Available online http:/amq.aiqua.it
ISSN (print): 2279-7327, ISSN (online): 2279-7335

Alpine and Mediterranean Quaternary, 26 (1), 2013, 5-14

IONIAN SEA SURFACE TEMPERATURE DURING THE SAPROPEL S1 DEPOSITION INFERRED FROM PLANKTONIC FORAMINIFERAL Mg/Ca AND $\delta^{18}O$

Caterina Bergami[1], Lucilla Capotondi[1], Daniela Salvagio Manta[2], Mario Sprovieri[2], Luigi Vigliotti[1]
[1] CNR - Istituto di Scienze Marine, ISMAR, Bologna, Italy
[2] CNR - Istituto per l'ambiente marino costiero, IAMC, Capo Granitola, Trapani, Italy
Corresponding author: Caterina Bergami <caterina.bergami@ismar.cnr.it >

ABSTRACT: Temperature variations during the Holocene sapropel S1 has been investigated by means of a multiproxy study on core ET99-M11 collected in the western Ionian Sea at a water depth of 2800 m.
Sea Surface Temperatures (SST) reconstruction has been made by measuring oxygen stable isotopes ($\delta^{18}O$) and Mg/Ca ratios on the planktonic foraminifers *Globigerinoides ruber* and *Globigerina bulloides*.
Results indicate that the investigated interval was characterized by water temperature increase, both at surface and in the sub-surface layers. Paleotemperature reconstruction based on Mg/Ca ratios shows higher temperature values during the two sub-units (S1a and S1b) of the sapropel S1, and lower during the sapropel interruption, the latter being synchronous to the well known 8.2 cold event. In addition, a number of several short-term cold oscillations which can be correlated with millennial scale climate events in the North Atlantic region is evidenced. This indicates a possible atmospheric connection between the Central Mediterranean and the North Atlantic region and the strong relation between climate and oceanographic changes during the sapropel deposition.

Keywords: sapropel S1, planktonic foraminifera, paleotemperature, Central Mediterranean, Mg/Ca.

1. INTRODUCTION

Organic-rich layers, named sapropels, characterize the Neogene sediments of the Mediterranean Sea (Olausson, 1961; Cita et al., 1977). These sediments contain abundant and well-preserved planktonic microfossils that make these intervals particularly suitable for high-resolution paleoclimatic reconstructions.

Planktonic foraminifera have proven to be excellent indicators of sea surface temperature, salinity, food availability and they have been used to detect long- and short-term climate changes in the Mediterranean Sea. Actually, the isotopic and trace elements composition of foraminifera shells provide a reliable record of seawater chemistry and as such are widely used by palaeoceanographers to reconstruct ocean and climate variability on geological timescales. Specifically, the $\delta^{18}O$ signal of planktonic foraminifera records the combined effects of global ice volume, sea surface temperature, and regional evaporation/precipitation budgets, while the Mg/Ca ratio of foraminiferal tests mainly depends on the temperature of the water in which the foraminifer calcifies, as basically deduced from cultivating work and field studies (e.g., Nürnberg, 1995, 2000; Nürnberg et al., 1996, 2000; Lea et al., 1999; Mashiotta et al., 1999; Elderfield & Ganssen, 2000: Dekens et al., 2002).

Foraminiferal Mg/Ca seawater thermometry is a rapidly developing and increasingly widely used tool for palaeoceanographic reconstructions (Nürnberg et al., 1996; Rosenthal et al., 1997; Lea et al., 1999; Elderfield & Ganssen, 2000; Lea at al., 2000; Anand et al., 2003; Barker et al., 2005). The exponential increase of bulk test Mg/Ca composition with seawater temperature is well established from deep-sea sediment core top (Rosenthal et al., 1997; Hastings et al., 1998; Elderfield & Ganssen, 2000; Lea at al., 2000; Rosenthal et al., 2000; Dekens et al., 2002; Rosenthal & Lohmann, 2002). However, the incorporation of Mg during shells calcification is a complex and imperfectly known mechanism with potential species-dependent effects and non-temperature biases such as those associated to carbonate ion content of seawater (Russell et al., 2004; Kisakürek et al., 2008) or salinity (Nürnberg et al., 1996; Lea et al., 1999; Kisakürek et al., 2008; Mathien-Blard & Bassinot, 2009; Arbuszewski et al., 2010). Although not numerically abundant, studies in the Mediterranean evidenced some problems in the application of this method. Ferguson et al. (2008) showed a significant response of foraminiferal Mg/Ca to salinity in the Mediterranean Sea revealing a clear relationship (16% Mg/Ca increase per psu) although associated to a large Mg/Ca data scattering. This result was later confirmed by Sabbatini et al. (2011), on the Mg/Ca ratios characterizing the planktonic species *G. ruber* from the whole Mediterranean Sea. Hoogakker et al. (2009) and Boussetta et al. (2011), who worked on core tops from the Red Sea and from the Mediterranean basin respectively, suggested that anomalously high Mg/Ca ratios of planktonic foraminifers from the Mediterranean Sea, could be also related to early diagenetic, high Mg-calcite overgrowths formed from $CaCO_3$ supersaturated interstitial seawater. Also, van Raden et al. (2011) suggested that the high Mg/Ca measured on two planktonic foraminifers (*Globigerina bulloides* and *Globorotalia inflata*) in the Western Mediterranean Sea is due to inorganic calcite coating on the foraminiferal tests. Finally, Kontakiotis et al.

