

## **Tropical Sea Surface Temperatures following the Middle Miocene Climate Transition from Laser-Ablation ICP-MS analysis of glassy foraminifera**

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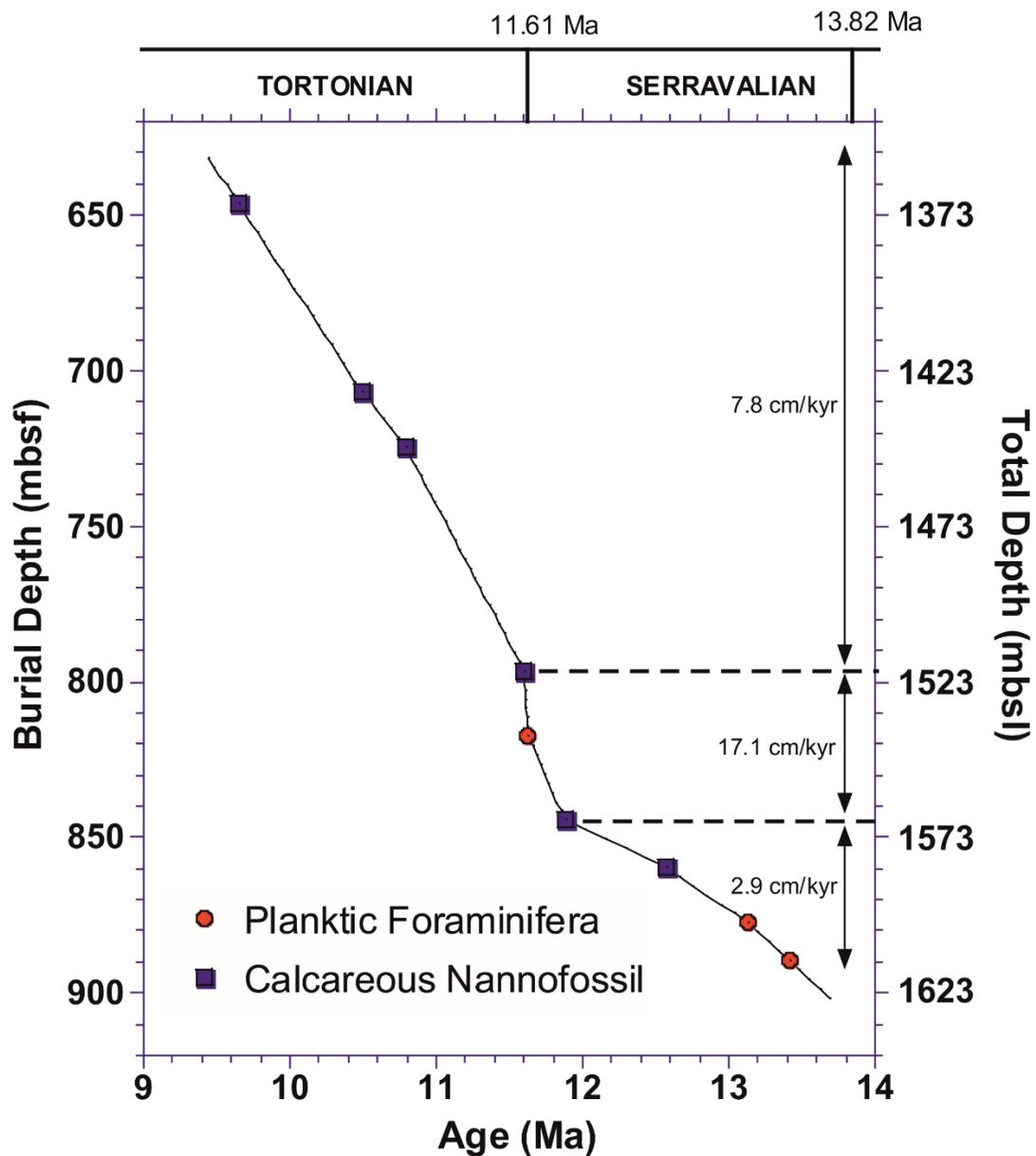
### **Additional Supporting Information (Files uploaded separately)**

Tables S1 to S3, and S5 to S9.

