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The high-resolution palaeoclimatic and palaeoceanographic history of the last 24,000 years in the central Aegean Sea, Greece

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ABSTRACT

The palaeoclimatic and palaeoceanographic history of the N. Skyros Basin, central Aegean Sea, was studied based on the planktonic foraminifera and the stable isotopes obtained from the sediments of a sediment core selected in this area. The data were further supported by pollen and dinoflagellate cyst data. The data correspond to a mean sampling interval of about 170 yrs and cover the last 24,000 yrs. The variations in almost all of the records showed synchronicity, suggesting the occurrence of a series of climatic changes. The most pronounced climatic changes during the last glacial and late glacial periods are as follows: (i) a brief relatively warm and humid event at 19.5 kyr, (ii) two cold spells, at 17 ka and 15.8 ka, (iii) the climatic oscillation during the GI-1 event, and (iv) the development of the Younger Dryas (GS-1) event in two phases. During the Holocene epoch, five brief cold and/or arid phases occurred, at around 10.5 ka, 8.2 ka, 7 ka to 6 ka, 5.0 ka and 3.0 ka. The most warm and humid Holocene events correspond to the time of the deposition of the two sapropel sublayers: S1a and S1b.
Almost all of these brief climatic changes are coeval with equivalent changes in high northern latitude areas and with changes in the intensity of the Siberian High, suggesting a climatic link between the studied area and the high-latitude areas. The prevalence of Holocene arid events, which coincide with equivalent events recorded in North-Eastern Africa and the Middle East, suggests a climatic link between the eastern and south-eastern regions of the Mediterranean Sea.

1. Introduction

Systematic study of palaeoclimatic data from the Mediterranean region has shown a series of climatic changes consistent with climatic changes obtained in high-latitude areas. The climatic changes are of long and short durations. The latter involve millennial to centennial climatic instabilities and have been obtained within: (i) the last glacial period, as changes paralleling the Dansgaard–Oeschger climatic variability characterised by oscillations in temperature and humidity amplification during Heinrich events (Sánchez Goñí et al., 2002), (ii) the late glacial period, as changes paralleling the GI-1a to GS-1 events based on the INTIMATE stratigraphy (Asioli et al., 2001; Cacho et al., 2001; Geraga et al., 2008; Lowe et al., 2008) and (iii) the Holocene epoch, as cold spells paralleling the North Atlantic Holocene stadials (Bond et al., 1997; Cacho et al., 2001; Sbaffi et al., 2004).

The palaeoclimatic data have been based on fluctuations in the isotopic signal, in the abundances of planktonic foraminifera and dinoflagellate assemblages and in pollen associations. Planktonic foraminifera have proven to be excellent indicators of sea surface temperature, salinity, food availability and in general changes in the state of the prevailing hydrographic systems in the water column (Thunell, 1978; Pujol and Vergnaud Grazzini, 1995), and they have been used for the detection of long- and short-duration palaeoclimatic and palaeoceanographic changes in the Mediterranean Sea (Aksu et al., 1995; Sbaffi et al., 2001; Perez-Folgado et al., 2003; Mudie et al., 2004; Geraga et al., 2005). Similarly, pollen data have been used to detect paleovegetational changes between glacial–interglacial periods as well as between stadials and interstadials around the Mediterranean Sea based on terrestrial (Rossignol-Strick and Paterne, 1999; Tzedakis et al., 2002) or on marine sediments (Rossignol-Strick, 1995; Sánchez Goñí et al., 2002; Geraga et al., 2005; Kotthoff et al., 2008). Dinoflagellate associations can provide information regarding the sea surface productivity and sea floor oxygenetion (Zonneveld et al., 2001; Marret and Zonneveld, 2003), sea surface temperature and salinity (Sangiorgi et al., 2002; Marret and Zonneveld, 2003; Mudie et al., 2004).

