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Surface-water conditions in the Mediterranean Basin during earliest Pliocene as revealed by calcareous nannofossil assemblages: Comparison between western and eastern sectors

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ABSTRACT

The abundant and diverse calcareous nannofossil assemblages found in the sediments of two ODP cores from the Western (Site 975B, South Balearic Basin) and Eastern (Site 969B, Mediterranean Ridge) Mediterranean Sea have been taken into account for the paleoenvironmental reconstruction of the surface water conditions during the first 490 kyrs immediately following the end of the Messinian Salinity Crisis, chronostratigraphically settled at 5.332 Ma. The areal distribution of the calcareous nannofossils is closely linked to their ecological and environmental affinities, mostly driven by temperature, salinity, nutrients or other chemical parameters of the water masses. Hence, taxa (or groups of taxa) showing well-known ecological behaviors were considered, and different environmental evolutions were recognized for the two sectors of the Mediterranean Basin during the early Zanclean (early Pliocene). Specifically, in the Western Mediterranean a switching from a warm and oligotrophic water environment, showing normal open-marine conditions, to a colder and eutrophic one, characterized by a decrease in salinity rates and the development of a more restricted environment, can be recorded. Conversely, in the Eastern Mediterranean the environmental setting immediately following the MSC is indicative of temperate waters and normal open-marine conditions, which evolves, in the younger layers, to a warmer environment characterized by high salinity rates and typical of a restricted marine context. The timing of the environmental transitions recognized at the two sites has been set through the Principal Component Analysis. Taxa and groups of taxa reflecting precise ecological affinities have been handled together and a transition interval have been defined between 5.20/5.15 Ma and 5.06/4.98 Ma, and between 5.10 Ma and 4.92 Ma in the Western and Eastern Mediterranean, respectively.

1. Introduction

1.1. Calcareous nannofossils as proxies for paleoenvironmental reconstructions

Calcareous nannofossil are the fossil remains (exoskeletal plates) of "Coccolithophores", planktonic unicellular algae (Haptophytae) representing one of the most important primary producers in the oceans. Pioneering studies regarding the actual distribution of the nannoflora assemblages in modern oceans (McIntyre and Bè, 1967; McIntyre et al., 1970; Okada and Honjo, 1973) indicate that the coccolithophore assemblages, that occupy the surface water, are strongly controlled by temperature and by other physical and chemical parameters of the water masses, such as salinity or nutrient availability (McIntyre and Bè, 1967; Brand, 1994; Winter et al., 1994). Nannofossil assemblages have the capability to record the environmental conditions of the surface water that they occupy during their life and, for this reason, they provide useful information to reconstruct the paleoenvironmental evolution of an area through time (Castradori, 1998; Negri and Giunta, 2001; Sbaffi et al., 2001). In this paper, the distribution patterns of the calcareous nannofossil taxa useful for paleoceanographic and paleoclimatic reconstructions are considered in order to investigate the strong variations that occurred within the Mediterranean Basin in the time interval immediately following the Messinian Salinity Crisis (Hsü et al., 1973, 1977).

For this purpose two Mediterranean ODP Sites, one located in the western sector (Site 975B) and the other in the eastern one (Site 969B) of the Mediterranean basin were investigated, with the aim of:

1) providing information about the surface water conditions of the Mediterranean Basin during the time interval immediately following the Messinian/Pliocene boundary (M/P b);
2) documenting changes of the chemical and physical parameters of the surface water through time;

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3) establishing a comparison between the eastern and the western sectors of the Mediterranean Basin as far as the surface water conditions concern, in the considered time span.

1.2. Present-day condition of the Mediterranean surface-water and ecological affinities of living coccolithophorids

Presently, the Mediterranean Sea (Fig. 1) is connected to the Atlantic Ocean through the narrow (14 to 44 km) and shallow (maximum depth 286 m) Strait of Gibraltar, and consists of a western and an eastern basins separated by the Sicily Channel (Figs. 1, 2). The Mediterranean Sea represents an important marginal basin of the Atlantic Ocean, source of high salinity waters that plays an important role in the North Atlantic Deep Circulation (Reid, 1994). In the mid-latitude sector, close to the Gibraltar Strait, the Atlantic Ocean is nowadays characterized by surface salinity rates between 36‰ and 37‰ (SeaDataNet), and by temperatures between 16 °C and 23 °C (McCartney, 1994; Ziveri et al., 2004; SeaDataNet). This latter configuration is only a part of a complex system of currents, the Atlantic Circulatory System, well developed from polar to equatorial latitudes and characterizing both the superficial and deep water masses (Ziveri et al., 2004). The modern circulation pattern of the Mediterranean Sea is defined by multiple gyres systems, generally showing a cyclonic motion in the northern part of the basin and an anti-cyclonic one in the southern part (Russenov et al., 1995; Larnicol et al., 2002). The thermohaline configuration of the modern currents dynamic is controlled by the positive ratio between evaporation and precipitation budget (Flores et al., 1997). The Mediterranean circulation belt is formed by three distinct water masses (superficial, intermediate and deep) distinguished on the basis of their density.

