THE INTENSIFICATION OF NORTHERN-COMPONENT DEEP WATER FORMATION DURING THE MID-PLEISTOCENE CLIMATE TRANSITION

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ABSTRACT

This work examines the deep-water hydrography at Ocean Drilling Program (ODP) Site 1063 (subtropical North Atlantic, ~4600m) throughout the mid-Pleistocene climate transition (MPT) by using high resolution benthic stable isotope ($\delta^{18}O$, $\delta^{13}C$) analyses from ~500 to 750 ka (Marine Isotope Stages [MIS] 13-18). The record fills a gap in published records creating a continuous composite stable isotope time series from ~250 to 1000 Ka (MIS 8-29). The benthic foraminiferal $\delta^{18}O$ composite provides age control through tuning to the global stack of Lisiecki and Raymo [2005].[1] The benthic foraminiferal $\delta^{13}C$ record provides a proxy for changes in the relative flux of the lower-most component of northern sourced deep waters throughout this time period. Comparing the $\delta^{13}C$ record to other records from the Atlantic basin indicates that a unique increase occurred in interglacial $\delta^{13}C$ values at Site 1063 beginning at ~700 ka (MIS 17). While interglacial values consistently overlap with those recorded in the deep South Atlantic prior to this time, they consistently approach those recorded in the deep North Atlantic thereafter. By comparing the Site 1063 data to 16 other published records from sites throughout the Atlantic Ocean, we deduce that an initial enhancement of NADW production likely occurred within MIS 19, but was not yet felt within the deepest region of the North Atlantic until MIS 17. The change in deep-ocean circulation found here occurred without any change in orbital forcing, and pre-dates the onset of more extreme Pleistocene interglacial warmth (MIS 11) by 300-400 kyr. These results provide new evidence supporting the northwest migration of the interglacial Arctic Front position during this time, likely relating to Eurasian ice sheet dynamics and intensifying glacial terminations within the Norwegian-Greenland Sea during the MPT.

INTRODUCTION

Mid-Pleistocene Transition (MPT)

-Prior to MPT: low-amplitude, symmetrical ~41kyr glacial cycles

-Following MPT: high-amplitude, asymmetrical ~100 kyr glacial cycles

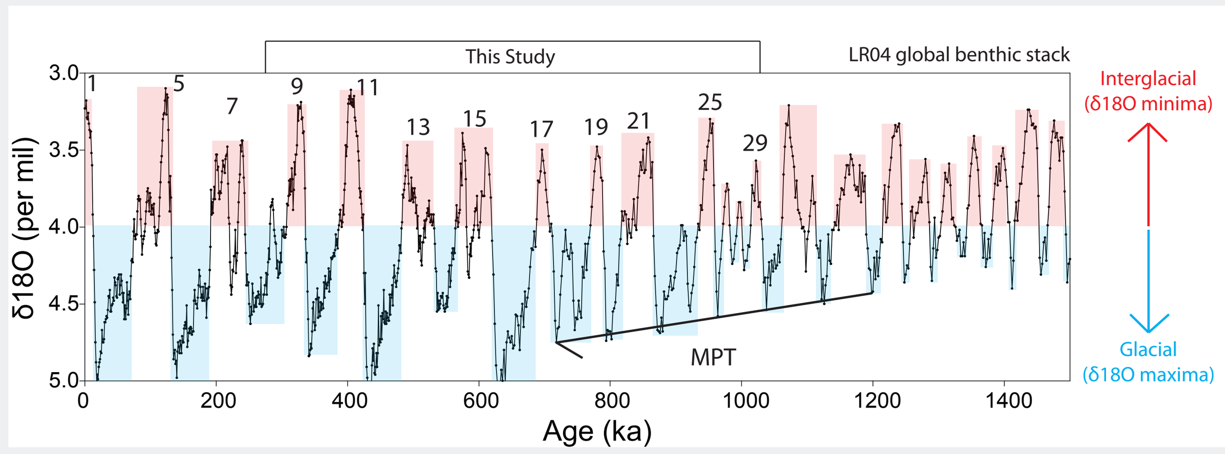

Figure 1: The global benthic $\delta^{18}O$ stack of Lisiecki & Raymo[1], with even numbered glacial Marine Isotope Stages (MIS) highlighted in blue, and odd numbered interglacial MIS periods highlited in red. The intensification of glacial periods during the MPT is evident, and is associated with the growth of thicker ice sheets in the Northern Hemisphere.