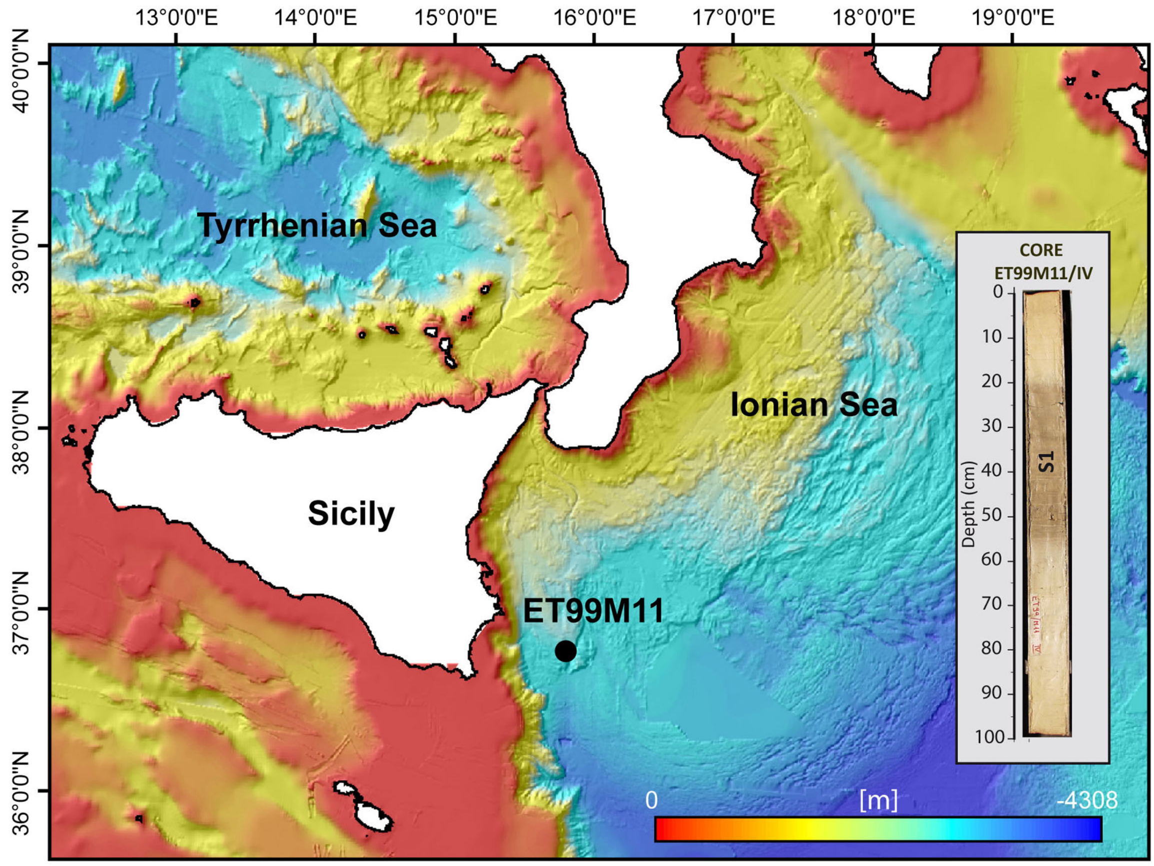

Fig. 1 - Location map of the core ET99M11 and section IV of the core with the indication of the sapropel S1 position. 450 m resolution DTM retrieved from http://portal.emodnet-hydrography.eu/EmodnetPortal/index.jsf#.

(2011) presented new Aegean Sea results which reveal Mg/Ca values that were unreasonably high to be explained by temperature or salinity variations alone, confirming that foraminiferal Mg/Ca is affected by diagenesis. Studies regarding foraminiferal Mg/Ca ratios during sapropels deposition are rare, however Ní Fhlaithearta et al. (2010) reliably constrained the magnitude and duration of the sapropel S1 interruption and other short-term cooling events using Mg/Ca thermometry from the benthonic microfauna in the Aegean Sea.

Here we present oxygen isotopes and Mg/Ca ratios data from planktonic foraminifera *Globigerina bulloides* and *Globigerinoides ruber* from sediments of sapropel S1 in the Ionian Sea, with the aim to reconstruct paleotemperature and paleoenvironmental changes which occurred during the sapropel S1 deposition in this basin.

2. REGIONAL SETTING

The Ionian Sea is a transition basin influenced by the flow and transformation of the major water masses constituting the intermediate and deep thermohaline cell of the Eastern Mediterranean conveyor belt (Malanotte-Rizzoli et al., 1997; Napolitano et al., 2000). Moreover, the Ionian circulation plays an important role in the redistribution of the different water masses to adjacent seas (Gačić et al., 2010).

