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Earth and Planetary Science Letters 242 (2006) 406–414
EPSL
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# Glacial–interglacial variability in the delivery of dust to the central equatorial Pacific Ocean

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Received 13 December 2004; received in revised form 1 November 2005; accepted 29 November 2005
Available online 19 January 2006
Editor: E. Boyle

**Abstract**

Fluxes of continental mineral aerosols (dust) were greater during glacial periods than during interglacials throughout most regions of the Earth. The equatorial Pacific Ocean was a possible exception to this pattern in that previous studies have reported either greater dust fluxes during interglacials or no consistent glacial–interglacial pattern of dust flux. We have applied the $^{230}$Th-normalization technique to derive five new records of dust flux from central equatorial Pacific Ocean sediments. In contrast to previous studies, which relied on stratigraphic accumulation rates, the $^{230}$Th-normalization technique produces internally consistent results, revealing fluxes to this region of continental lithogenic material that were positively correlated with global ice volume throughout the past 300,000 yr. Maximum glacial fluxes of continental mineral aerosols exceed minimum interglacial fluxes by about a factor of 2, similar to changes found elsewhere at low and mid-latitudes. This amplitude of variability is substantially smaller than that seen in some recent models, and these observations provide a calibration point for future model development.
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*Keywords:* equatorial Pacific; mineral aerosols; dust; sediment focusing

## 1. Introduction

Atmospherically transported mineral aerosols (dust) play a critical role in the Earth System by influencing climate, the structure of certain ecosystems, and biogeochemical cycles. Dust affects Earth's climate by influencing the radiative balance of the atmosphere through the scattering and absorption of light (for recent reviews, see [1,2]). Variability in the concentration of atmospheric dust may have played a direct role in forcing past climate change (e.g., [3,4]). Dust also supplies essential and often-limiting micronutrients (e.g., iron) to remote regions of the ocean (e.g., [5]). Consequently, the supply of dust potentially influences the physiological state and growth rate of marine phytoplankton, the structure of marine ecosystems, the inventory of fixed nitrogen in the ocean, and the partitioning of $CO_2$ between the atmosphere and the deep sea (e.g., [5–11]).

Paleo-records of dust deposition reveal important clues about past climate conditions, such as moisture balance within the dust source regions, the intensity and patterns of atmospheric circulation, and precipitation

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doi:10.1016/j.epsl.2005.11.061

along the pathways of dust transport and deposition (e.g., [1,2,12,13]). For these reasons, a substantial effort has been devoted to reconstructing the spatial and temporal variability of dust fluxes worldwide (e.g., [12,13]). Similarly, efforts are underway to incorporate dust into global climate models to explore the climate-related variability in dust generation, as well as dust-related feedbacks affecting climate change and biogeochemical cycles (e.g., [10,14–17]).

Records from ice cores (e.g., [18–20]) and from marine sediment cores (e.g., [13,21–23]) indicate that dust fluxes were generally greater during glacial periods than during interglacials (see summaries by [2,12,15]). Delivery of dust to the equatorial Pacific Ocean may have deviated from this pattern, however, in that dust fluxes there are reported to have been greater during interglacials (e.g., [13,24–26]), possibly reflecting climate changes in the source region.

Dust extracted from equatorial Pacific sediments has a composition distinctly different from that of the East Asian minerals that dominate the eolian component of North Pacific sediments, but similar to that of hemipelagic sediments off the coast of South America [26,27]. Rea [13,25] concluded that the Intertropical Convergence Zone (ITCZ) serves as a barrier to the southward transport of Asian dust, and that the principal source regions for dust delivered to the equatorial Pacific Ocean lie in northern South America. Rea [13,25] further noted that the pattern of greater dust fluxes to equatorial Pacific sediments during interglacials is consistent with paleolimnological evidence for wetter conditions in northern South America during glacial periods (drier interglacial conditions being more conducive to dust generation).

