Reports

Time-Transgressive Late Cenozoic Radiolarian Events of the Equatorial Indo-Pacific

Abstract. *A biostratigraphic study of late Cenozoic Radiolaria in the equatorial Indo-Pacific shows an asymmetrical distribution between synchronous and diachronous events. A majority of synchronous events (15 out of 19) are last occurrences; the majority of diachronous events (10 out of 13) are first occurrences. Extinctions may therefore be preferable to first occurrences in the selection of datum levels for the definition of biostratigraphic zonations and for correlation control within global time scales. Diachronous equatorial radiolarian events span 1 to 2 million years, several orders of magnitude longer than the nominal mixing time of the oceans, suggesting that the biological and physical exchange processes associated with speciation events may not follow simple advective mixing models.*

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A fundamental presumption of stratigraphic correlation is that biostratigraphic datum levels (first or last appearances of taxa) are synchronous, whereas other stratigraphic horizons (lithofacies boundaries, hiatuses, or seismic reflectors, for example) may be substantially time-transgressive. With the development of a precise paleomagnetic geochronology (*1*), biostratigraphers have been able to evaluate whether faunal and floral events are in fact synchronous by correlating these events to an independent time scale—the polarity reversal sequence. Such comparisons suggest that a substantial number of biostratigraphic events are synchronous to within a precision of about 0.1 to 0.4 million years; as a result, biostratigraphic zonations have been calibrated to absolute time scales for purposes of regional or even global correlation (*2*). However, some significant exceptions emerged when latitudinal dependence of floral and faunal zonations and of the associated stratigraphic marker horizons was recognized (*3*). Consequently, there is a clear basis for reexamining with much closer scrutiny whether fossil datum levels are indeed synchronous, both within and between latitudinal zones.

The classical sequences of equatorial radiolarian events of the late Cenozoic (*4*) show some consistent departures from the presumption that biostratigraphic events are synchronous. These exceptions appear to be real rather than artifacts of the combined effects of incomplete core recovery, low abundances of taxa, or poor preservation. If nonsynchronous stratigraphic events are indeed significant in the geologic record, documentation of this effect in diverse groups of fauna and flora is important not only for sharpening stratigraphic resolution, but also for interpretations of paleoceanography and evolutionary biology.

We examined radiolarian assemblages of Quaternary and late Neogene age (between about 1 and 15 million years ago) in five Deep Sea Drilling Project (DSDP) sites (Fig. 1). We selected a coring transect within a restricted latitudinal zone where faunal diversity remains uniform and comparable taxa occur; thus we attempted to minimize the complexities introduced by latitudinally dependent biozonations (*5*) and by geographic variations in taxon morphologies. Our objective was to determine whether some biostratigraphic horizons are demonstrably time-transgressive within the equatorial belt of the Indo-Pacific. In evaluating possible radiolarian events from which to choose (*4*), we selected principally first- and last-appearance datums of morphotypes, and only those taxa whose identity is relatively unambiguous by ordinary light-microscopic examination. With these criteria we identified 50 radiolarian events, insofar as the material would allow, from each of our five sites. Using independent control points, we constructed age-depth curves at each site (*6*) and derived an age estimate for those radiolarian events in which the taxon was sufficiently abundant to yield a reliable event determination.

We found that the 50 events fall into three categories: those that appear to be synchronous (agespan <0.4 million years) within our limits of resolution (19 events); those which are time-transgressive by about 1 million years or more (13 events); and those whose synchronous status is ambiguous (18 events). From this grouping, several patterns have emerged (Figs. 2 and 3). (i) Among those events that appear synchronous, the majority (15 of 19) are last occurrences (Fig. 2). We note that a number of other biostratigraphic events that have been reported as "globally synchronous" are also last occurrences (*7*). (ii) Among the events that are time-transgressive by more than 1 million years, most (10 of 13) are first appearances; furthermore, in eight of these ten cases the taxon appears first in the Indian Ocean and subsequently in the western and eastern Pacific (Fig. 3). (iii) The three extinction events that are most strongly time-transgressive show the inverse relation: these extinctions in the Pacific apparently pre-