At the near-surface level, which is the most important part of the water column with regard to the biological production, the Modified Atlantic Water (MAW) enters the western Ionian basin, the intermediate layer is influenced by salty and warm waters coming from the Levantine and Aegean basins (LIW: Levantine Intermediate Waters), whilst dense and oxygenated waters, mainly of Adriatic origin, spread into the Ionian deep layer.

The choice of the Ionian basin for this kind of high-resolution study is driven by the fact that its oceanographic setting is critical for the deep-water formation of the Mediterranean Basin and the oceanographic conditions, responsible of the sapropel deposition, are certainly influenced by the deep-sea ventilation. Moreover, concerning the planktonic foraminiferal distribution, this basin appears as a transitional area between the Southwestern and Eastern Mediterranean area (Pujol & Vergnaud Grazzini, 1995).

3. MATERIAL AND METHODS

The sedimentary core ET99M11 has been collected in the Ionian Sea (36°44’04”N, 15°50’94”E, 2800 m below sea level; Fig 1). In the core, the sapropel S1 interval is characterized by black-grey sediments extending from 54 to 22 cm depth in section IV of the core (Fig. 1).

3.1. Age model

The age model is that provided by Vigliotti et al. (2011 and Table 2 therein) based on four ^{14}C AMS datings integrated with tephra layers and planktonic foraminiferal bioevents. On this base sapropel S1, is chronologically confined between 10.4 and 5.7 cal ka BP and appear synchronous with analogous layer reported in the eastern Mediterranean sea. In detail, three different time intervals have been recognized: the S1a sub-unit spanning from 10.4 to 8.3 cal ka BP, the sapropel interruption from 8.3 to 7.8 cal ka BP, and the S1b sub-unit from 7.8 to 5.7 cal ka BP (Vigliotti et al., 2011).

3.2. Foraminiferal species used and their ecological features

G. ruber is a species living in the surface mixed layer and occurring in subtropical to tropical latitudes (Deuser, 1987; Ravelo & Fairbanks, 1992; Niebler et al., 1999). It is found at the base of the mixed layer (Field, 2004) and even has moderate abundances within the thermocline. In contrast to other species, *G. ruber* has a low-slope response to a deepening isotherm, which makes this species the most suitable to document near-surface temperatures when other species are living deeper (Field, 2004; Tedesco et al., 2007).

G. bulloides has a wide geographic distribution, ranging from the poles to the low latitudes (Niebler et al., 1999; Schmidt & Mulitza, 2002). This taxon most commonly lives in the surface mixed layer (Fairbanks et al., 1982; Hemleben et al., 1989), but it also occurs within the thermocline (Field, 2004).

Each species records the temperature variations of the water mass in which it thrives. Hence, the warmest water mass is the one in which *G. ruber* lives, and corresponds to the summer mixed layer (Pujol & Vergnaud-Grazzini, 1995; Rohling et al., 2004). The water mass recorded by *G. bulloides* is assumed to be a mixture between the late spring/early summer surface layer and deeper waters upwelled during those months at 50-100 water depth (Pujol & Vergnaud-Grazzini, 1995; Barcena et al., 2004; Hernàndez-Almeida et al., 2005).

3.3. Trace elements analysis (ICP-MS/ICP-AES)

Forty to sixty specimens of *G. ruber* (var. *alba*) were selected from the > 150 μm size fraction (26 samples) discarding specimens visibly contaminated by ferromanganese oxides. The foraminifera tests were next cleaned using a multistep trace metal protocol including reductive cleaning with buffered hydrazine (Boyle & Keigwin, 1985). Mg/Ca ratios were measured on a inductively coupled plasma mass spectrometer Varian ICP-MS and an inductively coupled plasma atomic emission spectrophotometer Varian Vista MPX at the Geochemistry Laboratory of the IAMC-CNR (Naples).

In detail, the tests were gently crushed and then cleaned following procedures modified from Lea & Boyle (1993). Briefly, samples were ultrasonically cleaned four times with ultrapure water (> 18 MΩ) and twice with methanol. Metal oxide coatings were reduced in a solution consisting of anhydrous-hydrazine, citric acid, and ammonium hydroxide and organic matter was oxidized in a solution of hydrogen-peroxide and sodium-hydroxide. All the water samples were treated under a laminar air flow clean bench to minimize contamination risks and the sampling materials were cleaned with high purity grade reagents. The remaining tests material was then dissolved in 0.1N nitric acid and simultaneously analysed for magnesium with the Varian ICP-MS inductively coupled plasma-mass spectrometer. A multi-element standard was prepared with ICP-MS grade High-Purity Standards. Based on repeated analyses of the standard and samples over several runs, on different days, the 2s error in the ICP analyses is estimated at ±5%. Replicate analyses on five samples yielded an average external precision (1σ) of about 5%. Calcium was measured with a Varian Vista MPX inductively coupled plasma-optical emission spectrometer (ICP-OES). Metal to calcium ratios were determined from intensity ratios with an external matrix-matched standard using the method developed by Rosenthal et al. (1999).

