High Interglacial Diatom Paleoproductivity in the Western Indo-Pacific Warm Pool During the Last Glacial Cycle

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To assess paleoproductivity changes in the westernmost Indo-Pacific Warm Pool (IPWP), we study variations of diatom production during the past 130,000 years off southern Sumatra (Figure 1).

Our study

1) compares the diatom valve concentration with the quantitative shifts in the species composition, and

2) resolves glacial-interglacial variations of the paleoproductivity of diatoms and its relation with the monsoon system, upwelling intensity, and nutrient (silica) availability.

Core location and surface currents

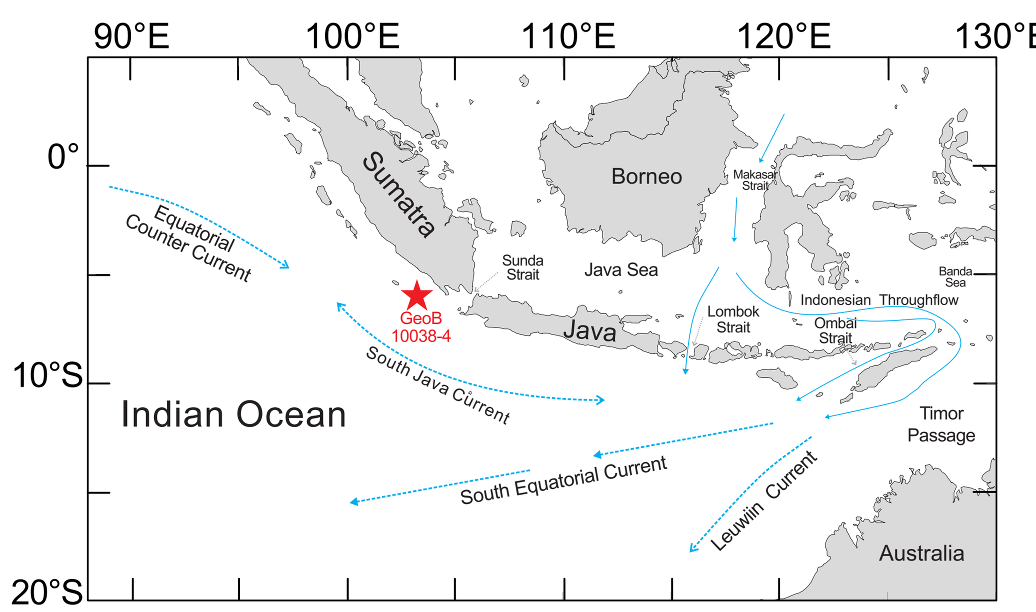

Figure 1. Location of core site GeoB10038-4 (orange star; 5º56.25'S, 103º14.76'E; 1819 m water depth) with surface currents (blue dashed arrows), and main geographic locations.

Dynamics of nutrients off southern Sumatra

During boreal summer (SE monsoon), high chlorophyll and the highest silica concentrations are recorded (Fig. 2E, H). This corresponds well with the Ekman offshore transport along the coast of SW Sumatra transporting nutrient-rich waters from deeper layers into the euphotic zone (Hendiarti et al., 2004).

During the NW monsoon season (boreal winter), the chlorophyll and silica concentrations remain low (Fig. 2B, F). From April through May (intermonsoon, Fig. 2C, G), lowest chlorophyll and silica concentrations occur, while values are still high between October and December (intermonsoon, Fig. 2E, I), due to the more nutrient-rich waters following the SE monsoon season (Hendiarti et al., 2004).