In contrast to the findings described above, a subsequent study of several cores from the central and eastern equatorial Pacific Ocean found no consistent relationship between dust accumulation and glacial–interglacial stage [28]. Within a single core, dust fluxes sometimes peaked during glacial periods and sometimes during interglacials. Patterns of dust accumulation through time were also found to differ from one core to another [28]. For example, over the last 300 ka, dust accumulation rates in core TT013-PC72 are inferred to have been greater by as much as a factor of 4 during glacial periods compared to interglacials [28], whereas dust fluxes are reported to have been greater during interglacials at the nearby site of core RC11-210 ([13]; core locations in Fig. 1). Such site-to-site variability is not expected, as atmospheric mixing during the long-distance transport of dust should lead to similar patterns of dust deposition at sites in close proximity to one another.

The equatorial Pacific is one of the principal High-Nutrient Low-Chlorophyll regions of the world ocean, where the photosynthetic efficiency of phytoplankton and nutrient utilization are limited by the supply of iron [29]. It is also one of the principal regions of $CO_2$ efflux from the ocean to the atmosphere [30]. Consequently, the partitioning of $CO_2$ between the ocean and the atmosphere could be sensitive to changes in the flux of dust to this iron-limited system, providing a strong incentive to develop accurate reconstructions of climate-related changes in dust supply to this region. Toward that end, we have studied five cores forming a meridional section across the equator at 140°W. Using the $^{230}$Th-normalization method to evaluate fluxes of common thorium ($^{232}$Th), a trace element that is enriched in continental crust and thereby serves as a geochemical tracer for dust, we find that dust fluxes in all five cores were systematically greater during glacial periods, by roughly a factor of 2.

## 2. Study area, cores, and stratigraphy

Cores were collected during the US Joint Global Ocean Flux Study (JGOFS) Equatorial Pacific Process Study along a transect across the equator at ~140°W

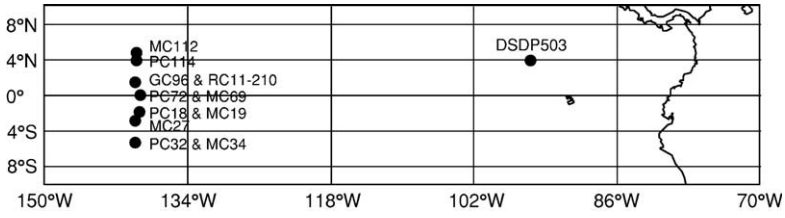


Fig. 1. Locations of sediment cores discussed in this paper. Cores from 140°W used in this study were collected during cruise TT013 of the R/V Thomas G. Thompson in 1992. Samples were obtained from multicores (MC) to ensure recovery of surface sediment, piston cores (PC) to obtain longer records, and from one gravity core (GC) at a site where an interval of missing sediment was suspected in a companion PC. Locations of cores (DSDP Site 503 and RC11-210) studied previously by Rea et al. [13,25,26] are shown for reference.

(Fig. 1). Radiocarbon dates (archived in the US JGOFS data base and available at http://usjgofs.whoi.edu) from bulk $CaCO_3$ were used to establish chronologies for the upper part of the record from each site. Oxygen isotope stratigraphies developed using benthic foraminifera are available for PC72 (equator; [28]) and PC18 (2°S; [31]). Chronologies for the other records beyond the range of $^{14}C$ dating were established by correlating major compositional features (e.g., $CaCO_3$ concentration) with their counterparts in PC18 and PC72 ([31] for other PCs; RFA, unpublished, for GC96). Locations of cores (DSDP Site 503 and RC11-210) studied previously by Rea [13,25] are shown in Fig. 1 for reference.

## 3. Methods

Several recent studies (e.g., [32–35]) have concluded that accumulation rates of equatorial Pacific sediments are strongly influenced by climate-related changes in sediment focusing (syndepositional focusing of settling particulate material by deep-sea currents). If true, then failure to recognize artifacts caused by sediment focusing may account for the inconsistencies among published records of dust deposition in this region. With this in mind, we sought to construct new records of dust accumulation using a strategy that corrects for sediment focusing.