The cleaning protocol and analytical approach used in this study is also comparable to methods reported by Elderfield & Ganssen (2000).

3.4. Isotopic analyses

The oxygen isotopic composition of *G. ruber* (var. *alba*) and *G. bulloides* were obtained from the sediment core. About 10-15 specimens in the > 150 μm size fraction were analyzed per sample (41 samples).

Samples were measured with an automated continuous flow carbonate preparation GasBench II device and a ThermoElectron Delta Plus XP mass spectrometer at the Laboratory of Geochemistry of the IAMC-CNR (Naples). Acidification of the samples was performed at 50°C. An internal standard (Carrara Marble with $\delta^{18}O$ = -2.43‰ vs. VPDB and $\delta^{13}C$ = 2.43‰ vs. VPDB) was run every six samples and the NBS19 international standard was measured every 30 samples. Standard deviations of carbon and oxygen isotope measures were estimated at 0.1 and 0.08‰, respectively. All the isotope data are reported in δ‰ versus VPDB.

3.5. Determination of Calcification Temperatures

3.5.1. Temperature estimates from $\delta^{18}O_{foram}$

To obtain the calcification temperatures we have used oxygen isotope data of *G. ruber* and *G. bulloides* ($\delta^{18}O_{foram}$) and of the water masses in which they calcify ($\delta^{18}O_{seawater}$).

Different equations have been proposed to convert $\delta^{18}O_{foram}$ in SST but based on what reported on Grauel & Bernasconi (2010) on sediment surface samples, *G. ruber* yield the most reliable calcification temperature applying the Shackleton (1974) palaeotemperature equation. In fact, according to the authors, who made a core-top study on $\delta^{18}O$ temperature reconstructions of *G. ruber* (white) and *U. mediterranea* in the central Mediterranean, reliable temperatures were produced using the Shackleton (1974) equation, whereas too low temperatures compared to the recent temperature conditions (on average ~4.4°C lower than predicted by Shackleton (1974) equation) were produced using the Mulitza et al. (2003) equation.

The equation of Shackleton (1974) is:

$$T_{iso} = 16.9 - 4.38 * \left(\delta^{18}O_{foram} - \delta^{18}O_{seawater}\right) + 0.1 * \left(\delta^{18}O_{foram} - \delta^{18}O_{seawater}\right)^2 \quad 1)$$

where T_{iso} is the calcification temperature and $\delta^{18}O_{foram}$ and $\delta^{18}O_{seawater}$ are reported vs. VPDB.

$\delta^{18}O_{seawater}$ values for sapropel time are those reported in Kallel et al. (1997 and Table 4 therein).

Values of $\delta^{18}O_{seawater}$ have been converted to Vienna Standard Mean Ocean Water (V-SMOW)‰ using the following equation:

$$\delta^{18}O_{seawater\,(PDB)} = \delta^{18}O_{seawater\,(SMOW)} - 0.27 \qquad 2)$$

3.5.2 Temperature estimates from Mg/Ca ratios

Although in the Mediterranean sea seems to be no significant correlation between Mg/Ca and $\delta^{18}O$-derived calcification temperatures (Ferguson et al., 2008; Sabbatini et al., 2011), several studies suggested an exponential correlation between Mg/Ca ratios from *G. ruber* shells and SST (e.g. Elderfield & Ganssen, 2000; Anand et al., 2003; Dekens et al., 2002). Generally, the adopted Mg/Ca-SST equation is that reported by Elderfield & Ganssen (2000) based on multispecies calibration:

$$Mg/Ca = 0.52\exp(0.10T_{Mg/Ca}) \qquad 3)$$

where $T_{Mg/Ca}$ is the calcification temperature and Mg/Ca is measured in mmol/mol.

4. RESULTS

4.1. $\delta^{18}O_{foram}$ and SST

The oxygen isotope data measured on the two species of planktonic foraminifera are illustrated vs. age in Fig. 2. The $\delta^{18}O$ values from *G. ruber* and *G. bulloides* during the investigated period average -0.56‰ and 1.12‰, respectively (Fig. 2) with associated variances of 0.46‰ and 0.62‰. *G. ruber* shows lower values than *G. bulloides* but the two records show the same trend during the investigated period, with a general lightening during sapropel deposition, and particularly during the S1a subunit.

The *G. ruber* calcification temperature, characterized by a general increase throughout the whole investigated period, ranges between 22.8 and 14.1°C with an average value of 20°C, while *G. bulloides* records a similar trend with an isotopic temperature ranging between 16.3 and 5.0°C, with an average value of 12.7°C (Fig. 2).

The heaviest isotopic values throughout the record are observed at 11.6, 10.7, 10.0, 9.5, 8.2, and 6.4 cal ka BP suggesting colder conditions during these intervals.

