1. **Titre**

Temporal and spatial reconstruction of intermediate water masses in the Bay of Biscay and the Iberian margin during the last climatic cycle

2. **Research unit**

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4. **Context, objectives and scientific interests**

The recent Quaternary is characterized by a succession of glacial-interglacial cycles that are punctuated by periodic changes in Earth's orbit around the Earth. However, many studies have shown that increasing insolation in response to the evolution of orbital parameters (eg, Milankovitch, 1941) can not by itself explain the relatively rapid transitions from glacial to interglacial Pleistocene conditions (ie, terminations, eg Tzedakis et al., 2017). The ocean plays an important role in controlling mechanisms that trigger and punctuate these terminations (Rahmstorf, 2002; Denton et al., 2010). For example, multi-millennial variations in the intensity of the Atlantic Meridional Oceanic Circulation (AMOC) in response to episodic inflows of freshwater from the melting ice sheets are assumed to play a major role in triggering terminations in the Northern Hemisphere (NH) (Shakun et al., 2012).

The last deglaciation (Termination 1) started in the NH about 19 ka ago (~ 19 - 10 ka BP, Clark et al., 2012) and marks the transition between the Last Glacial Maximum (LMG) and the Holocene. During the LGM, large ice sheets covered large areas of the NH: the Laurentide Ice Sheet (LIS), which covered much of the North American continent, and the European Ice Sheet (EIS: European Ice Sheet) (eg, Ehlers and Gibbard, 2004) (Fig. 1a). As these ice sheets retreated during Termination 1, large quantities of icebergs and freshwaters were delivered to the North Atlantic (eg, Clark et al., 2001, Denton et al., 2010). This resulted in the slowdown of the AMOC for several millennia, especially during two cold events between ~ 18.2 and 14.7 ka BP (Heinrich Stadial 1, HS1) and between ~ 12.7 and 11.7 ka BP (Younger Dryas, YD) (eg, McManus et al., 2004, Hall et al., 2006). During the LGM and Termination 1, the AMOC has undergone major changes. Several studies suggest that the North Atlantic Deep Water (NADW) has been replaced in part by a cold, nutrient-poor water mass, the North Atlantic Glacial Intermediate Water (GNAIW), dominant at above ~ 2000 m (eg, Lynch-Stieglitz et al., 2007, Marson et al., 2015) (Fig. 1). The GNAIW overlaid the nutrient-rich glacial analog of the Antarctic Bottom Waters (AABW) (Fig. 1). During HS1, a significant slowing of AMOC intensity was suggested (McManus et al., 2004). Since then, more recent studies have shown a more complex pattern emphasizing the importance of intermediate waters in its reorganizations. Indeed, studies have suggested that the Antarctic Intermediate Waters (AAIW) were able to penetrate to the high latitudes of the North Atlantic during HS1 and the YD competing with the GNAIW between ~ 1000 and 2500 m depth (Rickaby and Elderfield, 2005, Thornalley et al., 2010). A recent study in the Bay of Biscay (MD99-2328, Fig. 1), showing warm and well-oxygenated intermediate waters with an active current during HS1, would argue for a contribution of intermediate waters from southern origin (Mojtahid et al. , 2017).

