

What caused *G. truncatulinoides* to calcify in shallower water during the early Holocene in the western Atlantic / Gulf of Mexico?

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Abstract. In a recent paper we reconstructed the calcification depth of *G. truncatulinoides* since the last deglaciation in the Florida Straits. We highlighted a significantly different calcification depth between 8-10 ka and the late Holocene. This migration was found in three different cores over the western North Atlantic American continental margin. This paper presents new Mg/Ca ratio data on *G. truncatulinoides* in the Florida Strait and new stable isotopic measurements on *G. crassaformis* in the Gulf of Mexico. Preliminary interpretation to understand the cause of *G. truncatulinoides* migration in the water column at the beginning of the Holocene is given.

1. Introduction

Globorotalia truncatulinoides is a deep-dwelling planktonic foraminifera known to calcify around 200 meters depth in the western North Atlantic [5, 7, 8]. Paleoceanographic studies have used this species to reconstruct past thermocline condition assuming a constant calcification depth [14].

By comparing oxygen isotopic composition ($\delta^{18}\text{O}$) of surface dwelling and benthic foraminifera from cores along a depth transect [13], with *G. truncatulinoides* $\delta^{18}\text{O}$ in one of the deeper cores (KNR166-2-29JPC), we determined the calcification depth of this species over the past 12 ka in the Florida Straits (figure 1) [6]. This study showed that between 8 and 10 ka, *G. truncatulinoides* was calcifying in a much shallower habitat, around 130 m depth, than during the deglaciation or the late Holocene. We also showed that the large $\delta^{18}\text{O}$ signal associated with this migration is found in two other cores: RC12-10 in the western Gulf of Mexico and MD99-2203 off Cape Hatteras (figure 2). This is therefore a regional phenomenon over the western Atlantic continental slope that must have been triggered by environmental changes. The cause for this change of habitat is still unclear.

All the cores discussed in this paper are well dated. Cores KNR166-2-29JPC, RC12-10 and MD99-2203 have respectively 8, 7 and 11 radiocarbon dates over the period covered by this study [6, 15].

Here we present new data both on the Florida Straits core and on the Gulf of Mexico core to understand the context of this migration. Beyond elucidate the particular early Holocene migration in the western Atlantic margin region, we aim to constrain what parameters influence *G. truncatulinoides* calcification depth.

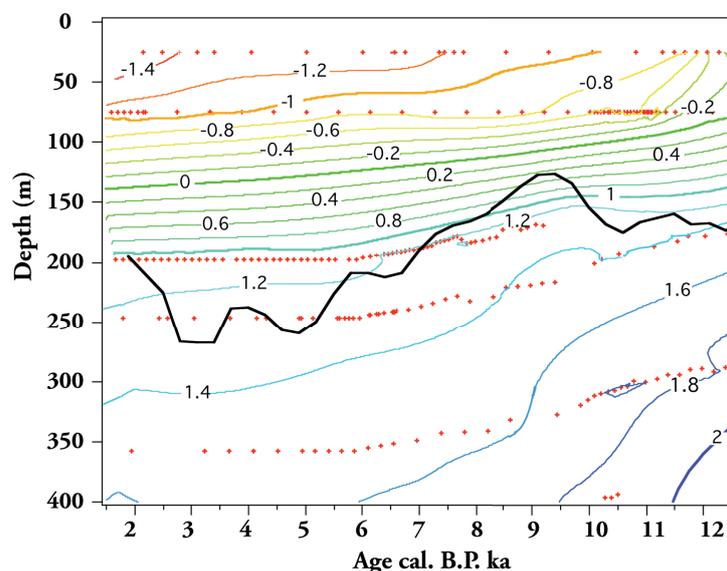


Figure 1: *G. truncatulinoides* calcification depth change in the Florida Straits over the last 12.5 ka (in calendar age B.P.). Red points: Pointer for $\delta^{18}\text{O}$ values at known water depth, from top to bottom: *G. ruber* (25m), *G. sacculifer* (75m), benthic foraminifera (modern depth : 198, 247, 358 and 446m). Thin colored lines: $\delta^{18}\text{O}$ isolines calculated by linear interpolation between $\delta^{18}\text{O}$ pointer values (red points). Thick black line: $\delta^{18}\text{O}$ and calcification depth of *G. truncatulinoides* from KNR166-2 29JPC measurements, $\delta^{18}\text{O}$ curve smoothed on 3 points.