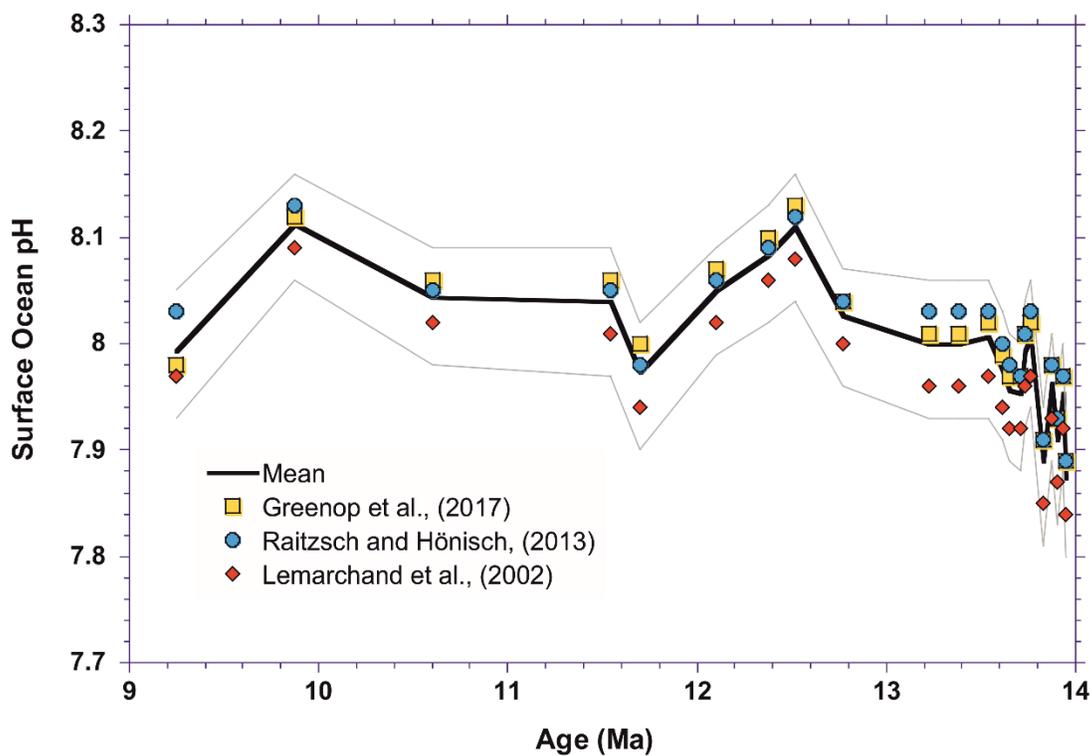
### **Introduction**

This supporting information contains the age-depth model for the Sunbird-1 well used in this study, a figure showing the surface pH record used to correct Mg/Ca for changes in the carbonate system, a figure showing the seawater Mg/Ca curve used to correct Mg/Ca for changes in seawater Mg/Ca, and a figure covariance between solution-based Mg/Ca ratios and those of Mn/Ca, Al/Ca, and U/Ca at Sunbird-1.

