# Supplementary Information

*Sampling strategy*

Our study is based on middle Miocene marine sediments recovered at Site U1338 (2°30.469′N, 117°58.178′W; 4200 m water depth) during IODP PEAT Expedition 321. Detailed site location, core recovery and lithological descriptions can be found in Pälike et al. (2010). Cores were sampled in ~5 cm intervals from a composite sequence (shipboard splice) from Holes U1338A, U1338B and U1338C (331.43 – 435.90 meters composite depth).

*Isotope analysis*

The $\delta^{18}O$ and $\delta^{13}C$ profiles from Site U1338 are plotted versus depth in Supplementary Fig. 1. Age tie points are given in Figures 1-2 and Supplementary Figs. 1-2. An expanded view of the late MCO interval (16-14.7 Ma) is provided in Supplementary Fig. 3. The average sedimentation rate is ~3.8 cm/kyr (1.8 to 6.0 cm/kyr). Orbital tuning and calculation of sedimentation rates were performed with AnalySeries 2.0.4.2 (Paillard et al., 1996).

*Time series analysis*

Wavelet software was provided by C. Torrence and G. Compo, and is available at URL: http://atoc.colorado.edu/research/wavelets/. Details of wavelet analysis are provided in Torrence and Compo (1998).

*Opal (biogenic silica) measurements and accumulation rates*

Samples for the analysis of opal were freeze-dried and ground in an agate mortar.

Opal content was determined by the sequential leaching technique of DeMaster (1981) with further modifications by Müller and Schneider (1993).
The opaline material is extracted with 1M NaOH at 85ºC in a stainless steel vessel under constant stirring, and the increase in dissolved silica is continuously monitored. For this purpose, a minor portion of the leaching solution is cycled to an autoanalyzer and analyzed for dissolved silicon by molybdate-blue spectrophotometry. The resulting absorbance versus time plot is then evaluated according to the extrapolation procedure of DeMaster (1981).

Opal accumulation rates were calculated as follows:
Opal accumulation rate = linear sedimentation rate x density (from GRAPE density data in Pälike et al., 2010) x opal weight percentage
Opal weight percentages were estimated using the 5 point running average opal (weight %) to Log(Si/Ti) power relationship ($y=1.4923*x^{3.203}$, $R^2=0.81969$) in Supplementary Fig. 4.

**References**

DeMaster, D. J., 1981. The supply and accumulation of silica in the marine environment. Geochimica et Chosmochimica Acta, v. 45, p. 1715-1732.

