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5. Quaternary Planktonic Foraminiferal Biostratigraphy, ODP Leg 182 Sites[1]

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ABSTRACT

The first and last appearances of Quaternary planktonic foraminifers in the Great Australian Bight were evaluated using datum levels from magnetostatigraphy, oxygen isotope stratigraphy, and calcareous nannofossil biostratigraphy to determine whether they were synchronous or diachronous with open-ocean biostratigraphic events. The first appearance of *Globorotalia truncatulinoides* is diachronous at 1.6–1.7 Ma at Site 1127 and 1.1–1.2 at Sites 1129 and 1132, similar to other local appearances in high latitudes. All other datum levels, however, are synchronous with open-ocean events, including the first appearance of *Globorotalia hirsuta* and the last appearances of *Globorotalia tosaensis* and pink *Globigerinoides ruber* in the Indo-Pacific region. A local reappearance of *Gt. hirsuta* at ~0.12 Ma and the disappearance of *Globorotalia crassaformis* at ~0.10 Ma were found to be useful for local biostratigraphy. Age control at the bottom of all of the sections is poor at this time, but results suggest that sedimentation recommenced starting at ~1.9 Ma above the regional unconformity that marks the base of seismostratigraphic Sequence 2. Sediment accumulation is distinctly reduced in the lower Pleistocene compared to the upper Pleistocene, perhaps in part because of processes associated with several omission surfaces.

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INTRODUCTION

Planktonic foraminifer datum levels were thought to be time transgressive in Quaternary sections from the Great Australian Bight (GAB) for several a priori reasons: (1) the surface waters of the GAB may have been physically isolated by the Australian landmass from subtropical watermasses where the marker species evolved and lived, (2) unfavorable watermass conditions may have excluded marker species from the region, and/or (3) the shallow water depth of the sites may have excluded globorotalid marker species, which typically live part of their adult life in waters deeper than the shelf edge (Hemleben et al., 1989).

To test whether the local datum levels are time transgressive or synchronous with global horizons, the ages of four datum levels were examined: (1) the first appearance datum level (FAD) of *Globorotalia truncatulinoides* and *Globorotalia hirsuta,* (2) the last appearance datum level (LAD) of *Globorotalia tosaensis,* and (3) the last appearance of pink *Globigerinoides ruber* in the Indo-Pacific region. Two other local events were found useful to regional GAB biostratigraphy: the local disappearance of *Globorotalia crassaformis* and the local reappearance of *Gt. hirsuta* near the tops of the sections. The ages of the biostratigraphic events were estimated in the Quaternary sections of Holes 1127B and 1132B, both of which have good age control. The datum levels were examined for consistency in three other nearby sections that also have expanded Quaternary sections.

Locale

The sites of this study come from two north-south transects in the GAB. The western transect lies on the eastern end of the Eyre Terrace and includes two sites: Site 1132 on the shelf edge in 218.3 m water depth and Site 1130 at 488 m water depth. The eastern transect lies on the west flank of an unnamed deep-sea canyon and includes three sites: Site 1129 from the shelf edge at 202.5 m water depth, Site 1131 from the upper slope at 332.4 m water depth, and Site 1127 from the slope at 479.3 m water depth.

At present, the details of local oceanography are poorly studied in the GAB, but several regional processes are reported that are relevant to distribution of planktonic foraminifers. Circulation above the GAB shelf is anticyclonic and drives general downwelling in the region (Herzfeld, 1997; Herzfeld and Tomczak, 1997). Several significant currents enter the region. The Leeuwin Current flows along the shelf edge from the west edge to about 130°W longitude and transports warm, low-salinity waters and subtropical species into the GAB (Herzfeld, 1997; Li et al., 1999). The warm current was also active during prior interglacial periods but was apparently inactive during glacial periods (Almond et al., 1993; Wells and Wells, 1994). The effects of the warm current in the GAB on foraminifer distributions in space and time have been reported and discussed by Almond et al. (1993), McGowran et al. (1997), and Li et al. (1999). The wind-driven Flinders Current enters the GAB from the east and flows along the upper slope. The current is associated with upwelling on the basis of modeling studies (Middleton and Cirano, 2001) as well as other physical processes (Herzfeld et al., 1998). There is some weak but tantalizing evidence suggesting that upwelling was enhanced above the outer shelf and upper slope during glacial periods (James et al., 2000), and this might be associated with the paleo-

Flinders Current. Such upwelling would enhance organic carbon and carbonate production on the massive bryozoan ramp of the GAB and enhance production of planktonic foraminifers in waters above the upper slope and shelf edge. Upwelling could also alter surface-water temperatures, salinity, and water-column structure, all of which could affect the distribution of foraminifers (Thunell and Honjo, 1987; Sautter and Thunell, 1991) and, in principle, exclude some species. At present, the GAB lies near the subtropical convergence zone and north of the polar front zone, the north boundary of which lies near 47°S latitude.

Other processes in the GAB might affect the distribution of planktonic foraminifers through time. Sea level fell to a maximum of ~120 m during the last glacial maximum (Peltier, 1998) and stood somewhat higher during glacial interstades (James et al., 2000). The lowered sea level reduced water depths on the shelf edge to perhaps 60 m, possibly restricting or excluding the deposition of fully adult forms of the globorotalid marker species important to Quaternary zonation.

