FINAL REPORT PROGRAM LEFE

Program LEFE/ IMAGO	**PAL**eoventilation **MED**iterranean **S**ea (**PALMEDS)**	Years 2019 – 2021

PI COLIN Christophe, Christophe.colin@universite-paris-saclay.fr and lab: GEOPS – UMR8148 Participating Laboratories : GEOPS and LSCE	Contribution to Other funding sources : No

Context :

Past variations in Mediterranean thermohaline circulation were highly sensitive to climate changes at both high and low latitudes of the Northern Hemisphere and have been associated with the deposition of organic-rich layers (ORLs) in the Western Mediterranean Sea (WMS) and of sapropels in the Eastern Mediterranean Sea (EMS). Paleo-hydrological processes and associated ventilation dynamics related to sapropel depositions are still debated because conventional water-mass proxies, such as $\delta^{13}C$ analysed on benthic foraminifera, cannot be used systematically due to the lack of benthic foraminifera in EMS sediments during time intervals when bottom waters were characterized by anoxic conditions.

Objectives / scientific questions :

The PALMEDS project objective was to better constrain the mechanisms behind the hydrological modifications during the rapid climatic events of the last glacial period and their possible impacts on the deposition of organic matter-rich deposits (i.e. ORL, sapropel). We have investigated the ^{14}C age difference between the deep, intermediate and surface water masses to determine the changes in ventilation of the intermediate and deep-water masses. The Nd isotopic composition (εNd) of planktonic foraminifera of sapropels of the last climatic cycle (S1 to S5) have been also investigated to constrain the origin of the water masses and constrain the hydrology behind anoxic events under environmental conditions (sea level, freshwater inflow from the African continent and hydrological connection at the Strait of Gibraltar different from the environmental conditions during the deposition of sapropel S1).

Main results

We have firstly analysed εNd and Rare Earth Elements (REE) concentrations of 24 depth profiles covering all Mediterranean sub-basins, which significantly increases the available dataset in the Mediterranean Sea (double the number of available εNd) and permit to better characterize the relationship between the dissolved εNd distributions and major water masses in the Mediterranean Sea and to investigate the impact and relative importance of local non-conservative modifications, which include input of riverine particles and waters (e.g. Nile River), aeolian-derived material and exchange with the sediments at continental margins (Montagna et al., 2022). We have then analysed the Nd isotopic compositions of mixed planktonic foraminifera from several sediment cores collected in the Nile deep-sea fan and in the central Mediterranean Sea (Tyrrhenian Sea, Ionian Sea, Adriatic Sea) in order to (i) to reconstruct past εNd of the Eastern Mediterranean Deep Water (EMDW) and to assess the relative contributions of Nile discharge and Modified Atlantic Water (MAW) inflow to the EMS hydrology, as well as their potential control on anoxic events over the last climatic cycle (Duhamel et al., 2020) ; (ii) to constrain water mass exchange between the EMS and WMS during the last climatic cycle (Colin et al., 2021).

Foraminiferal εNd records obtained on the Nile deep-sea fan display an increase in εNd values during the African Humid Periods (Duhamel et al., 2020). Superimposed on this precession forced variability, the record of variations in foraminiferal εNd indicates a 2-unit decrease in εNd during the interglacial Marine Isotope Stages (MIS) 5 and 1 compared to glacial MIS6, 4, 3 and 2. The εNd results suggest that decreases in εNd during MIS5 and MIS1 indicate an increase in the contribution of unradiogenic MAW to the EMS related to high sea-level stands and greater seawater exchange between the North Atlantic and Mediterranean basins. In addition, radiogenic seawater εNd values observed during African Humid Periods (and sapropel events) are associated with an intensification of Nile discharge and an increase in residence time of deep-water masses in the EMS, which induces an increase in the interaction between deep-water masses and radiogenic sediments along the margin of the EMS. Results confirm that an intensification of the hydrological exchanges between the western and eastern Mediterranean basins during high sea-level stand and the subsequent higher proportion of Atlantic Water in the Levantine Basin may have preconditioned the EMS to sapropel depositions during the last climatic cycle.