BACKGROUND

ODP Site 1063 (~4600m)

- deepest site with stable isotope records from N. Atlantic
- high sedimentation rates and good preservation
- located near modern NADW-AABW mixing zone
- relative flux between lower NADW and AABW

Previous Studies

- Poli et al. [2000][2], Ferretti et al. [2005][3], Billups et al. [2011][4]
- Older time slice: AABW influence
- Younger time slice: glacial AABW influence; interglacial NADW influence

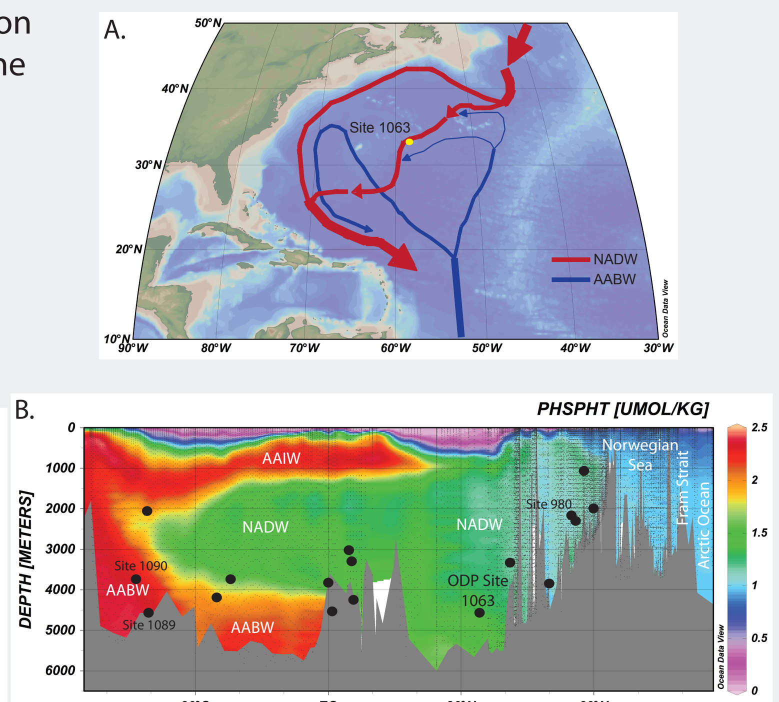

Figure 2: **A.** Bathymetric map identifying the location of ODP Site 1063 on the northeast Bermuda Rise, in relation to the generalized modern deep water circulation patterns of the NADW and AABW masses.[5] **B.** Cross-section showing the modern distribution of the NADW, AABW, and Antarctic Intermediate Water (AAIW) as identified by dissolved phosphate concentrations. Also shown are the depth distributions and locations of the 16 sites to which the stable isotope records from ODP Site 1063 are compared within this study. This cross section was constructed using Ocean Data View.[6]