Lithology of Sites

The five Quaternary sections selected for study contain expanded Quaternary sections ranging in thickness from 240 m in the western transect to 560 m in the eastern transect. The carbonate shelf-edge sections contain abundant bryozoan debris, which becomes finer grained and less dominant with depth in the sections and with distance from the shelf edge. Planktonic foraminifers are abundant in all depths of the sections but increase in relative frequency as the amount of coarse shelf rubble decreases (see "Lithostratigraphy" sections in Feary, Hine, Malone, et al., 2000).

METHODS

The Quaternary sections of Holes 1127B and 1132B were sampled at 1.5-m intervals or less, and Holes 1129C, 1130A, and 1131A were sampled at ~3-m intervals. Samples 15 cm × 3 cm in volume were dried in a forced air oven at 45°C, weighed, dispersed in a solution of Calgon (1% by weight), and washed in a sieve with 63-µm openings. The sand-sized residue was dried, weighed, and inspected using a binocular dissecting microscope.

Magnetostratigraphy is from Fuller et al. (submitted) [**N2**], and isotope stratigraphies are from Holbourn et al. (submitted) [**N1**], Andres and McKenzie (2000), and S. Siedlecki and G. Brooks (unpubl. data). Radiocarbon ages were reported from Hole 1130 (**Hine et al.,** this volume). Nannofossil datum levels are from **Ladner** (this volume). The unpublished data are shared from works in progress intended for publication at a later time. Ages for marine isotope stages (MISs) are from Bassinot et al. (1994). The ages of planktonic foraminifer datum levels are mostly from Berggren et al. (1995a), and the age of the last occurrence of pink *Gs. ruber* in the Indo-Pacific Ocean is from Thompson et al. (1979). The age of the basal Quaternary unconformity at the five sites was estimated by linear extrapolation from overlying datum levels.

RESULTS

The Quaternary planktonic foraminifer assemblage of the GAB is characteristic of a transitional assemblage (Bé and Tolderlund, 1971; Hutson, 1977; Bé and Hutson, 1977; "subtropical" assemblage of Hutson and Prell, 1980). The fauna is dominated in order of abundance by *Globorotalia inflata* (d'Orbigny), *Globigerina bulloides* d'Orbigny, the white form of *Gs. ruber* (d'Orbigny), right-coiling *Neogloboquadrina pachyderma* (Ehrenberg), *Globigerinita glutinata* (Egger), *Turborotalita quinqueloba* (Natland), and left-coiling *Gt. truncatulinoides* (d'Orbigny). The assemblage remains transitional in species composition throughout the Quaternary sections, indicating that the Subtropical Front remained south of the GAB throughout this period. The relative frequency of *Gs. ruber* correlates with warm and cold climatic periods (Brunner et al., 2001a, 2001b). These results are consistent with those of Almond et al. (1993).

All of the biostratigraphic markers, except sinistral *Gt. truncatulinoides,* are rare in abundance or occur only in trace quantities in the GAB. These include pink *Gs. ruber, Gt. crassaformis* (Galloway and Wissler), *Gt. tosaensis* Takayanagi and Saito, right-coiling *Gt. truncatulinoides,* and *Gt. hirsuta* (d'Orbigny). All of the biostratigraphic marker species, except sinistral *Gt. truncatulinoides,* are also more abundant in subtropical water masses than in transitional waters (Bé and Tolderlund, 1971; Spencer-Cervato and Thierstein, 1997). The first and last appearances and several reappearances of these taxa are reported in Figures **F1, F2, F3, F4,** and **F5** and in Table **T1.**

Indo-Pacific LAD of Pink *Gs. ruber*

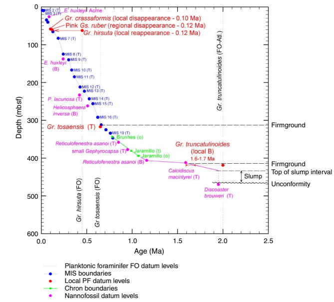
The pink form of *Gs. ruber* was observed only in one interval, a few meters thick, near the tops of the sections in the GAB (Fig. **F1;** Table **T1**), although single specimens do occur very rarely below this interval. Interpolation between oxygen-isotope stratigraphic boundaries indicates that the form makes its last appearance in Hole 1127B at 0.12 Ma (Fig. **F1;** Table **T1**), which is consistent with the age estimated by Thompson et al. (1979) and confirmed by others (i.e., Cang et al., 1988). The interval of pink forms was seen in all other sections from the GAB, except Hole 1132A where the base of MIS 5 may be absent.

FAD And Local Reappearance Of *Gt. hirsuta*

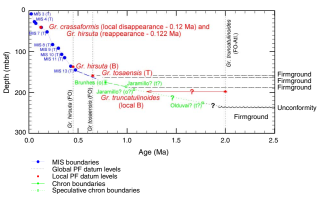
The form of *Gt. hirsuta* used for biostratigraphic purposes is similar to the distinctive variant 1 of Parker (Parker, 1962; Parker, 1967; Blow, 1969). In contrast to variant 3 of Parker, variant 1 occurs only in the late Quaternary, first appearing in the middle Brunhes Chron (Berggren et al., 1995a) in the southwestern Atlantic Ocean (Pujol and Duprat, 1983, who refer to variants 1 and 3 of Parker).