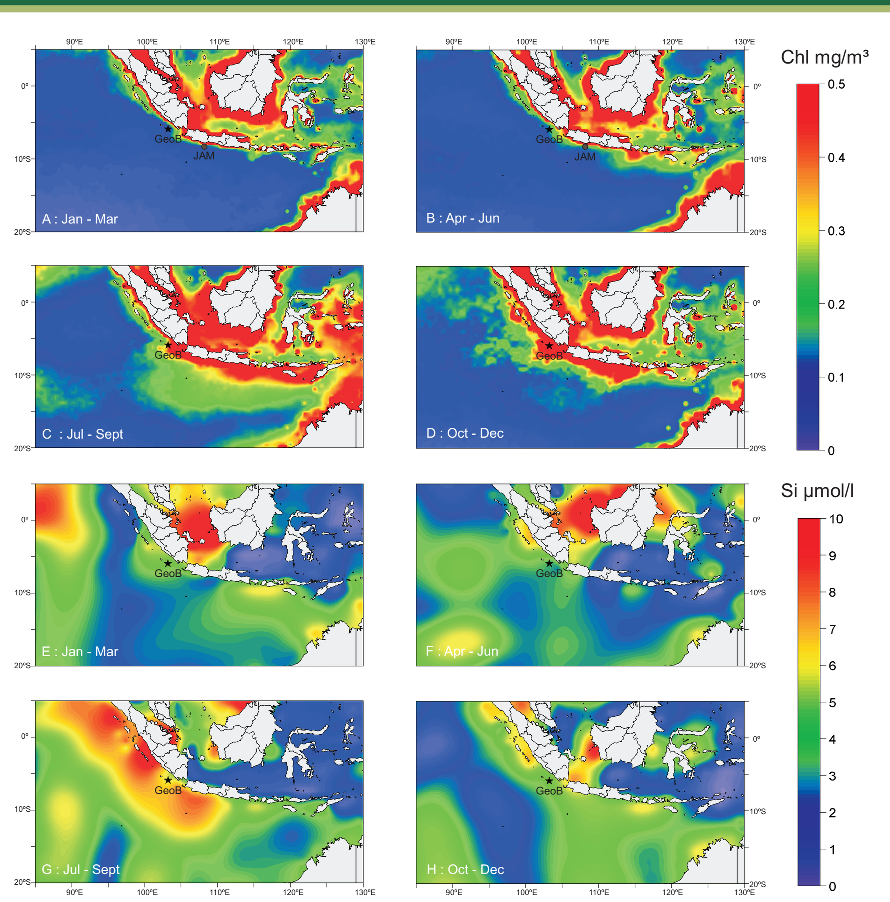

Figure 2. A-D: Seasonally averaged concentration of chlorophyll a (mg/m3) from the years 1998-2009 in 9 by 9 km resolution (acquired from Goddard Space Flight Center, http://oceancolor.gsfc.nasa.gov/SeaWIFS). E-H: Seasonally averaged concentration of surface silicate (µmol/l1) in 1 by 1 degree resolution (World Ocean Atlas, 2005, http://www.nodc.noaa.gov)

