Mixed Layer Characteristics in the Eastern Gulf of Cadiz During Dansgaard-Oeschger Interstadials 6–11

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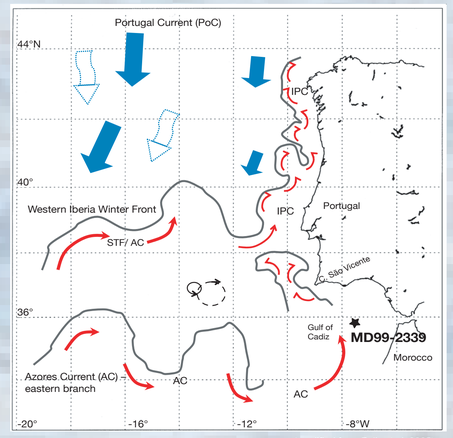
Introduction

In the Gulf of Cadiz, North Atlantic Central Water (NACW) is entrained into Mediterranean water forming the Mediterranean Outflow (MOW). Grain size records from site MD99-2339 revealed that the strength of the glacial MOW varied with the Dansgaard-Oeschger (DO) cycles; with a stronger outflow during DO stadials and parts of the Henrich events (Voelker et al., submitted). To study the response of the surface and shallow subsurface waters to DO forcing we generated multi-species stable isotope records for the interval of DO interstadial (IS) 6 to 11 (32.8-42.8 kyr BP) in core MD99-2339. The isotope data is supported by planktonic foraminifera fauna, sea surface temperature (SST), and ice-rafted debris (IRD) records. Surface layer conditions are reflected by isotope data of the planktonic foraminifera species *G. bulloides* and *G. ruber* white, conditions down to 500 m by *G. inflata* and *G. truncatulinoides*.

Fig. 1



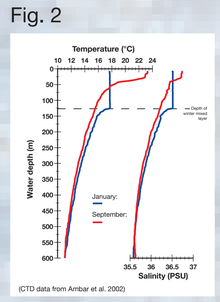
(modified from Peliz et al. 2005)

Oceanographic Setting

In winter-time, the surface water circulation on the western Iberian margin is marked by a warm, Azores front derived countercurrent close to the coast, the Iberian poleward current (IPC), and further offshore by the Portugal current (PoC), which transports fresh, ventilated waters southwards year-round. Surface waters at site MD99-2339 originate directly from the eastern branch of the Azores current, which itself branches off the Gulfstream and transports subtropical waters towards the Iberian margin. The winter mixed layer depth at site MD99-2339 is about 125 m deep, while the thermocline shoals to 40–50 m in summer (Fig. 2).

From May to September, upwelling is the dominant hydrographic feature on the Portuguese margin. One of the major upwelling filaments exists of Cape São Vicente, but local upwelling events can also occur off the Algarve, the southern Portuguese coast, and off Morocco, where upwelling has also been observed in the vicinity of the Strait of Gibraltar. During summer an upper slope current, the Portugal Coastal current, transports recently upwelled water to the south. At water depths of 100 - 500 m, the North Atlantic Central Water (NACW) forms basically the permanent thermocline. In the south the NACW is generally of subtropical (st) origin, formed along the Azores Front by subduction of regional mode waters due to strong evaporation. The NACW st is relatively warm and salty but poorly ventilated. In the Gulf of Cadiz, the NACW is entrained into the Mediterranean Outflow.

Fig. 2



(CTD data from Ambar et al. 2002)

Results and Discussion

The DO oscillations are visible in the oxygen isotope records of the surface and deep dwelling foraminifera indicating that they impacted the whole water column. Like in the Greenland ice core records, the changes are more pronounced in MIS 3 than in MIS 2 and 1 (Fig. 3). Summer SST during the Holocene and glacial warm periods – including the Last Glacial Maximum and the DO IS – exhibit a strong temperature stability with similar values throughout the last 48 kyr BP that are only about 1-2°C colder than the present day value (Fig. 2). Heinrich events 1, 4, and 5 were associated with pronouced surface water coolings of 8-10°C, while DO stadials, the Younger Dryas as well as Heinrich events 2 and 3 only led to a cooling of 2-4°C (Fig. 3, 4). Heinrich event 4, however, reveals a four-phased SST record with warm SST at the beginning of the cooling above Greenland and one interposed between two short coolings (Fig. 4). The second warming precedes and coincides with the IRD peak and is also visible (but less wide) in the non-distance weighted SST data (not shown), which does not fully exclude a bias from the transfer function but makes it less plausible. Future Mg/ Ca data will hopefully shed some light on this apparent contradiction between warm SST and IRD.

