GSA DATA REPOSITORY 2012265

Seasonal Laurentide Ice Sheet melting during the Mystery Interval

Carlie Williams, Benjamin P. Flower and David W. Hastings

Methods for *Globigerinoides ruber* $\delta^{18}O$ and Mg/Ca-SST:

When available, >60 individuals of the planktic foraminifera *Globigerinoides ruber* (white and pink varieties, separately; 250-355 µm size fraction) were picked for stable isotope and elemental ratio analysis. Once picked, samples were sonicated in methanol for five seconds to remove fossil particles from inside the *G. ruber* tests, dried, weighed and split in half. The first half was prepared and analyzed for Mg/Ca-SST as described in Williams et al. (2010). SST was calculated for both *G. ruber* (white and pink) using fixed exponential calibration curves based on sediment trap data from the Sargasso Sea: Mg/Ca= $0.449^{(0.09*SST)}$ for *G. ruber* (white) and Mg/Ca= $0.381^{(0.09*SST)}$ for *G. ruber* (pink) (Anand et al., 2003; Williams et al., 2010). This technique yields calcification temperatures with an accuracy of approximately ±1.2°C. Instrumental precision (1 standard deviation) for Mg/Ca is ±0.01 mmol/mol, based on analyses of approximately 1500 reference standards, over the course of 16 runs. Mean standard deviations of *G. ruber* (white and pink) replicate Mg/Ca analyses are ±0.077 and ±0.097 mmol/mol, respectively (based on > 11% of total data set replication).

The second half was pulverized for homogeneity and a 50–80 mg aliquot was analyzed for stable isotope ratios on a ThermoFinnigan Delta Plus XL dual-inlet mass spectrometer with an attached Kiel III carbonate preparation device at the College of Marine Science, University of South Florida (Fig. DR1; Williams et al., 2010). $\delta^{18}O$ data calibrated with standard NBS-19 are reported on the PDB scale. Long-term analytical precision based on >1000 NBS-19 standards is ±0.06‰ for $\delta^{18}O$.

The local $\delta^{18}O_{SW}$ was calculated by removing the isotopic effects of temperature with the Mg/Ca-SST proxy and applying the *Orbulina universa* high-light paleotemperature equation (Bemis et al., 1998). A constant 0.27‰ was added to convert resulting $\delta^{18}O_{SW}$ values to the Standard Mean Ocean Water (SMOW) scale. Compounded error for $\delta^{18}O_{SW}$ values, based on $\delta^{18}O$, Mg/Ca, SST calibration and paleotemperature equation errors is ±0.27‰. The incorporation of a ±0.8 m mean sea level error (Stanford et al., 2010) and ±0.1‰ error on the global glacial-interglacial $\delta^{18}O_{SW}$ change (Schrag et al., 2002) increases the resultant ice volume corrected $\delta^{18}O_{SW}$ (termed $\delta^{18}O_{GOM}$) error to ±0.28‰.

The $\delta^{18}O_{GOM}$ Proxy for LIS Meltwater:

The Mississippi River $\delta^{18}O$ end-member has likely varied through the last deglacial sequence due to changes in the amount and isotopic composition of LIS meltwater and precipitation over the Mississippi River drainage basin. However, small inputs of LIS meltwater into the GOM may be identified because its $\delta^{18}O$ value is considerably lower (-25 to -35‰; Fairbanks, 1989; Schrag et al., 2002) than other sources. Unrealistically large volumes of precipitation and/or Mississippi River runoff are required for the same isotopic shift in GOM $\delta^{18}O_{SW}$ (Fig. DR2).

The $\delta^{18}O_{GOM}$ value is used to identify LIS melting episodes during the last deglaciation because it incorporates an isotopic sea level correction and allows for a direct comparison to modern $\delta^{18}O_{GOM}$ data. As the modern GOM has a $\delta^{18}O_{GOM}$ value of approximately +1‰ (Fairbanks et al., 1992; LeGrande and Schmidt, 2006), proxy derived $\delta^{18}O_{GOM}$ data with values less than +1‰ may be interpreted as intervals of meltwater input.