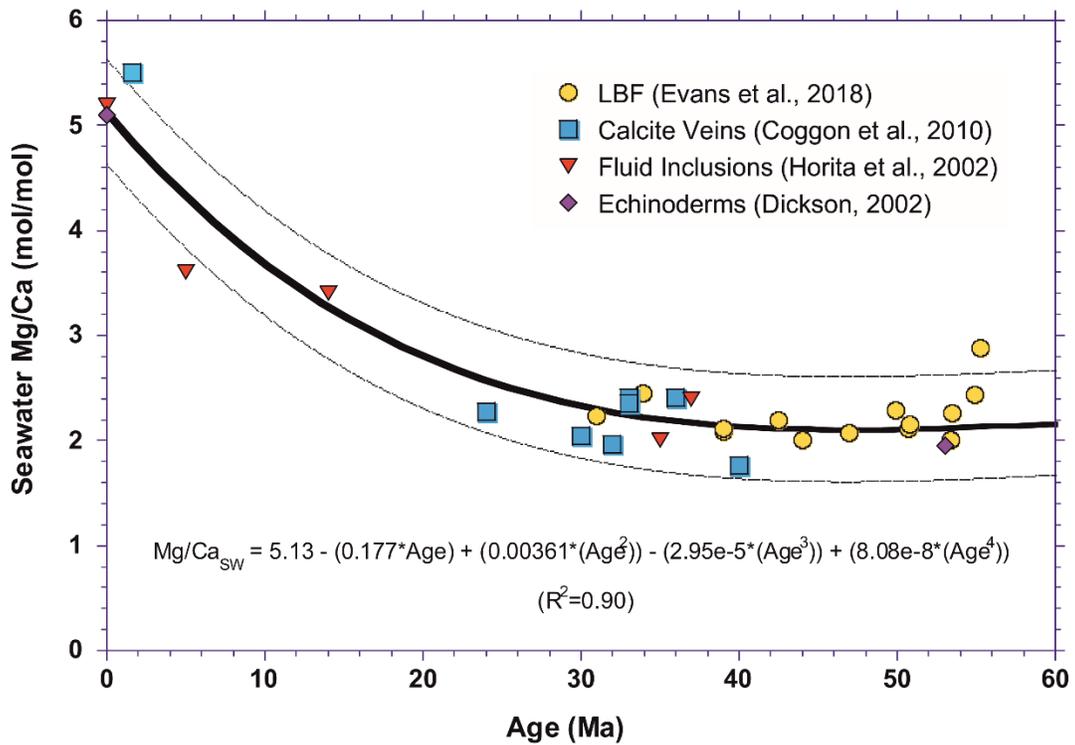
There are 9 data tables, with all but Table S<sub>4</sub> uploaded separately. Tables S<sub>1</sub> to S<sub>3</sub> show downcore % coarse fraction,  $\delta^{18}\text{O}$ , and solution-based ICP-MS data from Sunbird-1. Table S<sub>4</sub> shows the LA-ICP-MS parameters used. There are further tables of the LA-ICP-MS trace metal data for all profiles from the 1551-1554m sample, the downcore LA-ICP-MS Mg/Ca ratios for all samples, and the downcore LA-ICP-MS Mg/Ca ratios distinguishing between pooled and unpooled samples. The final two data tables are the sea surface temperature downcore records from LA-ICP-MS Mg/Ca data, and  $\delta^{18}\text{O}$  data.