Gt. hirsuta first occurs in one sample at 137.22 ± 1.5 m in Hole 1132 (Fig. **F2;** Table **T1**). The event is close in time to its evolutionary first appearance at 0.45 Ma and lies within MIS 12. The species promptly disappears from the section until near the top, where it reappears within the base of MIS 5 (Almond et al., 1993). On the basis of interpolation from oxygen-isotope stratigraphic boundaries, the reappearance occurs at 0.12 Ma in Hole 1127B and 0.13 Ma in Hole 1132B (Figs. **F1, F2;** Table **T1**). The species also reappears within MIS 5 in Holes 1131A,

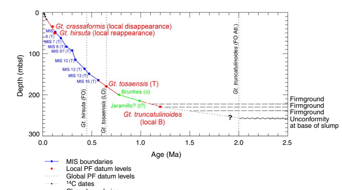
F1. Age model, Hole 1127B, p. 9.



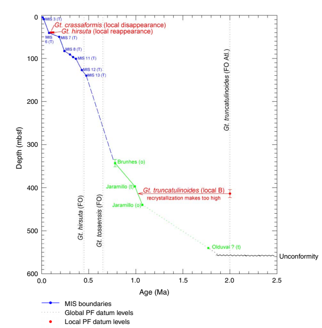
F2. Age model, Hole 1132B, p. 10.



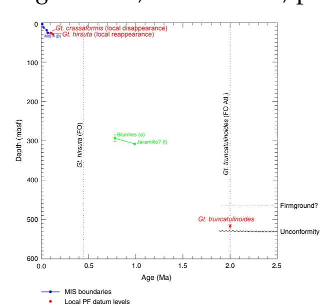
F3. Age model, Hole 1130A, p. 11.



F4. Age model, Hole 1129C, p. 12.



F5. Age model, Hole 1131A, p. 13.



1129C, and 1130A (Figs. F3, F4, F5) and persists in trace amounts to the tops of all sections.

T1. Depths and ages of foraminifers biostratigraphic datum levels, p. 14.

Local Disappearance of *Gt. crassaformis*

Gt. crassaformis is present intermittently in trace to rare amounts in intervals throughout the Quaternary but disappears within MIS 5 in the GAB. The species remains absent from the assemblage to the tops of all sections (Figs. F1, F2, F3, F4, F5; Table T1). Interpolation from oxygen-isotope stratigraphic boundaries in Holes 1127B and 1132B indicates that the event occurred at 0.10 and 0.12 Ma, respectively.

It is interesting to note that several subspecies of *Gt. crassaformis* were noticed within the Quaternary section in Hole 1127B. *Gt. crassaformis hessi* Bolli and Premoli Silva first appears at ~280.55 mbsf, just above the last appearances of *Gt. crassaformis viola* (Blow) and *Gt. crassaformis ronda* Blow.

LAD of *Gt. tosaensis*

The LAD of *Gt. tosaensis* was observed very close to 0.65 Ma (age of global extinction) in both Holes 1127B and 1132B (Figs. F1, F2; Table T1). The event lies at the base of MIS 16 in Hole 1127B. The datum level lies between the top of MIS 16 and the termination of the Brunhes Chron in Hole 1130A and, hence, may be synchronous (Fig. F3; Table T1). Poor preservation in the form of recrystallized coatings made impossible certain detection of the range of *Gt. tosaensis* in Holes 1129C and 1131A. The carbonate coatings are most prevalent in these holes between ~100 and 300 mbsf, where pore water alkalinity stands at a maximum (Swart et al., 2000; Feary, Hine, Malone, et al., 2000).

FAD And Local Appearance of *Gt. truncatulinoides*

The FAD of *Gt. truncatulinoides* is 2.58 Ma in the southwestern Pacific Ocean (Kennett, 1973; Jenkins and Srinivasan, 1986; Dowsett, 1989) and ~2.0 Ma in the upper Olduvai Subchron outside the southwestern Pacific Ocean (Berggren et al., 1995a, 1995b; Spencer-Cervato and Thierstein, 1997). However, the species makes its first entrance into high-latitude locales much later (see Dowsett, 1989).

Gt. truncatulinoides also enters the GAB late. It first appears between 1.6 and 1.7 Ma in Hole 1127B below the LAD of *Calcidiscus macintyrei* (Fig. F1; Table T1). This section has fair age control, better preservation than at other Leg 182 sites with expanded Quaternary sections, and excellent resolution due to its fast sedimentation rate. Hence, we place greatest reliance on the age estimated from this section. In contrast, *Gt. truncatulinoides* first appears more recently at ~1.1–1.2 Ma in Holes 1129C and 1132B on the basis of interpolation between subchrons. However, we suspect that severe recrystallization, so severe that it hinders fossil identification, has made the first appearance too shallow at Site 1129. Further, please note that the assignment of reversals to subchrons in lower Hole 1132B is considered highly speculative by M. Fuller and R. Garza (pers. comm., 2001) and requires verification from another stratigraphic instrument such as calcareous nannofossil biostratigraphy. The first appearance of *Gt. truncatulinoides* in Hole 1130A also may be consistent with an age of 1.2 Ma, but lack of age control makes the assertion uncertain (Fig. F3; Table T1). The first appearance in Hole 1131A is completely uncertain due to lack of age control. Fuller et al. (submitted) [N2] expressed uncertainty about correct identification of the true onset of the Brunhes and the termination of the Jaramillo at this locale.

It is ironic that the one marker species that is abundant in transitional water masses is the one that is time transgressive in its first entrance into the GAB.