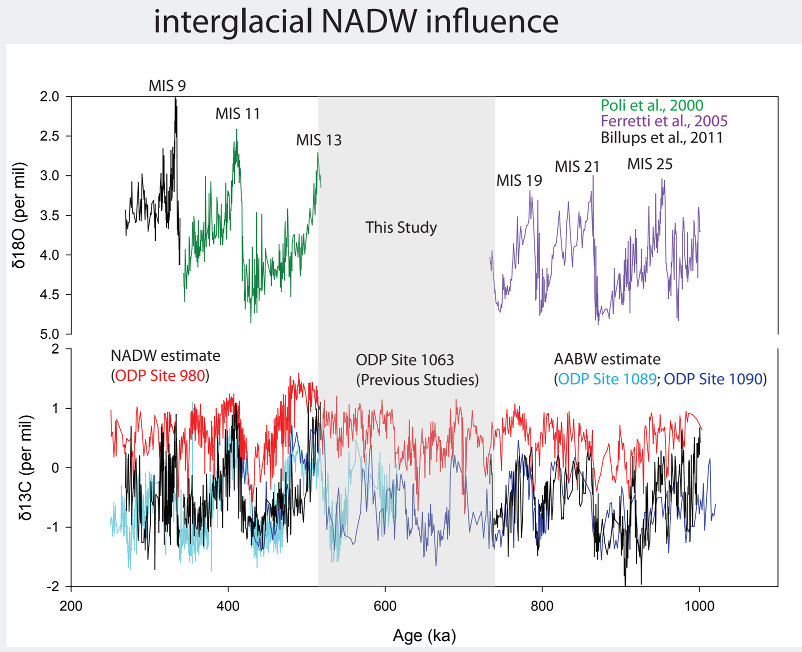

Figure 3: The previously published $\delta^{18}O$ (top) and $\delta^{13}C$ (bottom) records from ODP Site 1063.[2,3,4] The $\delta^{13}C$ record from ODP Site 1063 (black) is shown in reference to $\delta^{13}C$ records estimating the NADW (red) vs. AABW (blue) $\delta^{13}C$ signature throughout the same time interval.

HYPOTHESES

1. Enhanced NADW influence began between MIS 13 and MIS 18, during the MPT
2. Enhanced NADW influence reflects a change in basin-wide deep-water circulation
3. Change in circulation during the MPT occurred progressively rather than in response to one specific event