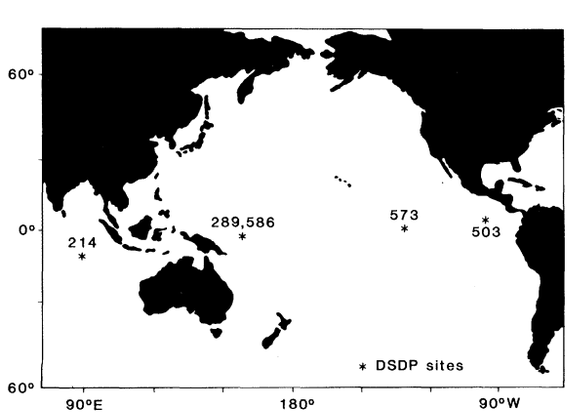

Fig. 1. Index map showing locations of DSDP sites studied.

cede corresponding events in the Indian Ocean by up to several million years (Fig. 3).

Our most significant finding is the asymmetrical distribution of events between first occurrences and last occurrences: the majority of synchronous datum levels are extinctions (Fig. 2), and a comparable majority of time-transgressive events are first appearances (Fig. 3). A comparable pattern was identified by Bretsky and Klofak (*8*) for benthic marine invertebrates in the Late Ordovician of eastern North America. We suspect that biostratigraphic datum levels for other planktonic and benthic marine organisms may exhibit this same asymmetrical pattern. If so, the implications are considerable for geochronology, particularly in the selection of biostratigraphic datum levels as components of regional or global time scales. Moreover, a detailed documentation of the time-transgressive nature of first-appearance events will have important implications for the formulation of, and discrimination between, various models of evolutionary dynamics, speciation, and migration patterns of new species.

Our evidence that some biostratigraphic events in the Indian Ocean are precursors to corresponding Pacific events is perhaps unexpected, in view of the strong westward zonal flow from the Pacific into the Indian Ocean at low latitudes (*9*). Nevertheless, our results suggest strongly that the oceanography and biology of the tropical Indian Ocean are influencing the tropical Pacific fauna and that these interactions occur on time scales on the order of 10^6 years, which is substantially longer than the nominal ocean-mixing time of 10^3 years.

These observations of time-transgressive radiolarian events are subject to two limitations. (i) We used indirectly calibrated drill sites (*6*) rather than core material that is directly dated paleomagnetically. As a result, only 32 of our 50 datum levels could be designated as clearly synchronous or time-transgressive (Figs. 2 and 3). With core material that is directly dated paleomagnetically, one might increase the precision in absolute age calibration and thereby the status of some of the 18 ambiguous datum levels (*10*) might be resolved. (ii) The broad spacing of sites (Fig. 1) does not allow us to ascertain whether the progressive closure of the Indonesian seaway during the Cenozoic may have been a controlling factor in producing nonsynchronous first appearances, and whether the apparent progression of some taxa from west to east within the tropical Pacific is significant (Fig. 3). If biological and physical oceanographic conditions in the tropical Indian Ocean have indeed preceded corresponding conditions in the tropical Pacific, we need considerably more sample control in the Indian Ocean to verify this effect.

