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# Present-day fluxes of coccolithophores and diatoms in the pelagic Ionian Sea

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ABSTRACT

Biogenic fluxes from two sediment traps in the Ionian sea (35°13′N, 21°30′E) at 500 and 2800 m water depth are discussed in relation with the main oceanographic and external forcing and compared with previous data from a nearby location. This study is part of a multi-year sediment trap deployment, aimed at assessing seasonality and interannual variability of biogenic and abiogenic fluxes. Here, we focus on fluxes related to two main phytoplankton groups: coccolithophores and diatoms.

At our mooring site, high-coccolithophore and low-diatom fluxes confirm the oligotrophic character of the pelagic eastern Mediterranean year-round. Coccolithophore assemblages are dominated by the cosmopolitan species *Emiliania huxleyi*, followed by the deep-dwelling *Florisphaera profunda* and by several minor species. Diatom assemblages are dominated by *Thalassionema bacillare* and *Nitzschia interruptestriata*, with ~100 common and minor species. Overall, the combined flux pattern of coccolithophores and diatoms shows a clear seasonality throughout the study period, which can be related to changing oceanographic conditions and a different depth of production within the photic zone. Worth to note is the extremely high abundance, with respect to previous pelagic records, of species indicative of an intense deep chlorophyll maximum (DCM), which could indicate a shoaling of the nutricline. This feature can be related to the variability that affects surface hydrography and the deep water masses.

Additionally, the occurrence of neritic, benthic and brackish to fresh-water diatom species, mainly in the deeper trap, could be linked to either lateral transport within the water column or the atmospheric input of Saharan dust, which is known to be common over the eastern Mediterranean especially during spring time.

Finally, correlation of the flux pattern at different depths allowed sinking speeds for total and biogenic particles to be calculated, which ranged from 70 to >200 m day$^{-1}$. Three possible mechanisms can explain such high sinking rates and the coincidence of biogenic and total particle fluxes in the traps: a) the ballast effect of coccoliths; b) the packaging effect of fecal pellets related to the grazing activity of zooplankton; and c) the ballast effect of dust particles.



## 1. Introduction

Understanding of present-day biogenic fluxes is of key importance in providing information on how the ecological signal is transferred from the surface waters to the sediment archives. In fact organic matter degradation, selective dissolution of the mineralized skeletons and lateral transport act on the settling particles, significantly modifying the original assemblage composition.

Previous studies on biogenic fluxes in the eastern Mediterranean are mostly related to their chemical composition (carbonate vs. silica) and report on the abundance of the main planktonic groups (Boldrin et al., 2002; De Lazzari et al., 1999; Socal et al., 1999; Turchetto et al., 2012), but without a detailed quantification of the contribution from the different species. Specific assessments of coccolithophore sinking assemblage composition and seasonal variations have been performed in several coastal settings offshore Crete (Malinverno et al., 2009; Triantaphyllou et al., 2004), while for the pelagic environment, the only study performed up to now refers to the Bannock Basin area (34°18′N, 20°01′E, i.e. Rutten et al., 2000; Ziveri et al., 2000).

To date, little is known about seasonal/interannual variations of diatom assemblages from the pelagic eastern Mediterranean, due to their secondary role in the total primary production of this basin. In fact most diatom studies refer to surface water assemblages from mainly coastal settings like the Adriatic (Cabrini et al., 2012; Godrijan et al., 2013; Viličić et al., 2002), Ionian (Moscatello et al., 2004; Rabitti et al., 1994; Socal et al., 1999) and Levantine Basin (Kimor and Wood, 1975; Polat et al., 2000). Although estimates of total diatom and biogenic silica flux exist for the northern Ionian Sea (Boldrin et al., 2002; De Lazzari

*Abbreviations:* Chl-a, Chlorophyll-a; SST, Sea Surface Temperature; MLD, Mixed Layer Depth; PA, Pelops Anticyclon; WCG, Western Cretan Gyre; NIG, Northern Ionian Gyre; EMT, Eastern Mediterranean Transient.

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et al., 1999), there are no previous data on the specific composition of the diatom assemblage in the sinking flux. In fact diatoms are a minor component in the present-day oligotrophic pelagic eastern Mediterranean and dissolution can severely affect their frustule (Ryves et al., 2001).

We present here new data from a one-year time series of biogenic fluxes from two sediment traps located respectively at 500 and 2800 m depth in the eastern Ionian Sea. We compare these to other data sets recovered from the same area at 2800–3000 m depth, in order to provide a pattern of flux variation on a longer time-scale. The aims of this work are:

- to describe the pattern of total particle flux, in terms of seasonality and interannual variability
- to document the combined fluxes of coccolithophores and diatoms and their seasonality. In particular, this is the first assessment of diatom assemblage composition and fluxes at the species level for the pelagic eastern Mediterranean.
- to detect evidence of small-scale oceanographic changes, as documented by variations in species assemblage composition
- to assess the settling velocities of biogenic particles as related to the main transport mechanisms and to identify the flux modifications with depth.

Overall, knowledge gained on how the ecological signal of the different species and groups is transferred to the bottom as sinking flux is of fundamental importance for the interpretation of the fossil record, especially where high-resolution archives of the past are available.

