. Postma & Drinia, 1993; Weltje & De Boer, 1993; Kroon et al., 1998; Van Vugt et al., 1998; Wehausen & Brumsack, 1999; Foucault & Mélières 2000; Lourens et al., 2001; Joannin et al., 2007; amongst others). Therefore, it is likely that the sediments of Cyprus should provide a relatively intact archive of past climatic variability, likely to be recognizable on orbital timescales.

Indeed, as seen in Figure 3, rhythmically recurrent deepening and shallowing is taking place, with a maximum palaeodepth recorded at 1119m and a minimum at 248m. Additionally, the geometry of the palaeobathymetric curve does not denote a stable trend of deepening or shallowing, but for the most part, particularly in the upper half of the section, has an approximately sinusoidal shape. Although the palaeobathymetric changes depicted in the palaeobathymetric curve, cannot be attributed solely to variations of the global sea level-as this cannot cause variations in bathymetry of more than 200m - however the almost constant periodicity and amplitude lead us to the conclusion that the alternating depth values recorded should rather be attributed to periodic climatic influences.

The dominance of infaunal benthic foraminifera and stress indicators (%S), suggests an ecologically stressed habitat (Nolet & Corliss, 1990; Jorissen et al., 1995; Kouwenhoven, 2000; Schmiedel et al., 2003; Drinia et al., 2005; Abu-Zied et al., 2008). Presumably the stressed

conditions are likely to be related to the influx of organic matter through freshwater input (e.g. analogous to periods of sapropel formation).

Palaeo-climatic changes enhanced palaeoproductivity and limited the availability of dissolved oxygen in bottom waters, temporarily establishing dysoxic conditions. Wetter and drier and/or cooler and warmer periods will be reflected on an orbital cyclicity within foraminiferal assemblages and facies changes. It is assumed that changes in foraminiferal ecology will reflect the orbital variations in atmospheric cells. An initial hypothesis, using the modern day climatic conditions as analogy, would predict that warm, dry conditions would be reflected through a dominantly oligotrophic foraminiferal assemblage, whilst cool, wet periods would favour the proliferation of eutrophic species.

A sapropel-like interval was deposited under these conditions. We maintain that the Pliocene sediments in the Pissouri Basin are probably linked to climate-driven changes in surface runoff (i.e. warmer temperatures and/or lower salinities), which influenced the levels of primary productivity. The implications of these hydrological changes would have had a profound influence on the local accumulation of sapropel-like sediments. According to Hilgen (1991), individual sapropels in the eastern Mediterranean can be correlated with minima of the precessional cycle. Other studies support the precessional cycle as the dominant factor influencing the lower to upper Pliocene climatic evolution (Tiedemann et al. 1994). In the absence of high resolution stratigraphic control, we can only speculate as to the precise nature of astronomical forcing behind the brown-white marl cycles studied herein. Apparently, this is a characteristic event of the Eastern Mediterranean Basin, which points to a major modification of the oceanographic conditions with the eutrophic situation becoming widely distributed.

It may be argued that the cyclicity documented in the depositional systems could be the product of mechanisms other than climate, such as tectonics and/or autocyclicity.

Episodic tectonic movements are known to induce rhythmic deposition of sediments. However, it would be expected that features typical of structurally unstable regimes would accompany such an interpretation, perhaps in the form of syn-depositional faulting, deformation structures, abrupt facies changes and/or angular unconformities between successive cycles. These features are rare to absent within the successions, only occurring between major changes in depositional regime

6. Conclusions

Cyprus constitutes an area inherently sensitive to the smallest of climatic perturbations. In this study it is concluded that changing foraminiferal ecology is consistent with shifts in the climate belts. However, a good age resolution of the cycles and an indication of sedimentation rate would be required.

7. Acknowledgments

Financial support for this research was provided by the Research Project 70/4/11078 of the University of Athens.

8. References

- Abu-Zied R.H., Rohling E.J., Jorissen F.J., Fontanier C., Casford J.S.L. and Cooje S. 2008. Benthic foraminiferal response to changes in bottom-water oxygenation and organic carbon flux in the eastern Mediterranean during LGM to Recent times, *Marine Micropaleontology*, 67, 46–68.
- Béthoux J.P., Gentili B., Morin P., Nicolas E., Pierre C. and Ruiz-Pino D. 1999. The Mediterranean Sea: a miniature ocean for climatic and environmental studies and a key for the climatic functioning of the North Atlantic, *Progress in Oceanography*, 44, 131–146.

