

# The Last Glacial Maximum and Holocene along the western Iberian Margin: paleoceanographic and paleoclimatic analyses

Carmen Argenio<sup>1</sup>, Pierluigi Palladino<sup>1</sup>, José-Abel Flores<sup>2</sup>, Filomena Ornella Amore<sup>1</sup>

<sup>1</sup>*Dipartimento di Scienze e Tecnologie, Università degli Studi del Sannio, Via dei Mulini - 82100 Benevento, Italy*

*[carmen.argenio@unisannio.it](mailto:carmen.argenio@unisannio.it) – [palladino.90pier@gmail.com](mailto:palladino.90pier@gmail.com) - [f.amore@unisannio.it](mailto:f.amore@unisannio.it)*

<sup>2</sup>*Departamento de Geología, Universidad de Salamanca, Plaza de los Caidos - 37008 Salamanca, Spain [flores@usal.es](mailto:flores@usal.es)*



# Time interval

During the past 25,000 years, the Earth system has undergone a series of **dramatic climate transitions** among which the most recent glacial period, peaked at about **21,000 years ago**, known as **“Last Glacial Maximum”**.

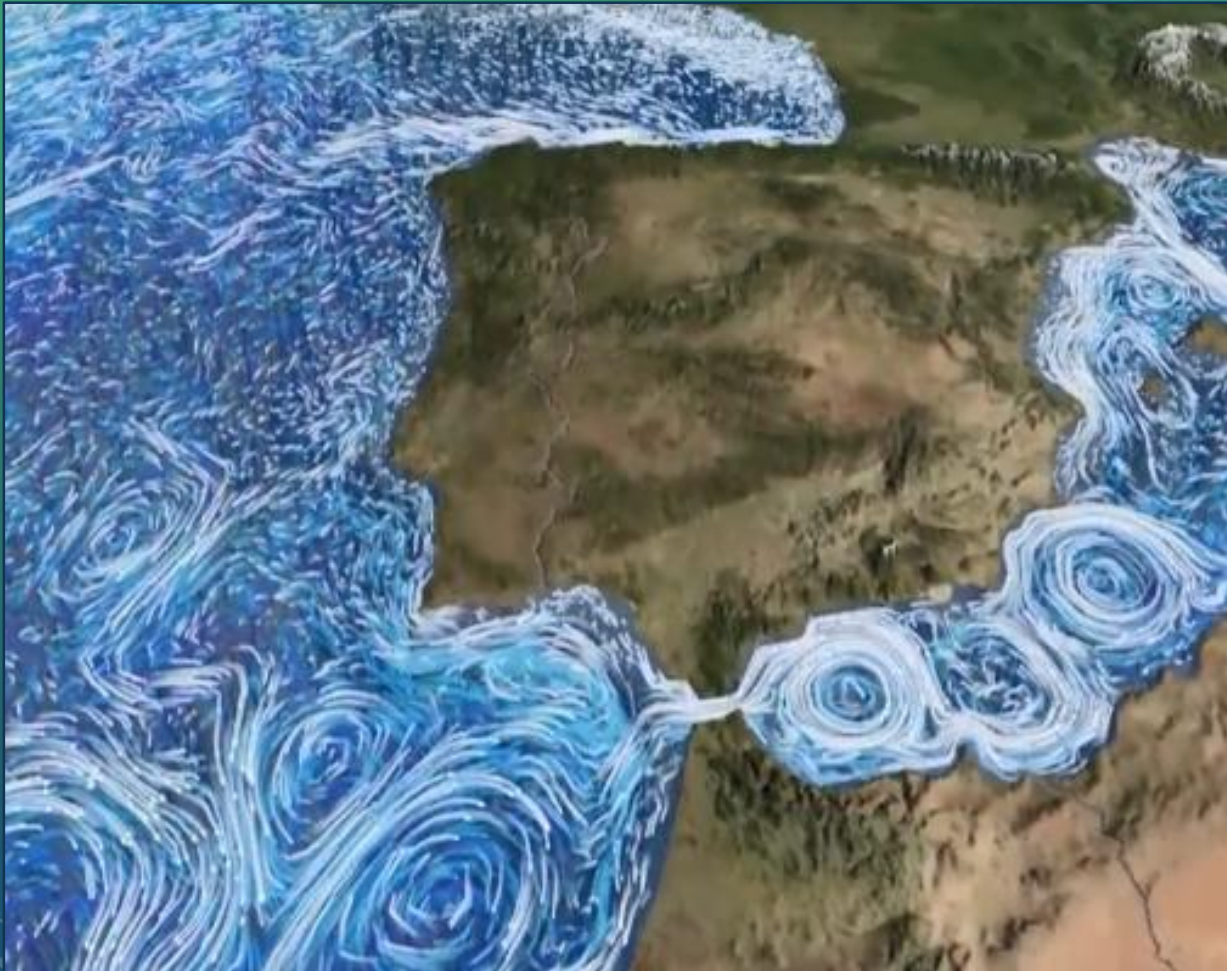
Coccoliths are an important tool to decipher global climate evolution in a so interesting geological interval and, according to this, the **final aim** of this study is to provide high resolution paleoceanographic and paleoclimatic analyses focused on the coccolithophore assemblages off the Iberian Margin.