Although our study did not include radiolarian events of the late Quaternary, a number of events occur in this stratigraphic interval (*11, 12*), some of which are clearly time-transgressive. The late Pleistocene form *Buccinosphaera invaginata*, for example, appears to have evolved earlier in the Indian Ocean than in the Pacific (*12*), a trend which is consistent with our observations for the late Neogene (Fig. 3). Precise documentation of time-transgressive trends for other Quaternary events will

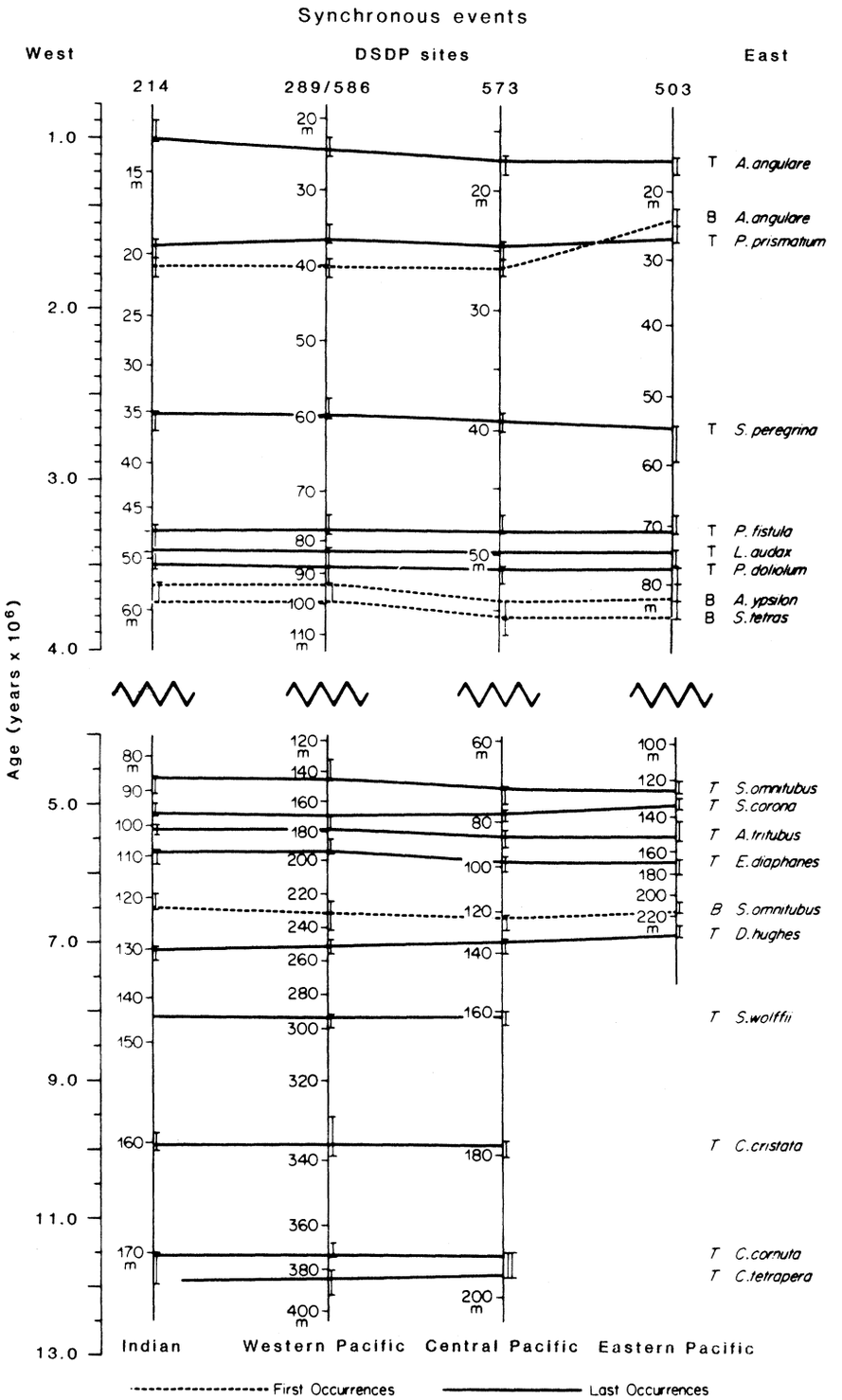

Fig. 2. Synchronous late Cenozoic radiolarian datum levels of the equatorial Indo-Pacific.

require magnetically or isotopically dated cores.