Paleo-fluxes were derived using the $^{230}Th$ profiling method [36–38], which is based on the assumption that the rain rate of particulate $^{230}Th$ sinking to the sea bed is equivalent to the known rate of $^{230}Th$ production by $^{234}U$ decay in the overlying water column. This assumption has found support both in modeling exercises [39] and through numerous studies of material collected by deep-sea sediment traps [40–43].

Using this approach, preserved fluxes of any sedimentary constituent (Fi) can be estimated as:

$$Fi = Ci \cdot \beta \cdot z / xs^{230}Th_0$$

where Ci is the concentration of the constituent of interest, and $\beta \cdot z$ is the rate of $^{230}Th$ production in the water column, $P_{Th}$ ($\beta = 2.63 \times 10^{-5}$ dpm $cm^{-3}$ $ka^{-1}$ and $z$ is the depth of the water column in cm). Decay corrections required to obtain the initial unsupported $^{230}Th$ concentration ($xs^{230}Th_0$) are made using an independent chronology (based on $^{18}O$ or $^{14}C$ in this case). An absolute uncertainty in paleo-fluxes derived with this method is estimated to be ~30%, based on recent calibration studies [39–42]. However, the point-to-point relative uncertainty in the change in flux through time is much less than this, and in the best case approaches the analytical uncertainty in determining the initial unsupported $^{230}Th$ concentration.

The $^{230}Th$ profiling technique offers two principal advantages over traditional stratigraphic methods in evaluating sediment accumulation rates. First, accumulation rates derived by normalizing to $^{230}Th$ are insensitive to sediment focusing, because $^{230}Th$ itself is attached to the particles redistributed by deep-sea currents. Second, accumulation rates derived by normalizing to $^{230}Th$ are relatively insensitive to errors in sediment chronology of as much as several thousand years. For example, the error in the decay-corrected unsupported $^{230}Th$ concentration is small if the error in the age is small relative to the radioactive half-life of $^{230}Th$ (75,200 yr). A 5000-yr error in a sample with a true age of 100,000 yr introduces an error in the $^{230}Th$-normalized flux of only ~4.6%. By contrast, inaccuracies of this magnitude (5000 yr) can introduce much larger errors into accumulation rates calculated from the difference in depth between two age control points if control points are linked to precession or obliquity cycles at 23 ka and 41 ka, respectively.

Following the principles developed by previous investigators [13], we assume that sedimentary lithogenic phases in remote areas of the central Pacific Ocean are of eolian origin (i.e., dust). Concentrations of continental lithogenic material were estimated by measuring common thorium ($^{232}Th$) which exists entirely within the lithogenic fraction of marine particulate material [44]. This approach is similar to that employed by other investigators who use Ti or Al to estimate the lithogenic content of marine sediments. Here, $^{232}Th$ offers an advantage over Ti or Al in that its concentration is measured simultaneously with that of $^{230}Th$.

Uranium and thorium isotopes were measured by isotope-dilution alpha spectrometry [45] for the most part, although some samples were analyzed by isotope dilution Inductively Coupled Plasma Mass Spectrometry [46]. Concentrations of unsupported $^{230}Th$ were derived by subtracting from the total (measured) $^{230}Th$ concentration the amount supported by uranium contained within lithogenic minerals, and any $^{230}Th$ produced by decay of authigenic U [45]. These corrections are small in carbonate-rich equatorial Pacific sediments (<3% each throughout the last glacial cycle for all cores; <7% and <11%, respectively, for older samples in PC72), so the uncertainty introduced by these corrections represents a small component of the overall analytical uncertainty in determining $xs^{230}Th_0$ (2% to 4%, 1 sigma), which results primarily from counting statistics.