# Iberian Margin: key area for climate's variability studies



- Key location for the investigation of Mediterranean Outflow Water through the Gibraltar Gateway and its influence on global circulation and climate;
- High sedimentation rate characterizing the area;
- High-fidelity records of millennial-scale climate variability;
- Possibility to correlate data to polar ice-cores and European terrestrial sequences.

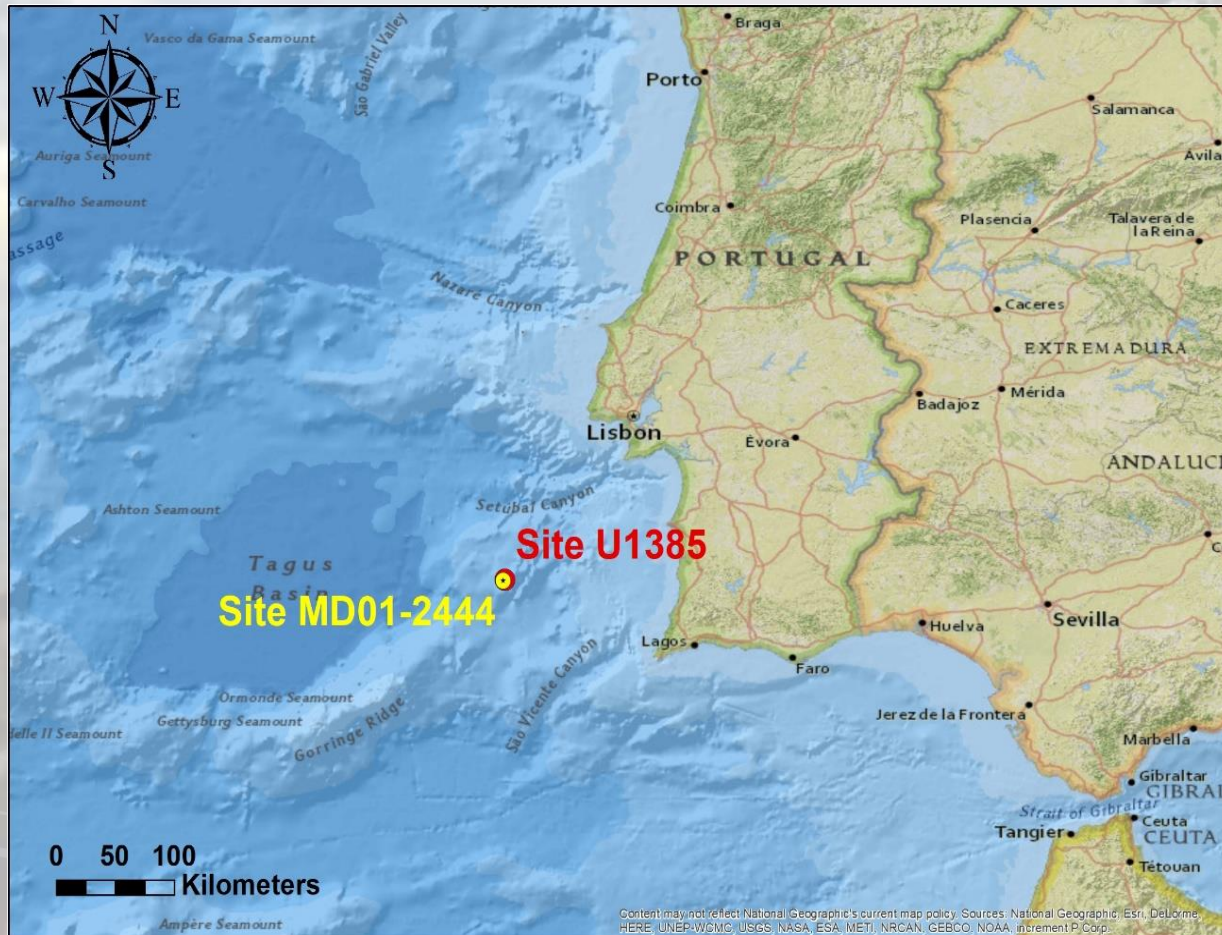
# Oceanographic setting



- **Mediterranean Outflow Water (MOW)** through the Gibraltar Gateway;