In conclusion, first, there is an asymmetrical distribution between diachronous and synchronous radiolarian events in the late Cenozoic of the equatorial Indo-Pacific. The majority of synchronous events are last occurrences. The majority of diachronous events (≥1.0 million years) are first appearances. We expect that other micro- and macrofossil events, particularly first appearances, may be substantially diachronous as well.

Second, extinction events may be preferable to first appearances for defining biostratigraphic zonal boundaries. Global time scales should be reevaluated, incorporating only those microfossil control points which are demonstrably synchronous.

Third, a number of radiolarian taxa appear to evolve first in the Indian Ocean, and subsequently in the western and eastern Pacific Ocean. This directionality is opposite to that of the westward oceanic circulation in equatorial latitudes. Nonsynchronous events may span several million years, or three orders of magnitude greater than the nominal mixing time of the oceans. Therefore, some biological or physical exchange processes, or both, may not follow simple advective models for mixing.

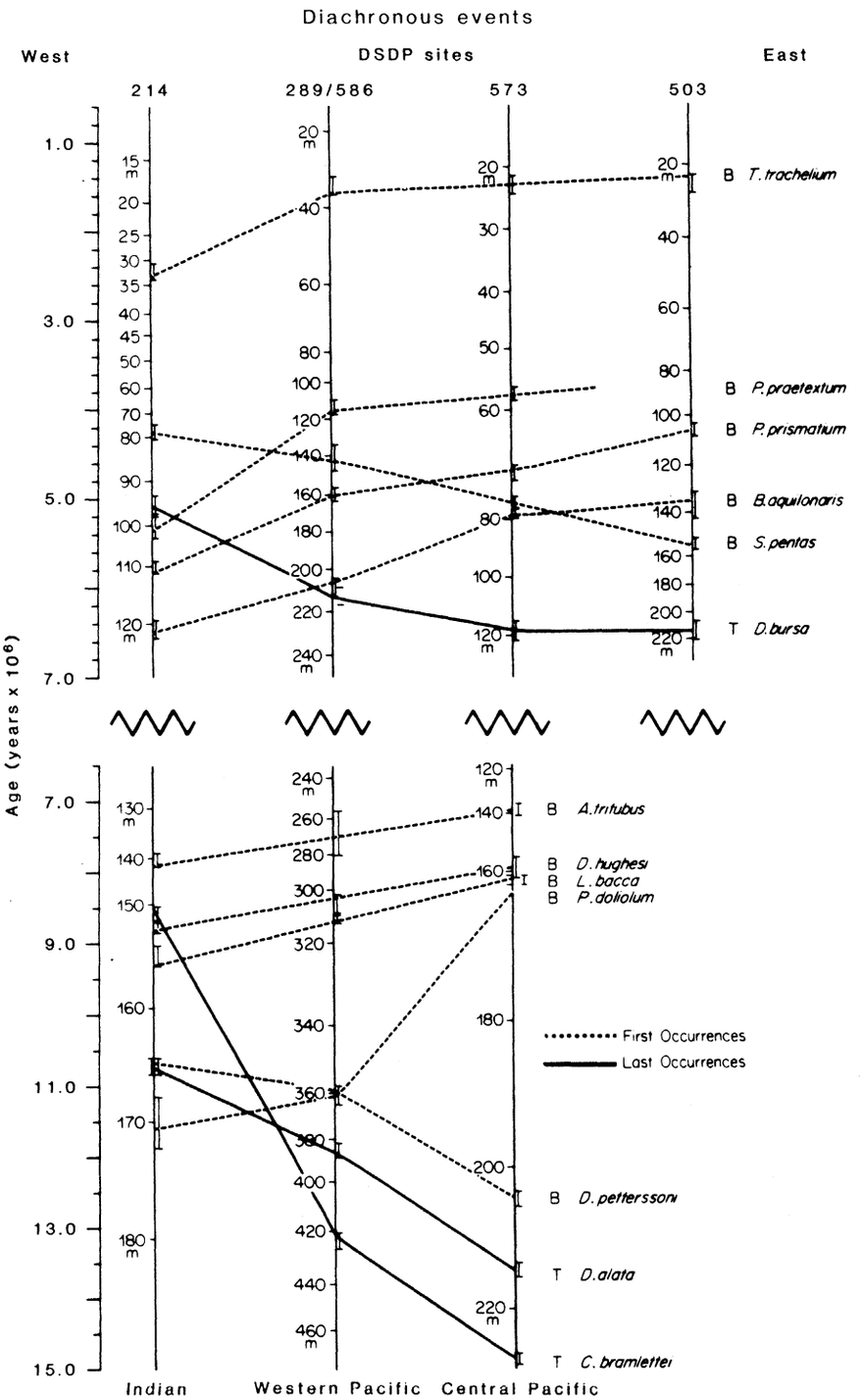

Fig. 3. Diachronous late Cenozoic radiolarian datum levels of the equatorial Indo-Pacific.

References and Notes

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3. The ages of numerous planktonic foraminiferal "horizons" appear to be dependent on latitude, including the first-appearance datums of *Globorotalia truncatulinoides* and *Globorotalia inflata* [J. P. Kennett, *Deep Sea Res.* **17**, 125 (1970)]; the first-appearance datum of *Globorotalia puncticulata* [J. P. Kennett, *Init. Rep. Deep Sea Drill. Proj.* **21**, 575 (1973)]; and the last-appearance datum of *Globorotalia* (Fohsella) *kugleri* [M. S. Srinivasan and J. P. Kennett, *Geo. Soc. Am. Bull.* **94**, 798 (1983)]. T. Saito [in *Pacific Neogene Datum Planes*, N. Ikebe and R. Tsuchi, Eds. (Univ. of Tokyo Press, Tokyo, 1984), p. 3] summarizes evidence for latitudinally dependent first and last appearances of planktonic foraminifera.