Variations of Diatom Paleoproductivity

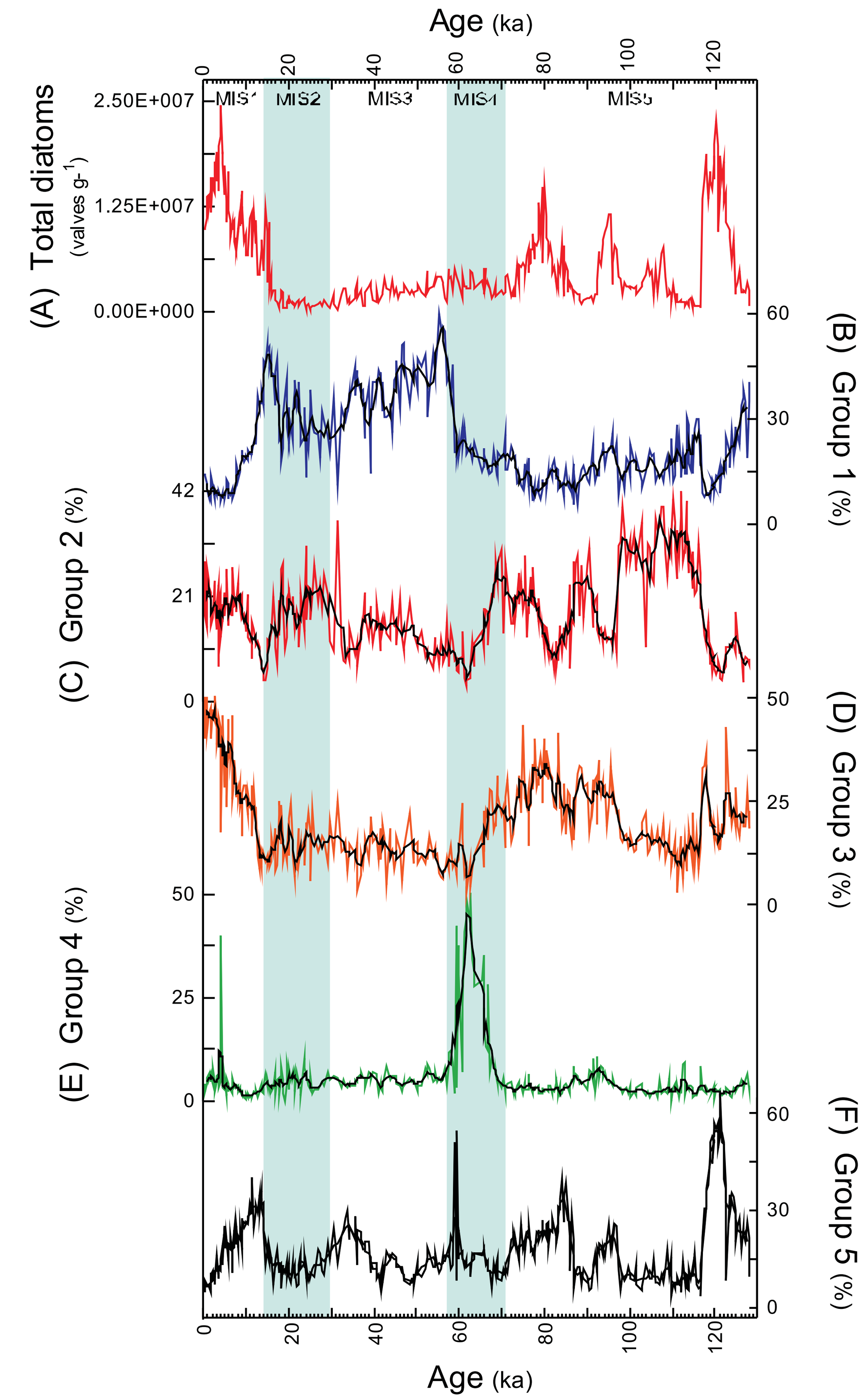

Figure 3. (A) Total diatom concentration (red line) and (B-F) relative contribution (%) of the five main diatoms groups (for the qualitative composition of each diatom group see the table below). The black foreground line in B-F represents the five-point running average. Marine isotopic stage (MIS) boundaries are defined after LR04-Stack (Liesiecki and Raymo, 2005). Glacial stages 2 and 4 are indicated by the light blue shadings.

Diatom groups build with Principal Component Analysis at site GeoB10038-4 and main oceanographic/atmospehric conditions.