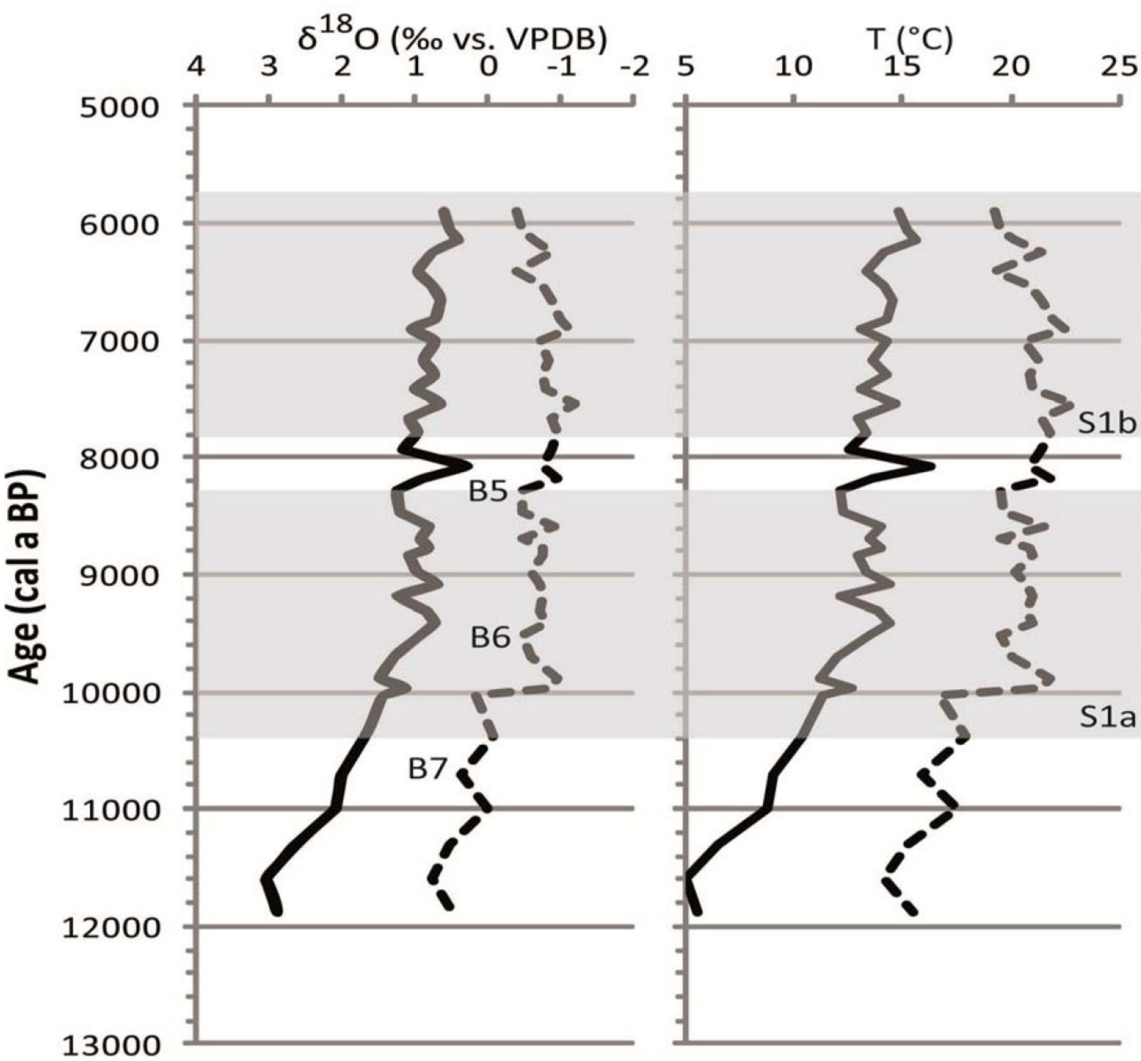

Fig. 2 - Down-core oxygen isotope records (‰ versus VPDB) and calculated isotopic temperature in °C in *G. ruber* var. *alba* and *G. bulloides* for core ET99M11 across the sapropel S1. The grey areas, representing the extent of the two sub-units of the sapropel S1, are from Vigliotti et al. (2011). B5-B7 label Bond cycles (Bond et al., 1997; 2001).

4.2. Mg/Ca ratios and SST estimates

During the interval of sapropel deposition Mg/Ca ratios range between 1.8 and 4.7 mmol/mol (Fig. 3) with an average value of 3.37 mmol/mol.

The estimated SST values range between 22.3 and 15.7°C during the subunit S1a, with an average value of 20°C, and between 22.4 and 18.6°C (average value 18.6°C) during the subunit S1b, while during the interruption the average value is 14.8°C (Fig. 4). The warmest period is observed at the beginning of the sapropel S1 deposition, and throughout the interruption a gradual cooling took place, leading to another warming phase during the subunit S1b.