Palaeoclimatic data have also been obtained in the eastern Mediterranean regions, and the climate changes have been compared to those from high-latitude areas (Aksu et al., 1995; Bar-Matthews et

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al., 1999; de Rijk et al., 1999; Tzedakis et al., 2002; Geraga et al., 2005). In particular during the Holocene epoch, there is a direct atmospheric link between the Aegean Sea surface temperature and the high-latitude climate. The observed Holocene cold spells follow a 2300-year periodicity (Rohling et al., 2002). The deposition, however, of the sapropel layers suggests that the climate in the eastern Mediterranean has also been influenced by the strengthening of the African monsoonal system in the south (Rossignol-Strick, 1983; Aksu et al., 1995; Rossignol-Strick and Paterne, 1999; Kotthoff et al., 2008).

In the present study, high-resolution palaeoclimatic data, revealed due to the variations in the oxygen isotopic signal and the abundances of planktonic foraminifera in association with the pollen dinoflagellate cyst analyses of marine sediments, are examined and compared with climatic events documented in north latitude areas. The marine sediments were collected from a 4-m-long gravity core that was taken from the central Aegean Sea and covered the last 24,000 yrs.

2. Regional setting and living assemblages

The sediment core (MNB3) used in this study was retrieved from N. Skyros Basin, an 800-m deep basin located in the central Aegean Sea (Fig. 1). It was separated by the N. Aegean Trough by a shallow sill 350-m deep. Three major water masses were identified in the water column of the studied area (Lykousis et al., 2002): (i) the surface water mass of low salinity (38.85 psu) and temperature (13.8 °C), which occupies the upper 100 m; (ii) the Levantine Intermediate Water (LIW), which lies between 100 and 400 m in depth and is characterised by increased temperature (14.2 °C) and salinity (39.1 psu); and (iii) the North Aegean Deep Water (NADW) of high density, formed locally at larger than the annual amounts during exceptionally dry and cold winter periods (Zervakis et al., 2000).

The N. Aegean Sea is characterised by a generally cyclonic circulation and an increased eutrophication compared to the S. Aegean Sea (Lykousis et al., 2002). The relatively increased eutrophication of the upper column (0–500 m) is attributed to the following: (a) the proximity to the inflow of the Balkan rivers in the N. Aegean Sea, (b) the inflow of Black Sea Water (BSW) and (c) the presence of cyclonic and anticyclonic eddies and thus to the development of down- and up-wellings of the organic matter.

The average modern foraminiferal assemblages in the studied area consist of *Globigerinoides ruber* (40–60%), *Globigerinita glutinata* (0–10%), *Turborotalita quinqueloba* (1–10%), *Globigerinoides sacculifer* (1–5%), *Globigerinella aequilateralis* (0–10%), *Globigerinoides tenellus* (1–5%) and *Neogloboquadrina dutertrei* (1–10%) (Thunell et al., 1978). The major factors controlling the above modern species are temperature and the salinity distribution associated with the distribution of BSW in the area (i.e. *N. dutertrei*; Thunell, 1978).

The average modern dinoflagellate assemblages in the studied area consist of *Impagidinium* spp., *Spiniferites* spp., *Operculodinium* spp., *Polysphaeridium zoharyi*, *Selenopemphix nephroides* and *Nematosphaeropsis labyrinthus* (Mudie et al., 2004). Almost all of the above species are restricted to sub-tropical and temperate regions with high salinity (>32‰; Mudie et al., 2004). However, the surface salinity seems to be the major factor controlling the distribution of dinocyst associations in the north and central Aegean, associated with the inputs of BSW in the Aegean Sea (Aksu et al., 1995; Mudie et al., 2004).

The climate in the studied area is characterised as a maritime Mediterranean type. The mean air temperature ranges between 7 °C (February) and 30 °C (August). The annual precipitation is 56 mm and ranges between 143 mm/month (December) and 2.2 mm/month (July).