Group	Variance (%)	Species	Main oceanographic/atmopsheric conditions
1	27.54	*Alveus marinus, Azpeitia barronii, Azpeitia nodulifera, Cyclotella litoralis, Fragilariopsis doliolus, Rhizosolenia bergonii, Roperia tesselata, Thalassiosira ferelineata, Thalassiothrix longissima*	Weakened winds, increased SST, increased mixed layer depth (MLD). Typical of the intermonsoon seasons
2	23.71	*Nitzschia bicapitata, N. interruptestriata, Paralia sulcata, Planktoniella sol, Thalassionema nitzschioides* var. *inflata, Thalassiosira lineata*	Weak upwelling, deep MLD. Early and late stages of NW and SE monsoon seasons.
3	13.89	RS of *Chaetoceros compresus*, RS of *Chaetoceros* sp. 1, *Thalassionema nitzschioides* var. *nitzschioides, T. nitzschioides* var. *parva*	Decreased frehwater discharge, weakened upwelling. Reflect the NW monsoon season.
4	9.41	*Actinocyclus octonarius, Thalassionema bacillare, T. frauenfeldii*	No particular atmospheric and/or oceanographic setting.
5	6.87	*Actinocyclus curvatulus, Azpeitia tabularis*, RS *Chaetoceros pseudobrevis, Thalassiosira oestrupii* var. *oestrupii*	High-productive, nutrient-rich waters, coastal upwelling. Reflect the SE monsoon season

Throughout the last glacial-interglacial cycle, the total diatom concentration varies on both the glacial-interglacial and the millennial and sub-millennial timescales (Fig. 3A). Highest diatom values are observed during MIS 5.5, 5.3, 5.1 and MIS 1. The 13 ka and ~23 ka cyclicity recorded between 130 and ~80 ka (Figure 4A, B) suggests the linkage between Northern Hemisphere precession-driven insolation and changes in diatom paleoproduction along southern Sumatra to have been closer during full interglacials (MIS 5).

Paleoceanographic Significance of Species Shift

The temporal distribution of the diatom groups (Fig. 3, B-F) does not allow identifying a unique dominant group during periods of diatom maxima (Fig. 3A). Some long-time temporal trends are seen. The good match between the distribution of upwelling-related group 5 (Fig. 3A, see also table) and maximum June insolation at 30ºN from late MIS 5 through early MIS 1 (Fig. 5B, C) evidences the close correspondence between diatom paleoproductivity off southern Sumatra and Northern Hemisphere summer insolation. This interpretation is supported by the (half)precessional periodicity of group 5 (Fig. 4I, J).

Highest contribution of the oligo-mesotrophic group 1 from early MIS 4 through late MIS 2 (Fig. 3B) matches well the lowest total diatom concentration, hence reflecting the weakening of the upwelling along southern Sumatra. The spectral signal of group 1 delivered in the ~23 ka band (stronger between 130 and 50 ka, Fig. 4C, D) suggests that, independent of the glacial-interglacial pattern of variability, diatoms in waters overlying site GeoB10038-4 responded to periods of strengthened intermonsoon throughout the last 130 ka.

Complementary to group 1, highest relative values of group 2 during insolation minima (Fig. 5C, D) are interpreted as the response of diatoms to the weakening of monsoon winds following the relaxation of the atmospheric pressure gradient over eastern Asia.

Conclusions

- First late Pleistocene diatom record from low-latitude oceans with predominant interglacial over glacial diatom productivity.

- The Northern Hemisphere summer insolation, the migration of the monsoon system, and the nutrient content of the upwelled waters led the dynamics of diatom productivity in the westernmost IPWP during the last glacial-interglacial cycle.

- Relevance of producing high-resolution diatom data in order to test the effect of wind strength and migration, and the nutrient availability on diatom productivity on both the Milankovitch and sub-Milankovitch timescales.

