Auxiliary information for for:

The Southwest Pacific subtropics responds to the last deglacial warming with changes in shallow water sources

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Paleoceanography

SOM#1 calculation of bioturbation estimates (text, table and figures)
SOM #2 calculation of $\delta^{18}O$ Sea Water estimation (text and figures)

SOM#1 Bioturbation -estimates

The raw isotope data suggested offsets in the timing of events between the two planktonic species. To assess the possible effect of changing abundances and differential bioturbation on the record, assemblage counts of these species were used to investigate bioturbation impacts on isotopic values (**Table S1**). Planktonic species of foraminifera from cores 87 JPC and 125 JPC were taken from ten 1cm sections of the core at depths surrounding the timing of deglacial isotopic depletions. All samples within the size fraction >150μm where successively split to yield a total of 300-500 planktonic foraminifera. For each sample population counts were conducted for *G. bulloides*, *G. inflata*, *N. pachyderma (left coiling), and N. pachyderma (right coiling)* according to the established taxonomy[e.g. *Bé*, 1977; *Thompson and Shackleton*, 1980] To obtain overall numbers per gram assemblage counts were back multiplied for splits to yield the total number of each species, and any individuals previously removed for isotopic or trace metal analysis were added to the total count per species in the sample. The samples were then divided by the original dry weight (g) yielding an estimate of species population per gram of sediment. In both cores there is no ash layer near the intervals examined..

Table S1

Core	Depth (average cm)	Age (ka)	*G. bulloides (individuals/gram)*	*G. inflata (individuals /gram)*	*Pachyderma left (individuals /gram)*	*Pachyderma right (individuals/gram)*
125 JPC	152.5	16.83	293.3	369.3	273.5	0
125 JPC	156.5	17.13	223.3	331.4	216.1	13.2
125 JPC	164.5	17.70	312.8	416.2	259.5	0
125 JPC	172.5	18.23	97.5	187.2	109.8	0
125 JPC	184.5	18.78	121.4	329.6	149.4	44
125 JPC	220.5	19.10	122.2	204.9	158.3	86
125 JPC	228.5	20.47	177.4	395.4	289.3	54
87 JPC	70.5	17.5	864.6	889.8	327.6	0
87 JPC	78.5	18.39	1081.3	1250.7	820.1	71.3
87 JPC	82.5	18.97	3095.7	3941.8	3424.7	85.6
87 JPC	86.5	19.52	6880.9	6976.2	3812.8	653.
87 JPC	94.5	20.58	5093.0	4572.1	3770.5	595.

Table S1| Population counts of planktonic foraminifera within cores 125 JPC and 87 JPC. These assemblage counts were used to assess differential bioturbation between the several species. This can impact offsets in foraminiferal isotope data.

A bioturbation model was used to verify empirically whether bioturbation affected the relative timing of the deglacial onset in the *G. bulloides* and *G. inflata*. An ideal model of isotopic values was developed in which the deglacial shift in isotopic values of *G. bulloides* and *G. inflata* were kept the same but the population counts were matched to test if a bioturbation impulse function is enough to create an offset in the resulting timing mimicking the observed deglacial onset. The bioturbation model takes the form below [*Hutson*, 1980]:

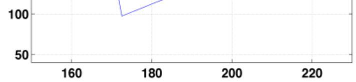
$$I(d) = \frac{\sum_{i=1}^{m} ()\cdot P()\cdot()}{\sum_{i=1}^{m} ()\cdot P()},$$

where $I(d)$ represents the mixed isotope value at depth d resulting from the impulse function; $H(i)$ represents the ith value of the impulse response function; $P(j)$ is the population total of the species at depth j; m is the vertical length of the impulse response function; j is the depth over which the impulse response function operates. The population assemblage data were linearly interpolated to represent every 1 cm of core from 155 to 230 cm (**Figure S1a**). The idealized isotopic values were constructed to have the onset of the glacial termination occur at 183cm for both species of foraminifera (**Figure S1b)**. For simplicity purposes the bioturbation impulse function was created as a Gaussian curve with an m of 31cm (**Figure S1c**). The bioturbation model illustrates that an isotopic offset cannot result from bioturbation if the population counts track with each other (**Figure S1d)**. This simulation confirmed that a bioturbation impulse function could not have caused the observed offset in the deglacial isotopic change. Therefore the offsets in the response of deglacial onset in *G. bulloides* and *G. inflata* must be real.