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6. We recalibrated all available stratigraphic marker horizons in our chosen drill sites to the revised Neogene time scale of W. A. Berggren *et al.* (*Geol. Soc. London Spec. Publ.*, in press). The stratigraphic control points and resulting age-depth curves are described by D. A. Johnson and C. A. Nigrini (in preparation).
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10. The following radiolarian events appear time-transgressive by 0.3 to 0.4 million years, an amount that was comparable to our stratigraphic resolution: base, *Lamprocyrtis nigriniae*; top, *Theocorythium vetulum*; top, *Spongaster pentas*; top, *Spongaster berminghami*; top, *Botryostrobus bramlettei, Spongaster berminghami* → *S. pentas*; top, *Calocycletta caepa, Stichocorys delmontensis* → *S. peregrina*; top, *Botryostrobus miralestensis*; top, *Diartus petterssoni, Diartus petterssoni* → *D. hughesi*; base, *Spongaster berminghami*; base, *Botryostrobus bramlettei*; top, *Lithopera neotera*; top, *Cyrtocapsella japonica*; top, *Lithopera renzae*; top, *Calcoycletta virginis*; top, *Calocycletta costata*.
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13. We thank J. Barron, L. Burckle, J. Hays, A. Knoll, D. Lazarus, J. Morley, W. Riedel, and A. Sanfilippo for continuing discussions and critique of this project; A Nigrini for assistance in setting up computer files for data storage; A. Peirson for sample preparation; and A. Tricca for preparing the manuscript. We thank G. Lombari for providing access to radiolarian counts from Miocene samples at site 289 and J.-P. Caulet for providing a preprint of his manuscript on the DSDP Leg 90 Radiolaria. We thank D. Lazarus, K. Takahashi, and L. Keigwin for reviewing the manuscript. Supported by NSF grant OCE82-08738. Woods Hole Oceanographic Institution Contribution 5964.

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