- Boltovskoy E., Wright R. (Eds.). 1976. *Recent Foraminifera*. Dr. W. Junk b.v., The Hague.
- Casford J.S.L., Rohling E.J., Abu-Zied R. H., Fontanier C., Jorissen F. J., Leng M. J., Schmiedl G. and J. Thomson. 2003. A dynamic concept for eastern Mediterranean circulation and oxygenation during sapropel formation, *Palaeogeogr. Palaeoclimatol. Palaeoecol.*, 190, 103–119.
- Cita M.B. 1973. Pliocene biostratigraphy and chronostratigraphy, in W.B.F. Ryan, K.J. Hsu et al, (eds), *Initial Reports of the Deep Sea Drilling Project*, v. 13. U.S. Government Printing Office, Washington, 1343-1379.
- Cita M.B. 1975. Studi sul Pliocene e sugli strati di passaggio dal Miocene al Pliocene VIII. Planktonic foraminiferal biozonation of the Mediterranean Pliocene deep sea record, revision, *Rivista Italiana di Paleontologia*, 81 (4), 527-544.
- Drinia H., Koskeridou E. and Antonarakou A. 2005. Late Pliocene benthic foraminifera and mollusks from the Atsipades section, central Crete: paleoecological distribution and use in paleoenvironmental assessment, *Geobios*, 38(3), 315–324.
- Ernst S.R. and Van Der Zwaan G.J. 2004. Effects of experimentally induced raised levels of organic flux and oxygen depletion on a continental slope benthic foraminiferal community, *Deep –Sea Research*, 51, 1709-1739.
- Foucault A. and Mélières F. 2000. Paleoclimatic cyclicity in central Mediterranean Pliocene sediments: The mineralogical signal, *Palaeogeogr. Palaeoclimatol. Palaeoecol.*, 158, 311–323.
- Gibson T.G. 1989. Planktonic/benthonic foraminiferal ratios: modern patterns and Tertiary applicability, *Marine Micropaleontology*, 15, 29–52.
- Hilgen F.J. 1991. Astronomical calibration of Gauss to Matuyama sapropels in the Mediterranean and implication for the geomagnetic polarity time scale, *Earth Planet. Sci. Lett.*, 104, 226–244.
- Joannin S., Quillévéré F., Suc J.P., Lécuyer C. and Martineau F. 2007. Early Pleistocene climate changes in the central Mediterranean region as inferred from integrated pollen and planktonic foraminiferal stable isotope analyses, *Quaternary Research*, 67, 264–274.
- Jorissen F.J., Barmawidjaja D.M., Puskaric S. and Van der Zwaan G.J. 1992. Vertical distribution of benthic foraminifera in the northern Adriatic Sea: the relation with the organic flux, *Marine Micropalaeontology.*, 19, 131– 146.
- Jorissen F.J., De Stigter H.C. and Vidmark J.V. 1995. A conceptual model explaining benthic foraminiferal microhabitats, *Marine Micropalaeontology*, 37, 67-76.
- Kaiho K. 1994. Benthonic foraminiferal dissolved-oxygen index and dissolved levels in the modern ocean, *Geology*, 22, 719–722.
- Kouwenhoven T.J. 2000. Survival under stress: benthic foraminiferal patterns and Cenozoic biotic crises, *Geologica Ultraiectina*, 186, 1–206.
- Kouwenhoven, T.J. and van der Zwaan G.J. 2006. A reconstruction of late Miocene Mediterranean circulation patterns using benthic foraminifera, *Palaeogeogr. Palaeoclimatol. Palaeoecol.*, 238, 373–385.
- Kouwenhoven T., Morigi C., Giunta S., Negri A., Krijgsman, W. and Rouchy J.M. 2006. Unravelling Messinian marine environments in the Eastern Mediterranean (Pissouri Basin, Cyprus): Constraints from integrated microfossil data, *Marine Micropaleontology*, 60, 17–44.
- Krijgsman W., Blanc-Valleron M.M., Flecker R., Hilgen F.J., Kouwenhoven T.J., Merle D., Orszag-Sperber F. and Rouchy J.M. 2002. The onset of the Messinian salinity crisis in the Eastern Mediterranean Pissouri Basin, Cyprus, *Earth and Planetary Science Letters*, 194, 299–310.
- Krijgsman W. 2002. The mediterranean mare nostrum of earth sciences, *Earth Planet Sci Lett.*, 205, 1–12
- Kroon D., Alexander I., Little M., Lourens L.J., Matthewson A., Robertson A.H.F. and Sakamoto T. 1998. Oxygen isotope and sapropel stratigraphy in the eastern Mediterranean during the last 3.2 million years, in: Robertson, A.H.F., Emeis, K.-C., Richter, C., Camerlenghi, A.