## 4. Results

Radionuclide concentrations used in this study are archived in the USJGOFS database (available at http://usjgofs.whoi.edu).

Accumulation rates of $^{232}$Th, our geochemical proxy for continental lithogenic material, in core TT013-PC72 are correlated positively with global ice volume. Larger $^{232}$Th fluxes occur at times of greater global ice volume (more positive $\delta^{18}$O) throughout the past 300 ka (Fig. 2). Records of $^{232}$Th accumulation covering at least one full glacial cycle were obtained at five sites along the transect at 140°W (Fig. 3). Among these records, temporal resolution is greatest for PC18 and PC72, which have average accumulation rates of ~1.6 cm/ka [31]. Resolution is lowest for PC32 (5°S; average

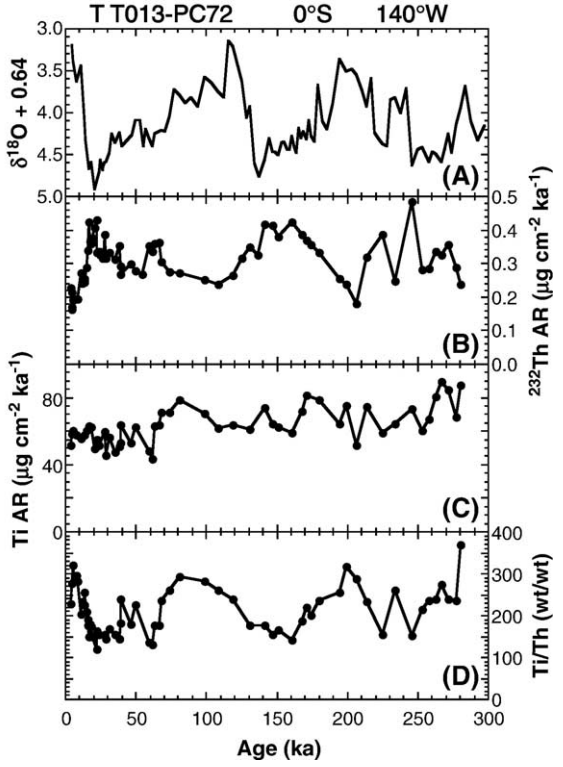


Fig. 2. A 300 ka record from TT013-PC72 (0.1137°N, 139.4015°W). (A) The oxygen isotope record from the benthic foraminifera *Cibicides wuellerstorfi*, used by Murray et al. [28] to produce the age model presented here, provides a proxy for global ice volume. (B) Accumulation rate of common thorium ($^{232}$Th) derived using the $^{230}$Th-normalization method [36–38]. (C) Accumulation rate of titanium (Ti) derived using the $^{230}$Th-normalization method. (D) Ratio (by weight) of Ti to $^{232}$Th. Concentrations of Ti measured by Murray et al. [28] at 5-cm depth intervals were interpolated onto the depths of our Th samples to calculate Ti accumulation rates and Ti/Th ratios.