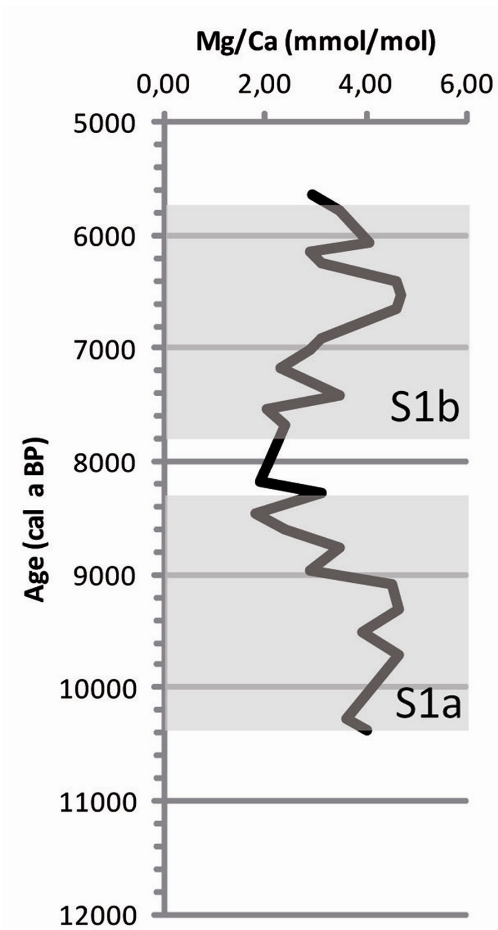

Fig. 3 - Down-core Mg/Ca ratios of *G. ruber* var. *alba* for core ET99M11 across the sapropel S1. The grey areas, representing the extent of the two sub-units of the sapropel S1, are from Vigliotti et al. (2011).

5. DISCUSSION

5.1. Paleotemperature estimates and difference between the two proxies

Our results show temperatures comparable to those reported during the sapropel S1 by Kallel et al. (1997).

In detail, in the investigated period, both proxies record comparable temperatures in terms of average values, however there are some dissimilarities at a smaller scale: in fact, whereas the isotopic temperature after a sharp increase at 10 cal ka BP does not show great fluctuations, paleotemperature reconstruction based on Mg/Ca ratios shows higher values in the interval from 10 to 8.8 cal ka BP and from 6.6 to 6.3 cal ka BP during the deposition of the two sub-units of sapropel S1, and lower values in the interval from 8.8 to 7.2 cal ka BP, with the lowest temperature recorded at 8.2 cal ka BP corresponding to the sapropel interruption (Fig. 4).

In detail, based on calculated isotopic temperatures, the sapropel S1 interval was characterized by a general increase in water temperatures at the surface and in the sub-surface layers, as clearly evidenced by *G. ruber* and *G. bulloides*, respectively.

The mean temperature estimate for *G. ruber* (20°C) is consistent with the growth temperature proposed by Kallel et al. (1997 and Table 4 therein) for the same species during the sapropel S1 deposition in the Ionian basin. The sapropel SST is also taken to be equivalent to the modern one in the Ionian basin and the growth temperature of *G. ruber* is found to correspond to the mean SST of the summer mixed layer (Manca et al., 2004). This datum further supports that, during the sapropel interval, the SSTs in the Ionian Sea were similar to the present ones.

The amplitude of the temperature changes recorded by *G. ruber* is broad, up to 8°C from the warmest to the coldest values and is consistent with paleotemperature variations documented in the same area during the sapropel S1 deposition by Emeis et al. (2000). This broad amplitude is due to the very thin summer mixed layer really sensitive to any runoff event or heating anomaly which would have great impact as compared with other thicker water masses (Gonzalez-Mora et al., 2008).

The variability of the *G. bulloides* data are even wider than those of *G. ruber* (around up to 10°C of difference between the coldest and the warmest samples), this although the general trends are similar. The mean temperature estimate for *G. bulloides* (12.7°C) is cooler by about 2°C respect to that of today. As *G. bulloides* is prolific at depths below the thermocline (Pujol & Vergnaud-Grazzini, 1995), the observed difference in temperature estimate respect to *G. ruber* suggest the presence of a marked thermocline or an increasing summer thermal gradient. Moreover, the large gradient between the temperatures recorded by *G. ruber* and *G. bulloides* can be interpreted as related to their seasonality (Pujol & Vergnaud-Grazzini, 1995) suggesting that the two different water masses remained isolated at the seasonal scale, due to a permanent seasonal stratification.

The mean temperature estimate, based on Mg/Ca ratios, for *G. ruber* is consistent with the isotopic temperature during S1a subunit (20°C) while is cooler by about 1.5°C during S1b subunit (18.6°C).

Discrepancies between temperature estimates from Mg/Ca ratios and calculated isotopic temperature may be ascribed to the different variables influencing the two proxies. The oxygen isotopic temperatures are based on biogenic $\delta^{18}O_{foram}$ which is affected by $\delta^{18}O_{water.}$ The variability between the Mg/Ca and oxygen isotope temperature reconstructions of *G. ruber* may, in part, be explained by changes in $\delta^{18}O_{water}$.