εNd records collected at intermediate depth (500 to 1375 m water depth) from the WMS and EMS suggests an efficient connection between the EMS and WMS and the transfer of radiogenic waters to the Tyrrhenian Sea via the Levantine Intermediate Water (LIW) during interglacial MIS (figure 1) (Colin et al., 2021). Conversely, during glacial MIS, εNd of the intermediate depth of the Tyrrhenian Sea are less radiogenic than the EMS, implying

limited hydrological connection between sub-basins during low sea-level stands (figure 1). Superimposed on these glacial-interglacial variations, increased εNd occurred during Heinrich Stadial events (Colin et al., 2021). This suggests a reduction in the formation of unradiogenic WIW in the Gulf of Lions due to the input of relatively fresh surface Atlantic water to the WMS and/or the inflow of radiogenic glacial LIW and upper EMDW to the Tyrrhenian Sea as a result of an active EMS convection related to saltier and colder conditions. Such potential millennial-scale pulses of LIW intrusion into the Tyrrhenian Sea may have led to an enhanced Mediterranean Outflow Water intensity in the Gibraltar Strait.

Finally, we use water-column radiocarbon reconstructions to assess the structure and age of the intermediate and deep-water masses in the central and eastern Mediterranean Sea since the last deglaciation. Today, the vertical mixing and thus the mixing time of the water masses occurs very quickly at the scale of the Mediterranean basin resulting in a minimal surface-to-deep gradient in ^{14}C with a ventilation age of ~100 years. Here, we reconstruct the first deglacial radiocarbon-based ventilation ages of intermediate and deeper water masses by measuring the ^{14}C age difference of pairs of planktonic and benthic foraminifera taken from marine cores bathed by intermediate and deep water masses collected in the Sicily Strait and Levantine basin, respectively. Our results show extremely ^{14}C depleted water masses between 11 kyr to 9 kyr associated to a reduction in Mediterranean convection and inducing significant water column stratification between ~700–1200 m water depth. This phase was followed by a break-up of the stratification at 700 m in the Levantine basin at 6.3 kyr, while re-ventilation at 1200 m occurred only since 4.5 kyr as indicated by the Sicily Strait record. The extremely reduced ventilation ^{14}C ages for the intermediate and deeper water masses between 11 kyr to 9 kyr is synchronous to a slow-down of the deep-water convection in the Adriatic Sea. These findings could call into question the long prelude of deep-water stagnation assessed by ocean-biogeochemical model and at the same time suggests for an alternative intermediate/deep-water source in the Aegean Sea characterized by radiocarbon-depleted waters.