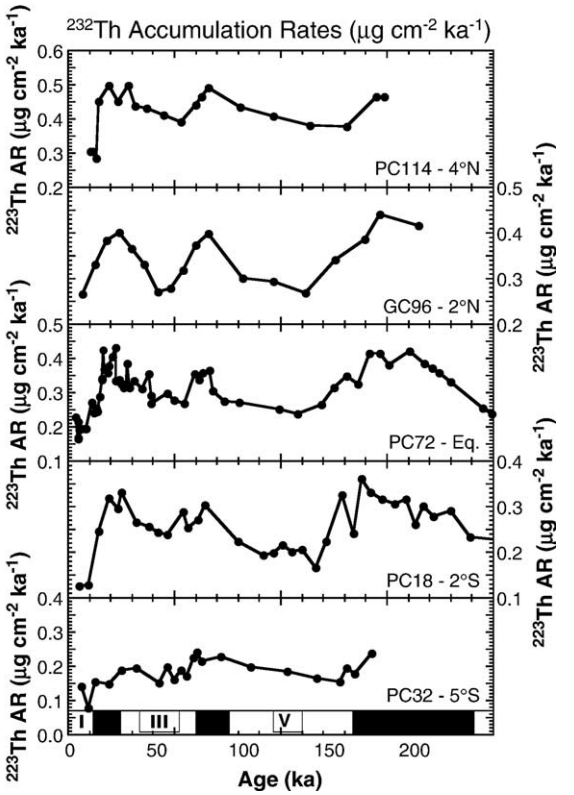


Fig. 3. Accumulation rate of common thorium ($^{232}$Th) derived using the $^{230}$Th-normalization method [36–38] for five cores collected along a transect normal to the equator at ~140°W (Fig. 1). The scale bar at the bottom indicates marine isotope stages. Interglacials are indicated by Roman numerals. Glacial stages, indicated by filled sections of the scale bar, are times of greater flux of $^{232}$Th, a geochemical proxy for continental dust.

$S$=0.5 cm/ka), and intermediate ($S$~1 cm/ka) at the other sites [31]. Glacial–interglacial changes in $^{232}$Th flux exhibit a maximum amplitude (glacial maxima to interglacial minima) of about a factor of 2 in PC18 and PC72 (Fig. 3). Lower amplitudes in the other cores reflect the filtering effect of bioturbation at sites with accumulation rates of ~1 cm/ka or less. Nevertheless, all five sites provide consistent records with systematically greater fluxes of $^{232}$Th during glacial periods.

Fluxes of $^{232}$Th decrease from north to south along the transect at 140°W, a pattern that is illustrated more clearly (Fig. 4) using time-slices from the Holocene and from the Last Glacial Maximum (LGM). Holocene fluxes decrease monotonically by about a factor of 3 from 5°N to 5°S, reflecting the greater supply of dust to the Northern Hemisphere [13]. Fluxes during the LGM are systematically greater than during the Holocene by an amount ranging from ~50% to a factor of 2, with the lower values reflecting the smoothing effect of

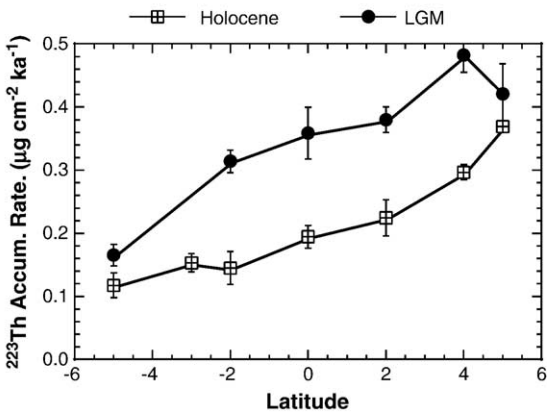


Fig. 4. $^{230}$Th-normalized accumulation rate of $^{232}$Th for Holocene (average±one standard deviation for all samples from each site with ages of 0 to 10 ka) and Last Glacial Maximum (average±one standard deviation for all samples from each site with ages of 17 to 28 ka). MC112 at 5°N provided a LGM sample, whereas only Holocene sediment was obtained from MC27 at 3°S.

bioturbation in the cores with lower sediment accumulation rates.

## 5. Discussion

### 5.1. Reliability of $^{230}$Th-normalized fluxes

We have employed the $^{230}$Th-normalization technique to evaluate sedimentary fluxes as a strategy to correct for sediment focusing and for minor unrecognized errors in age models, either of which may have created the inconsistencies noted above (Section 1) among prior records of dust deposition in equatorial Pacific sediments. Therefore, it is reasonable to ask if fluxes so derived are reliable.