Sedimentation

It is interesting to note that the sedimentation rate is faster above and slower below the onset of the Brunhes Chron on the basis of magnetostratigraphy (Fuller et al., submitted [N2]), seismic stratigraphy (Feary, Hine Malone, et al., 2000), calcareous nannofossil biostratigraphy (**Ladner,** this volume), and the planktonic foraminifer biostratigraphy herein. The slow interval contains several omission surfaces, which might have played a role in the slower sediment accumulation of the lower Pleistocene section (Figs. **F1, F2, F3, F4, F5;** Table **T1**). The age of the onset of sedimentation above the basal disconformity of seismostratigraphic Sequence 2 is ~1.9 Ma, on the basis of extrapolation from overlying datum levels (Table **T1**).

SUMMARY

One planktonic foraminiferal datum level was found to be time transgressive in the GAB relative to those of the open ocean, specifically the first appearance of *Gt. truncatulinoides,* which made its entrance into the GAB at 1.6–1.7 Ma. In contrast, the remainder of the datum levels appear synchronous with global events, specifically, the FAD of *Gt. hirsuta,* the LAD of *Gt. tosaensis,* and the Indo-Pacific LAD of pink *Gs. ruber.* Unfortunately, the FAD of *Gt. hirsuta* is difficult to apply because the species promptly disappears from the GAB after its first entrance at 0.45 Ma and does not reappear until 0.12 Ma. The reappearance, however, is a locally useful biostratigraphic event, as is the local disappearance of *Gt. crassaformis* at 0.10 Ma.

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Figure F1. Age model of Hole 1127B from the slope (479.3 m) of the eastern transect showing planktonic foraminifer biostratigraphic events. This section has the best age control of all those in this study. PF = planktonic foraminifer. B = bottom, T = top. MIS = marine isotope stage. o = onset, t = termination.

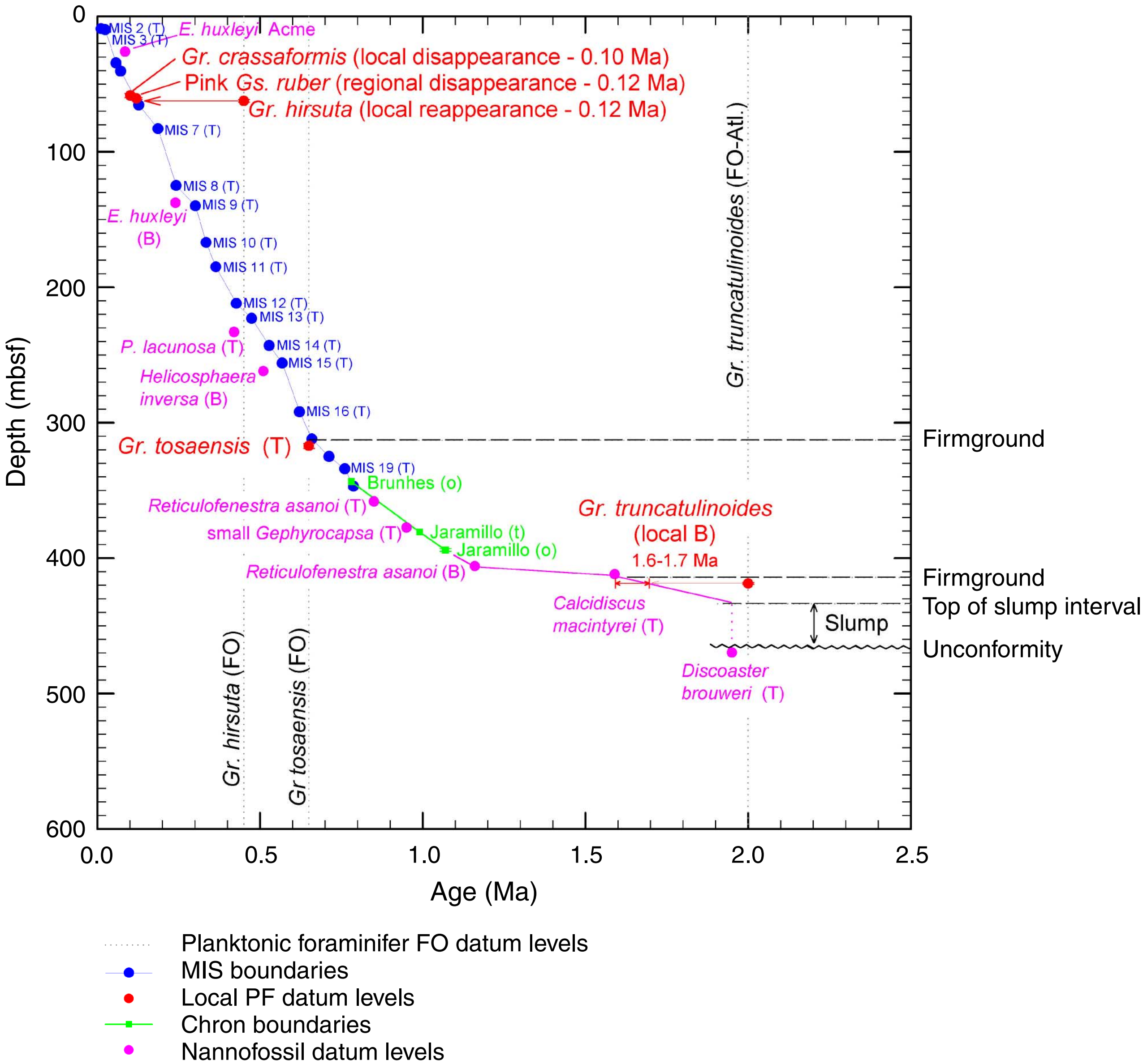

Figure F2. Age model of Hole 1132B from the shelf edge (218.3 m) of the western transect showing planktonic foraminifer biostratigraphic events. The section has the second best age control of all those is this study. PF = planktonic foraminifer. B = bottom, T = top. MIS = marine isotope stage. o = onset, t = termination.