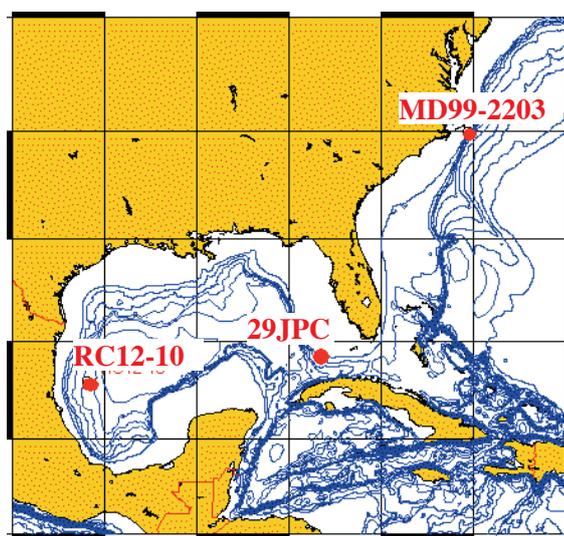


Figure 2: Location of the cores discussed in this paper.

2. New data and results

2.1. Mg/Ca ratio measurement of *G. truncatulinoides* in the core KNR166-2-29JPC and interpretation
 About 10 tests of *G. truncatulinoides* dextral in the 355-500 μm fraction has been picked in the core KNR166-2-29JPC (24°16 N, 83°16 W, 648 m) for Mg/Ca ratio measurement. We used the inductively coupled plasma atomic-emission spectrometers (ICP-AES), model Ultima-C Jobin Yvon of Georgia

Institute of Technology. Inter-laboratories comparison of Mg/Ca measurements has been checked by standard powder analyses [9]. Analyses of standard powder are typically within the 2 % error for a mean Mg/Ca ratio of 5.55 mmol/mol.

The Mg/Ca ratio of foraminifera test is now widely accepted as a paleotemperature proxy. Specimens for $\delta^{18}\text{O}$ analysis and Mg/Ca ratio measurement were picked in the same samples. $\delta^{18}\text{O}$ value and temperature from Mg/Ca ratio are substituted into the oxygen isotope paleotemperature equation [16], to estimate seawater $\delta^{18}\text{O}$ using the following equations:

$$T_{Mg/Ca} = \frac{1}{0.074} \times \ln\left(\frac{Mg/Ca}{0.62}\right) \quad \text{equation 1}$$

$$\delta^{18}\text{O}_{seawater} = \delta^{18}\text{O}_{foram} - 5\sqrt{4.38 - (4.38 - 0.4 \times (16.9 - T_{Mg/Ca}))} \quad \text{equation 2}$$

Equation 1 is the temperature – Mg/Ca ratio relationship for *G. truncatulinoides* [4]; equation 2 is the modified paleotemperature equation from [16], we applied a 0.27 correction to convert $\delta^{18}\text{O}_{foram}$ on the SMOW scale.

Temperature reconstruction and seawater $\delta^{18}\text{O}$, corrected for past ice volume change using the reconstruction of [18], are shown on figure 3. Estimated error on temperature reconstruction from *G. truncatulinoides* is 1.4°C; based on a simple error propagation, error on $\delta^{18}\text{O}_{seawater}$ reconstruction is about 1‰. Seawater $\delta^{18}\text{O}$ is regionally correlated to salinity, however we did not perform quantitative salinity calculation as the relationship may not be valid back in time.