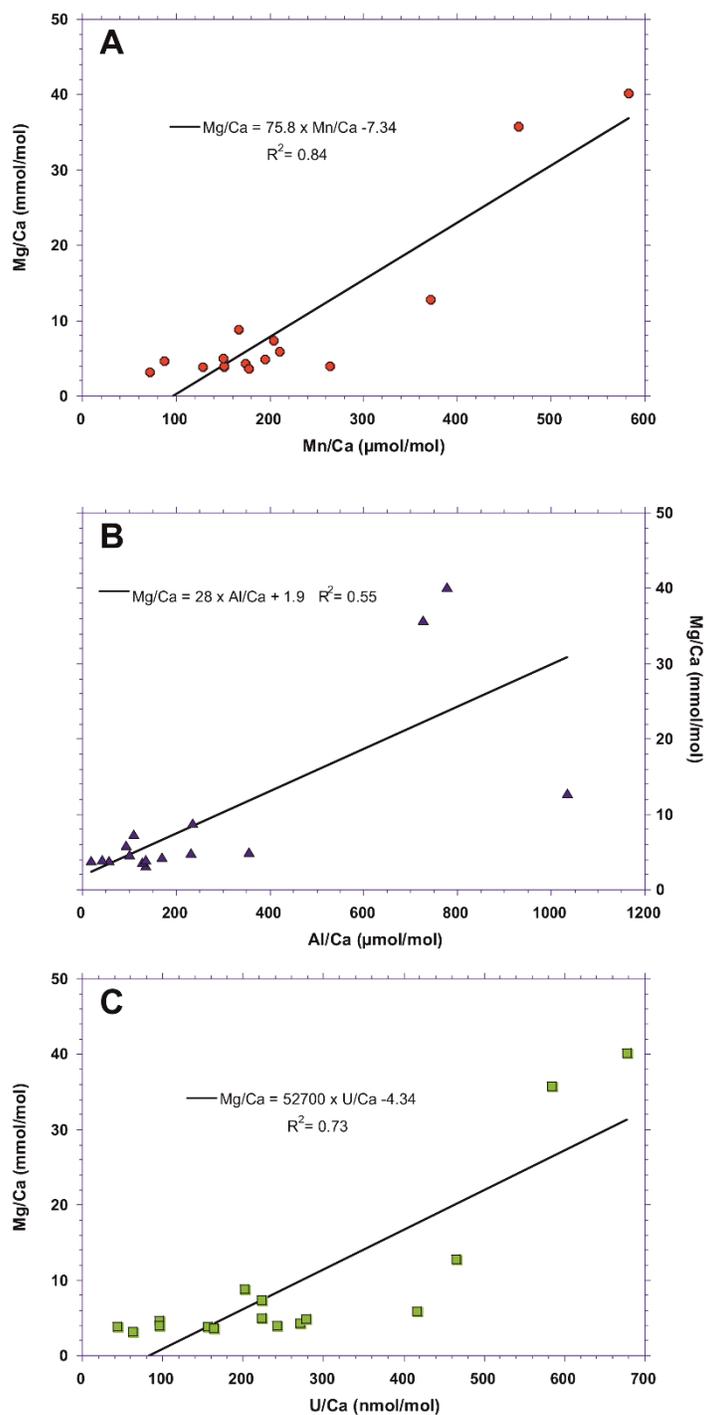
**Figure S1.** Age-depth model for Sunbird-1 using the biostratigraphic zonations of *Wade et al.* (2011) and *Backman et al.* (2012) on the geomagnetic polarity timescale of *Gradstein et al.* (2004) using linear interpolation between reliable biostratigraphic datums. Burial depth in the sediment and the total depth below the sea surface are given (water depth = 723m). Micropaleontological and calcareous nannoplankton assemblages for Sunbird-1 were analyzed by Haydon Bailey and Liam Gallagher of Network Stratigraphic Consulting.



**Figure S2.** Surface ocean pH determined using  $\delta^{11}\text{B}$  measurements on planktic foraminifera from a global distribution of open ocean sites (Sosdian et al., 2018). Three  $\delta^{11}\text{B}_{\text{SW}}$  scenarios are used (Greenop et al., 2017, Lemarchand et al., 2002, Raitzsch and Hönisch, 2013). Uncertainty envelopes denote the maximum and minimum pH at the 17% and 83% confidence interval, independent of the  $\delta^{11}\text{B}_{\text{SW}}$  scenario.



**Figure S3.** The evolution of seawater Mg/Ca ( $Mg/Ca_{sw}$ ) through the Cenozoic from records of large benthic foraminifera (LBF) (Evans et al., 2018) (yellow circles), calcite veins (Coggon et al., 2010) (blue squares), fluid inclusions (Horita et al., 2002) (red triangles), and echinoderms (Dickson, 2002) (purple diamonds). Fourth order polynomial fit (thick black line) through the compiled data. The thin lines represent a  $\pm 0.5$  mol/mol uncertainty window used in the following temperature calculations.



**Figure S4.** Covariance plots between *D. altispira* Mg/Ca and (a) Mn/Ca (red circles), (b) Al/Ca (blue triangles), and (c) U/Ca (green squares) from solution-based ICP-MS. R<sup>2</sup> correlations for all plots are given.

**Table S1:** Weighed coarse fraction (% >63 $\mu\text{m}$ ) in the Sunbird-1 core. The 1353-1356m, 1356-1359m, and 1575-1578m samples (marked by an asterisk) were rejected due to the presence of concrete, emplaced by the drilling process, artificially raising the % coarse fraction.

**Table S2:** *Globigerinoides obliquus*  $\delta^{18}\text{O}$  ratios in the Sunbird-1 core. Foraminiferal abundance from thirteen samples (marked with an asterisk) was insufficient for analysis.

**Table S3:** Solution-based *Dentoglobigerina altispira* trace metal/calcium ratios from Sunbird-1. We distinguish between those cleaned with and without the reductive cleaning step.

