FINAL REPORT PROGRAM LEFE

Program LEFE/ IMAGO	Project Title	Years 2017– 2019
	CITRON GLACE : Circulation InTeRmédiaire dans l'Océan iNdien depuis le dernier maximum GLACiairE	

PI: Sepulcre Sophie Sophie.sepulcre@universite-paris-saclay.fr, Université Paris Saclay, Laboratoire GEOPS UMR8148 Participating Laboratories : Géosciences Paris-Saclay GEOPS UMR8148 Laboratoire des Sciences du Climat et de l'Environnement LSCE UMR8212 Centre européen de recherche et d'enseignement de géosciences de l'environnement CEREGE UMR7330	Contribution to Other funding sources :

Context

Understanding past changes in the intermediate ocean circulation is a clue to better constrain variations in the inter-hemispheric connections, and exchanges between the ocean and the atmosphere, especially through the global Carbon cycle. Indeed, intermediate water masses (IWM) are a strong carrier of salt, heat and nutrient in the modern ocean, and their role through past glacial-interglacial cycles still remain to be documented.

Objectives / scientific questions

This project was focused on the Indian Ocean, since past IWM are poorly constrained in this area, although strong relationships exist with the Southern Ocean through the production (associated to upwelling) and the circulation of Antarctic Intermediate Water (AAIW). Two marine sediment cores were studied that cover the time period from the Last Glacial Maximum (LGM) to present to achieve these goals.

Main results

In a first article, Ma, et al. (2019) published benthic foraminiferal assemblages, stable isotope records ($\delta^{18}O$, $\delta^{13}C$) and the ^{14}C age difference with planktonic foraminifera ($\Delta^{14}C$). These records have allowed to reconstruct past changes in the IWM dynamics since the LGM, and especially strong variations in the AAIW contribution during the abrupt climatic events of the Last Deglaciation (Illustration 1 b, c and d and Illustration 2a). We highlighted the relationships between the Southern Ocean dynamics (especially through the strength of the southern upwelling) and the IWM circulation. In a second article, Ma et al. (2020) have shown the elemental ratios measured on the benthic species *Hoeglundina elegans* (Mg/Li, Sr/Ca), used to reconstruct the past IW carbonate concentrations [CO_3^{2-}]; the observed variations have been related to changes in the global Carbon cycle and the atmosphere-ocean connections, through the C transfer between deep and intermediate water (Illustration 1e and f and Illustration 2b). We compared results from core MD77-176 with a core from the Arabian Sea (MD77-191, 07°30'N-76°43'E, 1254m); we especially reconstructed the past variations in the nutrient content of the IWM through the Cd/Ca and Ba/Ca elemental ratios. Ma et al. (accepted after minor revisions in Climate of the Past) have demonstrated both the influence of local (such as the control of the monsoon of the primary productivity) and global processes (IWM production in the Southern Ocean) for the two studied areas.

Illustration 1: (a) Ice core atmospheric CO_2 from Antarctic Dome C (Monnin et al., 2001), (b) the intermediate water B-P ^{14}C age offset of MD77-176 in the BoB, (c and d) benthic $\delta^{13}C$ from studied Cores MD77-176 and MD77-191, respectively, and (e and f) compilation of [CO_3^{2-}] records from Cores MD77-191 and MD77-176. The gray-shaded intervals mark the two-step increase in atmospheric CO_2 (Monnin et al., 2001), and the yellow-shaded interval marks the 15–13.3 cal kyr BP interval.

Illustration 2: (a) Benthic $\delta^{18}O_{ivc}$ corrected from the ice-volume effect obtained from MD77-176 (Bay of Bengal;

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red line) and MD77-191 (Arabian Sea; black line), respectively. (b) *H. elegans* Mg/Li ratios obtained from MD77-191. (c) IWT record based on the Mg/Ca$_{Uvigerina}$ obtained from M78/1-235-1 in the tropical West Atlantic Ocean (Poggemann et al., 2018); the blue line is the smoothed curves using a 10-point average. The color-shaded intervals are the same as in Illustration 1.

All references can be found in Ma et al., 2019 and 2020 (see complete references below).

Illustration 1

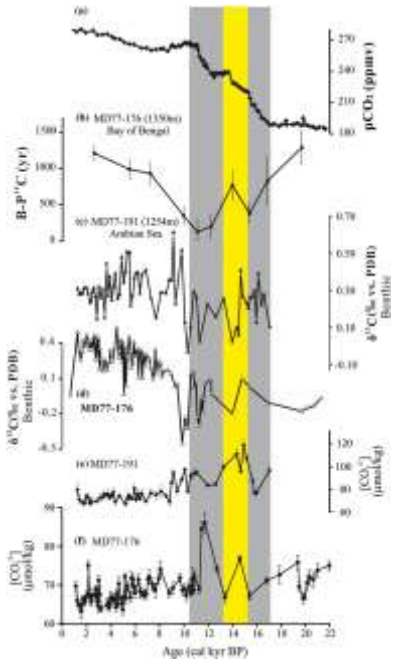
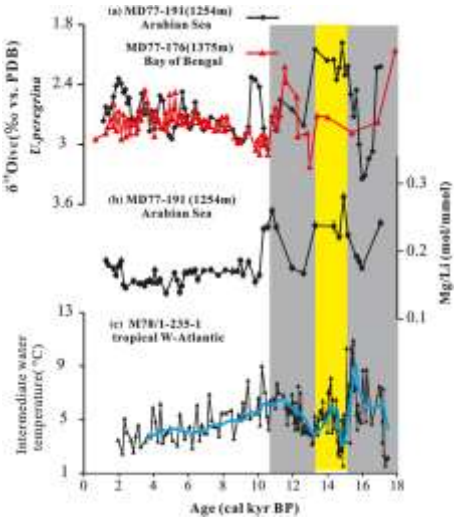


Illustration 2



Future of the project: The important results obtained during the CITRON GLACE project have highlighted the lack of concordant reconstructions in the Atlantic Ocean. Thus, a similar approach than the one used during CITRON GLACE has been proposed in the RIAD project (Reconstitution des eaux Intermédiaires dans l'Atlantique Nord depuis le Dernier Maximum Glaciaire), funded by the IMAGO program for the 2020-2022 time period.

Nombre de publications, de communications et de thèses

(citer au maximum 5 publications en lien direct avec le projet)

Ma, R., S. Sepulcre, L. Licari L., Haurine, F., Bassinot, F., Z. Yu and C. Colin, Changes in productivity and intermediate circulation in the northern Indian Ocean since the last deglaciation: new insights from benthic foraminiferal Cd /Ca records and benthic assemblage analyses, under review at Climate of the Past.

Ma, R., Sepulcre**,** L. Bassinot, F., Haurine, F., Tisnérat-Laborde, N. and Colin, C., 2020. North Indian Ocean circulation since the last deglaciation as inferred from new elemental ratio records for benthic foraminifera Hoeglundina elegans. Paleoceanography and Paleoclimatology, 35, e2019PA003801. https://doi.org/10.1029/2019PA003801

Ma, R., S. Sepulcre, L. Licari L., F. Z. Liu, N. Tisnérat-Laborde, N. Kallel, Z. Yu and C. Colin, 2019. Changes in intermediate circulation in the Bay of Bengal since the Last Glacial Maximum as inferred from benthic foraminifera assemblages and geochemical proxies, Geochemistry Geophysics Geosystems, 20, 1592–1608, https://doi.org/10.1029/2018GC008179.

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