A simple model calculation based on an evaporation rate of 1.5 m/yr (greater than the modern Dead Sea rate of 1.1-1.2 m/yr (Lensky et al., 2005)) and a 13‰ fractionation between seawater and water vapor (Dansgaard, 1964), illustrates the improbability that large deviations from the modern GOM evaporation rate would significantly alter $\delta^{18}O_{GOM}$ values during the deglacial sequence. If evaporative processes remove 1.5% of the 100 m thick GOM surface layer, the $\delta^{18}O_{GOM}$ would increase by only 0.21‰, which is within error of $\delta^{18}O_{GOM}$ estimates. Furthermore, this does not account for regional inputs such as precipitation and ocean currents, which may also decrease $\delta^{18}O_{GOM}$ values.

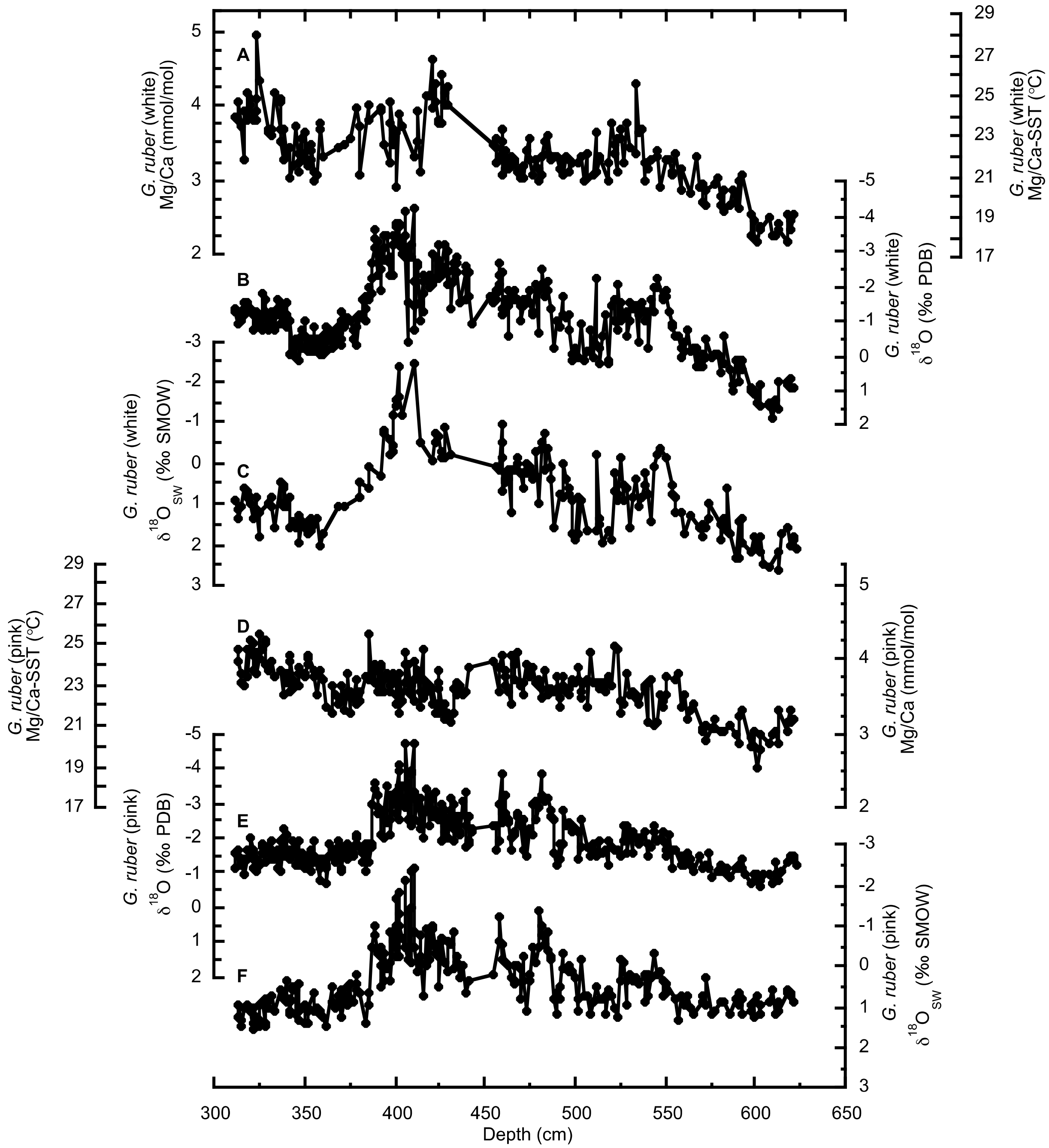

Figure DR1. *G. ruber* δ^{18}O and Mg/Ca-SST data vs. depth. A: *G. ruber* (white) Mg/Ca (mmol/mol) and SST (°C) (Williams et al., 2010). B: *G. ruber* (white) δ^{18}O (this study). C: *G. ruber* (white) $\delta^{18}O_{SW}$ (this study). D: *G. ruber* (pink) Mg/Ca (mmol/mol) and SST (°C) (Williams et al., 2010). E: *G. ruber* (pink) δ^{18}O (this study). F: *G. ruber* (pink) $\delta^{18}O_{SW}$ (this study).