- **Portugal Current System – PC** (northward displacement of the semi-permanent subtropical Azores High pressure system);
- **Iberian Poleward Current – IPC** (southward displacement of the semi-permanent subtropical Azores High pressure system);
- Intra-seasonal climate oscillations induced by the **North Atlantic Oscillation**.

# «The Shackleton Site»

During Integrated Ocean Drilling Program Expedition 339 five sites have been drilled in the Gulf of Cádiz and two sites have been drilled off the West Iberian margin.



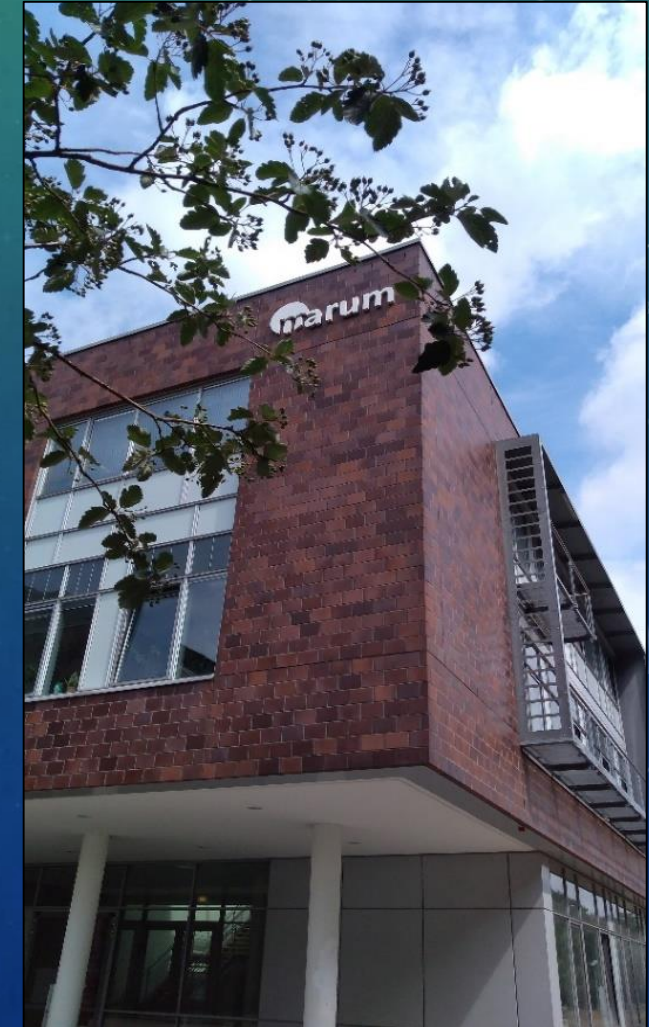
In particular, the IODP Site U1385 ( $37^{\circ}34.285'N$ ;  $10^{\circ}7.562'W$ ) is interest of this study.

