Alkenone Paleotemperatures in the Eastern Tropical Pacific Since the LGM: Magnitude and Timing of Deglacial Warming

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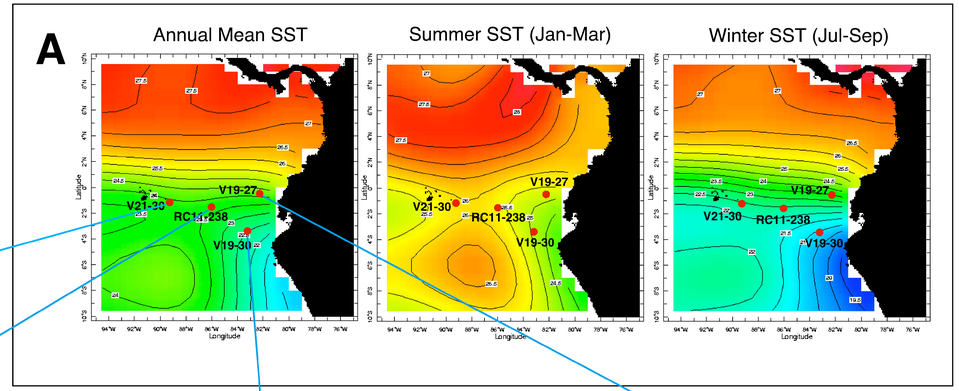
Paper #: PP11A-0202

ABSTRACT. High productivity and relatively cool tropical temperatures in the upwelling environment of the eastern equatorial Pacific (EEP) make alkenone paleothermometry (based on the unsaturation index Uk'_{37}) an attractive method for reconstructing past sea surface temperatures (SST). However, because of the complex temporal and spatial ocean dynamics in this region, interpretation of Uk'_{37} data requires careful consideration of production and sedimentation processes affecting alkenone delivery and burial in seafloor sediments. Here we report new results from application of this method in four EEP cores (V21-30, V19-27, V19-30, RC11-238) spanning the last 30,000 years. Results indicate a range of Last Glacial Maximum cooling between 1.3° and 2.8°C relative to present, while the timing of deglacial warming is generally in phase with planktonic $\delta^{18}O$, within the resolution of the records. A warming trend through the Holocene is evident in a site offshore Ecuador (V19-27), which supports the idea of a cooler early-middle Holocene due to more persistent upwelling and weaker ENSO. Core-top alkenone SST values are in general warmer than annual mean modern temperatures, possibly indicating a seasonal production bias or lateral delivery of alkenones from warmer waters north of the equator. While attesting to the essential robustness of alkenone paleothermometry in this region, these results also underscore the need for more systematic study and evaluation of this method as a monitor of regional paleoceanographic change.