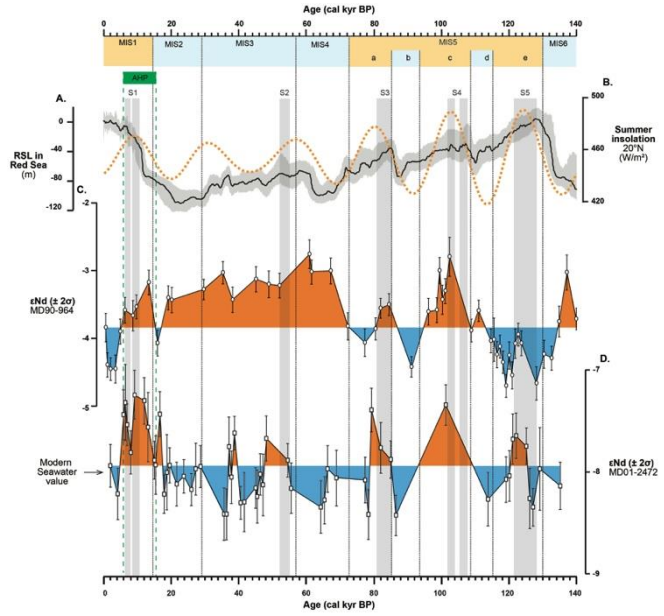

Figure 1

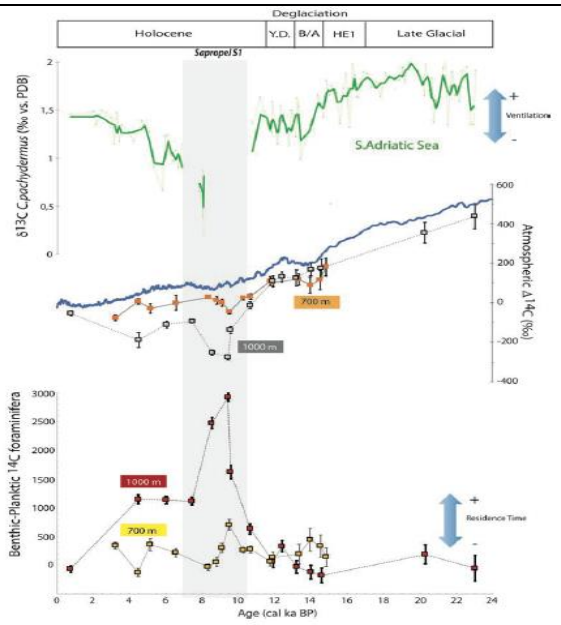

Figure 2

Figure 1 : Comparison of εNd records obtained from cores MD90-964 located in the Levantine Basin at 1375 m water depth (Duhamel et al., 2020) and MD01-2472 located in the Corsica Trough at 500 m water depth (Colin et al., 2021).
Figure 2 : Comparison between $\delta^{13}C$ of the benthic foraminifera *C. pachydermus* from the south Adriatic Sea (deep-water source of eastern Mediterranean deep-water) and ^{14}C age difference between paired benthic and planktic foraminifera and oceanic ^{14}C activity ($\Delta^{14}C$) of intermediate and deep-water in the Sicily Strait (Siani et al., in preparation).

Future of the project :

This project continuous with the PhD program of Gao Guohui where a set of εNd results have been produced by PALMEDS project.

Number of publications, communications and theses

Publications:

Duhamel M., Colin C., Revel M., Siani G., Dapoigny A., Douville E., Wu J., Zhao Y., Liu Z., Montagna P., 2020. Variations in eastern Mediterranean hydrology during the last climatic cycle as inferred from neodymium isotopes in foraminifera, Quaternary Science Reviews, 237, 106306.

Colin, C., Duhamel, M., Siani, G., Dubois-Dauphin, Q., Ducassou, E., Liu, Z., Wu, J., Revel, M., Dapoigny, A., Douville, E., Taviani, M., Montagna, P., 2021. Changes in the intermediate water masses of the Mediterranean Sea during the last climatic cycle - New constraints from neodymium isotopes in foraminifera, Paleoceanography and Paleoclimatology, 36(4).

Montagna P., Colin C., Frank M., M., Störling, T., Tanhua, T., Rijkenberg, M., Taviani, M., Schroeder, K., Chiggiato, J., Gao G., Dapoigny A., Goldstein, S.L., 2022. Dissolved neodymium isotopes in the Mediterranean Sea, Geochimica et Cosmochimica Acta, Vol. 322, 143-169.

Thèses :

2016-2019 : Maxence Duhamel - Restitution de l'hydrologie passé de la Méditerranée à partir de la composition isotopique du Nd analysé dans les foraminifères de carottes sédimentaires marines. Soutenu en avril 2020.

2017-2021 : Sonda Zouari - Les environnements du détroit Siculo-Tunisien et paléohydrologie de la Méditerranée pendant le Quaternaire Supérieur. Soutenu en juillet 2021.

2020-2024 : Gao Guohui - Studies of geochemical proxies on foraminifera of marine sediments of cores of the Mediterranean Sea to constrain hydrological changes of deep and intermediate water masses of the Mediterranean Sea during the last climatic cycles. Bourse du China Scholarship Council (CSC) de 4 ans.

Communications :

G. Siani, N. Kallel, E. Michel, S. Zouari, C. Colin[1] N. Tisnerat. Deglacial radiocarbon ventilation age changes in the central and eastern Mediterranean Sea, INQUA Roma 14-21 juillet 2023.

Data availablility

All data are reported in Duhamel et al 2020 and Colin et al 2021 and on the following web site: https://doi.org/10.1594/PANGAEA.926899.