SOM #2 δ^{18}O Sea Water Estimation

The oxygen isotopic composition of foraminiferal calcite provides information about the oxygen isotope composition of the water mass. The, largest influences on δ^{18}O of ocean water ($\delta^{18}O_{SW}$) are the temperature at which the calcite precipitates and the ice volume effect on the global ocean. The effect of these two parameters must be removed to use $\delta^{18}O_{SW}$ to estimate changes in salinity and latitude of the source location of subsurface waters. The equation of *Shackleton* (1974) describes the thermal of effect on δ^{18}O during calcification

$$T°C = 16.9 - 4.0(\delta^{18}O_{calcite} - \delta^{18}O_{w})$$



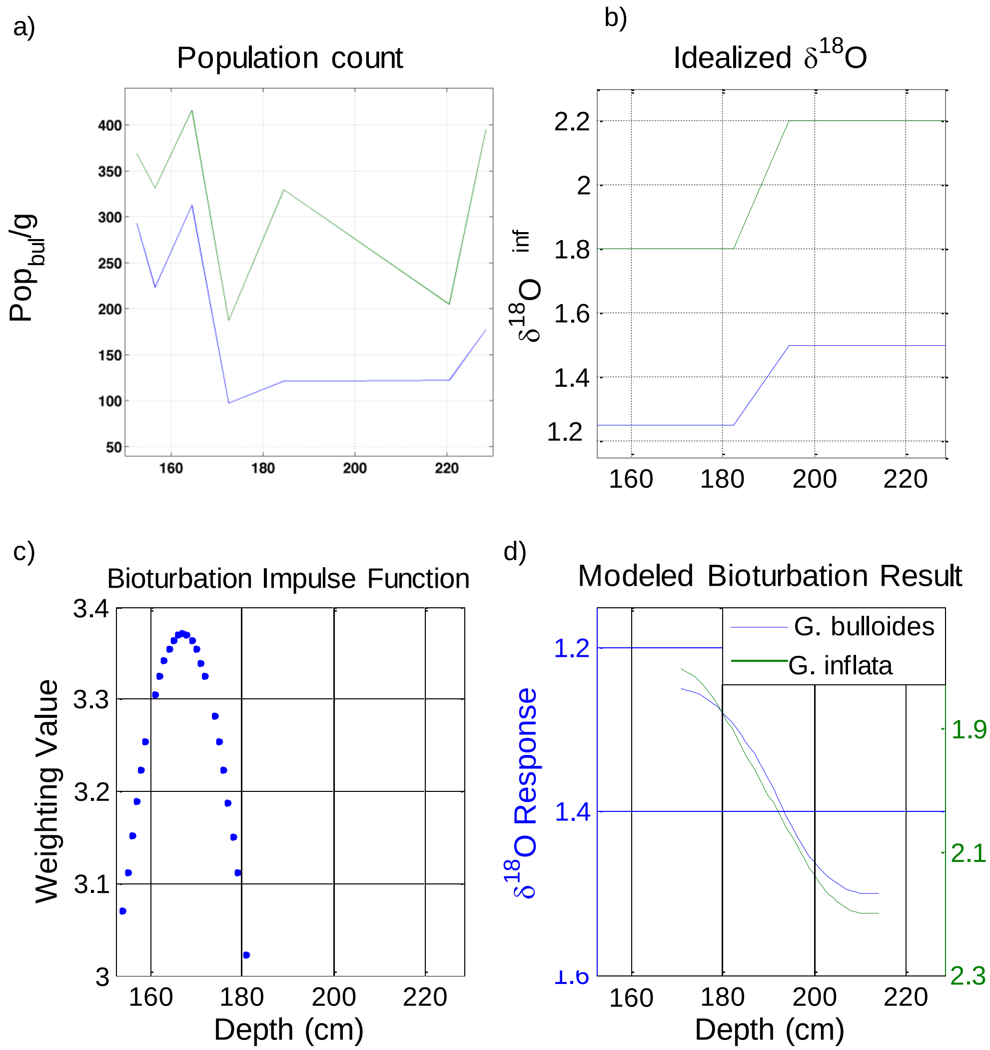


Figure S 1| An evaluation of the influence of bioturbation on the offset in the timing of the deglacial onset in species *G. bulloides* and *G. inflata* in core JPC125. a) Assemblage counts of the population of *G. bulloides* (blue) and *G. inflata* (green) per gram of sediment. b) An idealized model of δ^{18}O for *G. bulloides* (blue) and *G. inflata* (green) with the isotopic signature of the deglacial onset occurring at the same depth in the core. c) A model of the bioturbation impulse function as is may affect the top 30 cm of sediment idealized to be a Gaussian filter which passes through the data set. d) The impulse response function as bioturbation affects the δ^{18}O for *G. bulloides* (blue) and *G. inflata* (green). The effect of the bioturbation impulse on oxygen isotopes does not impact the timing of the isotopic deglacial onset, and it can be concluded that the offset in our actual record is not a result of bioturbation.