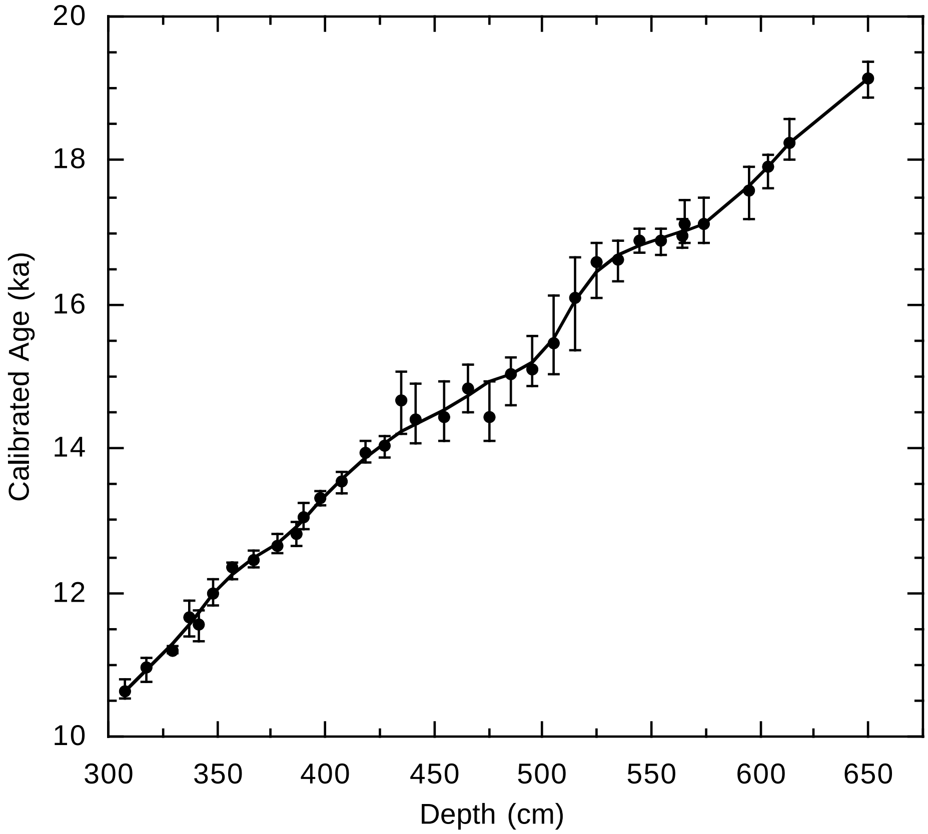

Figure DR2. The age model for core MD02-2550 is based on 35 radiocarbon dates from planktonic foraminifera (*G. ruber*, pink and white). Core depth was converted to calendar age by applying a weighted curve fit with a 15% smoothing factor. Error bars represent 2-standard deviation error in calibration from radiocarbon to calendar years (Williams et al., 2010). German pine chronologies and radiocarbon-dated foraminifera from Cariaco Basin suggest that the low-latitude western Atlantic surface ocean reservoir age decreased by 100-400 yrs at the onset of the Younger Dryas, which may significantly affect the timing of both the Cessation Event and MOC change (Kromer et al., 2004; Muscheler et al., 2008; Hua et al., 2009; Reimer et al., 2009). Because