## 2. Oceanographic setting

The eastern Mediterranean is overall an oligotrophic basin, due to its anti-estuarine circulation (Sarmiento et al., 1988). Nutrient-depleted surface waters enter the western Mediterranean through the Straits of Gibraltar and the eastern Mediterranean through the Sicily Channel, while nutrient-enriched intermediate waters exit at depth through these sills (Lascaratos et al., 1999). An increase in oligotrophy is observed within the eastern Mediterranean towards the east (Barale and Zibordi, 1994; D'Ortenzio and Ribera d'Alcalà, 2009; Siokou-Frangou et al., 2010) due to increasing nutrient depletion, as a consequence of biological utilization. Moreover, the whole eastern Mediterranean is characterized by extremely high nitrogen to phosphorous ratios, resulting in phosphorous-limitation, which also increases towards the east (i.e. Krom et al., 1991).

Primary production in the eastern Mediterranean is low, 20.3–45 mg C $m^{-2}$ $year^{-1}$ (Zohary and Robarts, 1998 and Dugdale and Wilkerson, 1988, respectively). In the study area, satellite measurements at the sea surface indicate chlorophyll-a (Chl-a) concentrations are always below 0.5 mg $m^{-3}$ (Acker and Leptoukh, 2007). The seasonal cycle of primary production is inversely related to Sea Surface Temperature (SST) and strongly related to the seasonally-varying Mixed Layer Depth (MLD): an increase in phytoplankton is detected at the sea surface early after winter mixing and significant subsurface production continues until June (Napolitano et al., 2000). Within the phytoplankton, a strong contribution is given by picoplankton (Li et al., 1993), nannoflagellates, small dinoflagellates and coccolithophores (Boldrin et al., 2002; Socal et al., 1999). Conversely, diatoms from the Ionian Sea area usually show low abundance and biomass (Rabitti et al., 1994; Socal et al., 1999) year-round, but can represent an important fraction of phytoplankton biomass (up to 14%) only in winter time.

Although oligotrophic as a whole, the eastern Mediterranean shows significant lateral variations in the distribution of surface Chl-a concentration. Such variations are related to the pattern of the surface circulation, which determines the overall vertical movements of the upper water masses and consequently regulates the distribution of nutrients to the photic layer and thus phytoplankton activity. In the Ionian Sea the mesoscale circulation is driven by the prevalent wind forcing: north-westerly winds determine an overall cyclonic surface circulation in the northern part, prevalently anticyclonic in the southern part (Molcard et al., 2002), although this general pattern may reverse on decadal time scales as a function of changing wind forcing and/or internal feedback processes related to the formation of deep water masses (Borzelli et al., 2009; Civitarese et al., 2012; Gacic et al., 2010; Hamad et al., 2006; Klein, 2000; Malanotte-Rizzoli et al., 1997; Manca, 2000; Manca et al., 2003; Pinardi et al., 1997).

An additional source of nutrients to the pelagic Ionian sea is potentially provided by the input of dust, of Saharan provenance, which was estimated to supply, through combined wet and dry deposition, about 0.22–0.32 g $m^{-2}$ $y^{-1}$ of inorganic nitrogen (Herut et al., 1999; Kouvarakis et al., 2001; Markaki et al., 2003) and 0.021–0.040 g $m^{-2}$ $y^{-1}$ of inorganic phosphorous (Guerzoni et al., 1999; Herut et al., 1999; Markaki et al., 2003) in the eastern to southeastern Mediterranean. Although the role of dust in effectively fertilizing the surface waters of the eastern Mediterranean is debated (Eker-Develi et al., 2006; Herut et al., 1999; Krom et al., 1991, 2005), dust input is believed to contribute to new production (Guerzoni et al., 1999; Herut et al., 2005; Krom et al., 2004; Schulz et al., 2012).

## 3. Materials and methods

### 3.1. Sediment traps

Two sediment traps (PPS5/2, 1 $m^2$ collection area) were moored in the Ionian sea over the deep anoxic Urania Basin (35°13′N, 21°30′E, Fig. 1) at 500 and 2800 m water depth, from September 1999 to May 2000. A total of 24 samples were collected for each trap, with individual sampling intervals of ~10 days.

Upon recovery of the traps, swimmers were removed from the samples of the shallower trap by hand picking. No swimmers were recovered from the deeper trap. All samples were then split into eight equal fractions and stored for subsequent analyses.

### 3.2. Coccolithophores

For coccosphere analysis, each 1/8 sub-sample was split into 10 equal fractions using a McLane rotary wet splitter (deviation between aliquots <4%), and 1–2 subsamples were used for counting (1/80 to 1/40 of the initial sample, depending on the amount of sediment). For coccolith analysis, one 1/80 subsample, where necessary, was further split into 10 equal fractions and 1 or 2 combined fractions were used (total 1/800 to 1/400, depending on the amount of the original initial material). These latter sub-samples were processed following the method of Bairbakhish et al. (1999) in order to remove organic matter and disaggregate particles, so that coccolith data represent the contribution from both the original loose coccoliths and coccospheres that were disaggregated during sample preparation.

Samples for either coccosphere or coccolith determination were then filtered onto a millipore cellulose acetate filter (0.45 μm pore size, 47 mm diameter), oven dried at 40 °C and stored in plastic petri dishes.

A portion of each filter was mounted on a glass slide and analyzed along radial transects from the center to the edge using a polarized light optical Olympus microscope at 1000×. For coccosphere determination, 3–82 specimens were counted on an area of 5–20 $mm^2$, depending on their concentration on the filter. For coccolith determination, a first count included a total of ~40 to 500 specimens among major species on an area of 0.2–5 $mm^2$, depending on coccolith concentration on the filter. Minor and rare species were counted on a further area of 1–10 $mm^2$. Taxonomic identification follows the nomenclature of Jordan et al. (2004), Malinverno et al. (2008), Young et al. (2003). The list of all species recovered in both traps as either coccospheres or coccoliths is reported in Table 1 with average percent values of occurrence in the traps.