RESULTS

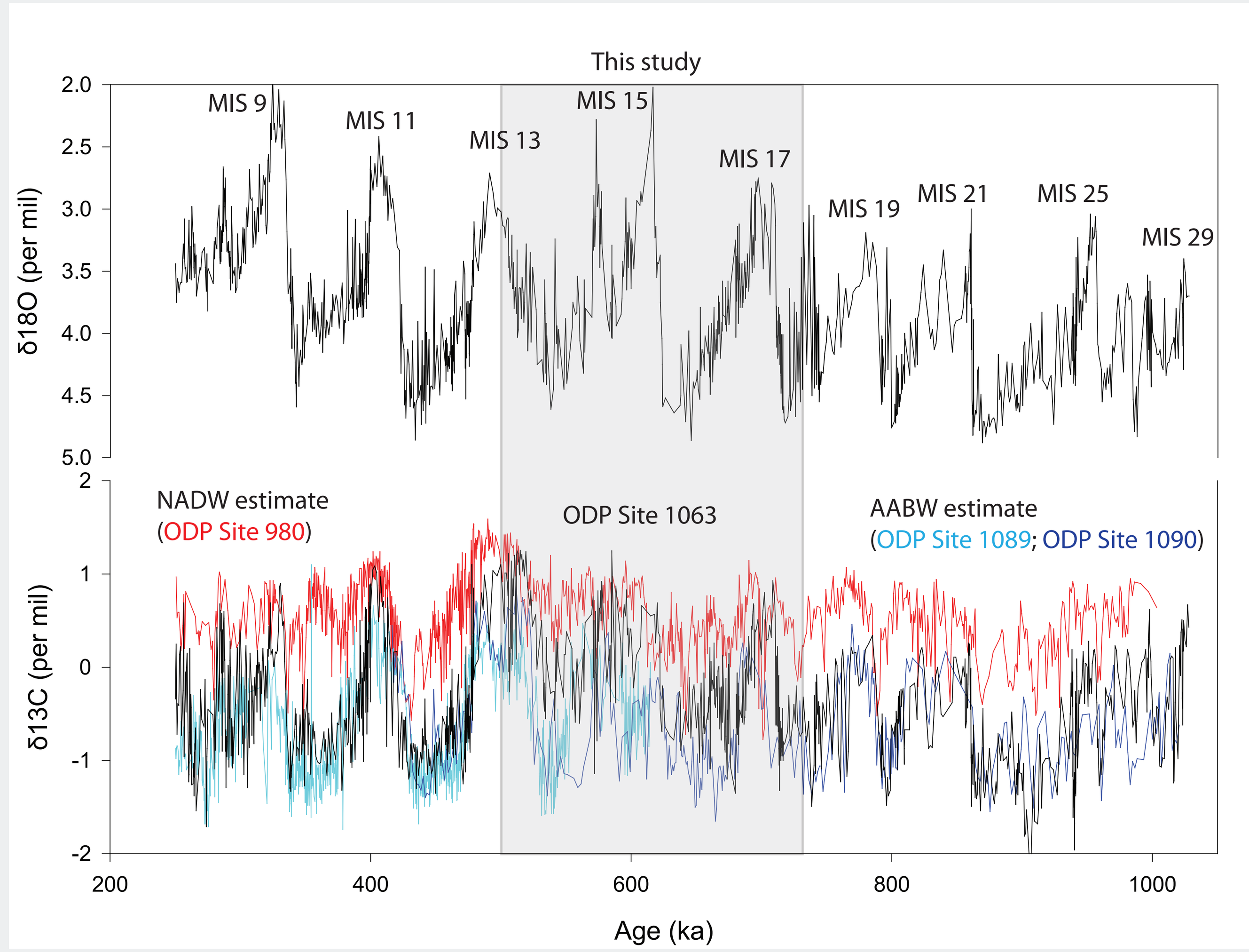

Figure 4: The composite stable isotope records constructed at ODP Site 1063 by incorporating the $\delta^{18}O$ (top) and $\delta^{13}C$ (bottom) records produced within this study (grey bar) with those previously published from the site[2,3,4] and tuned to the LR04 stack.[1] The $\delta^{13}C$ record from Site 1063 when compared to others estimating the approximate NADW (red) and AABW (blue) $\delta^{13}C$ signatures suggests an increased interglacial influence of NADW at the site beginning at the onset of MIS 17 at ~700ka, which continued throughout each interglacial period thereafter.

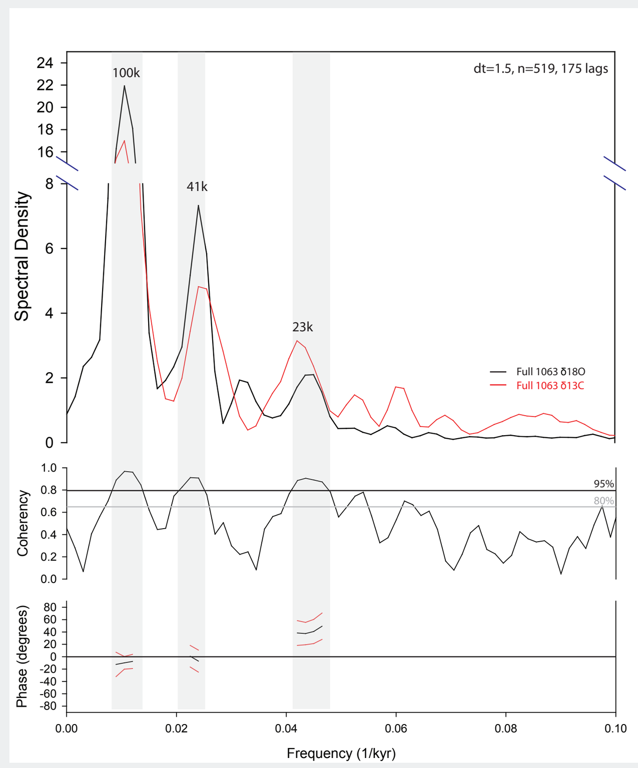

Figure 5: Cross-spectral results between the composite $\delta^{18}O$ (black) and $\delta^{13}C$ (red) records from Site 1063 which show significant spectral peaks at all three major orbital periods (100k, 41k, 23k), and are highly coherent (> 95% confidence). The phase relationship shows that changes in ice volume ($\delta^{18}O$) and in circulation ($\delta^{13}C$) are in phase at the 100k and 41k period, while changes in ice volume lead circulation at the 23k period, consistent with other records from the deep North Atlantic. Additional cross spectral analyses were conducted on two time slices (older and younger than ~700ka), showing no change in this phase relationship. Therefore, no change in orbital forcing was responsible for the deep circulation change found here.