time-dependent reservoir corrections are not yet available for the western low-latitude Atlantic or GOM, we present our data with the potential caveat that reservoir age may modify our interpretations.

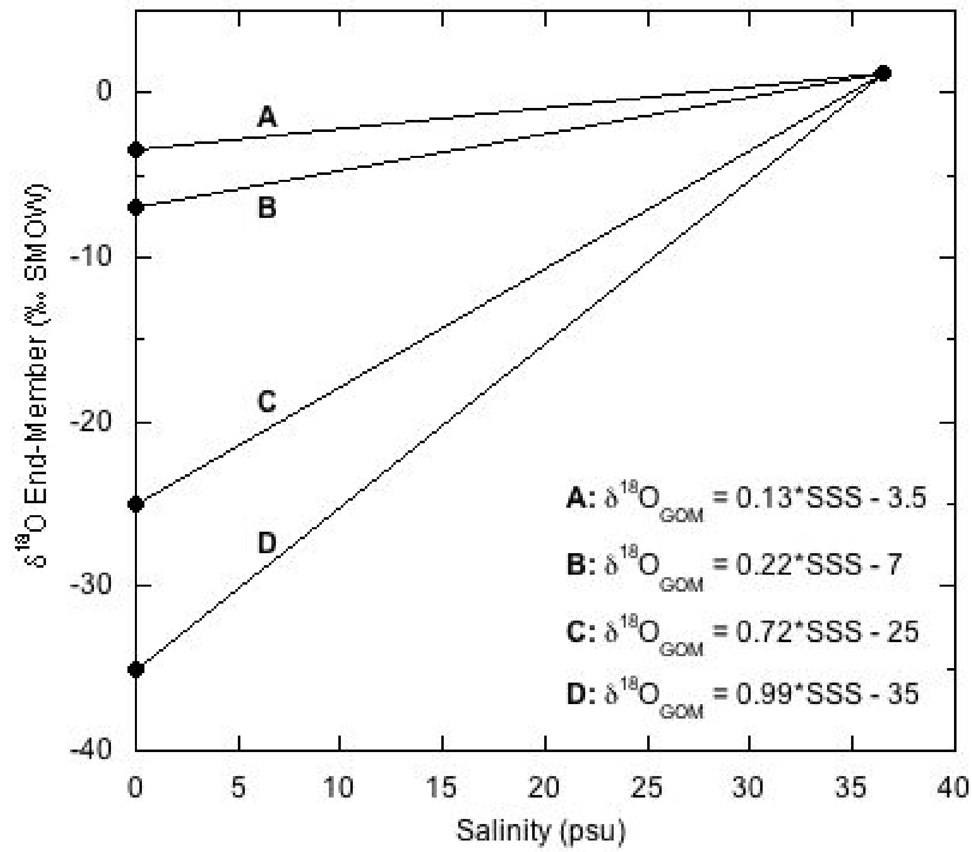

Figure DR3. Mixing model used to quantify the relationship between $\delta^{18}O$ and salinity. Calibrations are based on A: Modern precipitation $\delta^{18}O$ end-member (-3.5‰) (Bowen and Revenaugh, 2003). B: Modern Mississippi River $\delta^{18}O$ end-member (-7‰) (Ortner et al., 1995). C and D: Estimated LIS $\delta^{18}O$ end-member (-25 and -35‰, respectively) (Fairbanks, 1989; Schrag et al., 2002). The lower potential $\delta^{18}O$ end-member values yield slopes that indicate lesser salinity changes per unit $\delta^{18}O$.

