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Sediment flux across the Great Barrier Reef Shelf to the Queensland Trough over the last 300 ky

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Abstract

The continental margin off northeast Australia, comprising the Great Barrier Reef (GBR) platform and Queensland Trough, is the largest tropical mixed siliciclastic /carbonate depositional system in existence. We describe a suite of 35 piston cores and two Ocean Drilling Program (ODP) sites from a 130×240 km rectangular area of the Queensland Trough, the slope and basin setting east of the central GBR platform. Oxygen isotope records, physical property (magnetic susceptibility and greyscale) logs, analyses of bulk carbonate content and radiocarbon ages at these locations are used to construct a high resolution stratigraphy. This information is used to quantify mass accumulation rates (MARs) for siliciclastic and carbonate sediments accumulating in the Queensland Trough over the last 31,000 years. For the slope, highest MARs of siliciclastic sediment occur during transgression (1.0 Million Tonnes per year; MT yr^{-1}), and lowest MARs of siliciclastic (<0.1 MT yr^{-1}) and carbonate (0.2 MT yr^{-1}) sediment occur during sea level lowstand. Carbonate MARs are similar to siliciclastic MARs for transgression and highstand (1.1–1.4 MT yr^{-1}). In contrast, for the basin, MARs of siliciclastic (0–0.1 MT yr^{-1}) and carbonate sediment (0.2–0.4 MT yr^{-1}) are continuously low, and within a factor of two, for lowstand, transgression, and highstand. Generic models for carbonate margins predict that maximum and minimum carbonate MARs on the slope will occur during highstand and lowstand, respectively. Conversely, most models for siliciclastic margins suggest maximum and minimum siliciclastic MARs will occur during lowstand and transgression, respectively. Although carbonate MARs in the Queensland Trough are similar to those predicted for carbonate depositional systems, siliciclastic MARs are the opposite. Given uniform siliciclastic MARs in the basin through time, we conclude that terrigenous material is stored on the shelf during sea level lowstand, and released to the slope during transgression as wave driven currents transport shelf sediment offshore. © 2000 Elsevier Science B.V. All rights reserved.

Keywords: sequence stratigraphy; sedimentation rates; sediment flux; Queensland Trough; Great Barrier Reef; Late Quaternary

1. Introduction

The relative change in sea level is an important control on the evolution of sedimentary sequences on passive continental margins (e.g. Vail et al., 1977; Miller et al., 1998), but the sedimentary response to sea level change varies from one margin to another because of regional differences in subsidence rate, sediment supply, climate, and sediment composition (e.g. Miall, 1997; Rankey, 1997; Galloway, 1998; Karner and Marra, 1998). In particular, there is a fundamental difference between the response of siliciclastic and carbonate margins to relative sea level change (Posamentier and Vail, 1988; Sarg, 1988; Eberli, 1991; Coniglio and Dix, 1992; James and Kendall, 1992). The maximum sediment flux from the continental shelf to the slope and basin is