In our reconstructions, we assumed a constant $\delta^{18}O_{water}$ during the entire investigated interval, but it is

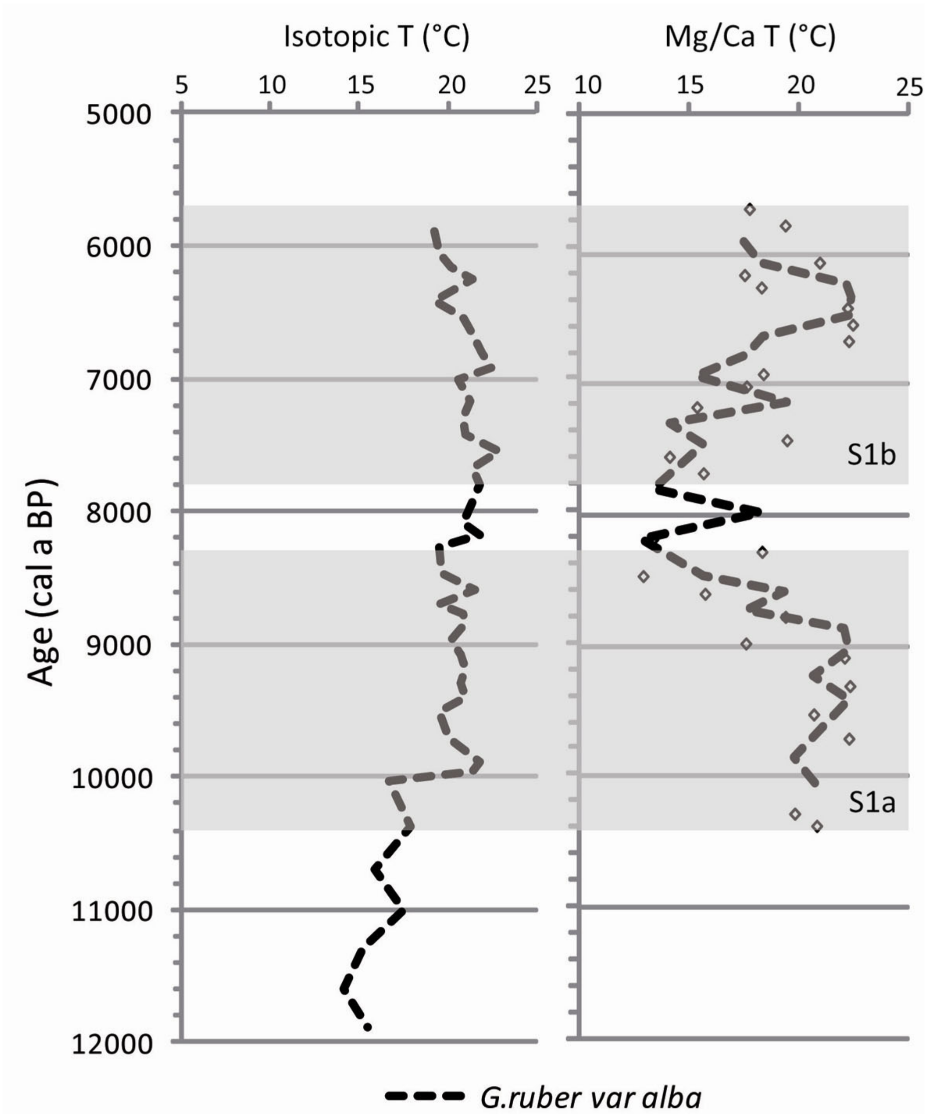

Fig. 4 - $\delta^{18}O$ and Mg/Ca *G. ruber* var. *alba* inferred temperature records from core ET99M11. The grey areas, representing the extent of the two sub-units of the sapropel S1, are from Vigliotti et al. (2011). Open symbols represent Mg/Ca data, overlain with a line representing a 200 year Gaussian smoothing.

reasonable that during the sapropel deposition the well documented enhanced run-off and the subsequent different evaporation/precipitation budget, and the presence at the surface of freshwater-diluted lenses influenced this value. On the contrary, Mg/Ca ratios in modern planktonic foraminifera are assumed and have been demonstrated to be predominantly a function of the temperature of the water in which they grew, while salinity is a secondary factors that exert influences on shell Mg content, but not in the Mediterranean, where several authors (Ferguson et al., 2008; Sabbatini et al., 2011 and references therein) suggested that Mg/Ca ratios can be strongly affected by the high salinity values typical of this basin. In detail, measured Mg/Ca values of planktonic foraminifera, collected in the eastern and central Mediterranean basins, correlate poorly with the calcification temperatures but more significantly with calcification salinities, demonstrating that the salinity can be a primarily influencing factor in these environments. However, during the sapropel deposition, surface water salinity decreased and became almost homogeneous over the whole Mediterranean basin with an average value for the Ionian sea of 35.2 PSU (Kallel et al., 1997 and Table 4 therein), which is close to that of the western Mediterranean basin (e.g. Alboran Sea) where the Mg/Ca ratios are not influenced by the salinity regime (Ferguson et al., 2008). Then it is reasonable that, during the sapropel deposition, the salinity did not exert influences on shell Mg content, being the Mg/Ca ratios primarily influenced by SST variations.