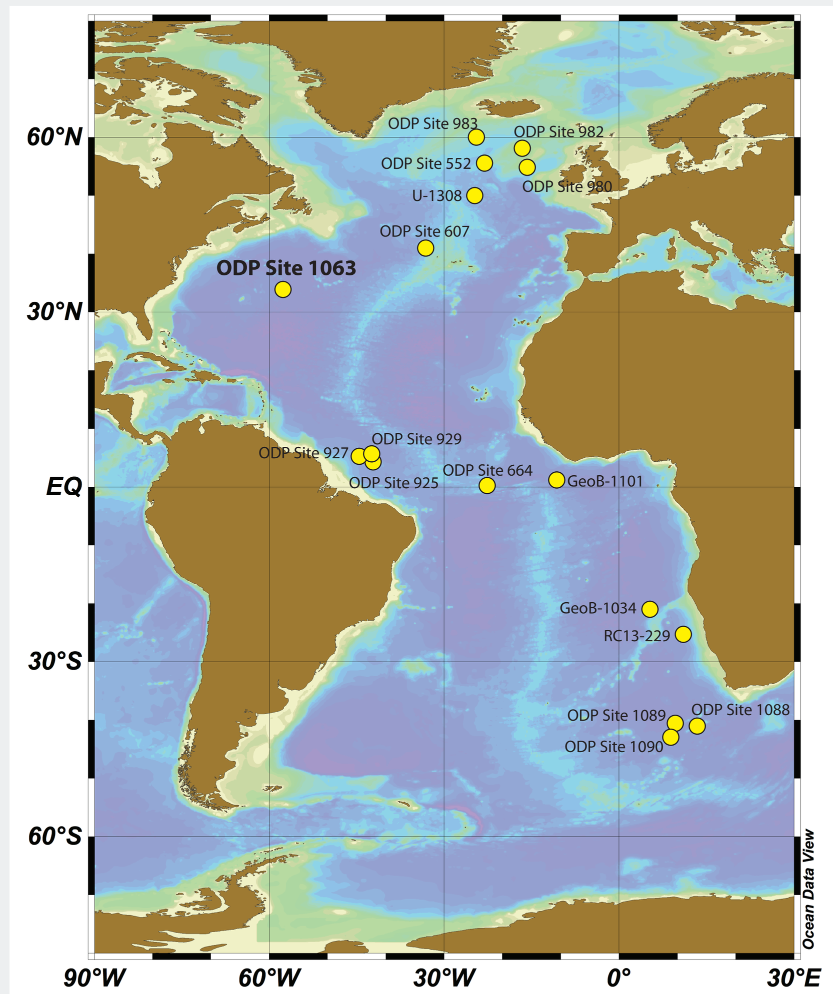

Figure 6: Map identifying the site locations of the 16 additional stable isotope records used to compare to the composite Site 1063 record to determine the scale, timing, and geo-spatial extent of the NADW enhancment, which this study found beginning at the onset of MIS 17 at ODP Site 1063. Bathymetric map constructed using Ocean Data View.[6]

RESULTS (continued)