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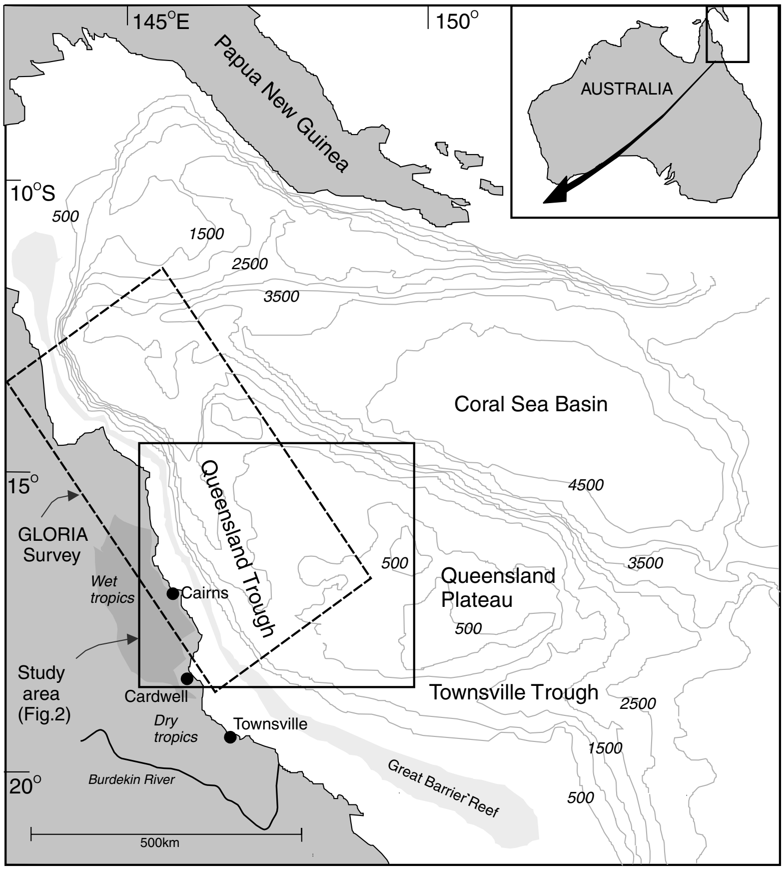


Fig. 1. The Coral Sea and the northeast margin of Australia showing major physiographic provinces, the location of the study area (solid box), and the approximate limits of the GLORIA side scan sonar survey (dashed box; Fig. 6). The Great Barrier Reef (GBR) shelf extends from the east margin of the GBR to the coast. Fluvial discharge in this region comes from two sources: the wet tropics centred on Cairns, and the dry tropics over the remaining terrestrial areas. The dominant source of fluvial sediment to the GBR Platform in this region, the Burdekin River, is shown south of Townsville draining the dry tropics. Isobath interval, 500 m.

believed to occur during sea level lowstands in siliciclastic systems (e.g. Van Wagoner et al., 1988; Nelson, 1990), but during sea level highstands in carbonate systems (e.g. Boardman and Neumann, 1984; Droxler and Schlager, 1985; Boardman et al., 1986).

Some continental margins, where sediment is composed of substantial portions of both terrigenous material and biogenic carbonate, are best classified as mixed siliciclastic/carbonate systems (Mount, 1984). As highlighted by several workers (e.g. Dolan, 1989; Eberli, 1991; Cant, 1992; Coniglio and Dix, 1992), the response of these hybrid systems to sea level and climate change remains an open issue because there are relatively few quantitative studies of their behaviour through time.

The northeast continental margin of Australia (Fig. 1) is the largest extant mixed siliciclastic/carbonate depositional system (Maxwell and Swinchatt, 1970; Davies et al., 1991). One portion of this margin, the Queensland Trough, represents a continental slope and rift-basin situated immediately east of the central Great Barrier Reef (GBR) province (Fig. 1). The Queensland Trough (Fig. 2) has been a repository for biopelagic sediment, and for terrigenous and carbonate sediment from the continental shelf, since long before the initiation of the Great Barrier Reef at ca. 0.5 Ma (Harris