Lacking any absolute standard against which the accuracy of flux reconstructions can be assessed, we look for evidence of internal consistency among records as a measure for assessing the reliability of the results. Two internal consistency tests can be applied to the temporal variability of the inferred dust fluxes. First, the $^{230}$Th-normalized fluxes of $^{232}$Th in TT013-PC72 are positively correlated with global ice volume (compare Fig. 2A and B), consistent with other records of dust supply worldwide. Second, the $^{230}$Th-normalized fluxes of $^{232}$Th are internally consistent among all five cores in terms of both timing and amplitude of the climate-related changes in $^{232}$Th flux (Fig. 3), allowing for the fact that the amplitude is reduced by bioturbation in cores that have the lowest accumulation rates (Section 4). This internal consistency among cores supports the reliability of the $^{230}$Th-normalized fluxes, and is in stark contrast to the results of previous studies (e.g., [28]) relying on stratigraphic accumulation rates, where records of late-Pleistocene dust fluxes were found to vary substantially from core to core (Section 1).

The southward decrease in $^{232}$Th flux observed in our data, amounting to about a factor of 3 (Fig. 4), is also consistent with the broad spatial pattern of dust fluxes that has been reconstructed for the Pacific basin [13]. Fluxes of dust are much greater in the North Pacific region than south of the equator due to the extensive source areas associated with Asian deserts. This consistency of spatial patterns, like the internal consistency among the patterns of temporal variability noted above, supports the reliability of the $^{230}$Th-normalized fluxes.

Whether or not climate-related changes in biological productivity might systematically bias $^{230}$Th-normalized fluxes is also worth considering, as pointed out by Thomas et al. [47]. For example, an increase in biological productivity within the equatorial upwelling zone would produce a corresponding increase in the flux of biogenic particles throughout the water column. If the flux of $^{230}$Th scavenged from the water column increases significantly with increasing flux of biogenic particles, then the assumption that the flux of $^{230}$Th is constant and equal to its known production rate would be violated. Furthermore, the increased delivery of $^{230}$Th to the sediments during intervals of high productivity might be misinterpreted as evidence for sediment focusing, since both processes could result in fluxes of $^{230}$Th to sediments exceeding the local rate of supply by uranium decay [47–49].

Thomas et al. [47] proposed that increased productivity during glacial periods was responsible for the strong correlations observed among accumulation rates of various constituents in central equatorial Pacific sediments. Their reasoning was that fluxes of biogenic phases (e.g., barite) would scale directly with productivity, while scavenging and removal from the water column of other constituents (e.g., continental dust, interplanetary dust, $^{230}$Th and $^{10}$Be) would track changes in the flux of biogenic particles as well.

Climate-related changes in biological productivity would certainly impact the flux of many sedimentary constituents. However, fluxes of particulate substances are known to respond to changes in productivity with sensitivities that vary from constituent to constituent. By contrast, syndepositional focusing of settling particles, which sink primarily as large aggregates of smaller individual grains, is expected to exert less discrimination among particulate constituents. Therefore, it ought to be possible to resolve changes in productivity from

changes in sediment focusing by the nature and pattern of constituent fluxes recorded in sediments.

Comparing the behaviors of $^{230}$Th and barite illustrates the contrasting sensitivity to varying productivity of different sedimentary constituents. Fluxes of $^{230}$Th are nearly insensitive to changes in productivity. A synthesis of worldwide results found that fluxes of $^{230}$Th collected by sediment traps deployed at open-ocean sites increase by about 10–20% in response to a factor of 2 increase in particle flux [38]. Within more limited geographic regions, the sensitivity may be even less than this. For example, Scholten et al. [43] found the flux of $^{230}$Th collected by sediment traps deployed at ~3 km depth in the Arabian Sea to be essentially equal to the production rate in the overlying water column at each of three sites studied, despite a range in excess of a factor of 3 in the long-term mass flux of particles among the sites.