It is located at 2585 meters below sea level (mbsf) on a spur, Promontorio dos Principes de Avis, along the continental slope of the southwestern Iberian margin, which is elevated above the abyssal plain and outside the influence of turbidites.

The age model was calculated using 64 tie points from Datema et al., 2019.

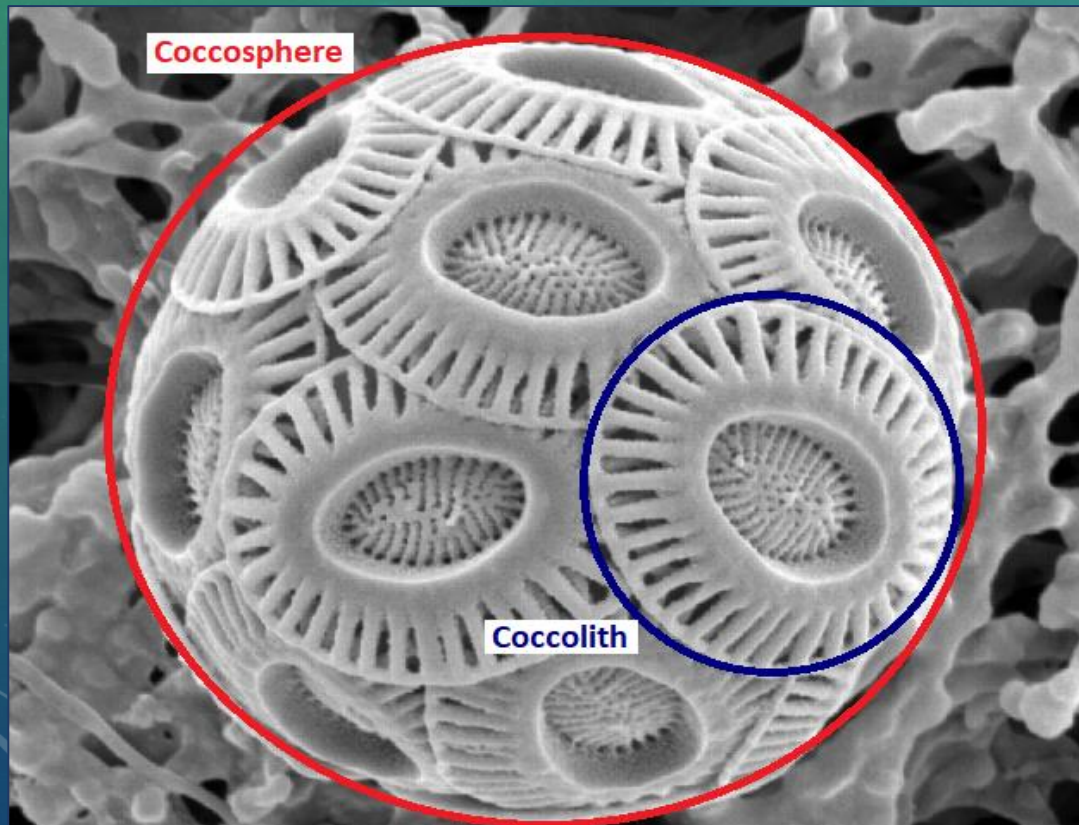
# Material and methods: sampling

This study is conducted through samples from the IODP Site U1385 acquired at the **Bremen Core Repository**. In detail, four sections of the core A were sampled using scoops of 5 cc for a total of 495 samples.



# Coccolithophores

Coccolithophores are *haptophyte algae* living in the photic zone where there is an optimal level of incoming sunlight to perform photosynthetic processes.