To remove the ice volume effect on the $\delta^{18}O_{calcite}$ the, $\delta^{18}O_{bul}$ as measured (‰VBD), must be converted to units of units of standard mean ocean water used in the measurement of global mean ice volume:

$$\delta^{18}O_{bul}(\text{‰ VBD}) = \delta^{18}O_{bul}\ (\text{‰ SW}) - 0.27$$

The ice volume effect on $\delta^{18}O_{bul}$ (SW) can be back calculated by using the published 30 kyr sea level reconstruction [*Peltier and Fairbanks*, 2006] and converting their sea level height values to an estimate of $\delta^{18}O_{SW}$ caused by the storage of ice at high latitudes:

$$\delta^{18}O_{ice}(SW)=SLH*(-0.011)$$

This provides the effect of the ice volume, as interpreted by sea level change. The storage of ice at high latitudes results in the enrichment of ocean isotopic values, and the negative signal must be added back to the $\delta^{18}O_{bul}$ (SW) to acquire a $\delta^{18}O$ that no longer reflects a change in ice volume ($\delta^{18}O_{equ}$):

$$\delta^{18}O_{bul} + \delta^{18}O_{ice}= \delta^{18}O_{equ}$$

The SST as inferred from the Mg/Ca calibration [*Schiraldi*, 2013] (**Figure S2**) was used to estimate the thermal effect on $\delta^{18}O_{calcite}$. Substituting this SST into the equation above [*Shackleton*, 1974] allows the calculation of $\delta^{18}O_{SW}$:

$$\delta^{18}O_{SW}\ (SW) = (T°C-16.9)/4.0 - \delta^{18}O_{calcite}\ (SW)$$

The resulting $\delta^{18}O_{SW}$ value now reflects only salinity and Rayleigh distillation and can be used to interpret the latitude and or salinity of the water masses [*Broecker and Peng*, 1993]. Combining the 1σ standard error of the SST calibration, 0.8°C, with the 1σ standard error of the $\delta^{18}O_{bul}$ calculation, .08‰, yields a 1σ standard error of $\pm$.21‰ in the $\delta^{18}O_{sw}$ calculation (**Figure S3**).

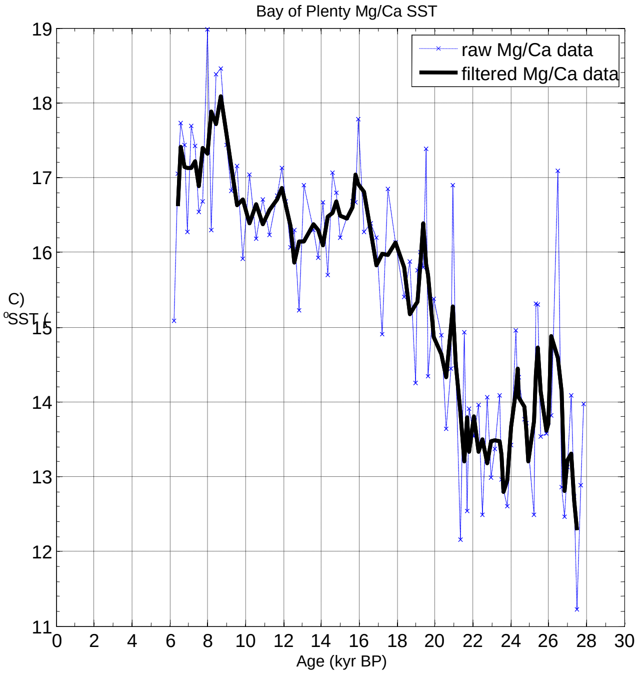


Figure S2 Mg/Ca based temperature estimates reported against age for core 87 JPC (dotted blue line), a 3-point running mean (solid black line).