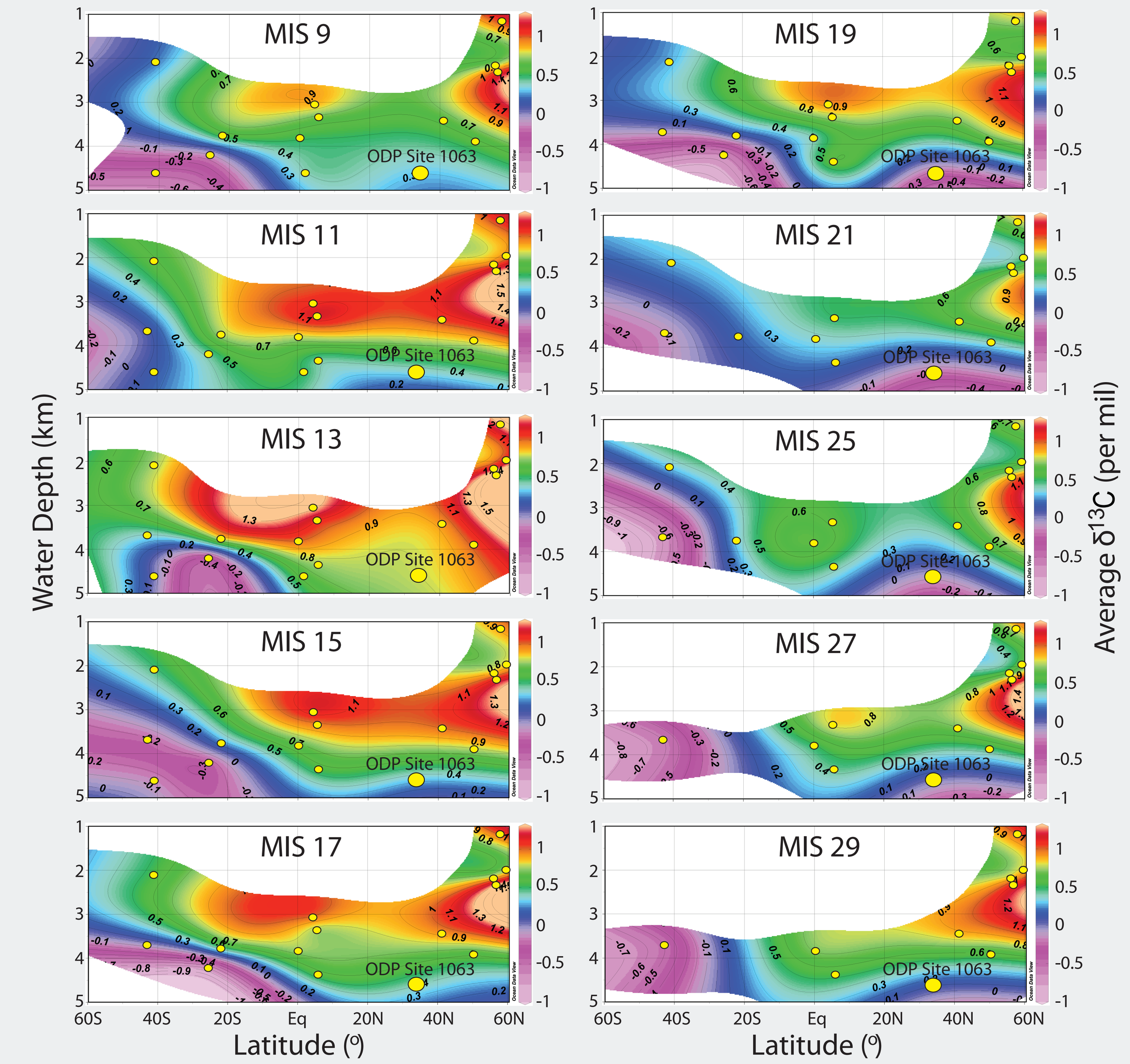

Figure 7: Cross section distribution of average $\delta^{13}C$ values throughout the deep Atlantic Ocean (60ºS to 60ºN) during each of the 10 interglacial periods (MIS 9 to MIS 29) within this study. These cross sections were constructed by importing the average $\delta^{13}C$ values from each site during successive interglacial maxima ($\delta^{18}O$ minima) into the Ocean Data View program.[6] The gridding between data points at each site location was accomplished by using the DIVA gridding option, while ignoring bad estimates. These cross sections show that prior to MIS 17, AABW (blue/purple) remained the dominant deep water mass in the deep Atlantic Ocean, with relatively weak NADW (green/yellow/red) influence. Progressively, from MIS 21 to MIS 17, the influence of NADW throughout the entire Atlantic Ocean basin increased, ultimately affecting the deepest region of the North Atlantic during interglacial periods after MIS 17.

EXTRA-REGIONAL IMPLICATIONS

Progressive enhancement of interglacial NADW influence from MIS 21 to MIS 17 linked to changes in the source region of NADW formation:

- Faunal, stable isotope, and carbonate preservation evidence from North Atlantic for progressive influx of saline surface waters into Norwegian-Greenland Sea[7,8]
- Stable isotope, IRD, and carbonate preservation evidence for increasing contrast between interglacial and glacial surface water conditions within Norwegian-Greenland Sea[9,10]
- Geologic and sedimentological evidence for large increase in ice volume of Kara and Barents Sea ice sheets (Eurasian Ice Sheet) on continental margins adjacent to the Norwegian-Greenland Sea[11,12]

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