In contrast to $^{230}$Th, barite accumulation rates are extremely sensitive to changes in productivity. For example, the accumulation rate of barite in central equatorial Pacific sediments increases by about a factor of 4 in response to a doubling of productivity. Both production and preservation influence barite accumulation, creating a nonlinear relationship between barite accumulation rate and productivity in this region [50]. Changes in productivity should therefore elicit very different responses in the accumulation rates of barite and $^{230}$Th, whereas sediment focusing should affect these particulate constituents more equally.

Accumulation rates of barite and of $^{230}$Th in TT013-PC72 exhibit remarkably similar patterns throughout the past 300 ka [32]. Both tracers have maximum fluxes during glacial periods, and for both tracers the range between glacial maximum and interglacial minimum fluxes is about a factor of 4. This one-to-one relationship between the accumulation rates of barite and $^{230}$Th is not consistent with their very different sensitivities to changes in productivity and particle flux, but it is consistent with the expected common response of all sedimentary constituents to changes in sediment focusing. Marcantonio et al. [32] applied similar reasoning to the differential sensitivity of $^{230}$Th and $^{10}$Be to varying particle flux, and used the relatively constant $^{10}$Be/$^{230}$Th ratio over the past 300 ka in TT013-PC72 to argue against large changes in biological productivity and particle flux at that location.

Based on the various lines of reasoning described above, we conclude that flux of $^{230}$Th to central equatorial Pacific sediments has not been influenced significantly by changes in productivity as suggested by Thomas et al. [47]. Observed changes in the accumulation rate of $^{230}$Th more likely reflect sediment focusing than variable productivity. Therefore, we consider $^{230}$Th-normalized fluxes to be more reliable than stratigraphic accumulation rates for reconstructing climate-related changes in dust flux to this region.

### 5.2. $^{232}$Th as a tracer for continental mineral aerosols

There is no chemical or mineralogical technique that provides a quantitative and unambiguous determination of the eolian component of marine sediments. As in previous studies (e.g., [13,28]), we assume that sedimentary lithogenic phases in remote regions of the Pacific Ocean were supplied by atmospheric transport. Possible transport of lithogenic material by the Equatorial Undercurrent is addressed in the next section.

Lithogenic phases in equatorial Pacific sediments consist of material derived from both continental and oceanic crust. Applying factor analysis to the elemental composition of Pacific sediments, Olivarez et al. [26] concluded that continental and oceanic sources contribute, on average, about equal amounts of lithogenic material to the sediments of RC11-210 (location in Fig. 1). They also reported that the contribution from each source varied with time, ranging from roughly one third to two thirds of the total. Ideally, one would quantify the time-varying fluxes of both the continental and oceanic end members. However, doing so is beyond the scope of this project, as it would require extensive information about the elemental and isotopic composition of the lithogenic phases to quantify the amount derived from each source.

Although individual fluxes of oceanic and continental material cannot be evaluated precisely, combining the $^{232}$Th fluxes reported here with previously published titanium results [28] allows us to place some constraints on the glacial–interglacial changes in supply from each source. Concentrations of $^{232}$Th are generally much lower in oceanic crust than in continental crust; e.g., 1.2 and 16 ppm Th, respectively, in the Hawaiian Basalt and continental eolian end members of North Pacific sediments constructed by Kyte et al. [51]. End member concentrations vary, depending on the source. For example, average $^{232}$Th concentrations in oceanic crust and upper crust used in the normative calculations of Olivarez et al. [26] are 0.22 and 10.7 ppm, respectively (original data from [52]). Regardless of this variability among sources, $^{232}$Th concentrations are clearly much greater in continental crust, by an order of magnitude or more, compared to oceanic crust. With roughly equal contributions from oceanic and continental end members in equatorial Pacific sediments [26],

fluxes of $^{232}$Th will be dominated by the continental end member. Therefore, the flux of $^{232}$Th provides a reliable, if not precise, tracer of past changes in the supply of continental lithogenic material.