#### ICP-MS: Thermo Element XR

|                                      |                    |
|--------------------------------------|--------------------|
| RF Power                             | 1300 Watts         |
| Torch Position (X, Y, Z)             | 2.5, -0.2, -4.5 mm |
| Argon Carrier Flow (optimised daily) | ~0.90 l/min        |
| Argon Coolant Flow                   | 14 l/min           |
| Argon Auxiliary Flow                 | 0.80 l/min         |
| Sweep Time                           | 350 ms             |
| Cones                                | Ni                 |

#### Laser Ablation System: RESolution S-155

|                                   |                       |
|-----------------------------------|-----------------------|
| Helium Flow                       | 350 ml/min            |
| N <sub>2</sub> Flow               | 4 ml/min              |
| Spot Size                         | 50 $\mu\text{m}$      |
| Scan Speed                        | 3 $\mu\text{ms}^{-1}$ |
| Fluence                           | 3.5 $\text{Jcm}^{-2}$ |
| Repetition Rate                   | 2.0 Hz                |
| ThO <sup>+</sup> /Th <sup>+</sup> | <0.4%                 |
| U <sup>+</sup> /Th <sup>+</sup>   | ~1                    |

**Table S4.** Operating parameters of LA-ICP-MS for *Dentoglobigerina altispira* analyses. ICP-MS parameters were optimized daily during tuning, and typical operating values are stated.

**Table S5.** *Dentogloboquadrina altispira* LA-ICP-MS Mg/Ca ratios from the 1551-1554m sample in the Sunbird-1 core. Up to 10 profiles through 10 tests were analyzed for each species. Highlighted samples were excluded due to elevated Mn/Ca and/or Al/Ca ratios.

**Table S6.** Summary of *Dentogloboquadrina altispira* Mg/Ca ratios in the Sunbird-1 core from LA-ICP-MS analyses. Highlighted samples do not contain the required number of profiles for the Mg/Ca value to be considered representative for the sample.

**Table S7.** Summary of pooled and unpooled *Dentogloboquadrina altispira* mean Mg/Ca ratios in the Sunbird-1 core from LA-ICP-MS analyses. Minimum and maximum age refer to the age range of the pooled samples (Table 1).

**Table S8.** Sea Surface Temperatures calculated from the unpooled and pooled *Dentogloboquadrina altispira* mean Mg/Ca ratios in the Sunbird-1 core from LA-ICP-MS analyses (Supplementary Table S7). Minimum and maximum age refer to the age range of the pooled samples (Table 1). pH is calculated by linear interpolation between the pH measurements of *Sosdian et al.* (2018) (Supplementary Figure S2). pH corrected Mg/Ca is calculated using the multi-species calibration of *Evans et al.* (2016) (Equation 1). Seawater Mg/Ca is calculated from this study using Supplementary Figure S3. The pre-exponential (B) and exponential (A) constants of the Mg/Ca-temperature calibration are calculated using the calibration of *Evans et al.* (2016b), (Equation 2 and 3). Temperature is calculated as  $\ln((\text{Mg/Ca})/B)/A$ , using the values of B and A calculated in the previous columns. Maximum and Minimum temperatures refer to the full range of absolute temperatures derived incorporating the analytical and calibration uncertainty. Analytical Error Only Maximum and Minimum temperatures refer to the range of temperatures derived from the analytical and analytical uncertainty only.

**Table S9.** Supplementary Table S9: Sea Surface Temperatures calculated from *Globigerinoides obliquus*  $\delta^{18}\text{O}$  ratios in the Sunbird-1 core (Supplementary Table S2) using the calibration of *Bemis et al.* (1998) (Equation 4). Calibration uncertainty includes  $\pm 0.091$  ‰ due to any potential influence of salinity (*LeGrande and Schmidt, 2006*) and seawater  $\delta^{18}\text{O}$  (*Cramer et al. 2011*). This  $\delta^{18}\text{O}_{\text{SW}}$  was converted from VSMOW to VPDB by incorporating a  $-0.27$  ‰ correction (*Hut, 1987*). Maximum and Minimum temperatures refer to the full range of absolute temperatures derived incorporating the analytical and calibration uncertainty. Analytical Error Only Maximum and Minimum temperatures refer to the range of temperatures derived from the analytical uncertainty only.