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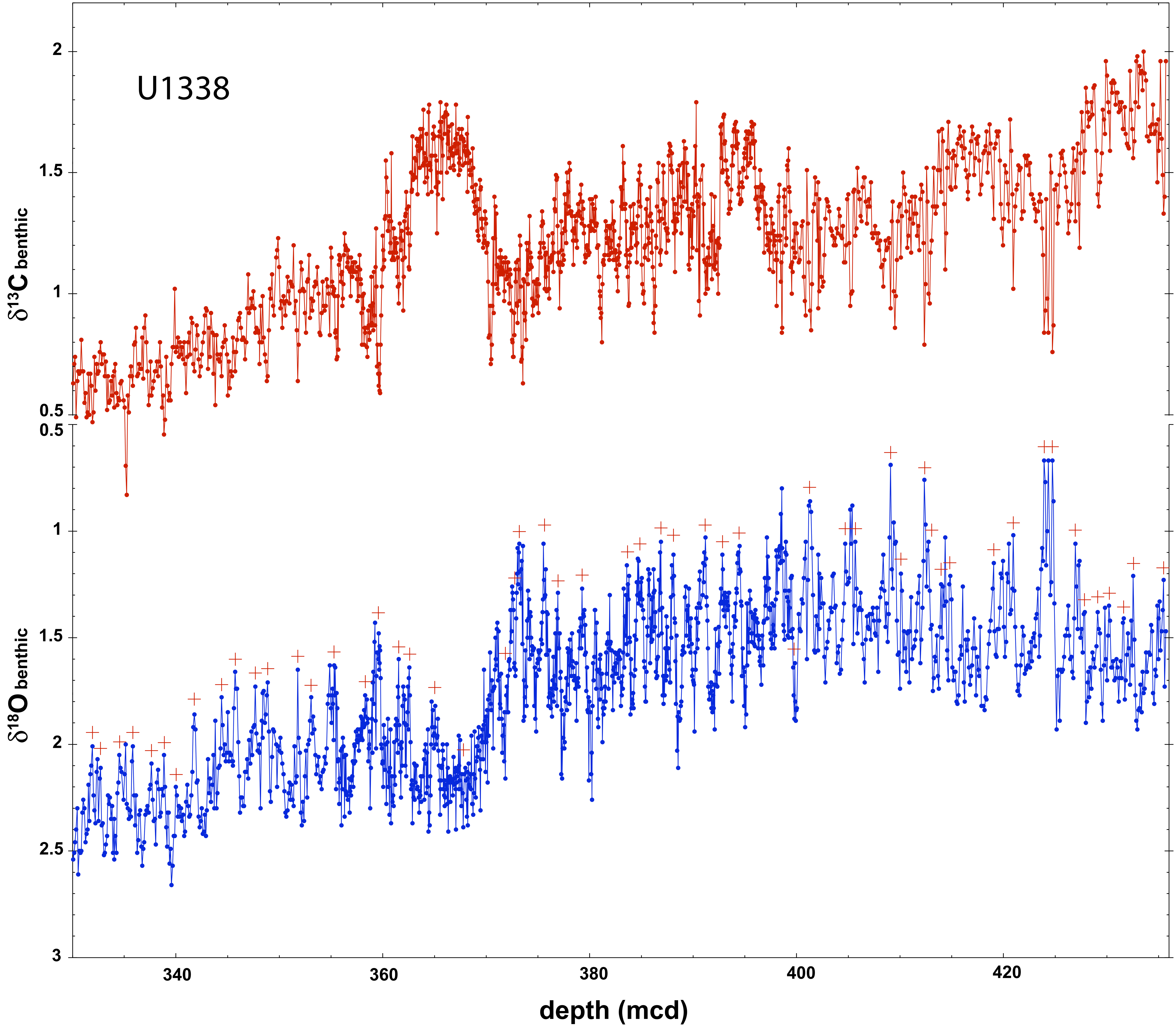
**Supplementary Figure captions**

**Supplementary Figure 1:** IODP Site U1338 benthic $\delta^{13}C$ (**a**) and $\delta^{18}O$ (**b**) records versus composite depth (mcd). Red crosses indicate age control points. CM6 represents the last and most prominent 400 kyr $\delta^{13}C$ maximum of the "Monterey Excursion".