Whereas $^{232}$Th is greatly enriched in the continental crust, the concentration of Ti may be greater in the oceanic end member, especially if it is composed of Ocean Island Basalt (OIB; e.g., 1.7% and 0.62% Ti, respectively, in the Hawaiian Basalt and continental eolian end members of Kyte et al. [51]). The Marqueseas Islands represent a potential source of OIB material to the cores included in this study [53,54]. Therefore, comparing fluxes of $^{232}$Th and of Ti provides a semi-quantitative measure of the corresponding fluxes of continental and oceanic lithogenic phases. In contrast to the $^{232}$Th record, which exhibits a strong correlation with global ice volume (compare Fig. 2B and A), we find no detectable climate-related change in the $^{230}$Th-normalized flux of Ti in core TT013-PC72 (Fig. 2C). Either the source of lithogenic material has changed through time, such that the interglacial source has a larger Ti/Th ratio than the glacial source (Fig. 2D), or there are multiple sources of lithogenic material, and the relative supply from each source changes with global ice volume. Discriminating unambiguously between these two possibilities will require further study of the composition of the lithogenic phases in these sediments. However, building upon the previous work of Olivarez et al. [26], who showed that both oceanic and continental sources contribute to the lithogenic material in equatorial Pacific sediments, we interpret the results in Fig. 2 to indicate a glacial increase in the flux of a Th-rich continental end member superimposed on a relatively constant supply of a Ti-rich Ocean Island Basalt. This explanation is reasonable in that it is consistent with widespread evidence for increased fluxes of continental dust during glacial periods [12,13].

### 5.3. Eolian versus oceanic transport

The prevailing view has long been that eolian processes dominate the supply of lithogenic material to remote regions of the Pacific Ocean [13]. If this is true, then a local maximum in lithogenic flux would be expected to occur under the ITCZ (~4°N to ~8°N), where reduced atmospheric turbulence and increased washout by precipitation combine to enhance the removal of dust from the atmosphere (e.g., [53,55]). Recently, however, it has been suggested that the Equatorial Undercurrent (EUC) serves as the principal source of dissolved iron, and possibly of lithogenic particles as well, to this region [56–58]. If the EUC were an important source of lithogenic particles to this region, then a local maximum in lithogenic flux would be expected to occur at the equator. Contrary to this expectation, we find no evidence for a local maximum at the equator (Fig. 4), supporting the view that eolian transport is the principal vector delivering lithogenic material to the central equatorial Pacific Ocean, both during the Holocene and during the LGM.

## 6. Summary

Our results demonstrate that the glacial–interglacial pattern of continental dust flux to the central equatorial Pacific Ocean is similar to that observed worldwide. Using the $^{230}$Th-normalization technique to correct for sediment focusing, we find that maximum glacial fluxes exceed interglacial fluxes by about a factor of 2 (Figs. 3 and 4), similar to the amplitude of glacial–interglacial variability recorded at other low and mid-latitude sites [12,15]. Greater fluxes of dust to the central equatorial Pacific Ocean during glacial periods is also consistent with the growing body of evidence for drier conditions during the LGM in northern and equatorial South America [59], the likely source area for dust delivered to this region [13].

Recent modeling studies have simulated dust fluxes to the central equatorial Pacific Ocean during the LGM that are greater than during the Holocene by more than an order of magnitude [15–17]. Our results indicate that glacial sources of dust for this region have been overestimated in those models, and provide a valuable calibration point for future model development. Similarly, modeling studies that simulate the impact of dust deposition on marine biota, nutrient cycles, and atmospheric $CO_2$ (e.g., [10,11]) will benefit from the reliable reconstruction of glacial–interglacial variability in the flux of dust to the central equatorial Pacific Ocean.

## Acknowledgments

This paper was improved by comments from Karen Kohfeld, Sidney Hemming, Peter de Menocal, Rick Murray, Steve Hovan and an anonymous referee. Funding was provided by the U.S. National Science Foundation. LDEO Contribution Number 6843.

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