Species	Living Depth	Hydrographic and Biological Indications
Surface Dwellers		
G. ruber white	upper 50 m	mixed layer; associated with Azores Current/ Iberian poleward current (in winter-time)
G. bulloides	upper 100 m	upwelling
Interim Depths		
N. pachyderma (r)	upper 100-200 m	subthermocline water; pre-upwelling season
Deep Dwellers		
G. inflata	100 to 300 m	deep winter mixed layer
G. truncatulinoides	down to 500 m	below mixed layer; seasonal deep mixing; NACW; higher abundances in winter

Fig. 3

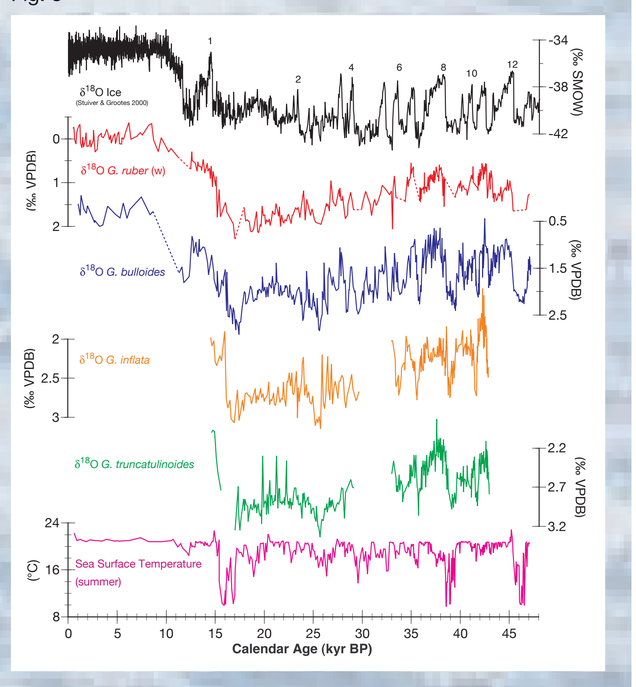
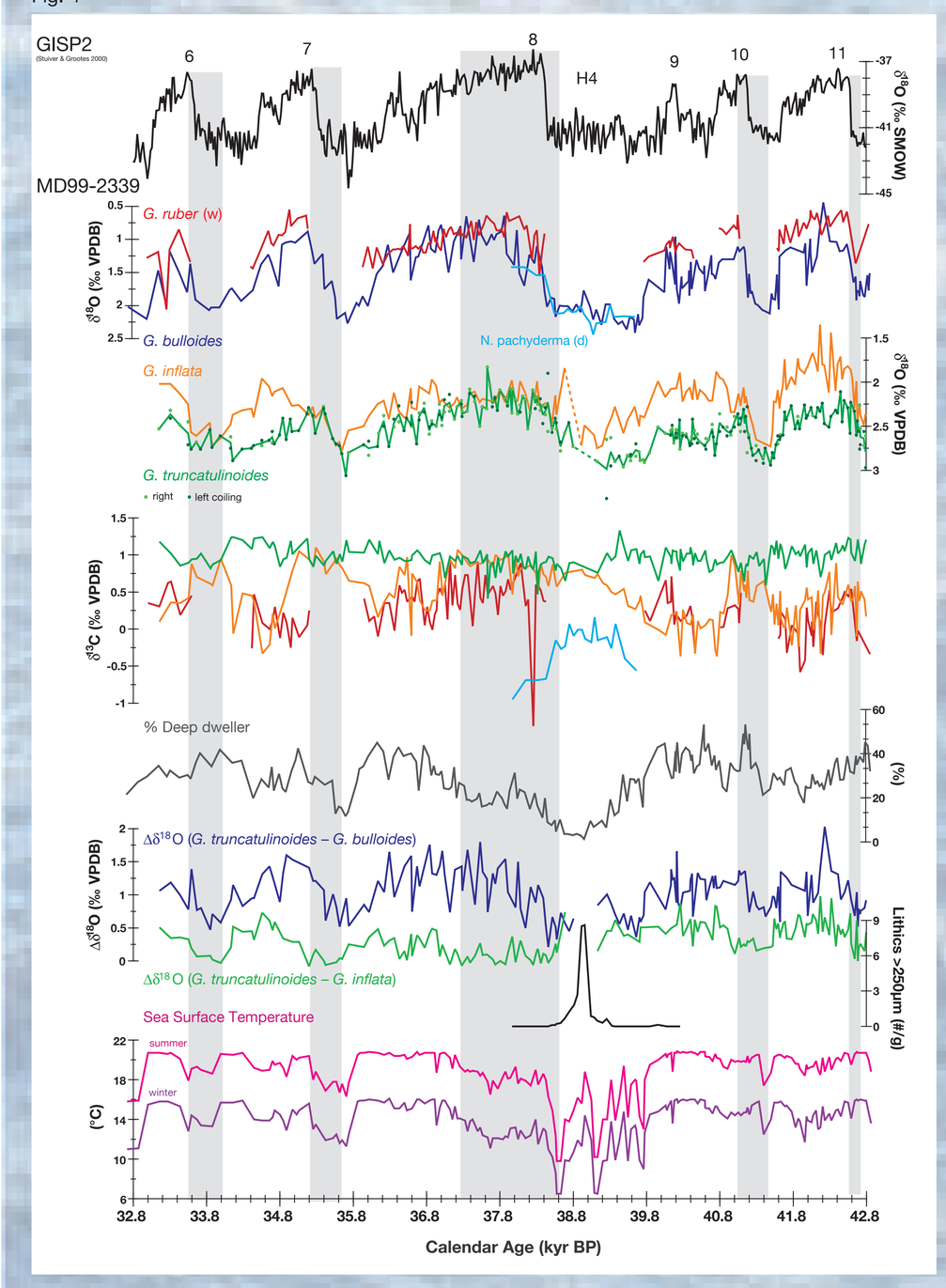