USEFUL PROXIES  
FOR PALEOCEANOGRAPHY AND  
PALEOCLIMATOLOGY

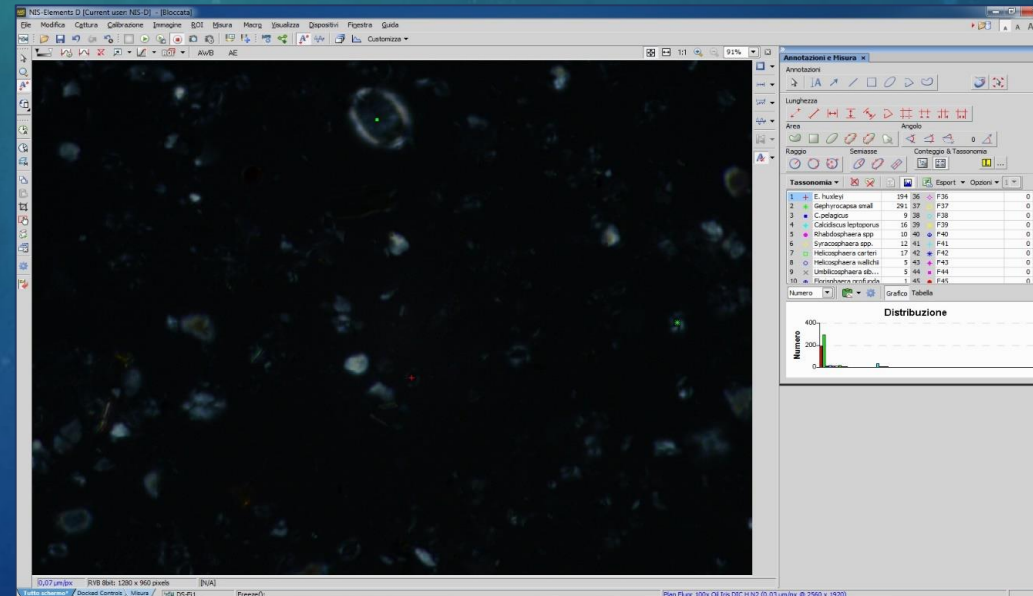
# Methods

Quantitative analysis of 32 slides prepared and analysed following the methodology illustrated in Flores and Sierro (1997)

Light microscope Nikon Eclipse-E600 at 1000x magnification

- COUNTING OF 300 COCCOLITHS > 3  $\mu\text{m}$  PER SLIDE
- ABSOLUTE ABUNDANCE (N; coccoliths per gram of sediment)
- NANNOFOSSIL ACCUMULATION RATE (NAR; coccoliths  $\text{cm}^{-2} \text{ka}^{-1}$ )

Software package NIS-Elements-D





# Methods

Quantitative analysis of 32 slides prepared and analysed following the methodology illustrated in Flores and Sierra (1997)

