DEGLACIAL NEODYMIUM ISOTOPIC RATIOS IN THE FLORIDA STRAITS AND THE RESPONSE OF INTERMEDIATE WATERS TO REDUCED MERIDIONAL OVERTURNING CIRCULATION

A Senior Scholars Thesis

by

ALYSSA LYNNE FRANKLIN

Submitted to the Office of Undergraduate Research
Texas A&M University
in partial fulfillment of the requirements for the designation as

UNDERGRADUATE RESEARCH SCHOLAR

April 2010

Major: Geology

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Approved by:

Research Advisor:	Franco Marcantonio
Associate Dean for Undergraduate Research:	Robert C. Webb

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ABSTRACT

Deglacial Neodymium Isotopic Ratios in the Florida Straits and the Response of Intermediate Waters to Reduced Meridional Overturning Circulation. (April 2010)

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The relationship between intermediate watermass response to Atlantic Meridonial Overturning Circulation (AMOC) during two abrupt cooling events of the last deglacial, the Younger Dryas (YD) and Heinrich Event 1 (H1) is controversial and has been studied using conventional paleo-circulation tracers.

In this study we measure Nd isotopes in sediments of the Florida Straits to investigate this discrepancy. Nd isotope ratios in the authigenic component of marine sediments are thought to be a reliable tracer of past changes in ocean circulation. We will use the Nd isotopic ratios of Fe-Mn oxide leachate of deep-sea sediments (representative of the seawater fraction of Nd) to understand the behavior of AAIW during the YD and H1 climate events. Two cores within the Florida Straits are selected because this site has been exposed to a combination of re-circulated North Atlantic subtropical gyre waters and AAIW.

Our preliminary data suggest that the northward incursion of AAIW was weaker during the YD and H1 events. Specifically, ε_{Nd} values are significantly lower during cold periods (i.e., YD and H1), than during the warmer Holocene epoch. This is consistent with interpretation of $\delta^{18}O$ analyses on sediments from the same cores. Such a trend supports the idea that during the Younger Dryas, there was a reduction within the Florida Current of the flow of intermediate, southern-sourced waters.

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CHAPTER I

INTRODUCTION

Climate and ocean circulation have been observed to be a strongly coupled system. However it is still unknown how changes in ocean circulation affect climate, or vice versa. Ocean water masses have store energy in the form of latent heat, circulate and subsequently release that energy thousands of miles from where the heat was originally absorbed by the water, resulting in a moderated climate gradient between the equator and poles.

The driving force of ocean circulation is based on water density as a function of salinity and temperature. When a water mass is heated it becomes less dense and will rise above the more cold, and saline fluid. After the water releases heat it will cool and sink to a level in the water column of similar buoyancy. The ocean conveyor belt behaves as a result of these interactions. Warmer shallow waters circulate around the Antarctic, through the Pacific, Indian and Atlantic oceans. The most important part of the conveyor belt exists where there is deepwater formation that takes place in the North Atlantic and the Southern Ocean as these warmer currents lose heat and become denser. The formation and flow of North Atlantic Deep Water (NADW) begins in the Norwegian and Labrador Sea and flows southward to join the Antarctic Circumpolar

This thesis follows the style of *Nature Geoscience*.

Current. Here, it is upwelled to form the shallower Antarctic Intermediate Water (AAIW), which then moves northward as part of the return flow into the Atlantic Ocean. The movement north of AAIW is an important, but perhaps least known, part of the heat modulation processes that take place on our planet. The heat balance associated with the ocean conveyor belt can be offset either causing climate change or as a result of climate change.

Climate and ocean circulation

The changes that have taken place in the thermohaline conveyer belt (in the Atlantic Ocean also known as the Atlantic Meridonial Overturning Circulation, i.e., AMOC) play a very important role in Earth's climate. The relationship between its strength and global temperatures of the past 25 kyr is not well constrained. In particular, interactions between AAIW and NADW can constrain if changes in circulation are associated with abrupt cooling events of the last deglacial. The Younger Dryas (YD) and Heinrich Event 1 (H1) are two of these global cooling events that are associated with changes in the AMOC. The relationship between intermediate watermass response to AMOC is controversial and has been studied using the conventional Cd paleocirculation tracer in benthic foraminifera and neodymium (Nd).