Fig. 4



Interstadials

With the exception of DO IS 8, oxygen isotope values of *G. ruber* white are lighter than those of *G. bulloides*, conform with the living depth in the uppermost water column. Part of this signal could also be a seasonal signal as *G. bulloides* might be associated with the upwelling events during summer. The deep dwelling species show a two-phased behavior during the interstadials: at the beginning of an IS *G. inflata* and *G. truncatulinoides* have the same or similar oxygen isotope values (grey bars), but they diverge later on with *G. inflata* revealing lighter oxygen and carbon isotope values. The time elapsed until this change in the water column occurred varies between the IS. Like for the surface dwellers DO IS 8 is also exceptional in the deep dweller record as the transitional phase with parallel values lasted > 1000 years. The similar values – both in oxygen and carbon isotopes and equal to lower $\Delta\delta^{18}O$ – indicate a well mixed upper water column. The reduced stratification in the water column also supported an increased abundance of deep dwelling foraminifera (*G. inflata, G. truncatulinoides, G. scitula, G. crassaformis, G. aequilateralis, G. calida*), even though abundances reached maxima later on in some IS. The isotopic offset between *G. inflata* and *G. truncatulinoides* increased, when SST exceeded 19.5°C for a longer period of time. The reason for this SST threshold is not known, yet. If the isotopic offset was caused solely by temperature it implies a gradient of 1–3°C between the calcifications depths of the two deep dwellers. The offsets also indicates increased water column stratification. The similarity between the *G. ruber* white and *G. inflata* carbon isotope variations suggests that both species recorded the same water mass, most probably the conditions in the deep winter mixed layer. The only small-scale carbon isotope oscillations in the *G. truncatulinoides* record, on the other hand, reveal that this species calcified throughout the whole studied interval in a water mass with fairly stable nutrient/ ventilation conditions. This hinds to the poorly ventilated NACW st, which was either located deeper or *G. inflata* calcified higher up in the water column than at the beginning of the IS. The seasonal temperature gradient in the upper water column, reflected by the oxygen isotope difference between *G. truncatulinoides* and *G. bulloides* varied between 3 and 6°C, with a higher gradient during the interstadials. This gradient is similar to the one observed today, so that hydrographic conditions during the interstadials appear to have been like the present ones.

Stadials

Other than in the Greenland ice core and subpolar North Atlantic SST records SST at site MD99-2339 did not drop at the interstadial/ stadial transitions. Warm SST even prevailed through nearly half of the Greenland stadial phases and did not drop at all between IS 10 and 9. This continued heat supply, also present during Heinrich event 4 (see above) indicate that the Azores current and thereby the northern boundary of the subtropical gyre were quite persistent and were only pushed southward, when conditions further to the north had deteriorated enough to also affect subtropical latitudes. Icebergs reached the site only during Heinrich events 1, 2, and 4 (Voelker et al., submitted), but apparently left no fresh water imprint in the oxygen isotope records - not even in the one of the subpolar species *N. pachyderma* (r). The smaller oxygen isotope differences during most of the stadials indicate reduced stratification in the upper water column. However, the higher $\delta^{13}C$ values during the stadials reveal that the nutrients were largely used up; apparently higher up in the water column as deep dweller abundances were reduced, especially during Heinrich event 4 and the coldest part of the stadial preceeding IS 7.

Conclusions

Planktonic foraminifera proxy data reveal a complex pattern of upper water column changes in the central Gulf of Cadiz with conditions during interstadials apparently being very similar to today. Other than in the Greenland ice cores and many other North Atlantic records water column conditions at site MD99-2339 do not show a clear interstadial - stadial pattern of change as changes occurred within interstadials. A well mixed upper water column was present throughout stadials and early phases of interstadials.

References:

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