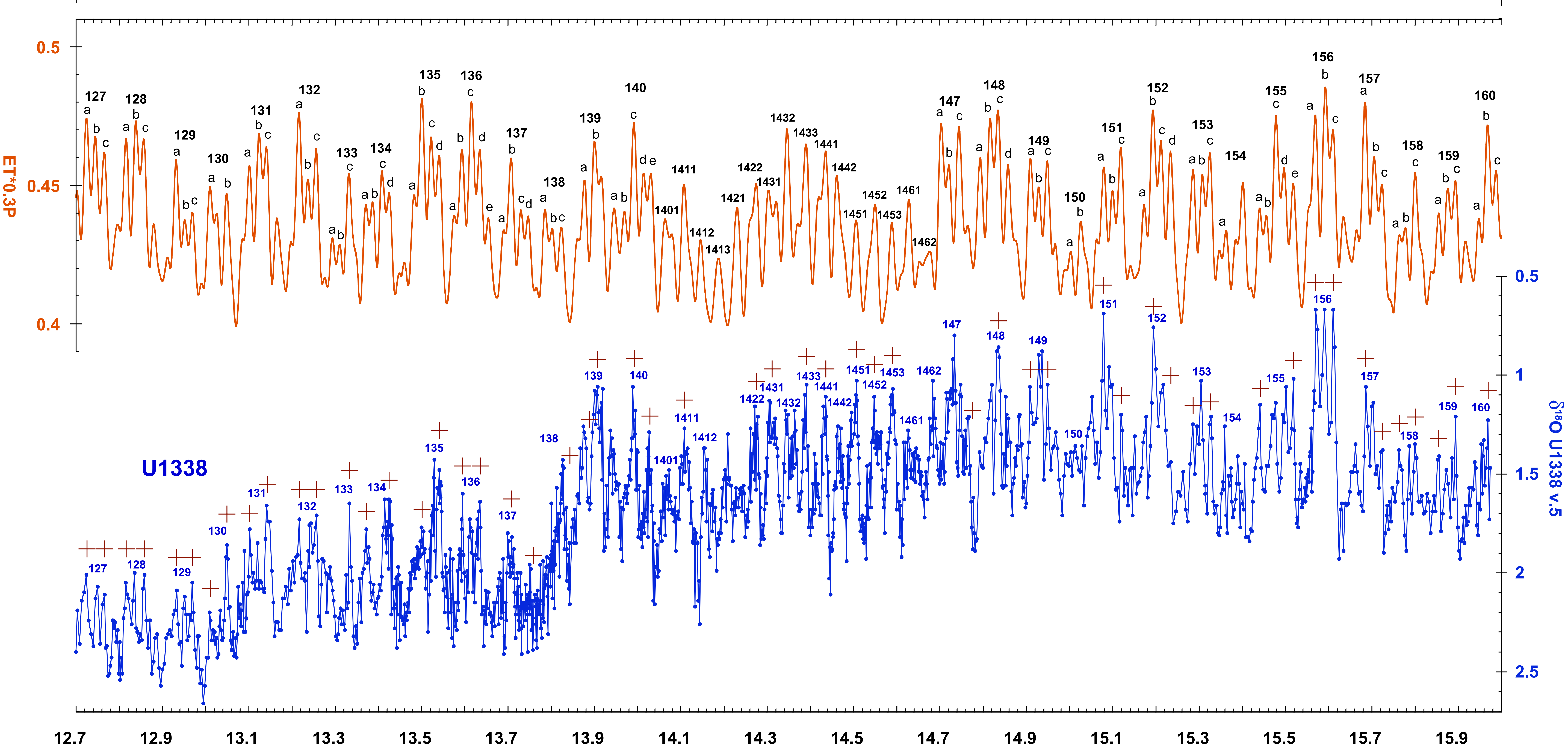
**Supplementary Figure 2:** Astronomically-tuned chronology over middle Miocene interval (16-13 Ma) in IODP Site U1338. (**a**) Eccentricity-tilt-precession tuning target (ET+0.3P) over interval 16 Ma and 12.7 Ma from Laskar et al. (2004). (**b**) IODP Site U1338 benthic $\delta^{18}O$ record. Red crosses indicate age control points. Eccentricity and obliquity maxima are labeled with numbers, precession maxima modulated by eccentricity are labeled with letters.

**Supplementary Figure 3:** Expanded view of late MCO interval (16-14.7 Ma) at IODP Site 1338. (**a**) Silica content expressed as Log(Si/Ca). (**b**) Proportion of sediment coarse (>63 μm) fraction. (**c**) Carbonate percentages calculated from XRF and GRAPE density data from Lyle et al. (2012). (**d**) Benthic foraminiferal $\delta^{13}C$. (**e**) Benthic foraminiferal $\delta^{18}O$. (**f**) Sedimentation rates. (**g**) Eccentricity-tilt-precession tuning target (ET+0.3P) from Laskar et al. (2004). Orange shading marks warm intervals, characterized by intense $\delta^{18}O$ and $\delta^{13}C$ minima, poorer carbonate preservation, lower sedimentation rates and higher Log(Ti/Ca) at eccentricity maxima.

**Supplementary Figure 4:** Relationships of opal weight percentages to XRF scanner derived Log(Si/Ti) at IODP Site 1338. Regressions were calculated using 2.5 cm resolution (**a, c**) and 5 point moving average smoothed (**b, d**) XRF scanner records. Linear regressions exhibit good correlations at low opal percentages, but tend to overestimate intermediate and to underestimate high opal values. Exponential regressions tend to overestimate high opal values, while power regressions exhibit highest $R^2$ and best fit at intermediate and high values.