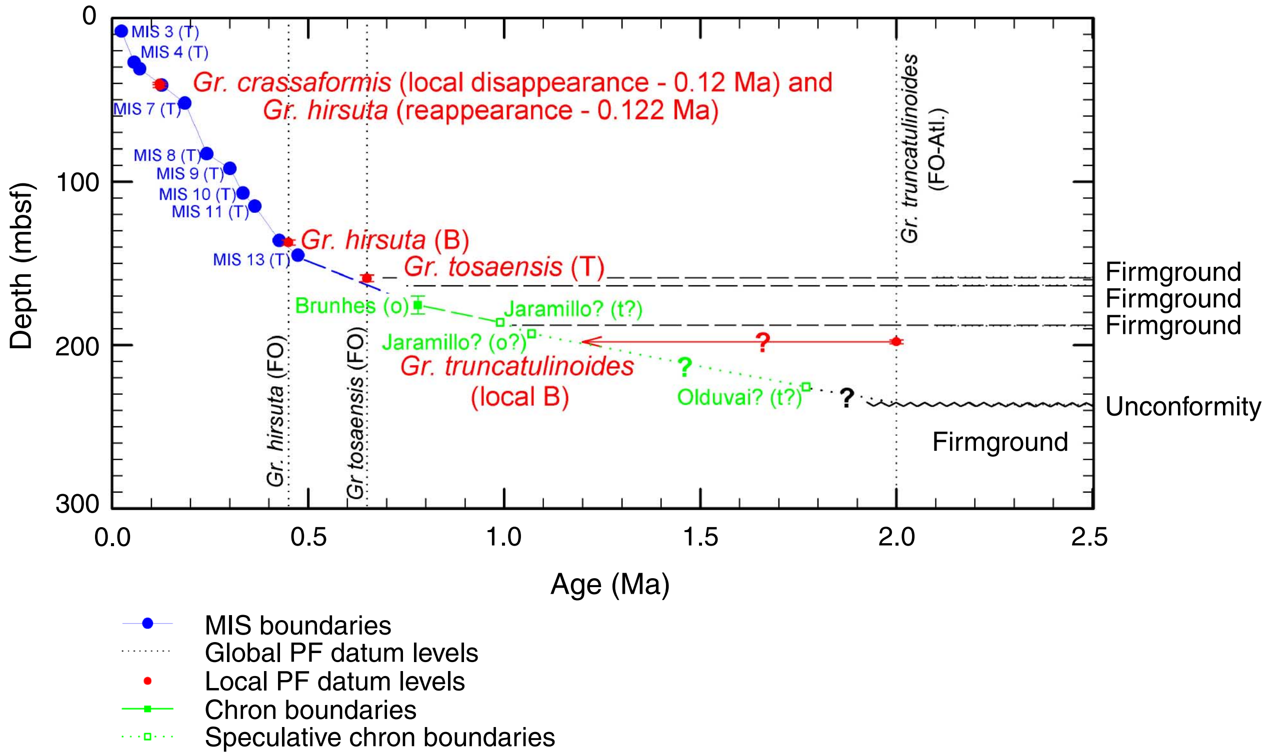

Figure F3. Age model of Hole 1130A from the Eyre Terrace (488 m) of the western transect showing planktonic foraminifer biostratigraphic events. PF = planktonic foraminifer. B = bottom, T = top. MIS = marine isotope stage. o = onset, t = termination.