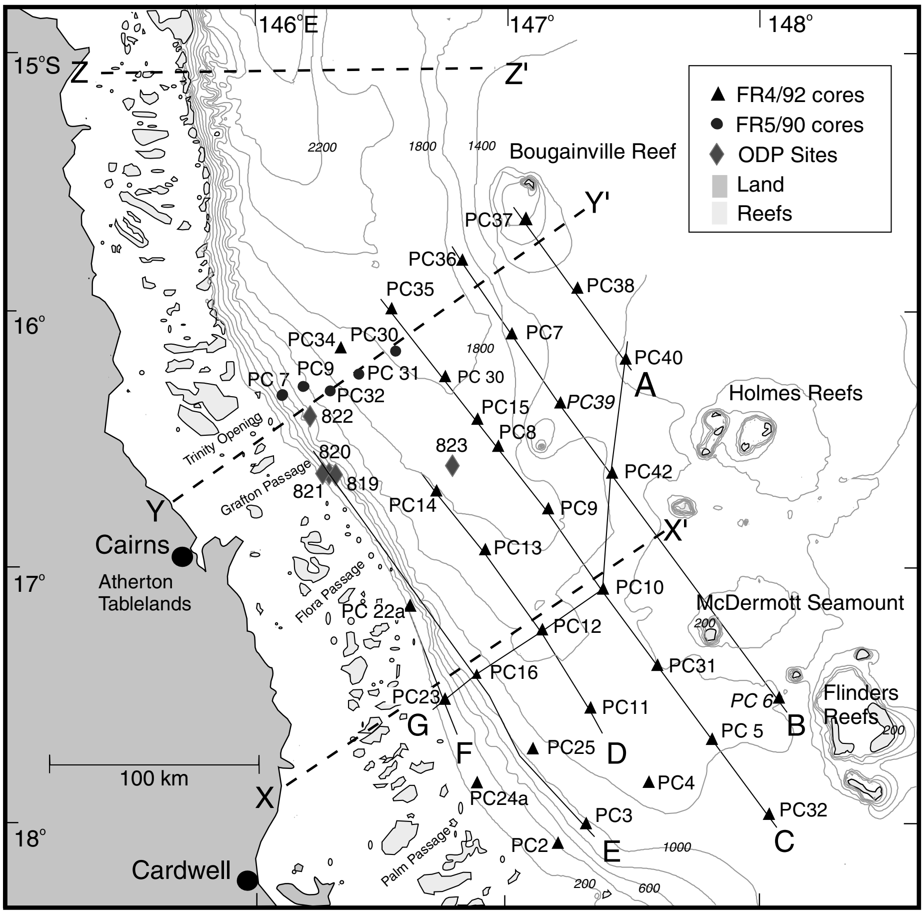


Fig. 2. Detailed map of the north–central Great Barrier Reef (GBR) shelf and south–central Queensland Trough showing the location of *RV Franklin* piston cores and relevant Ocean Drilling Program (ODP) Leg 133 Holes within the study area. Piston core transects shown in Fig. 9 are noted by solid lines A through G. Bathymetric cross sections shown in Fig. 5 are noted by dashed lines X–X′, Y–Y′ and Z–Z′. Isobath interval, 200 m.

et al., 1990; Davies et al., 1991; Davies and McKenzie, 1993).

Results from Ocean Drilling Program (ODP) Site 820 on the upper slope of the Queensland Trough (Fig. 2) suggest that the northeast Australian margin may have a complex response to sea level change which differs from that of previously described siliciclastic, carbonate, or mixed continental margins.

In this paper we construct high-resolution stratigraphic records for upper Quaternary sediment at 35 locations across the Queensland Trough (Table 1; Fig. 2). Thereby, we quantify the amount of siliciclastic and carbonate sediment deposited on the slope and basin of the Queensland Trough through time. Our results demonstrate that the maximum and minimum carbonate accumulations occur during highstand and lowstand, respectively, and that maximum and minimum siliciclastic accumulation occurred during transgression and lowstand, respectively. Potential causes for this sedimentary response of the east Queensland margin are discussed.

2. Background

2.1. North Queensland margin

The North Queensland margin, between 15 and

Table 1
Description of piston cores from the Queensland Trough (analyses performed on cores include (Appendix A): C = carbonate; SI = stable isotopes; L = Lithology; MS = magnetic susceptibility; R = radiocarbon ages; G = greyscale; B = biostratigraphy)