*E. huxleyi*



*G. muelleriae*



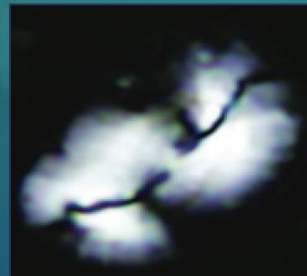
*C. pelagicus pelagicus*



*F. profunda*



*H. carteri*



*G. oceanica*



small

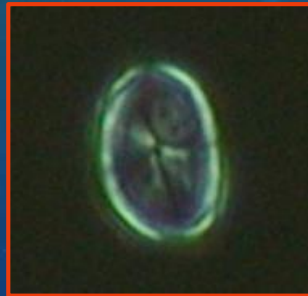
*Gephyrocapsa*



*Umbellosphaera spp.*



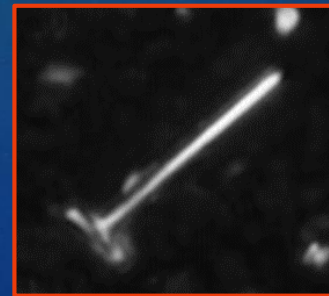
*S. pulchra*



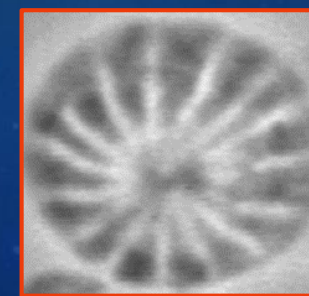
*U. sibogae*



*Rhabdospaera spp.*



*O. fragilis*



# RESULTS AND DISCUSSION

The palaeoceanography off the Iberian margin was characterized by the occurrence of changes in coccolithophore productivity, nutricline depth and upwelling intensity.

These changes are related to two different kinds of superimposed phenomena undergone by Earth climate system:

- glacial/interglacial oscillations, caused by Earth orbital changes;
- millennial-scale events linked to climate events as incursions of iceberg-melting waters, iceberg-induced turbulence and sediment discharges.

# RESULTS AND DISCUSSION: PALEOCEANOGRAPHIC PROXIES DURING GLACIAL-INTERGLACIAL OSCILLATIONS

➤ **Paleoceanographic proxies analysis allowed, in first instance, to recognize a variability occurring on a plurimillennial scale consisting in glacial/interglacial oscillations.**

- Total NAR was used as a coccolithophore paleoproductivity proxy, index of abundance variability through time. In general, higher values of NAR were recorded during the interglacial periods, while decreasing values were recorded during glacial periods. In detail, small placoliths reached higher values during the Holocene. This increasing productivity was ascribed to the development of the modern seasonal surface hydrography characterized by a more persistent Iberian Poleward Current (IPC).
- N ratio, used as indicator of primary productivity of the upper photic zone, showed a good productivity, during the entire interval, except for three negative peaks. One of negative peaks was recorded during the LGM at 18,40 ka, at the same time a positive peak in *Florisphaera profunda* record was showed. These conditions are indicative of a deeper nutricline. The abundance of *F. profunda* in water samples from the NW Iberian margin has been unequivocally linked to the downwelling regime and low-productivity conditions (Ausín et al., 2018).  
The dissolution index presented, in general, good values because of a low dissolution during both Holocene and LGM.
- During LGM increasing values of *Helicosphaera carteri* and *Braarudosphaera bigelowii* were recorded. These parameters are indicative of high turbidity and decreasing water salinity. Low values of *Helicosphaera carteri* and reworked species were recorded during the Holocene. *Braarudosphaera bigelowii* showed a peak at 11,48 ka with decreasing values recorded during the Holocene.
- Opposed to higher values recorded during LGM, *Emiliana huxleyi* > 4µm, *Gephyrocapsa muellerae* and *Coccolithus pelagicus* subsp. *pelagicus* showed low values during the Holocene.

In contrast, warm species showed a different pattern. *Gephyrocapsa oceanica*, considered a good proxy for coastal productivity due to upwelling and high nutrient availability (Amore et al., 2012; Guerreiro et al., 2014), showed decreasing values during LGM.

The warm water group (WWG) is associated to seasonal incursions of warmer, subtropical waters in condition of prevailing IPC influence (occurrence of wetter and warmer conditions). Today these conditions are observed during negative North Atlantic Oscillation (NAO) years. Small peaks of WWG during LGM indicate the seasonal incursion of warmer, sub-tropical waters, possibly related to a Paleo-IPC. Both NAR and percentage values of the WWG showed a peak at 6,54 ka corresponding to the “Holocene climatic optimum”. Increased WWG abundances during the Holocene indicated a prevalence of IPC in the study area.

## RESULTS AND DISCUSSION: PALEOCEANOGRAPHIC PROXIES DURING MILLENIAL SCALE EVENTS

➤ Furthermore, a millennial-scale variability, superimposed to the plurimillennial scale variability, was recognized too allowing to differentiate three main periods.