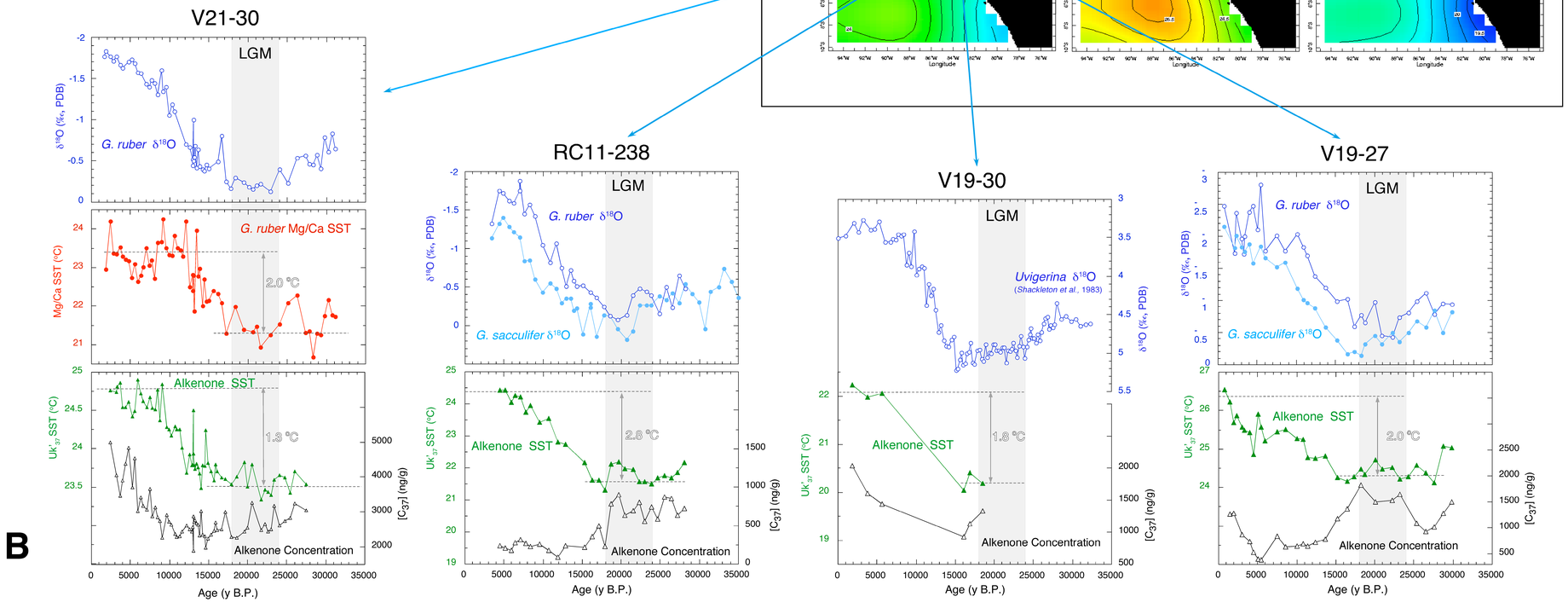
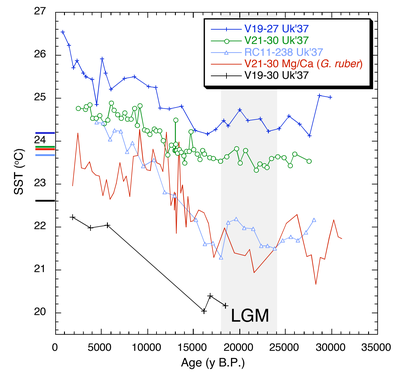


Figure 1. (A) Location of sites relative to modern SST structure (annual mean, summer, and winter). The pronounced seasonal SST cycle (up to 5°C) results from intensified divergent upwelling during Jul-Sep, when strengthened southeast trades blow northward across the equator (e.g. *Chelton et al.*, 2001). The studied sites lie directly under the cool upwelling province of the equatorial cold tongue which is typically centered 1°-2° south of the equator, and are thus optimal for recording G-I SST variability associated with equatorial upwelling. **(B) Temperature reconstructions from the studied cores.** SST estimates based on the alkenone unsaturation ratio Uk'_{37} (defined as [C37:2]/[C37:2+C37:3]) are shown in green. Alkenone SST is calculated using the calibration of *Prahl et al.,* (1988). G-I alkenone SST amplitudes vary substantially among sites, ranging from 1.3°C in V21-30 to 2.8°C in RC11-238. These two sites also display dramatic differences in total alkenone concentration ($[C_{37}]$, with V21-30 having 3-fold higher $[C_{37}]$ than RC11-238 in the glacial intervals and up to 20-fold higher in the Holocene. The G-I concentration trends are opposite in the two sites, increasing in V21-30 and decreasing in RC11-238. The extremely high $[C_{37}]$ values in V21-30 are in part attributable to the site's shallow depth (617 m) and proximity to the oxygen minimum zone. V19-27 and V19-30 display similar LGM-Holocene SST amplitudes of ~2.0°C, but opposite concentration trends. Comparison of the alkenone SST histories from all sites with their respective $\delta^{18}O$ stratigraphies shows no clear evidence of a temperature lead or lag relative to $\delta^{18}O$. The planktonic (*G. ruber* and *G. sacculifer*) $\delta^{18}O$ data and age models of V21-30, RC11-238, and V19-27 are from *Koutavas and Lynch-Stieglitz* (2003). The benthic $\delta^{18}O$ data and age model of V19-30 are from *Shackleton et al.,* (1983). The LGM time slice is selected as the interval 24,000-18,000 y B.P. The *G. ruber* Mg/Ca SST data of V21-30 (red) were obtained with the calibration of *Nürnberg et al.,* (1996). Core depths are as follows: V21-30, 617 m; RC11-238, 2573 m; V19-30, 3091 m; V19-27, 1373 m.