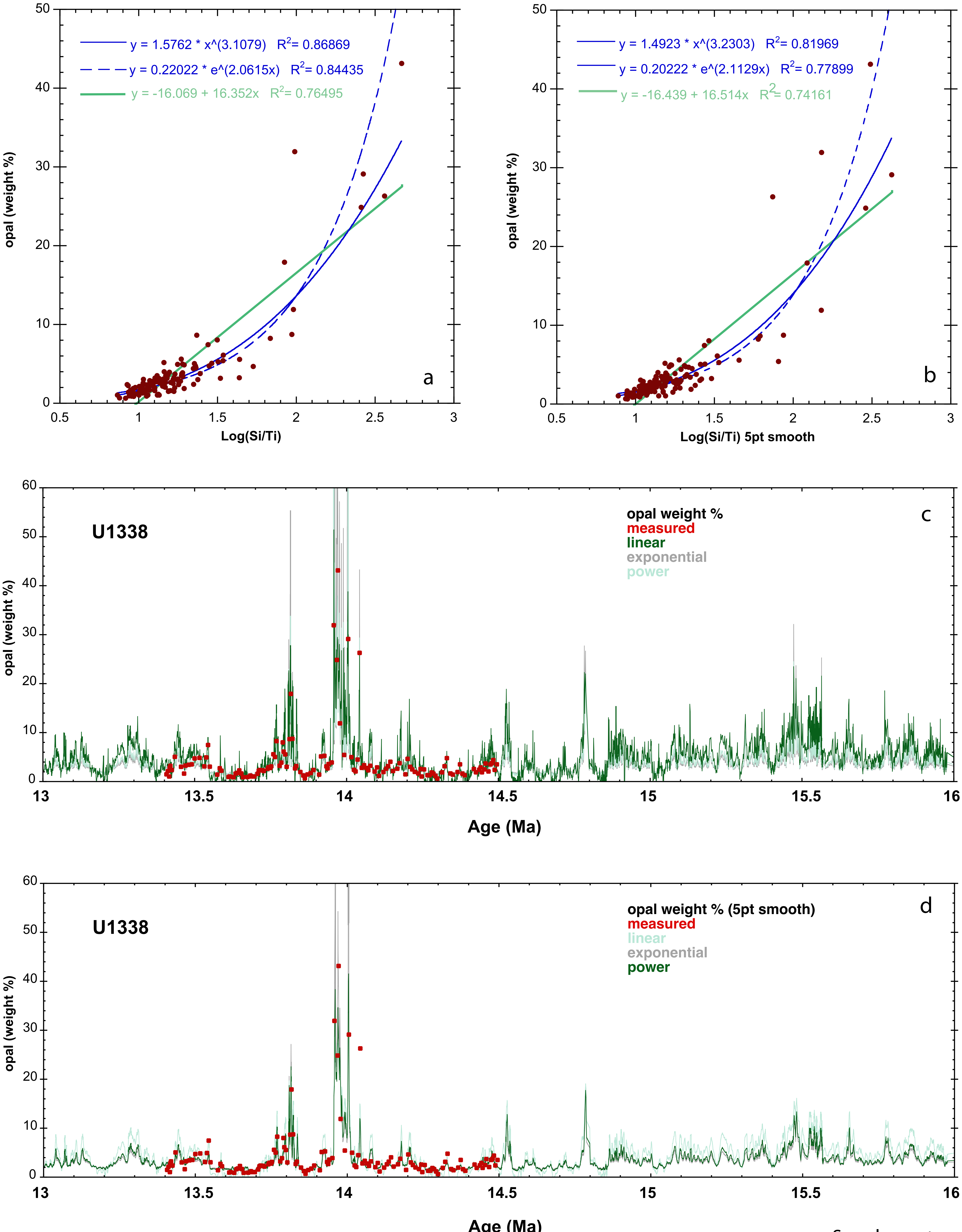



Supplementary Figure 1




Supplementary Figure 2


Supplementary Figure 3




Supplementary Figure 4