The surface waters flow between 0 and 500 m depth (Pinardi and Masetti, 2000) and are associated to the inflow of the Atlantic Waters (AW) through the Gibraltar Strait (Wüst, 1961), which once entered the Mediterranean Sea is called Modified Atlantic Water (MAW). This current is subjected to different responses to both seasonal variations linked to meteorological changes, and interannual variations mostly due to anomalies in the atmospheric forcing and ocean dynamics (Pinardi and Masetti, 2000; Larnicol et al., 2002). The MAW is responsible for the formation of the cyclonic gyre in the Alboran Sea (westernmost Mediterranean; Fig. 1) between Spain and Morocco and is further identified as the Algerian current along the northern coast of Africa, where it becomes warmer (Jaber et al., 2014) and forms several short lifetime cyclonic and anti-cyclonic eddies (Larnicol et al., 2002). At the Sicily Channel (Fig. 1), about one third of the surface waters flows in the Tyrrhenian Sea (Bethoux, 1980) to the north and, forming a large cyclonic gyre that comprises the entire Western Mediterranean Sea, flows in the Alboran Sea (Millot and Taupier-Letage, 2005). The remnant part of the surface waters runs in the Sicily Channel and along the southern Mediterranean coasts, forming both the cyclonic circulation patterns of the Western Crete (Eastern Ionian Sea) and Rhodes (Levantine Sea) gyres, and the anti-cyclonic Gulf of Syrte (north of Libya) and Shikmona and Mers a-Matruh (north of Egypt) gyres (El-Gindy and El-Din, 1986; Said, 1990) (Fig. 1).

The Levantine Intermediate Water (LIW) develops from the southeastern sector of the Rhodes Island (Lascaratos et al., 1993; Millot and Taupier-Letage, 2005), in the eastern part of the Mediterranean Sea, as the result of the sinking of the surface water current, which becomes warmer, saltier (Emeis and Shipboard Scientific Party, 1996; Drakopoulos and Lascaratos, 1999; MEDAR-Group, 2002) and denser, in response to the evaporation processes taking place in this part of the basin (Robinson et al., 2002). The LIW flows westward between 150 and 600 m depth, forming the Ionian Sea cyclonic gyre, the Libyan anti-cyclonic gyre (from the Sicily Channel to the Tyrrhenian Sea), and finally reaches the Gibraltar Strait flowing along the northern coasts of the Mediterranean Sea (Millot, 1987).

The deep water currents are divided into the Western Mediterranean Deep Water (WMDW), formed by the Tyrrhenian and the Gulf of Lions deep waters, and Eastern Mediterranean Deep Water (EMDW), defined by the Aegean and the Adriatic deep waters (Knappertsbusch, 1993; Demirov and Pinardi, 2002). The EMDW forms between 1000

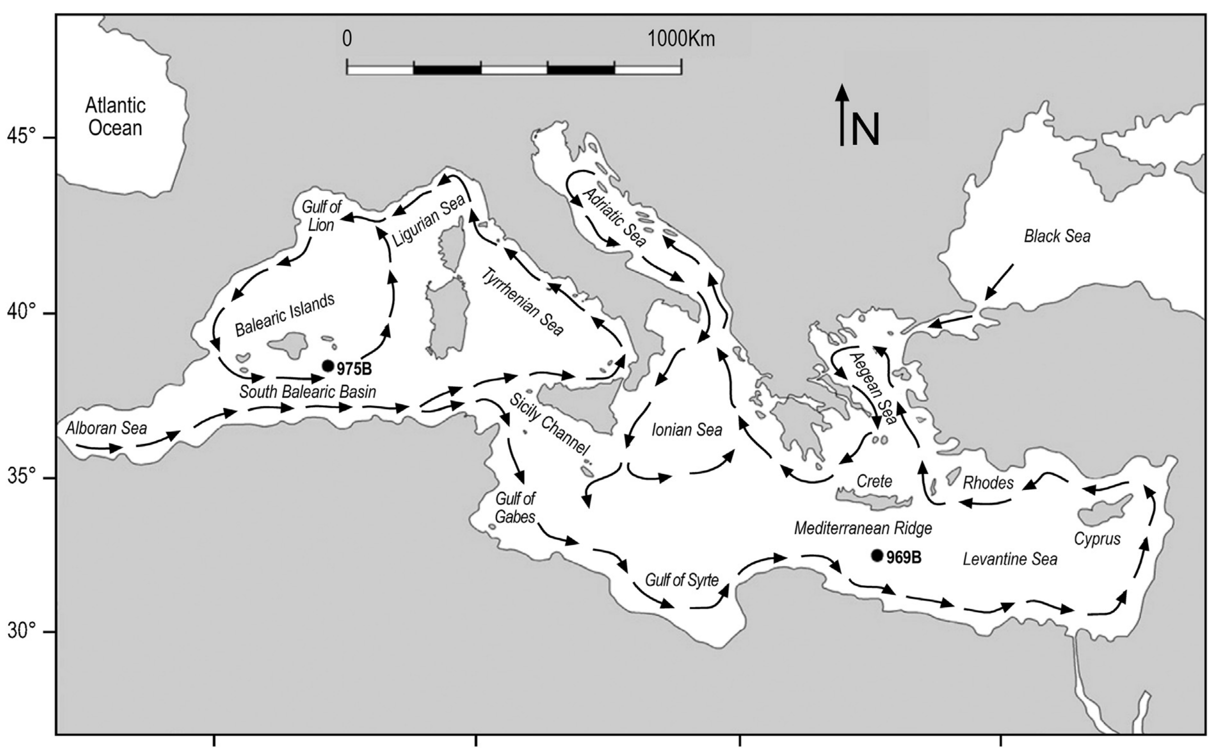

Fig. 1. Location Map. Geographic map of the Mediterranean showing the surface water circulation pattern highlighted by the black arrows. Black dots mark the locations of ODP sites 975B (Western Mediterranean) and 969B (Eastern Mediterranean).