For example, Came and colleagues analyzed Cd_w levels incorporated into benthic foraminifera deposited at two sites in the Florida Straits. Their results indicate that the onset of cold events during the last deglacial resulted in a weakening of southern-sourced water through the Straits, an important conduit for AAIW[1]. In contrast, Pahnke and colleagues measured ε_{Nd} values in sediment from the Brazil Margin and the Tobago Basin in the western tropical Atlantic. Results of this study indicate enhanced northward advection of AAIW during global cooling events of the last deglacial[2].

Purpose of this study

Conflicting evidence of the interactions of AAIW and NADW during abrupt cooling events presents a need to look more closely at the issue. Our study seeks to understand this relationship by coupling the benthic Cd work[1] with a Nd isotope profile of the sediment samples from the same location. Nd isotope ratios extracted from the authigenic Fe-Mn component of deep sea sediments can record the sea water isotopic composition, making it a valuable proxy for studying past changes in circulation. Hence, we attempt to further our understanding of the relationship between a reduced AMOC and whether or not AAIW increased in strength, penetrating farther north during YD and H1.

CHAPTER II

METHODOLOGY

Bulk sediment samples were treated with 10% buffered acetic acid to remove the carbonate component. This was repeated until all of the carbonate was removed. The remaining sediment was rinsed with milliQ water to stop the reaction with the acetic acid. Then 0.02 M hydroxylamine hydrochloride (HH) in acetic acid was used to leach the Fe-Mn authigenic component of the sediment. The Nd incorporated in this fraction is representative of the seawater Nd isotopic composition. The samples were treated with the HH for two hours to complete this process. The Fe-Mn leachates were then dried down and processed through RE spec (Eichrom) columns to extract the rare earth elements. The rare earths were then processed through LN spec (Eichrom) columns to collect Nd. Nd isotopic ratios were obtained through analysis by thermal ionization mass spectrometry at Texas A&M University. Benthic foraminifera $\delta^{18}O$ data was provided by Matthew Schmidt in the Department of Oceanography at Texas A&M University.

CHAPTER III

STUDY SITES

Two sediment cores, JPC 26 and KNR166-2-31JPC (the latter core was studied by Came and colleagues), were chosen to study the intensity of AAIW during abrupt global cooling periods (Fig. 1). These cores are located in the Florida Straits at water depths of 546 m and 751 m respectively. This location is currently bathed by a mixture of southern sourced waters and North Atlantic subtropical gyre waters. At water depths below 400 m approximately 80% of the current is southern sourced[3]. These cores contain sediments ranging from 0 to 25 kyr that have been deposited at sedimentation rates of 8- 200 cm/kyr. Such rates ensure that climate events of the last deglacial will be captured so that we can shed light on relative strengths of northern- and sourthern-sourced waters in the Florida Straits.

CHAPTER IV

RESULTS AND DISCUSSION

Nd as an alternative proxy

Nutrient proxies such as Cd and phosphate, stable isotopes such as $\delta^{13}C$, and radioactive isotopes such as $^{231}Pa/^{230}Th$ can be useful tracers of ocean water masses. However they can be susceptible to influence by non-conservative effects such as temperature and water chemistry. This can produce conflicting results and opposing interpretations of paleocirculation.