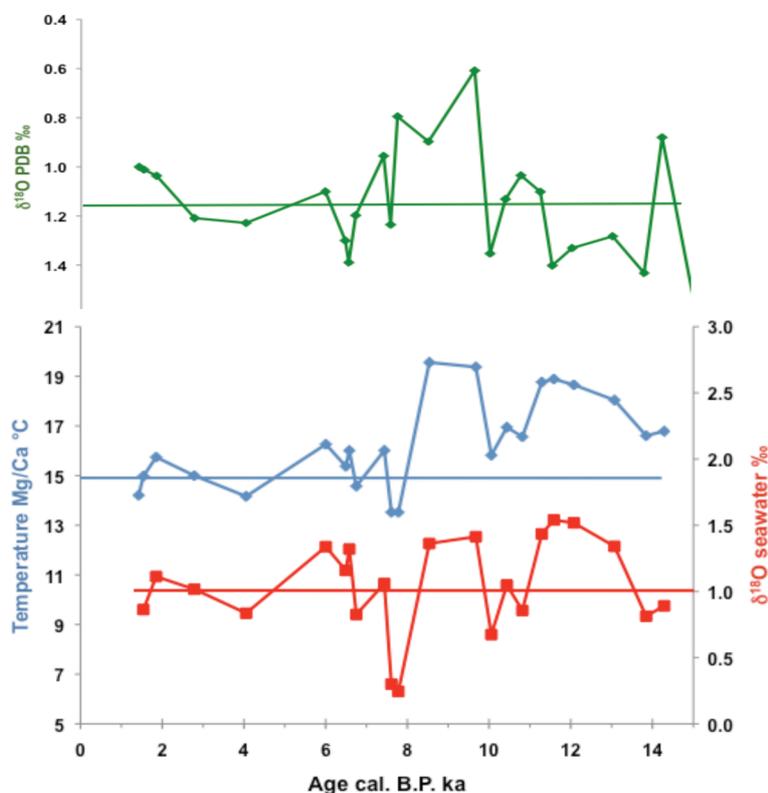


Figure 3: $\delta^{18}\text{O}$ PDB ‰ (green), temperature from Mg/Ca ratio (blue) and seawater $\delta^{18}\text{O}$ (red, corrected for sea level change) from *G. truncatulinoides* in the Florida Strait core KNR166-2-29JPC. The large $\delta^{18}\text{O}$ signal is also found in cores RC12-10 and MD99-2203 where *G. truncatulinoides* were picked in narrower size fractions.

Temperature reconstructions of *G. truncatulinoides* calcification habitat show a large step-like decrease of about 4°C at 8 ka (figure 3). The $\delta^{18}\text{O}_{\text{seawater}}$ doesn't show this step-like transition. The mean early Holocene $\delta^{18}\text{O}_{\text{seawater}}$ is about 0.3‰ higher than the value for the late Holocene (i.e. about 0.6‰ salinity, taking the mean $\delta^{18}\text{O}_{\text{seawater}}$ /salinity relationship for the Western North Atlantic region between 0 and 500 meters depth). Contemporaneous to the temperature drop, the $\delta^{18}\text{O}_{\text{seawater}}$ show a large event of about 0.7‰ at 8 ka. Although the chronology differs somewhat, this depletion corresponds probably to the surface water event documented by [11] around 8.4 ka. These authors estimated that it reflects a salinity drop of about 5.5‰ and hypothesize that it precedes the widespread 8.2 ka event. Our data make a discussion about the chronology of these events difficult but it shows that the freshwater discharge reached thermocline depth. Clearly more investigations are needed to understand the cause and impact of such event.

2.2. $\delta^{18}\text{O}$ composition of *G. crassaformis* in the core RC12-10 and interpretation

Globorotalia crassaformis is also a deep-dwelling planktonic foraminifera species. Modern observation in Cariaco Basin indicates an habitat similar to *G. truncatulinoides* between 100-500 m [17]. Optimum conditions for *G. crassaformis* include a shallow thermocline, high productivity in surface waters, and a distinct subsurface oxygen minimum where sinking organic matter is oxidized [10].

We selected about four specimens of *G. crassaformis* per samples in the 425-500 μm fraction from the core RC12-10 (23°N, 95°53 W, 3054 m) for stable isotope measurements (figure 4). Samples were analyzed on a MAT 253 mass spectrometer equipped with an automated Kiel Carbonate device at Georgia Institute of Technology. Long term reproducibility is < 0.07‰ for $\delta^{18}\text{O}$.