✓ Heinrich stadial 1 (HS1)

- Decreasing values of NAR were recorded during stadial events as HS1. The minimum coccolithophore productivity characterizing HS1 can be associated to hydrologic changes in the upper water column: the arrival of cold, less-saline waters caused a strong stratification. Melting icebergs, derived from the northern ice-sheets, delivered meltwater and ice rafted debris to the study region. During HS1 a weak Atlantic Meridional Overturning Circulation (AMOC) phase occurred, both the Subpolar and Subtropical fronts migrated southward and iceberg melting waters reached the Iberian margin. In these conditions a productivity decrease was recorded.
- N ratio showed a negative peak at 16,74 ka corresponding to a positive peak in *Florisphaera profunda* pattern showing that a deeper nutricline occurred at this time.  
At 16,74 ka a small negative peak of the dissolution index was recorded too indicating a phase of major dissolution.
- *Helicosphaera carteri* and reworked species showed decreasing NAR and increasing percentage values during HS1. In detail, a peak at 15,83 ka was recorded in reworked species percentage values in accordance with an increasing sedimentation rate. This can be associated with increased MOW transport during HS1.
- *Emiliana huxleyi* > 4µm NAR showed high values during HS1 as *Gephyrocapsa muelleri* and *Coccolithus pelagicus* subsp. *pelagicus*. Furthermore, in the same interval, a peak in percentage values of *Coccolithus pelagicus* subsp. *pelagicus* was recorded. *Coccolithus pelagicus* subsp. *pelagicus* (subspecies living on the border of subarctic biogeographic province) showed a distribution pattern that supports the arrival of cold surface waters. *Gephyrocapsa muelleri* is a nutrient-rich, cold-water indicator (Amore et al., 2012; Palumbo et al., 2013; Parente et al., 2004; Colmenero-Hidalgo et al., 2004; Silva et al., 2008), although its abundance varies regardless of absolute SST changes (Incarbona et al., 2010). Higher percentage values than NAR values of *Emiliana huxleyi* > 4µm and *Gephyrocapsa muelleri* were recorded in particular at 15,83 ka. At the end of HS1 iceberg drift caused an increase of cold and shallow waters favouring the proliferation of these two cold species.
- Low NAR and percentage values of WWG were recorded during HS1. A negative peak at 17,17 ka was recorded for both *Florisphaera profunda* and *Gephyrocapsa oceanica* values.

## ✓ Bølling-Allerød (B/A)

- Higher values of NAR were recorded during interstadial events. Total NAR values increased progressively through B/A until a peak at 12,77 ka. This is probably due to an increase in sediment and nutrients discharges as consequence of ice melting and increasing rainfall with consequent river discharges. According to this, an increase of the sedimentation rate was recorded too during the same period with a peak at 12,77 ka. An increase in small placoliths values was recorded during B/A reaching higher values during the Holocene. The high coccolithophore productivity characterizing the B/A is referable to a shallow nutricline linked to increased upwelling.
- A negative peak in N ratio was recorded during the final phase of the B/A, at 13,25 ka. A positive peak in *Florisphaera profunda* pattern was recorded at 13,25 ka highlighting the occurrence of a deeper nutricline.

The dissolution index showed a negative peak at 14,06 ka, index of a major dissolution. It was probably caused by an increase in sediment discharges as recorded by the increasing sedimentation rate.

- *Helicosphaera carteri* and reworked species showed increasing NAR and decreasing percentage values during the B/A. High turbidity, caused by a rainfall increment and an enhanced continental-fresh water input, occurred according to the increasing sedimentation rate. This context favoured low salinity conditions as confirmed by a peak of *Braarudosphaera bigelowii* at 14,06 ka. This is a species indicative of low salinity conditions generally occurring with a major water dilution (Amore et al.2000; Negri & Giunta 2001; Buccheri et al. 2002).
- A decrease of *Emiliana huxleyi* > 4µm percentage values and a decrease in both NAR and percentage values of *Coccolithus pelagicus* subsp. *pelagicus* were recorded during B/A when environmental conditions favoured the increase of warm taxa caused by IPC prevalence.
- Increasing values during the B/A were recorded for all warm species. The warming occurred during B/A was testified by an increasing in subtropical (WWG) taxa values. The B/A warming was promoted by the northward extension of the subtropical gyre. *Florisphaera profunda* showed an increasing surface water productivity during B/A. This species is regarded as a deep-photic species occurring below oligotrophic surface waters and in condition of a major stratification of the water column. *Gephyrocapsa oceanica* showed high values in particular at the end of the B/A indicating eutrophic conditions in this period. *G. oceanica* is usually well adapted to more coastal regions and relatively low salinity conditions.