- (Eds.), Proceedings of the Ocean Drilling Program, *Scientific Results Ocean Drilling Program*, College Station, TX, 181–190.
- Leckie R.M., Yuretich R.F., West O.L.O., Finkelstein D. and Schmidt M. 1998. Paleooceanography of the southwestern Western Interior Sea during the time of the Cenomanian-Turonian boundary Late Cretaceous, *SEPM Concepts in Sedimentology and Paleontology*, 6, 101–126.
- Loubère P. 1996. The surface ocean productivity and bottom water oxygen signals in deep water benthic foraminiferal assemblages, *Marine Micropaleontology*, 28, 247–261.
- Loubère P. 1997. Benthic foraminiferal assemblage formation, organic carbon flux and oxygen concentrations on the outer continental shelf and slope, *Journal of Foraminiferal Research*, 27, 93–100.
- Lourens L.J., Antonarakou A., Hilgen F.J., Van Hoof A.A.M., Vergnaud-Grazzini C. and Zachariasse W.J. 1996. Evaluation of the Plio–Pleistocene astronomical timescale, *Paleoceanography*, 11 (4), 391–413.
- Lourens L.J., Wehausen R. and Brumsack H.J. 2001. Geological constraints on tidal dissipation and dynamical ellipticity of the Earth over the past three million years, *Nature*, 409, 1029–1032.
- Lourens L.J., Hilgen F.J., Shackleton N.J., Laskar J. and Wilson D. 2004. The Neogene Period. In: Gradstein F., Ogg I., Smith A. (Eds.), *A Geological Timescale 2004*. Cambridge University Press, UK.
- Marino G., Rohling E.J., Rijpstra W.I., Sangiorgi F., Schouten S. and Sinningh-Damste J.S. 2007. The Aegean Sea as driver of hydrographic and ecological changes in the eastern Mediterranean, *Geology*, 35 (8), 675–678.
- Nolet G.J. and Corliss B.H. 1990. Benthic foraminiferal evidence for reduced deep-water circulation during sapropel deposition in the eastern Mediterranean, *Marine Geology*, 94, 109–130.
- Orszag-Sperber F., Rouchy J.M. and Elion P. 1989. The sedimentary expression of regional tectonic events during the Miocene–Pliocene transition in the southern Cyprus basins, *Geol. Mag.*, 126, 291–299.
- Orszag-Sperber F., Caruso A., Blanc-Valleron M.-M., Merle D. and Rouchy J.-M. 2009. The onset of the Messinian salinity crisis: Insights from Cyprus sections, *Sediment. Geol.*, 217, 52–64.
- Pinardi N. and Masetti E. 2000. Variability of the large scale general circulation of the Mediterranean Sea from observations and modelling: a review, *Palaeogeog. Palaeoclimatol. Palaeoecol.*, 158, 153–173.
- Postma G. and Drinia H. 1993. Architecture and sedimentary facies evolution of a marine expanding half-graben (Crete, Late Miocene), *Basin Research*, 5, 103–124.
- Pujol C. and Vergnaud-Grazzini C. 1995. Distribution of live planktic foraminifers as related to regional hydrography and productive systems of the Mediterranean Sea, *Marine Micropaleontology*, 25, 187–217.
- Robertson A.H.F., Eaton S., Follows E.J. and McCallum J.E. 1991. The role of tectonics versus global sea-level change in the Neogene evolution of the Cyprus active margin, *International Association of Sedimentologists*, Special Publication, 12, 331–369.
- Robertson A.H.F., Eaton S.E., Follows E.J. and Payne A.S. 1995. Sedimentology and depositional processes of Miocene evaporites from Cyprus, *Terra Nova*, 7, 233–254.
- Robertson B.E. 1998. Systematics and paleoecology of the benthic Foraminifera from the Buff Bay section, Miocene of Jamaica, *Micropaleontology*, 44, 1–266.
- Rogerson M., Kouwenhoven T.J., Van der Zwaan G.J., O’Neill B.J., Postma G., Kleverlaan K. and Tijbosch H. 2006. Benthic foraminifera of a Miocene canyon and fan, *Marine Micropaleontology*, 60, 295–318.
- Rohling E.J., Abu-Zied R., Casford J.S.L., Hayes A. and Hoogakker B.A.A. 2009. The marine environment: present and past, in: Woodward, J.C. (Ed.), *The Physical Geography of the Mediterranean*. Oxford University Press, Oxford, pp. 33–67.