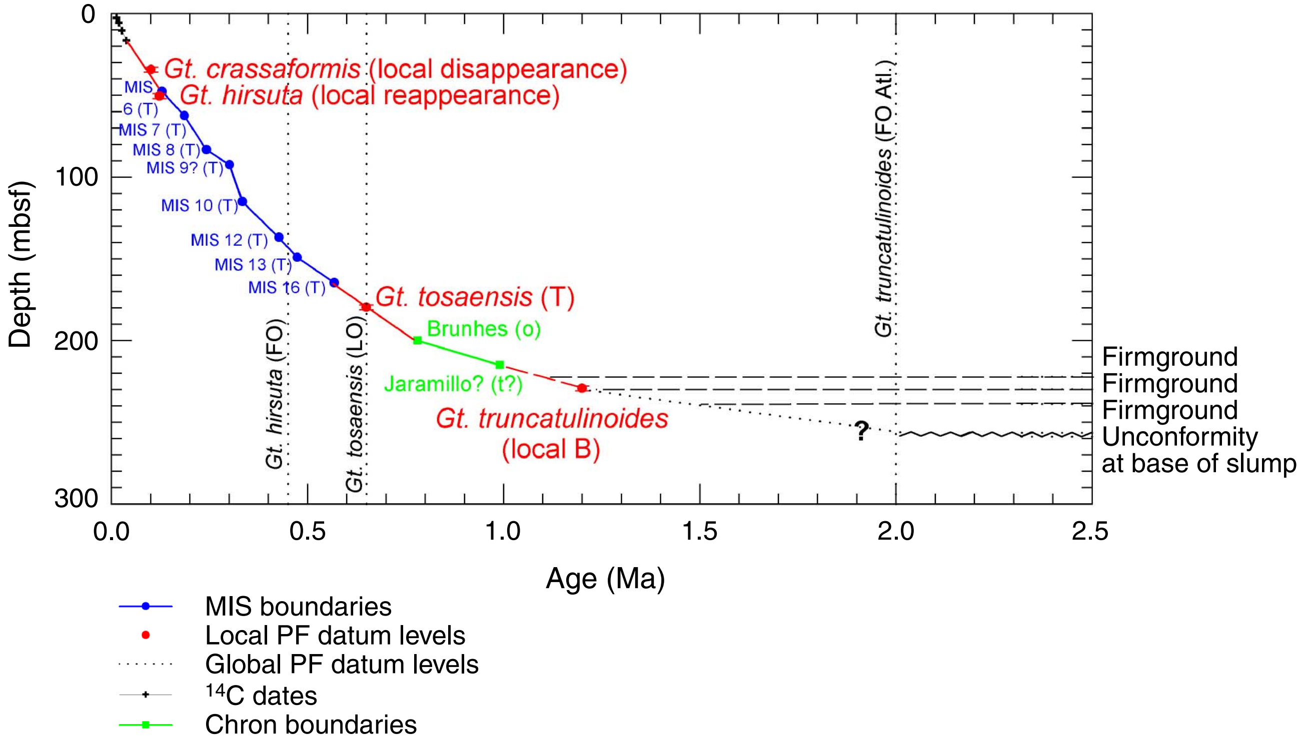

Figure F4. Age model of Hole 1129C from the shelf edge (202.5 m) of the eastern transect showing planktonic foraminifer biostratigraphic events. PF = planktonic foraminifer. B = bottom, T = top. MIS = marine isotope stage. o = onset, t = termination.

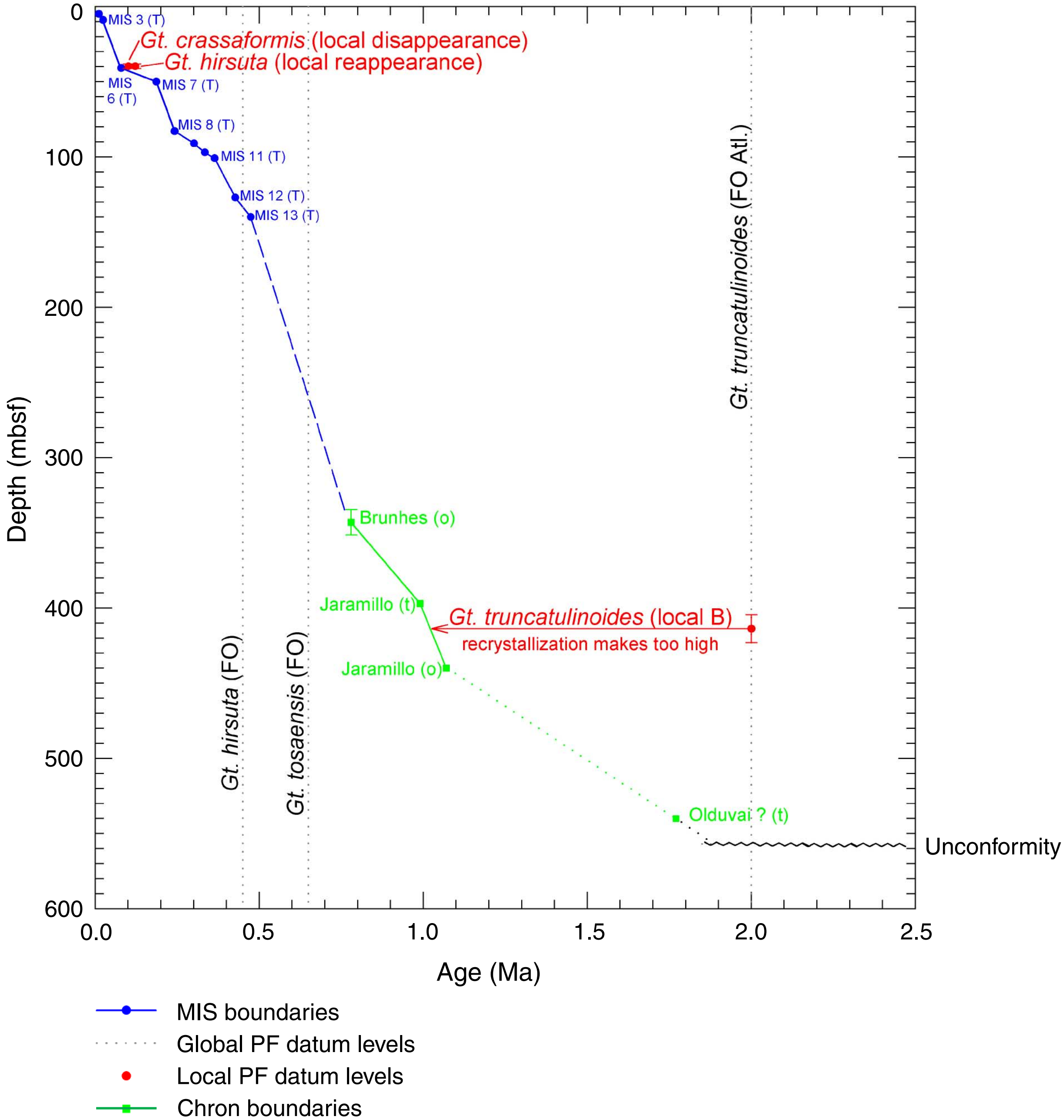

Figure F5. Age model of Hole 1131A from the upper slope (332.4 m) of the eastern transect showing planktonic foraminifer biostratigraphic events. PF = planktonic foraminifer. B = bottom, T = top. MIS = marine isotope stage. o = onset, t = termination.