References

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Spectral Analysis

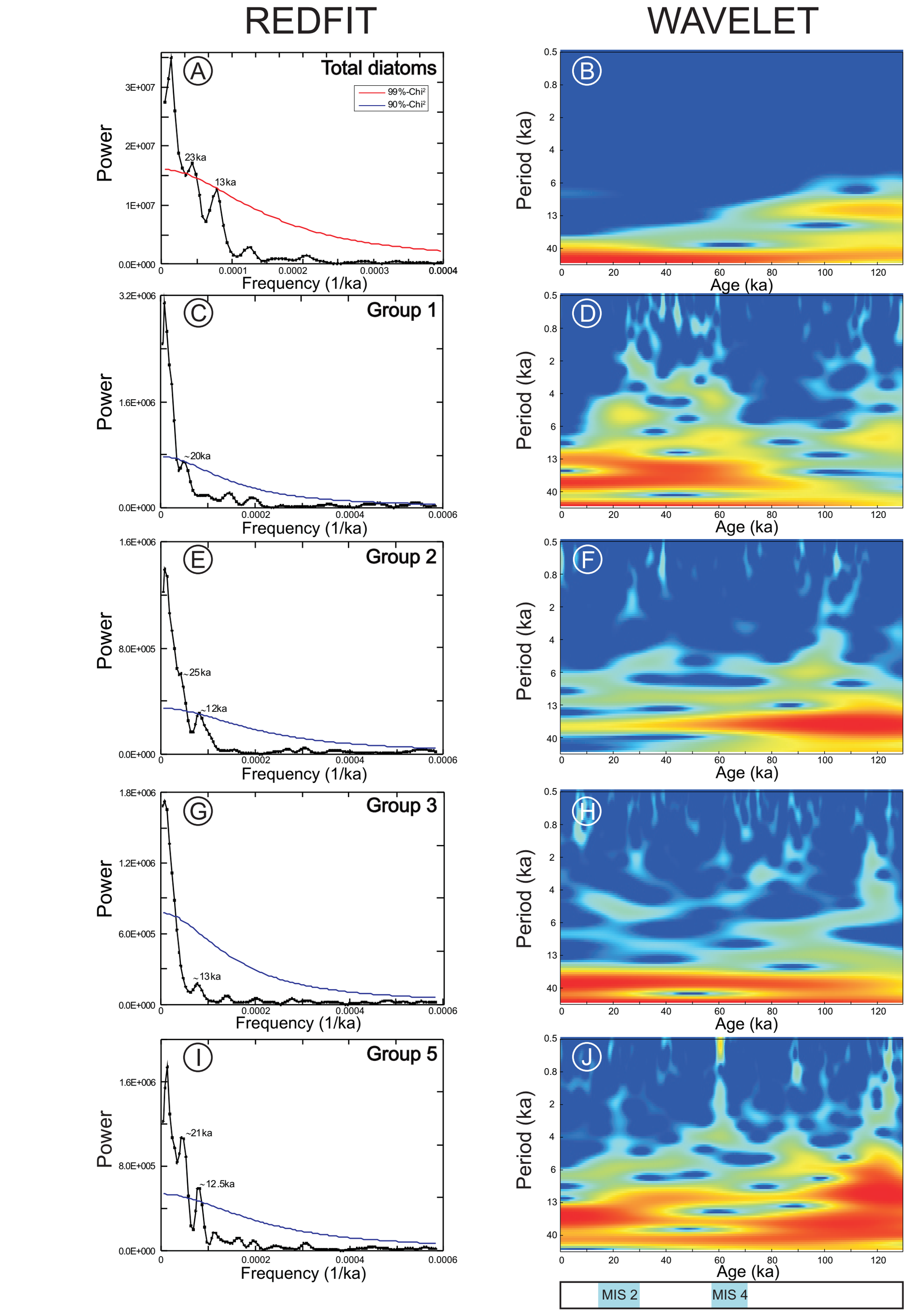

Figure 4. Spectral analysis of total diatom concentration (A, B), and diatom groups (E-J) at site GeoB10038-4 using the software programs REDFIT and Wavelet.