In addition, we may exclude the possibility that post-deposition process or the presence of a Mg-rich calcite coating influences the results, firstly because sapropel layers are really conservative environments often characterized by the lack of bioturbation and often apparently high sedimentation rates. Secondarily, we observed in our samples, that the sapropel microfauna association was typically characterized, as observed by other authors (Capotondi et al., 1999; Negri et al., 1999), by the occurrence of specimens showing a very thin test structure, easily observed at the optical microscope, which point to a very good test preservation with no or few secondary calcite overgrowth.

Concluding, our data show that fluctuations in the Mg/Ca ratios are more pronounced than in the isotopic values suggesting a promising tool for paleotemperature reconstruction also in the Mediterranean, but only when the influence of salinity will be entirely clarified.

5.2. Mediterranean connection with the North Atlantic Ocean

Climate changes during the Holocene have been gathering increasing attention because of the occurrence of millennial-scale abrupt climate changes, of possible hemispheric extent, during this period (e.g., Bond et al., 2001; Gupta et al., 2003; Mayewski et al., 2004), when the boundary conditions such as CO_2 concentration and ice volume were relatively constant and similar to the present ones.

In the North Atlantic, ice-rafted debris (IRD) events exhibit a distinct pacing on millennial-scale during the Holocene (Bond et al., 2001). Recently, several authors identified the expression of these events also in the sedimentary record of the Mediterranean Sea (e.g. Cacho et al., 2001; Frigola et al., 2007; Rouis-Zargouni et al., 2010; Incarbona et al., 2008; 2010; Vallefuoco et al., 2011; Capotondi & Vigliotti, 1999).

Comparison of our record of $\delta^{18}O_{foram}$ with North Atlantic Holocene millennial scale climatic variability (Bond et al., 1997) allowed to highlight several short-term cold oscillation at around 10.7, 9.5, and 8.2 cal ka BP comparable with the events numbered 7, 6, and 5 by Bond et al. (2001; 1997) (Fig.2).

This indicates a possible atmospheric connection between the Central Mediterranean and the North Atlantic region and the strong relation between climate and oceanographic changes during the sapropel S1 interval. One of these climatic features has been already documented by several authors in other areas of the Mediterranean Sea (e.g. Rohling et al., 1997; De Rijk et al., 1999; Sangiorgi et al., 2003; Vigliotti et al., 2011; Asioli et al 1999; Ariztegui et al., 2000), and was related to the so-called "8.2 event" (Alley et al., 1997) and the associated $\delta^{18}O$ increase of Greenland ice cores.

Based on the isotopic temperature signal, during the three events the magnitude of the sea surface cooling is comparable to that proposed by Bond et al. (1997) in cores from the North Atlantic ocean, and does not exceed 2°C. Based on the Mg/Ca temperature reconstruction, the cooling exceeded 2°C only during the event centred at 8.2 cal ka BP with a decrease in temperature of at least 5°C corresponding to the shift also proposed by Alley et al. (1997) during this event. Then in the studied core the Mg/Ca method evidences very sharp short time fluctuations much less evident with the isotope paleotemperature method.

Then, our data suggest a strong sensitivity of the Central Mediterranean basin, during the sapropel S1 time interval, to changes occurred in the North Atlantic and therefore supports the high low latitude climatic Mediterranean interplay also evidenced in Colleoni et al. (2012) for the Plio-Pleistocene time interval.

6. SUMMARY

A high-resolution investigation on the Holocene sapropel S1 in the Ionian Sea was performed based on planktonic foraminifera geochemical data (stable oxygen isotopes and Mg/Ca ratios) proxies.

This study documents promising results of the Mg/Ca paleothermometry applied to planktonic species.

The first phase of the sapropel S1 was characterized by higher temperature, also consistent with the modern ones in the Eastern Mediterranean basin, while the second phase registered cooler temperature by about 2°C.

During the sapropel interval, several cooling episodes, time equivalent to the millennial climatic variability in the North Atlantic, were recognized at 10.7, 9.5, and 8.2 ka BP, the latter corresponding to the well known "8.2 event" and synchronous to the sapropel interruption. The climatic oscillations recorded by our study suggest an hemispheric-scale atmospheric connection in the Central Mediterranean basin.

ACKNOWLEDGEMENTS

Part of this study was funded by the projects SINAPSI and Ricerca Spontanea a Tema Libero (RSTL n. 154; "Sapropels S1 e S5: archivi della variabilità climatica indotta dal regime monsonico"). We thanks M. Coltelli, P. Del Carlo and L. Vezzoli to provide Core ET99M11. We also thank Alessandra Negri and an anonymous rewiever who greatly improved the manuscript with their comments. This is the ISMAR contribution 1784.

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Ms. received: November 29, 2012
Final text received: February 2, 2013