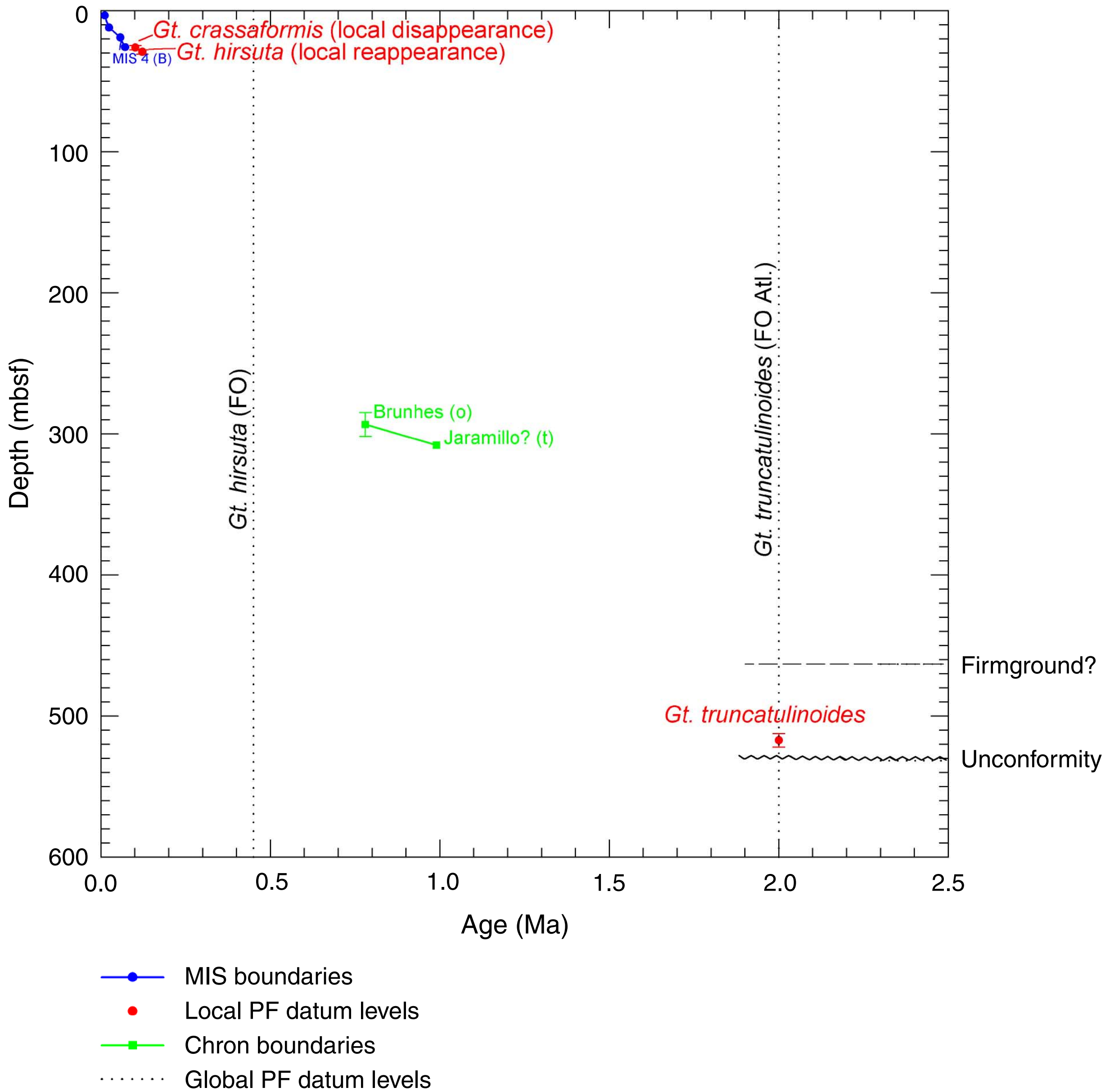

Table T1. Depths and ages of foraminifers biostratigraphic datum levels. (See table notes. Continued on next page.)