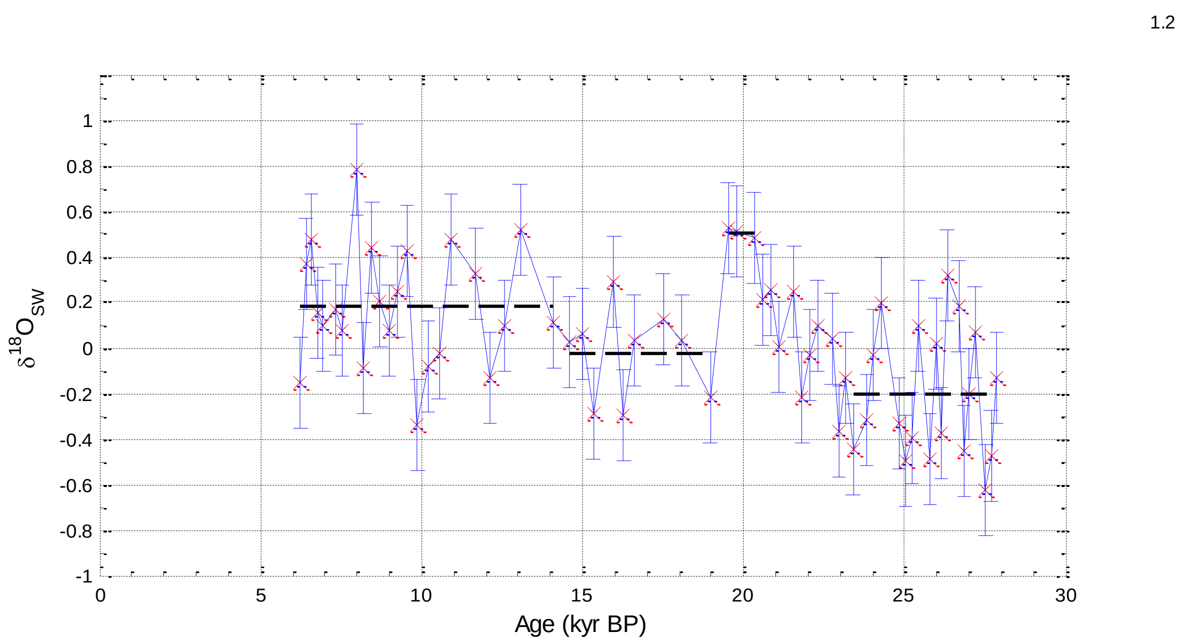


Figure S3| Reconstructed $\delta^{18}O$ of sea water ($\delta^{18}O_{SW}$) for core 87 JPC from the Bay of Plenty. In order to analyze $\delta^{18}O_{SW}$ the ice volume and temperature effect on $\delta^{18}O$ was first removed. The sea level reconstruction by Peltier and Fairbanks [2006] and the temperature equations of Shackleton et al. [1974] were used to remove these effects resulting in a reconstruction of $\delta^{18}O_{SW}$. The error bars reported are due to uncertainties in the variables input into these equations: $\delta^{18}O$ sea level estimation, the $\delta^{18}O$ of G. bulloides, and the Mg/Ca calibration. Four can be seen in the reconstruction (black dashed line). The one sigma error bar of $\pm 0.2‰$ associated with errors in the estimations translated through the $\delta^{18}O_{sw}$ calculation are shown.

Supporting Material References

Bé, A. W. H. (1977), An ecological, zoogeographic, and taxonomic review of Recent planktonic foraminifera, in *Oceanic Micropaleontology*, edited by A. T. S. Ramsay, pp. 1-100, Academic Press, San Diego, Calif.

Broecker, W. S., and T.-H. Peng (1993), What caused the glacial to interglacial CO_2 change?, in *The Global Carbon Cycle*, edited by M. Heimann, pp. 95-115, Springer-Verlag, New York.

Hutson, W. H. (1980), Bioturbation of deep-sea sediments: Oxygen isotopes and stratigraphic uncertainty, *Geology*, *8*, 127-130.

Peltier, W. R., and R. G. Fairbanks (2006), Global glacial ice volume and Last Glacial Maximum duration from an extended Barbados sea level record, *Quaternary Science Reviews*, *25*, 3322- 3337.

Schiraldi, B. (2013), A Multi-Proxy Look at Deglacial Southwest Pacific Ocean Sea Surface Temperature and Thermocline Source Water Changes, 156 pp, Rutgers University, unpublished.

Shackleton, N. J. (1974), Attainment of isotopic equilibrium between ocean water and the benthonic foraminifera genus Uvigerina: isotopic changes in the ocean during the last glacial, in *Les méthodes quantitatives d'étude des variations du climat au cours du Pléistocene*, edited by J. Labeyrie, pp. 203-209, Colloques Int. duc. N. R. S.

Thompson, P. R., and N. J. Shackleton (1980), North Pacific palaeoceanography: Late Quaternary coiling variations of planktonic foraminifer *Neogloboquadrina pachyderma*, *Nature*, *287*, 829-833.