Figure 2. Composite of all SST records on a common scale. In this figure four Uk'_{37} and one Mg/Ca SST records from the studied sites are plotted on common temperature and age scales. Color bars on the SST axis mark modern annual mean SST values at each site from the *Levitus and Boyer* (1994) climatology. A variety of patterns are discernible in the data:



(1) In 3 of the 4 studied cores, core-top Uk'_{37} temperatures overestimate annual mean SST (by 0.8°-2.2°C) although they are generally within the seasonal range observed over each station. This may indicate a warm season bias in alkenone production. An alternate possibility which needs to be ruled out is that lateral transport of alkenones is occurring from the warmer waters north of the equator (Figure 1A). In this context we note that the southernmost site (V19-30, black) which is farthest removed from the equatorial SST front does *not* display a warm core-top bias.

(2) All of the SST data series show clear G-I warming trends which in most cases continue through the Holocene. The amplitude of deglacial SST change ranges between 1.3° and 2.8°C, and in no case exceeds 3.0°C even if peak-to-peak differences are used. Considering that these records span a range of water depths (617-3091 m) and sedimentary environments, and utilize two independent palethermometry methods, we believe they place reasonably confident limits on the range of SST variability in the equatorial Pacific cold tongue during the last 30,000 y.

(3) The most coherent site-to-site SST variability is observed between the Uk'_{37} records of V19-27 (deep blue) and V21-30 (green). Coupled with the relatively high sedimentation rate (13 cm/ky) and extensive radiocarbon dating of V21-30 (*Koutavas and Lynch-Stieglitz,* 2003), we are inclined to suggest that these are the more robust histories of temperature variability in the environment (and season) of the alkenone-producer organisms in this region. However, the Uk'_{37} record of RC11-238 (light blue), positioned between V19-27 and V21-30, records a different and much higher G-I signal which remains to be explained. Downcore records from additional sites are in progress to address this issue.

(4) There is no unequivocal evidence in the Uk'_{37} reconstructions for a lead of surface ocean warming relative to $\delta^{18}O$, previously reported from long Mg/Ca reconstructions (*Lea et al.*, 2000), with the possible exception of core V21-30 which shows a small warming step at 21,000 y B.P. We note however that the application of foraminifer-based age models to alkenone data-series, inherent here, may not always be appropriate, and that independent dating of the alkenones is desirable to constrain the temporal evolution of Uk'_{37} SST before comparing with foraminifer proxies.

CONCLUSIONS

1. Alkenone paleotemperatures from four sites in the EEP cold tongue indicate a range of glacial interglacial SST amplitudes between 1.3° - 2.8°C. More work is needed to narrow down this range and resolve the spatial pattern of SST variability.
2. The timing of deglacial surface warming appears to be in phase with the $\delta^{18}O$ of planktonic or benthic foraminifera, but this conclusion is tentative since age differences between foraminifera and the alkenone fraction in the same sample cannot be ruled out.
3. Late Holocene Uk'_{37} values overestimate annual mean SST in 3 of 4 sites which may imply a warm season alkenone production bias, or possibly lateral transport of alkenones from the north.
4. Notwithstanding the above open issues, in our judgment alkenone paleothermometry holds great promise as a paleoceanographic tool in the eastern tropical Pacific, particularly in deep sites where dissolution hinders the application of foraminifer Mg/Ca or faunal census methods.

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ACKNOWLEDGMENTS

We thank Jean Lynch-Stieglitz, Peter deMenocal, Grace Kim and Heather Griffith for help with the $\delta^{18}O$ and Mg/Ca data of core V21-30. Support for the curating facilities of LDEO is provided by NSF and ONR. A. Koutavas acknowledges the support of a NOAA Postdoctoral Fellowship on Climate and Global Change, administered by UCAR.