		Hole 1127B			Hole 1131A		Hole 1129C			Hole 1130A		Hole 1132B		
	Age (Ma)	Estimated local age (Ma)	Depth of datum (mbsf)	Stratigraphic error (m)	Depth of datum (mbsf)	Stratigraphic error (m)	Estimated local age (Ma)	Depth of datum (mbsf)	Stratigraphic error (m)	Depth of datum (mbsf)	Stratigraphic error (m)	Estimated local age (Ma)	Depth of datum (mbsf)	Stratigraphic error (m)
Planktonic foraminifer datum level														
T *Gr. crassaformis* local disappearance	?	0.10	58.45	1.50	26.32	1.50		39.72	1.50	34.40	1.50	0.13	39.98	0.74
T pink *Gs. ruber*[7]	0.12	0.12	60.71	0.75	—	—		—	—	—	—	—	—	—
B reappearance *Gr. hirsuta*[8]	~.12	0.12	62.46	1.00	29.32	1.50		39.72	1.50	50.46	1.50	0.13	41.48	0.76
B *Gr. hirsuta*[9]	0.45	—	—	—	—	—		—	—	—	—	—	137.22	1.50
T *Gr. tosaensis*[9]	0.65	0.68	317.25	1.80	—	—		—	—	179.70	1.50	—	159.22	2.00
B *Gr. truncatulinoides* (Atl. and Ind.)[9]	2	1.70	418.71	0.75	517.26	4.76	1.10	413.80	9.31	229.30	1.50	1.18	197.89	1.20
Magnetostratigraphic boundaries[1, 10]														
Brunhes (o)	0.78	—	343.40	—	293.45	8.45		343.00	4.20	200.00	—		175.50	5.50
Jaramillo (t)	0.99	—	380.70	—	308.00	—		397.90	5.00	215.00	—		186.00*	
Jaramillo (o)	1.07	—	394.00	1.00	—	—		440.00	5.00				193.00*	
Olduvai (t)	1.77	—	—	—	—	—		540.00	—				225.50*	
MIS boundaries[2, 3, 4, 11]			Approximate depth[2]		Approximate depth[3]			Approximate depth[3]		Approximate depth[4]			Approximate depth[3]	
T MIS 2	0.011		9.20		3.50			5.00		—			—	
T MIS 3	0.024		9.90		12.00			9.00		—			4.00	
T MIS 4	0.057		34.50		19.00			30.00		—			?	
T MIS 5	0.071		40.50		26.00			36.00		—			?	
MIS 5.1	0.079		41.00		—			—		—			—	
MIS 5.2	0.086		44.00		—			—		—			—	
MIS 5.3	0.097		46.00		—			—		—			—	
MIS 5.4	0.106		50.00		—			—		—			—	
MIS 5.5	0.122		62.50		—			—		—			—	
T MIS 6	0.129		65.50		36.00			41.00		47.73			41.50	
T MIS 7	0.186		83.00					50.00		62.45			52.00	
T MIS 8	0.242		125.00					83.00		83.38			83.00	
T MIS 9	0.301		140.00					91.00		92.45			92.00	
T MIS 10	0.334		167.00					97.00		115.10			107.00	
T MIS 11	0.364		185.00					101.00		—			115.00	
T MIS 12	0.427		212.00					127.00		136.95			136.00	
T MIS 13	0.474		223.00					140.00		149.21			145.00	
T MIS 14	0.528		243.00							—				
T MIS 15	0.568		256.00							164.73				
T MIS 16	0.621		292.00											
T MIS 17	0.659		312.00											
T MIS 18	0.712		325.00											
T MIS 19	0.76		334.00											
T MIS 20	0.787		347.00											
Nannofossil datum level[5]			Depth											
Emiliania huxleyi Acme[9]	0.085		26.10											
B *Emiliania huxleyi*[12]	0.24		137.71											
T *Pseudoemiliania lacunosa*[12]	0.42		233.10											
B *Helicosphaera inversa*[12]	0.51		262.00											
T *Reticulofenestra asanoi*[12]	0.85		358.20											
T small *Gephyrocapsa* spp.[12]	0.95		377.40											
B *Reticulofenestra asanoi*[12]	1.16		406.01											
T *Calcidiscus macintyrei*[9]	1.59		412.01											

Table T1 (continued).

		Hole 1127B			Hole 1131A		Hole 1129C			Hole 1130A		Hole 1132B		
	Age (Ma)	Estimated local age (Ma)	Depth of datum (mbsf)	Stratigraphic error (m)	Depth of datum (mbsf)	Stratigraphic error (m)	Estimated local age (Ma)	Depth of datum (mbsf)	Stratigraphic error (m)	Depth of datum (mbsf)	Stratigraphic error (m)	Estimated local age (Ma)	Depth of datum (mbsf)	Stratigraphic error (m)
B. bigelowii acme			456.00		522.00					234.34			222.91	
T *Discoaster brouweri*[12]	1.95		469.70											
Breaks in sedimentation														
Omission surface										222.30	—		158.48	—
Omission surface			313.00	—						229.80	—		163.41	—
Omission surface			414.35	—	463.30	—				238.80	—		188.09	—
Unconformable base of Sequence[2]		1.95	463.28	3.66	531.49		1.89	556.70		259.25	—	2.00	236.30	—
Radiocarbon dates[6]														
2.73 mbsf										13.30	0.09			
2.73 mbsf										13.60	0.15			
5.73 mbsf										19.00	0.15			
5.73 mbsf										24.50	0.30			
10.45 mbsf										26.90	0.19			
10.45 mbsf										27.70	0.36			
16.47 mbsf										38.40	0.39			

Notes: T = top, B = bottom, o = onset, t = termination, Atl. = Atlantic Ocean, Ind. = Indian Ocean. * = highly speculative assignment of reversals to chron boundaries (M. Fuller, pers. comm.). 1 = Fuller et al. (submitted) [N2], 2 = Andres and McKenzie (2000), 3 = Holbourn et al. (submitted), [N1], 4 = S. Siedlecki and G. Brooks (unpubl. data), 5 = Ladner (this volume), 6 = Hine et al. (this volume), 7 = Thompson et al. (1979), 8 = Almond et al. (1993), 9 = Berggren et al. (1995a), 10 = Berggren et al. (1995b), 11 = Bassinot et al. (1994), 12 = Sato and Kameo (1996).

CHAPTER NOTES*

N1. Holbourn, A., Kuhnt, W., and James, N., submitted, *Paleoceanography.*

N2. Fuller, M. Molina Garza, R., Antretter, M., and Lichowski, F., submitted, *Aust. J. Earth Sci.*

*Dates reflect file corrections or revisions.