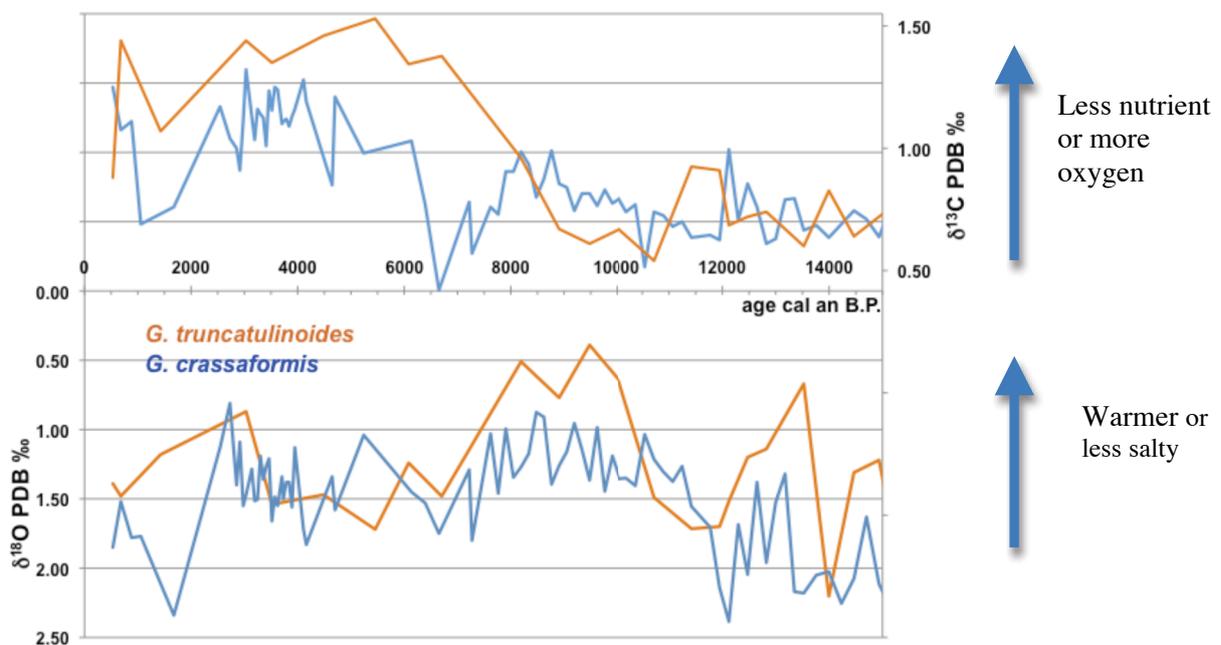


Figure 4: Stable isotopic analysis of *G. crassaformis* (blue) and *G. truncatulinoides* (orange) in the core RC12-10 in the Gulf of Mexico. $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ are respectively plotted on the upper and lower panel.

The isotopic composition of *G. crassaformis* in the core RC12-10 has been analyzed at a much higher resolution than for *G. truncatulinoides* which explain the higher variability. More importantly, *G. crassaformis* $\delta^{18}\text{O}$ signal doesn't show any large amplitude change over the last 11 ka. The large decrease in *G. truncatulinoides* $\delta^{18}\text{O}$ value between 8-10 ka, interpreted as an upward migration, is not seen in *G.*

crassaformis record. *G. crassaformis* abundance is very low at the top of the core, we therefore don’t interpret the heavier value over the last 2 ka.

The $\delta^{13}\text{C}$ signal of both deep-dwelling planktonic species in the RC12-10 core is also plotted on figure 4. The $\delta^{13}\text{C}$ of deep-dwelling planktonic, less influenced by atmospheric exchange than surface dwelling foraminifera, should reflect the seawater biological productivity (organic matter formation/oxidation ratio) and thermocline ventilation. The *G. truncatulinoides* $\delta^{13}\text{C}$ values are low during the deglaciation/early Holocene and increase by about 0.7‰ around 8 ka. This increase reflects a more nutrient depleted or more oxygenated habitat which is at odds with a deeper calcification depth in the late Holocene. The mean $\delta^{13}\text{C}$ of *G. crassaformis* is also higher in the late than in the early Holocene but the amplitude of the change is about 0.4‰.

Another environmental piece of information can be retrieved from *G. crassaformis* abundance in the core RC12-10 [15]. This species was less abundant between 11-13 ka (age cal) and seems to almost disappear from the Gulf of Mexico around 8 ka (age cal) [11]. Knowing the ecological preference of this species, this probably reflects a drop in productivity and/or more oxygenated subsurface condition around 8 ka.