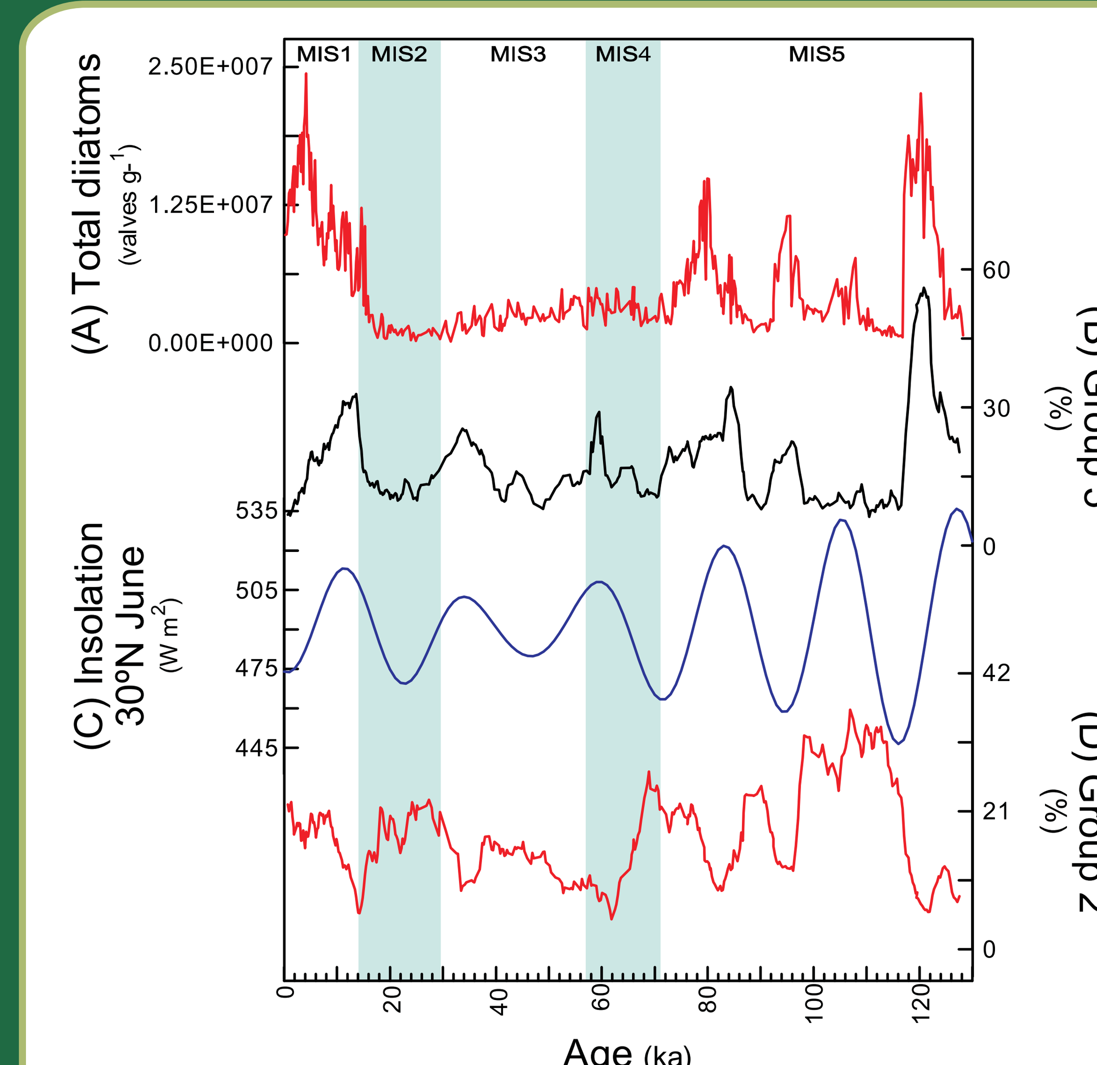

Figure 5. (A) Total diatom concentration (red line, GeoB10038-4), (B) five-point running average oF Group 5 (black line, GeoB10038-4), (C) June insolation, 30ºN (W/m^2, blue line) (Berger and Loutre, 1991), and (D) five-point running average of Group 2 (red line, GeoB10038-4). Glacial stages 2 and 4 are indicated by the light blue shadings.

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