The properties of the Sm-Nd system make it a valuable tracer of ocean water masses. ^{147}Sm is decayed by α decay to ^{143}Nd. Both are light rare earth elements that have similar ionic radii and electronic structure. Nd is more incompatible with respect to the mantle and is preferentially incorporated into the crust over Sm. ^{143}Nd is measured against ^{144}Nd which is non-radiogenic. Due to the long half life of the Sm-Nd system (106 byr), variations in the $^{143}Nd/^{144}Nd$ ratio is small. Nd isotopic ratios are commonly normalized relative to the present chondritic uniform reservoir value (CHUR) of 0.512638, expressed in ε_{Nd} notation:

$$\varepsilon_{Nd} = \left[\frac{\left({}^{143}\mathrm{Nd}/{}^{144}\mathrm{Nd}\right)_{sample} - \left({}^{143}\mathrm{Nd}/{}^{144}\mathrm{Nd}\right)_{CHUR}}{\left({}^{143}\mathrm{Nd}/{}^{144}\mathrm{Nd}\right)_{CHUR}} \right] \times 10^4$$

Radiogenic isotopes are good water mass tracers because their ratios are not affected by ocean water composition or biological processes. Nd is a good paleocirculation proxy because it has a residence time of 600- 2000 years in the ocean[4] which is less than the residence time of water in the ocean. Additionally its residence time is not too long, which would have resulted in a mixed signal, nor too short, which would not have allowed for water masses to develop unique signatures. ε_{Nd} values are distinct for various ocean basins because seawater Nd is controlled by continental weathering processes and subsequent riverine discharge. Because various regions of the continents formed at different times, each region can have unique ε_{Nd} values. For example, the interior of continents such as North America and Europe formed in the Protereozoic and Archean. Because this crust has had a long time to evolve, it is more unradiogenic and represented by low Sm/Nd ratios. This produces low isotopic signatures for the North Atlantic Basin, $\sim\varepsilon_{Nd} = -13.5$. In contrast, intraplate volcanism and island arc volcanism throughout the Pacific Ocean produce rocks from young mantle material. These rocks are more radiogenic, having a high Sm/Nd ratio, resulting in higher ε_{Nd} values for Pacific water masses ranging $\varepsilon_{Nd} = 0$ to $+4$. These two ε_{Nd} values can be viewed as endmembers, and when the endmembers are mixed isotopic signatures result that range between -6 and -9, as is the signature for waters formed in the Southern Oceans[4].

Preliminary results of JPC 26

The oxygen isotope data reveals distinctive trends throughout the last deglacial. During the Holocene (0-350 cm), $\delta^{18}O$ values maintain a steady mean around 1.7. There is an abrupt shift to an $\delta^{18}O$ average of 1.5 during YD. The subsequent warm period, Bølling-Allerød, results in $\delta^{18}O$ values much closer to 2.0, but once again in H1 there is a drop to $\delta^{18}O$ values around 1.4. The limited Nd data we have on JPC 26 of sediment deposited during or close YD and H1 shows correlation with $\delta^{18}O$ values (Fig. 2). During the Holocene ε_{Nd} values are more radiogenic, and average about -7.7. At the edge of YD ε_{Nd} values are less radiogenic, averageing -8.8. Additionally we only have data at the edges of H1 that plots around ε_{Nd} values of -8.3. This amount of data is not sufficient for understanding northward advection of AAIW in the past. Therefore we must continue to collect data.

Discussion

Despite the fact that our current data is very limited, it still reveals interesting trends. The ε_{Nd} values we have from JPC26 correspond to the $\delta^{18}O$ values provided by Schmidt. These $\delta^{18}O$ values reveal that during the last deglacial, the Holocene and the Bølling-Allerød had higher $\delta^{18}O$ values corresponding to lower water temperatures and the globally cool periods, YD and H1 had lower $\delta^{18}O$ values indicating warmer water temperatures. Additionally, the correlation of less radiogenic values during YD and H1 may indicate that there was a reduced influence of AAIW, especially considering that during these events, AAIW was probably more radiogenic than today. This initial data supports that NADW was stronger during cold periods and AAIW was stronger during warm times, however we must acquire more data from JPC 26 and JPC 31 to fully explore this hypothesis.

CHAPTER V

CONCLUSION

AAIW circulation is believed to play an important role in global ocean circulation. The relationship between this intermediate watermass response to AMOC is controversial and has been studied using conventional paleo-circulation tracers, resulting in conflicting results. By using Nd as a paleo-circulation tracer we hope to confine the behavior of AAIW in response to variability in NADW and AMOC of the last deglacial.