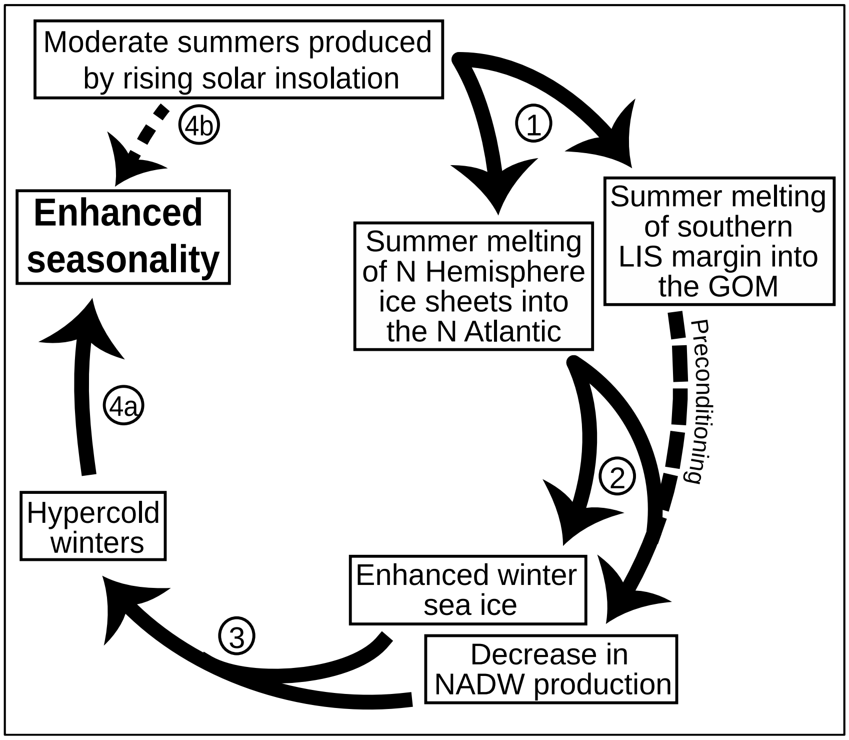

Figure DR4. Schematic illustrating the mechanisms of enhanced seasonality during the last deglaciation. Initially, meltwater produced by moderate summer conditions, entered the GOM and North Atlantic (1), which resulted in enhanced winter sea ice and a decrease in North Atlantic Deep Water (NADW) production (2), leading to increased continentality of the region and hypercold winters (3). Hypercold winters (4a), in combination with moderate summer conditions produced by rising solar insolation (4b), enhanced seasonal temperature contrast during the Mystery Interval.

Supplemental References

Anand, P., Elderfield, H., and Conte, M.H., 2003, Calibration of Mg/Ca thermometry in planktonic foraminifera from a sediment trap time series, Paleoceanography, v. 18, p. 1050-1064, doi: 10.1029/2002PA000846.

Bemis, B.E., Spero, H.J., Bijma, J., and Lea, D.W., 1998, Reevaluation of the oxygen isotope composition of planktonic foraminifera: Experimental results and revised paleotemperature equations, Paleoceanography, v. 13, p. 150-160, doi: 10.1029/98PA00070

Bowen, G., and Revenaugh, J., 2003, Interpolating the isotopic composition of modern meteoric precipitation, Water Resources Research, v. 39, 1299, doi: 10.1029/2003WR002086.

Dansgaard, W., 1964, Stable isotopes in precipitation, Tellus, v. 16, p. 436-468, doi: 10.1111/j.2153-3490.

Fairbanks, R.G., 1989, A 17,000-year glacio-eustatic sea level record: influence of glacial melting rates on the Younger Dryas event and deep-ocean circulation, Nature, v. 342, p. 637-642, doi: 10.1038/342637a0.