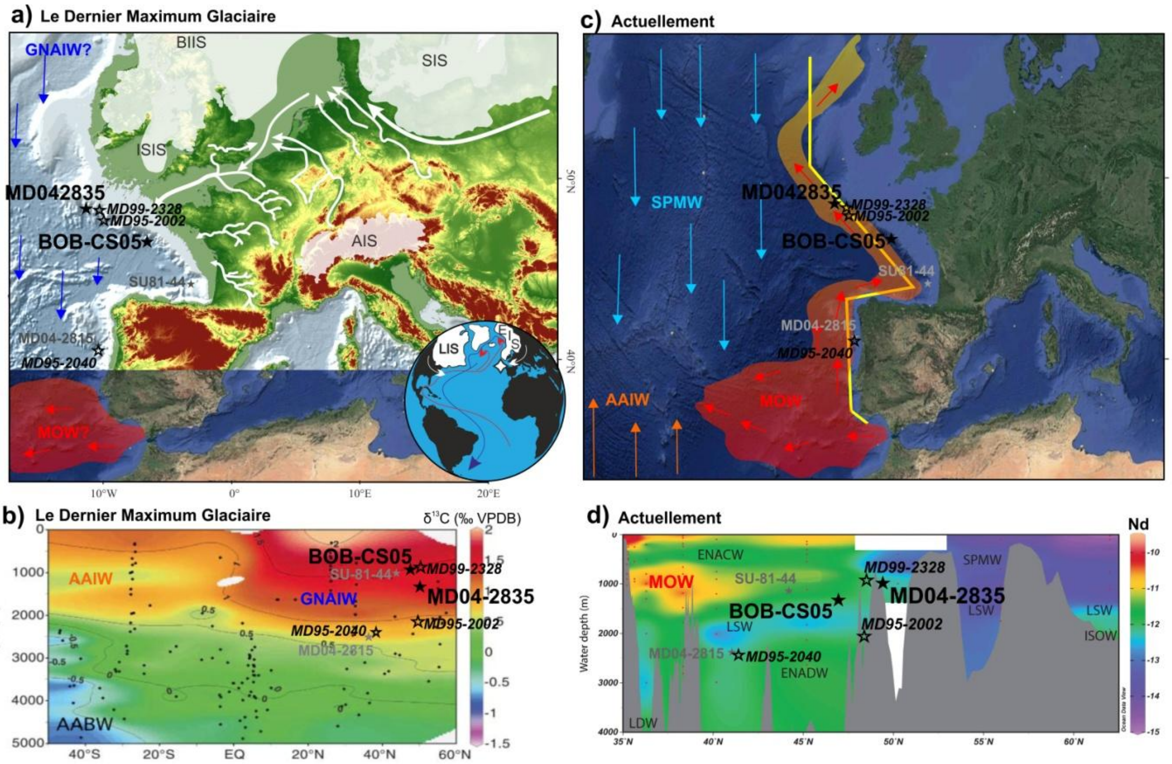

Figure 1: a) Modified figure from Toucanne et al. (2015) showing palaeogeography in Western Europe with the maximum extension of the EIS (including SIS and BIIS) as well as the Paleofleuve Manche hydrographic network (white arrow) during the LGM. The hypothetical range of the MOW (Mediterranean Outflow Water) (in red) and the influence of the GNAIW (blue arrows) are indicated for intermediate water depths (~ 1000 m). Bottom right, a simplified diagram of the circulation of the Atlantic Ocean, with surface waters moving north (red arrows) and the return deep water (blue arrows). ISIS: Irish Sea Ice Stream; AIS: Alpine Ice Sheet; b) The distribution of $\delta^{13}C$ of benthic foraminifera in the western and central Atlantic during the DMG (Lynch-Stieglitz et al., 2007); c) Current configuration of the Bay of Biscay and the Iberian Peninsula margins. The current extent of the MOW circulation along the northeastern Atlantic is indicated (modified from (Iorga and Lozier, 1999). The blue arrows, indicating the current influence of SPMW (Subpolar Mode Waters) and the AAIW, are given as an indication for intermediate water depths (~ 1000 m) according to Dubois-Dauphin et al (2017). The yellow line indicates the transect of the measurements ƐNd of Dubois-Dauphin et al. (2017) presented in Figure 1d; d) Modified figure (Dubois-Dauphin et al., 2017) presenting the interpolated values of ƐNd of seawater along a latitudinal transect (yellow line, Fig. 1c). LSW: Labrador Sea Water; ISOW: Iceland-Scotland Overflow Water; ENACW: East North Atlantic Central Water; LDW: Lower Deep Water; ENADW: East North Atlantic Deep Water. The positioning of our cores according to their latitudes and respective depths is given as an indication in figures b and d.

In order to better encounter this issue, it is therefore necessary to better comprehend intermediate water dynamics and their evolution during the last deglaciation, particularly in the eastern part of the Atlantic and at mid-latitudes where the data is still poor. The Bay of Biscay and the Iberian margin are key areas because of the simultaneous influence of the LIS and EIS (eg, Mojtahid et al., 2005, Eynaud et al., 2007, Toucanne et al., 2010) (Fig. 1).

This project will therefore attempt to meet two specific objectives:

> **- Perform a robust spatio-temporal reconstitution of intermediate water masses (~ 500 - 2000 m depth) in the mid-latitudes of the North-East Atlantic during the last ~ 30 ka.**
> **- Understand the role of the AMOC and more particularly intermediate water masses in the rapid climatic oscillations of the last deglaciation.**

5. Summary of the thesis project

The global climatic trends observed at the end of the 20th century, or their projection for the end of the 21st century, mask a complex reality with marked regional structures and integration over time of fluctuations which often have their origins in the exchanges between the hydrosphere, the cryosphere and the atmosphere. These exchanges remain poorly understood, including their role in climate control. In this global context, the thesis project focuses on the mid-latitudes of the North-East Atlantic (Bay of Biscay and Iberian margin) and has the general aim of understanding the role of ocean circulation and especially intermediate water masses in rapid climatic oscillations during the last period of massive melting of the ice sheets. This spatio-temporal reconstitution will be carried out using a multiproxy approach (micropaleontological, geochemical and sedimentological tools) of the physical and ecological characteristics of intermediate water masses.

Methodology: To attain the general objectives, we will use numerous palaeoceanographic tracers of temperature, salinity, oxygenation, productivity (eg, $\delta^{18}O$, Mg/Ca, Mn/Ca of benthic and planktonic foraminifers, assemblages of foraminifers and dinoflagellate cysts, transfer functions), environmental pressure (XRF analyzes), current (grain size, particularly the "sortable silts" index), and origin of water masses (ƐNd, $\delta^{13}C$ in foraminiferal tests). An experimental approach targeting the calibration of Sr/Ca proxy on benthic foraminifers as a tracer of the origin of water masses is also intended. This project is based on four sedimentary cores previously partially studied and selected on the basis of their sedimentological quality over the studied periods of time and their geographical position in the main path of intermediate water masses at the continental slope (Fig. 1).

Requested skills: Experience in paleoceanography and micropaleontology, preferably on benthic foraminifera, is required. The work of taxonomic determination under a binocular loupe requires meticulousness and rigor. An excellent written and oral practice of English is highly recommended.

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6. Partnership

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