## ✓ Younger Dryas (YD)

- Decreasing values of NAR were recorded during YD. In this timeframe the arrival of colder and less saline waters took place along the western Iberian margin: these conditions likely promoted increased surface stratification rather than upwelling of nutrient-rich waters. During YD a weak Atlantic Meridional Overturning Circulation (AMOC) phase occurred, both the Subpolar and Subtropical fronts migrated southward and iceberg melting waters reached the Iberian margin. In these conditions a productivity decrease was recorded.
- Both N ratio showed a negative peak at 12,42 ka. The dissolution index showed slightly decreasing values since 12,42 ka.
- During YD both *Helicosphaera carteri* and reworked species recorded decreasing values.
- High values of *Emiliana huxleyi* > 4µm and *Gephyrocapsa muellerae*, with a downward trend towards the Holocene, were recorded during YD. A peak in percentage values of *Gephyrocapsa muellerae* was recorded at 12,42 ka.
- Low values of the WWG and *Florisphaera profunda* were recorded during YD. High values of *Gephyrocapsa oceanica* were recorded at the same time, probably due to a major turbidity.

# CONCLUSION

Coccolithophores assemblages variations were controlled by climate events resulting by hydrographic and environmental conditions changes.

During interglacial periods favourable conditions for coccolithophore growth occurred with the quasi-predominance of warming, together with intense upwelling seasons. Higher productivity, shallower nutricline and upwelling occurrence were observed in particular for the Bølling-Allerød (B/A). This reconstruction is in good accordance with a strong influence of Azores Current and Iberian Poleward Current (IPC). During periods of IPC prevailing influence coccolithophore assemblages reflected the increase of warm taxa.

Opposite conditions, characterized by lower productivity, deeper nutricline and weak upwelling, were observed during HS1 and the YD. The occurrence of weak upwelling caused unfavourable conditions for coccolithophore growth. This suggests a long-term influence of the Portugal Current (PC) during the glacial periods on coccolithophore assemblages.

# References

- AMORE F.O. et al. (2000) - In: Hart, M.B. (Ed.), *Climates: Past and Present*. Spec. Publ. - R. Geol. Soc. Lond., 181, 95–111.
- AMORE F.O. et al. (2012) - *Marine Micropaleontology* 90-91, 44-59.
- AUSÍN B. et al. (2018) - *Biogeosciences* 15, 245-262.
- BUCCHERI G. et al. (2002) - *Marine Geology* 186, 447–470.
- COLMENERO-HIDALGO E. et al. (2004) - *Palaeogeography Palaeoclimatology Palaeoecology* 205, 317–336.
- DATEMA M. et al. (2019) - *Paleoceanography and Paleoclimatology* 34, 1139-1156.
- GUERREIRO C. et al. (2014) - *Deep Sea Research Part II: Topical Studies in Oceanography* 104, 335-358.
- INCARBONA A. et al. (2010) - *Paleoceanography* 25, 2218.
- NEGRI A. & GIUNTA S. (2001) - *Palaeogeogr. Palaeoclimatol. Palaeoecol.* 169, 101–112.
- PALUMBO E. et al. (2013) - *Journal of Quaternary Science* 28(3), 320-328.
- PARENTE A. et al. (2004) - *Micropaleontology* 50(1), 107–120.
- SILVA A. et al. (2008) - *Continental Shelf Research* 28, 2601–2613.