Fairbanks, R.G., Charles, C.D., and Writght, J.D., 1992, Origin of global meltwater pulses, *in* Talyor, R.E., ed., Radiocarbon after Four Decades: New York, Springer, p. 473-500.
Hua, Q., Barbetti, M., Fink, D., Kaiser, K.F., Friedrich, M., Kromer, B., Levchenko, V.A., Zoppi, U., Smith, A.M., and Bertuch, F., 2009, Atmospheric 14C variations derived from tree rings during the early Younger Dryas, Quaternary Science Reviews, v. 28, p. 2982-2990, doi: 10.1016/j.quascirev.20 09.08.013.
Kromer, B., Friedrich, M., Hughen, K.A., Kaiser, F., Remmele, S., Schaub, M., and Talamo, S., 2004, Late Glacial ^{14}C Ages from a Floating, 1382-Ring Pine Chronology, Radiocarbon, v. 46, p. 1203-1209.
LeGrande, A.N., and Schmidt, G.A., 2006, Global gridded data set of the oxygen isotopic composition in seawater, Geophysical Research Letters, v. 33, L12604, doi: 10.1029/2006gl026011.
Lensky, N., Dvorkin, Y., Lyakhovsky, V., Gertman, I., and Gavrieli, I., 2005, Water, salt, and energy balances of the Dead Sea, Water Resources Research, v. 41, W12418, doi: 10.1029/2005WR004084.
Muscheler, R., Kromer, B., Björck, S., Svensson, A., Friedrich, M., Kaiser, K.F., and Southon, J., 2008, Tree rings and ice cors reveal ^{14}C calibration uncertainties during the Younger Dryas, Nature Geoscience, v. 1, p. 263-267, doi: 10.1038/ngeo128.
Ortner, P.B., Lee, T.N., Milne, P.J., Zika, R.G., Clarke, M.E., Podesta, G.P., Swart, P.K., Tester, P.A., Atkinson, L.P., and Johnson, W.R., 1995, Mississippi River flood waters that reached the Gulf Stream, Journal of Geophysical Research, v. 100, p. 13,595-513,601, doi: 10.1029/95JC01039
Reimer, P.J., Baillie, M.G.L., Bard, E., Bayliss, A., Beck, J.W., Blackwell, P.G., Ramsey, C.B., Buck, C.E., Burr, G.S., Edwards, R.L., Friedrich, M., Grootes, P.M., Guilderson, T.P., Hajdas, I., Heaton, T.J., Hogg, A.G., Hughen, K.A., Kaiser, K.F., Kromer, B., McCormac, F.G., Manning, S.W., Reimer, R.W., Richards, D.A., Southon, J.R., Talamo, S., Turney, C.S.M., van der Plicht, J., and Weyhenmeyer, C.E., 2009, Incal09 and Marine09 radiocarbon age calibration curves, 0-50,000 years cal B.P, Radiocarbon, v. 51, p. 1111-1150.
Schrag, D.P., Adkins, J.F., McIntyre, K., Alexander, J.L., Hodell, D.A., Charles, C.D., and McManus, J.F., 2002, The oxygen isotopic composition of seawater during the Last Glacial Maximum, Quaternary Science Reviews, v. 21, p. 331-342, doi: 10.1016/S0277-3791.
Stanford, J.D., Hemingway, R., Rohling, E.J., Challenor, P.G., Medina-Elizalde, M., and Lester, A.J., 2010, Sea-level probability for the last deglaciation: A statistical analysis of far-field records, Global and Planetary Change, v. 79, p. 193-203, doi: 10.1016/j.gloplacha.2010.11.002.
Williams, C., Flower, B.P., Hastings, D.W., Guilderson, T.P., Quinn, K., and Goddard, E.A., 2010, Deglacial abrupt climate change in the Atlantic Warm Pool: A Gulf of Mexico perspective, Paleoceanography, v. 25, PA4221, doi: 10.1029/201PA001928.