Our preliminary data support that the northward incursion of AAIW was weaker during the YD and H1 events. Specifically, ε_{Nd} values are significantly lower during cold periods than during the warmer Holocene epoch. In order to fully explore our ideas, we must construct a higher resolution plot of Nd values in sediment cores from the Florida Straits.

REFERENCES

1. Came, R.E., Oppo, D.W., Curry, W.B., and Lynch-Stieglitz, J. Deglacial variability in the surface return flow of the Atlantic meridional overturning circulation. *Paleoceanography* **23,** PA1217 (2008).

2. Pahnke, K., Goldstein, S.L., and Hemming, S.R. Abrupt changes in Antarctic Intermediate Water circulation over the past 25,000 years. *Nature Geoscience* **1**, 870-874 (2008).

3. Schmitz, W.J., and Richardson, P.L. On the sources of the Florida Current. *Deep Sea Research* **38**, 379-409 (1991).

4. Frank, M. Radiogenic isotopes: Tracers of past ocean circulation and erosional input. *Reviews of Geophysics* **40,** (2002).

APPENDIX

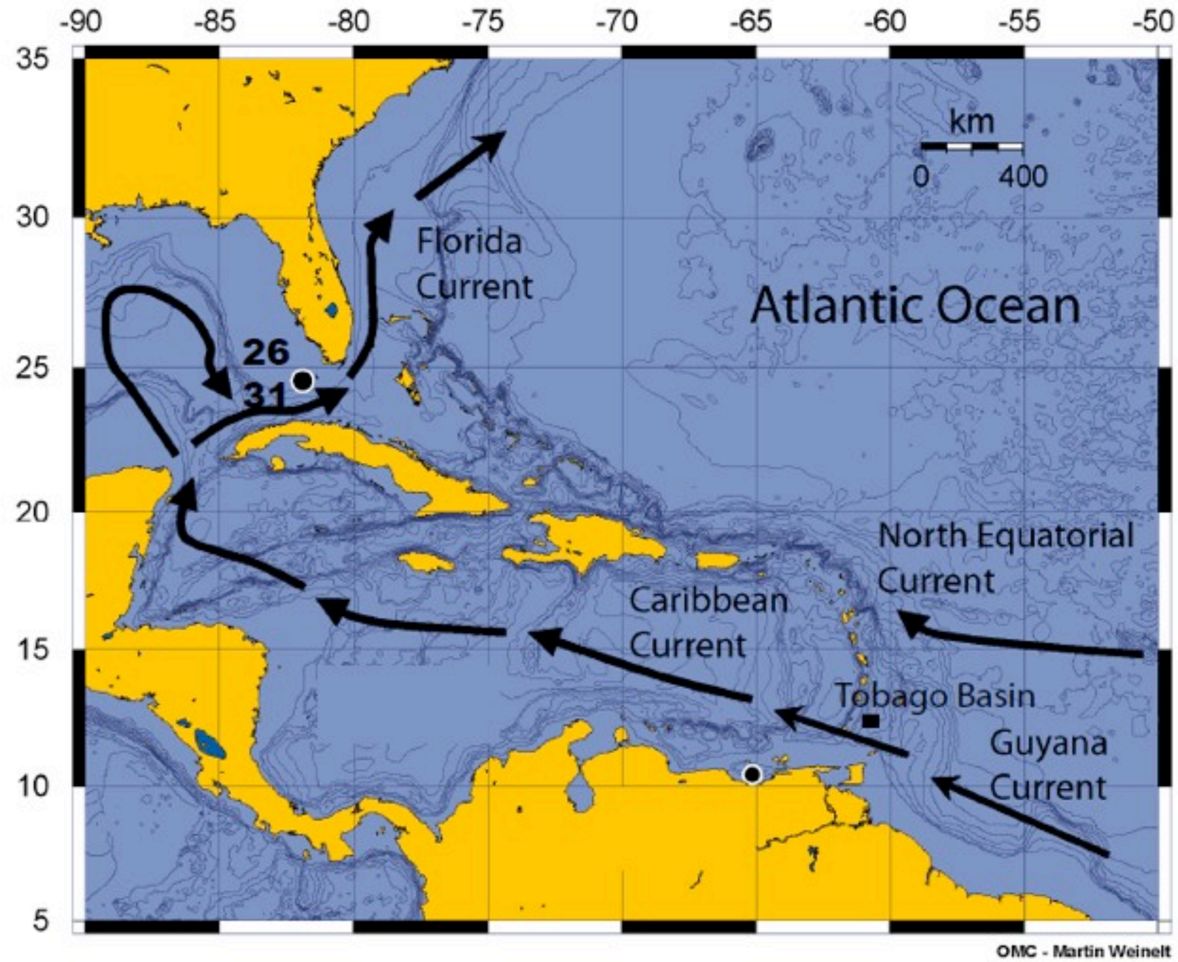

Figure 1. Map of surface currents in the Caribbean and the Gulf of Mexico and the locations of JPC 26 and JPC 31 within the Florida Straits (from Franco Marcantonio, personal communication).

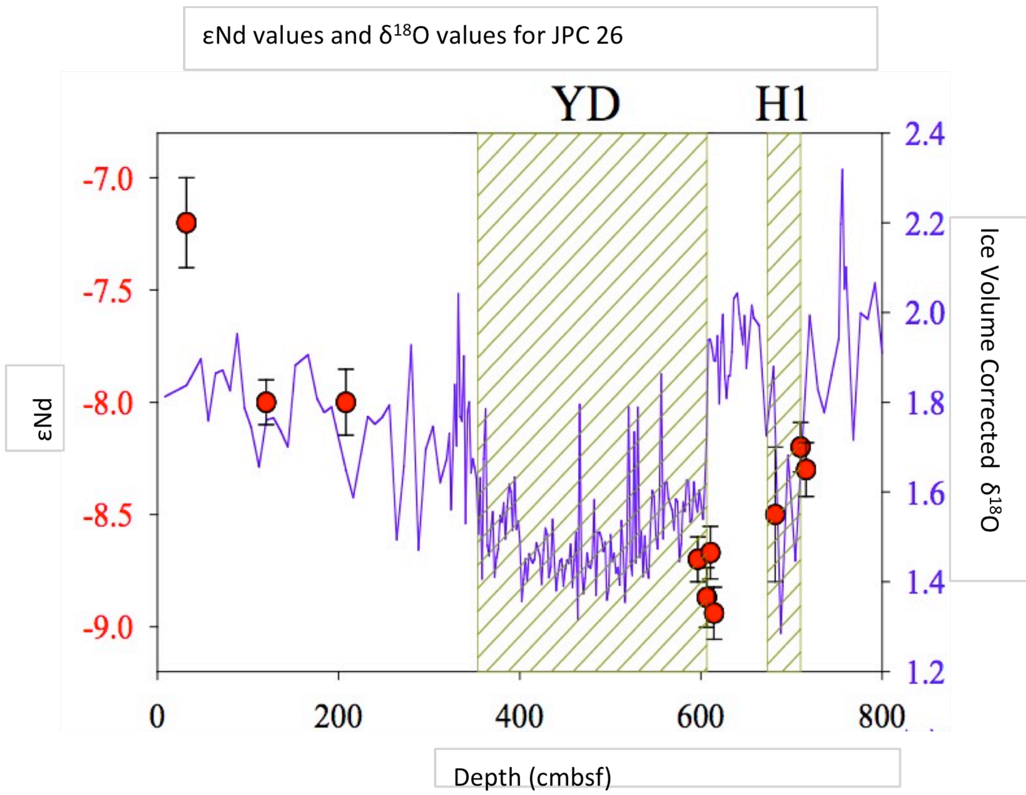

Figure 2. ε_{Nd} (left y-axis) and ice volume corrected benthic $\delta^{18}O$ (right y-axis) versus depth for JPC26. Lower $\delta^{18}O$ values indicate higher water temperatures (from Franco Marcantonio, personal communication).

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