3. Discussion

3.1. Estimating physical water column properties changes

Calcification habitat of *G. truncatulinoides* in the Florida Straits shows a step-like cooling around 8 ka, contemporaneous with the large $\delta^{18}\text{O}$ signal increase previously identified. This cooling is expected with a migration toward deeper calcification depth in the late Holocene. The reconstructed seawater $\delta^{18}\text{O}$ /salinity values don’t show such transition between the early and the late Holocene.

Foraminifera, and particularly deep-dwelling species, add a secondary calcite (or crust) to their shell when they sink at deeper level in the water column [12]. One could argue that different amount of crust in the test between the deglaciation and the Holocene might create the observed signals. Several arguments oppose to calcite crust influence: 1) The *G. truncatulinoides* $\delta^{18}\text{O}$ signal at 8-10 ka is observed in three different cores where specimens were picked in different size fractions; 2) it would be odd if *G. truncatulinoides* added a crust to its test at the same time in the three different locations; 3) [12] showed that calcite crust has heavier $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$. $\delta^{18}\text{O}$ values around 8-10 ka are depleted but not the $\delta^{13}\text{C}$ values (figure 4).

We use *G. crassaformis* that has, at present day, a similar calcification depth than *G. truncatulinoides* to check whether or not the shallowing of calcification depth was a common feature among thermocline dwelling foraminifera. The $\delta^{18}\text{O}$ of *G. crassaformis* don’t show the large change seen in *G. truncatulinoides* signals. *G. crassaformis* probably kept the same calcification habitat over the last 11 ka and this habitat experienced no significant temperature or salinity variation. From temperature, seawater $\delta^{18}\text{O}$ reconstruction from *G. truncatulinoides* in the Florida Straits and *G. crassaformis* data from the Gulf of Mexico core, we therefore conclude that seawater temperature and salinity don’t seem to be the main cause for the observed *G. truncatulinoides* migration.

3.2. Estimating nutrient/productivity water column changes

The $\delta^{13}\text{C}$ of *G. truncatulinoides* and abundance change of *G. crassaformis* in the Gulf of Mexico show large changes contemporary with the migration of *G. truncatulinoides*. The quasi-disappearance of *G. crassaformis* around 8 ka can be interpreted as a decrease in productivity and/or more oxygenated subsurface water. This is in agreement with the $\delta^{13}\text{C}$ enrichment of *G. truncatulinoides* in RC12-10 from the early to the late Holocene. Over the Western Atlantic Carolina slope, [19] also found a more productive surface water from 15 to 10 ka than over the Holocene. These authors suggest a change in the mode of productivity that might have resulted from larger seasonality or winter mixing. The Cd/Ca data on the Bermuda Rise also indicates a decrease in nutrient content from about 10 ka to the Holocene [2, 3]. Change in surface water of the Gulf of Mexico occurs at this same period [15]. Although all these observations might have different origins, they tend toward a general change in productivity over the

western subtropical Atlantic around 10-8 ka. Possible mechanism for the change in nutrient content/productivity can be ocean circulation change [2, 3] or the end of deglacial discharge over these continental slope areas. The input of meltwater, charged with nutrient and particles, in the Gulf of Mexico stopped at 9.5 ka [1]. We hypothesize that the migration of *G. truncatulinoides* calcification depth might have been triggered by change in nutrient and productivity. The lack of knowledge on *G. truncatulinoides* ecology prevents further interpretation but point out to important work to carry on.

4. Conclusion

With these new developments on subsurface water condition in the Gulf of Mexico and the Florida Straits, we show that:

- *G. truncatulinoides* was calcifying at warmer temperature when it recorded the heavy $\delta^{18}\text{O}$ which confirms a shallower habitat.
- Subsurface temperature and salinity probably didn't change drastically over the last 11 ka and don't explain the migration.
- The cause for *G. truncatulinoides* migration lies probably in a major nutrient/productivity change.

Further work is necessary to answer the questions:

- What *G. truncatulinoides* feed on?
- What caused this drastic change in water nutrient composition?
- How is it related to change in ocean circulation?

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