3. Materials and methods

The present study is based on the high-resolution analyses (foraminifers and palynomorphs) of the hemipelagic sediments sampled from a long gravity core, MNB3, (Long: 25.00.00′, Lat: 39.15.43′) retrieved by R/V *Aegaeo* from the N. Skyros Basin in the central Aegean Sea (Fig. 1). The core was selected at a water depth of 800 m and is 401 cm long. Each sample of sediment covered an approximately 1-cm-thick interval in the core.

The planktonic foraminifera analysis is based on 191 samples taken at a mean interval of 2 cm. The samples were disintegrated by hydrogen peroxide and then sieved through a 150-μm mesh. The dry and weighed samples were split into separate aliquots. At least 300 planktonic specimens were identified and counted in each sample. The specimens of *Globigerinoides sacculifer* and *Globigerinoides trilobus* were summarised. Each taxon is expressed as a percentage of the total assemblage. The number of planktonic specimens per weight of dry sediments >150 μm (PFN) was estimated as an index of planktonic foraminifera productivity. The downcore ratio between *Globigerina bullloides* and *Globigerinoides ruber* was estimated. This ratio is an index of oceanographic conditions showing periods of strong summer stratification of the water column where oligotrophic taxa dominate (low values, <2.4) and periods of strong winter mixing of the water column where eutrophic taxa dominate (high values, >2.4; Sbaffi et al., 2004). An index of the variation in the sea surface temperature (SST) was constructed based on the downcore variation of planktonic foraminifera abundances, and it will be referred to as the Planktonic Climatic Curve (PCC). The PCC was estimated using the sum of the warm species (*G. ruber*, *G. sacculifer*, *G. aequilateralis* and *O. universa*) versus the sum of the warm plus cold species (*G. scitula*, *T. quinqueloba* and *G. glutinata*) (Thunell, 1978; Pujol and Vergnaud Grazzini, 1995; Aksu et al., 1995; Rohling et al., 1997).

A total of 162 samples along the core were analysed for the determination of the oxygen isotopes on the tests of the planktonic foraminifera *Globigerinoides ruber alba* (>150 μm). The analyses were carried out at the Laboratory of Geology and Geophysics in Edinburgh University.

Palynological analysis was also performed on the core sediments. The pollen record consisted of 126 samples of about 6–8 cm^3 (5-g dry weight sediment) taken at an average of 3-cm intervals, covering the entire sequence of the core sediments. Palynomorph extraction was conducted with wet sieving through 125-mm and ultrasonic 10-μm sieves. The palynomorphs were extracted using 10% HCL and 38% HF to dissolve carbonates and silicates, then 10% KOH was used to dissolve the soluble organic matter of the sediments. Every treatment was followed by washing samples with de-ionised water. Finally, one *Lycopodium* spore tablet was added to each sample during the treatment to ensure estimation of the absolute abundances and reliability of quantitative data. The residues were mounted in glycerine gel on microscope slides for analysis under a binocular NIKON transmission microscope, and one or two slides of each processed sample were analysed with ×1500 magnification. Pollen and dinoflagellate cysts examined from the same samples, and when possible 400 specimens, were identified in each case.

The concentration of the pollen grains (number of specimens per weight of dry sediment) ranged between 15,000 and 30,000 grains/g. For the construction of the pollen diagrams, selected taxa from the pollen percentage data were plotted against age, together with the total arboreal and the non-arboreal pollen (AP and NAP) concentration. The percentages of the abundance of the selected taxa were based on the total of the pollen assemblage excluding *Pinus*.

The chemical treatment of the palynological samples and the aerobic decay of the sediments may lead to selective destruction of the dinoflagellate cysts (Marret and Zonneveld, 2003). Zonneveld et al (2001) have shown that cyst species can be distinguished into three main groups based on their resistance to aerobic matter degradation: sensitive, moderate and very resistant species. In the present study, the most sensitive species to aerobic decay is primarily *Brigantedinium* spp., the moderately sensitive species are *Lingulodinium machaerophorum* and *Spiniferites* (including *S. bentorii*, *S. mirabilis*, *S. ramosus*, *S. hyperacanthus* and *S. elongatus*) and the most resistant species are