- Rouchy J.M., Orszag-Sperber M., Blanc-Valleron F., Pierre M.-M., Rivière C., Combourieu-Nebout M. and Panayides N. 2001. Paleoenvironmental changes at the Messinian–Pliocene boundary in the eastern Mediterranean: southern Cyprus basins, *Sediment. Geol.*, 145, 93–117.
- Schmiedl G., Mitsuiche A., Bec S., Emeis K.C., Hemleben C., Schulz H., Sperling M., Weldeab S. 2003. Benthic foraminiferal record of ecosystem variability in the eastern Mediterranean Sea during times of sapropel S5 and S6 deposition, *Palaeogeog. Palaeoclimatol. Palaeoecol.*, 190, 139–164.
- Soria J. M., Caracuel J. E., Corbí H., Dinarès-Turell J., Lancis C., Tent-Manclús J. E. and Yébenes A. 2008. The Bajo Segura Basin (SE Spain): implications for the Messinian salinity crisis in the Mediterranean margins, *Stratigraphy*, 5 (3-4), 257-263.
- Sprovieri R. 1993. Pliocene Early Pleistocene astronomically forced planktonic foraminifera abundance fluctuations and chronology of Mediterranean calcareous plankton bioevents, *Rivista Italiana di Paleontologia e Stratigrafia*, 99 (3), 371-414.
- Stow D.A.V., Braakenburg N.E. and Xenophontos C. 1995. The Pissouri Basin fan-delta complex, southwestern Cyprus, *Sedimentary Geology*, 98, 254-262.
- Thunell R.C. 1978. Distribution of recent planktonic foraminifera in surface sediments of the Mediterranean Sea, *Marine Micropaleontology*, 3, 147–173.
- Tiedemann R., Sarnthein M. and Shackleton N.J. 1994. Astronomical timescale for the Pliocene Atlantic $d^{18}O$ and dust flux records of ODP Site 659, *Paleoceanography*, 9, 619–638.
- Triantaphyllou M. V., Antonarakou A., Drinia H., Dimiza M. D., Kontakiotis G., Tsiolakis E. and Theodorou G. 2010. High resolution biostratigraphy and paleoecology of the early Pliocene succession of Pissouri basin (Cyprus island), *Bulletin of the Geological Society of Greece*, Proceedings of the 12th International Congress, Patras, May, 2010.
- Triantaphyllou M., Antonarakou A., Lourens L., Ziveri P., Tsiolakis E., Tsaila-Monopolis S., Theodorou G., Dermizakis M., Kontakiotis G., Konstantinidou E. and Athanasiou M. 2008. Calcareous plankton events and climate variability during late Zanclean in the eastern Mediterranean (Pissouri basin, Cyprus), *33th International Geological Conference (IGC)*, Oslo, Norway.
- Van der Zwaan G.J. 1982. Paleocology of Late Miocene foraminifera, *Utrecht Micropaleontological Bulletin*, 25, 1–201.
- Van der Zwaan G.J., Duijnste I.A.P., den Dulk M., Ernst S.R., Jannink N.T. and Kouwenhoven T.J. 1999. Benthic foraminifers: proxies or problems? A review of paleoecological concepts, *Earth-Science Reviews*, 46, 213–236.
- Van der Zwaan G.J., Jorissen F.J. and de Stigter H.C. 1990. The depth dependency of planktonic/benthic foraminiferal ratios: constraints and applications, *Marine Geology*, 95, 1–16.
- Van Hinsbergen D.J.J., Langereis C.G. and Meulenkaamp J.E. 2005: Revision of the timing, magnitude and distribution of Neogene rotations in the western Aegean region, *Tectonophysics*, 396, 1-34.
- Van Vugt N., Steenbrink J., Langereis C.G., Hilgen F.J. and Meulenkaamp J.E. 1998. Magnetostratigraphy-based astronomical tuning of the early Pliocene lacustrine sediments of Ptolemais (NW Greece) and bed-to-bed correlation with the marine record, *Earth and Planetary Science Letters*, 164, 535-551.
- Verhallen P.J.J.M. 1991. Late Pliocene to Early Pleistocene Mediterranean mud-dwelling foraminifera: influence of a changing environment on community structure and evolution, *Utrecht Micropaleontol. Bull.*, 40, 220 pp.