Core	Latitude (°S)	Longitude (°E)	Depth (mbsl)	Date recovered	Length (m)	Analyses	Sandy turbidites
PC 2	18°05.8	147°13.0	332	30/4/92	0.60	MS, G	Y
PC 3	18°01.5	147°19.7	870	30/4/92	0.71	MS, G	
PC 4	17°51.6	147°34.8	1225	1/5/92	2.54	MS, G	Y
PC 5	17°41.8	147°49.8	1193	1/5/92	3.76	MS, G	
PC 6	17°32.0	148°05.0	1193	1/5/92	3.43	MS, G, SI	
PC 7	16°6.36	147°01.4	1488	5/5/92	3.60	C, MS, G	
PC 8	16°32.9	146°58.9	1712	2/5/92	3.64	MS, G	Y
PC 9	16°47.7	147°10.6	1616	2/5/92	3.56	MS, G	Y
PC 10	17°06.3	147°23.4	1334	3/5/92	3.69	MS, G	
PC 11	17°34.3	147°20.9	1320	1/5/92	3.88	MS, G	
PC 12	17°16.0	147°08.5	1443	1/5/92	3.48	MS, G	
PC 13	16°57.1	146°55.2	1507	1/5/92	3.81	MS, G	
PC 14	16°43.4	146°43.9	1574	2/5/92	4.48	MS, G, SI	Y
PC 15	16°26.5	146°53.6	1626	2/5/92	3.83	MS, G, B	
PC 16	17°25.9	146°53.5	1043	10/5/92	3.50	C, MS, G, SI, R, L	
PC 22a	17°10.3	146°36.9	167	10/5/92	1.36	C, MS, G	
PC 23	17°32.2	146°45.5	225	10/5/92	3.74	C, MS, G, R, L	
PC 24a	17°51.9	146°53.5	225	10/5/92	1.82	MS, G	Y
PC 25	17°43.7	147°06.3	984	10/5/92	3.57	MS, G	
PC 30	16°16.7	146°45.8	1797	2/5/92	3.64	MS, G	Y
PC 31	17°24.5	147°36.9	1308	2/5/92	3.50	MS, G	
PC 32	17°59.3	148°02.4	1134	3/5/92	3.68	MS, G, B	Y
PC 34	16°09.8	146°20.0	1667	4/5/92	4.16	MS, G	
PC 35	16°00.9	146°33.0	1857	5/5/92	3.25	MS, G, SI, R	
PC 36	15°49.5	146°49.2	1824	5/5/92	3.94	MS, G, SI	Y
PC 37	15°39.8	147°04.2	1458	5/5/92	3.80	MS, G	
PC 38	15°56.0	147°17.0	1340	5/5/92	3.65	MS, G	
PC 39	16°22.9	147°13.4	1334	5/5/92	3.86	MS, G, SI, L	
PC 40	16°12.3	147°28.5	1168	5/5/92	3.20	MS, G	
PC 42	16°39.1	147°25.8	1389	6/5/92	3.26	C, MS, G, SI, R	
FR5/90 PC 7	16°20.7	146°06.6	706	30/5/90	1.29	MS, G	
FR5/90 PC 9	16°18.2	146°11.2	1242	30/5/90	1.10	MS, G	
FR5/90 PC 30	16°10.8	146°33.0	1798	3/6/90	4.95	MS, G, B	Y
FR5/90 PC 31	16°15.6	146°24.2	1650	3/6/90	5.24	MS, G, B	Y
FR5/90 PC 32	16°19.5	146°17.9	1490	4/6/90	4.07	MS, G, B	Y

18°S (Fig. 1), is of particular interest for studies of mixed siliciclastic-carbonate systems as it encompasses both end-member depositional systems. Rivers contribute around 2.6 Million Tonnes per year ($MT\,yr^{-1}$) of terrigenous material annually to a broad shelf (e.g. Belperio, 1983; Neil and Yu, 1995; Woolfe et al., 1998), the middle and outer shelf parts of which contain the Great Barrier Reef (GBR), an extensive periplatform carbonate complex (Maxwell and Swinchatt, 1970).

North Queensland experiences a "quasi-monsoonal" climate with pronounced "wet" and "dry" seasons (Gentilli, 1971; Suppiah, 1992). Differences in topography and coastline cause considerable spatial variability in seasonality, rainfall, and vegetation (Downey, 1983; Sumner and Bonell, 1986; Kershaw, 1994). Two general climate zones exist (Fig. 1). The rugged region surrounding Cairns comprises the "wet tropics", with moderate to high rainfall ($1500–5000\,mm\,yr^{-1}$) throughout the year and abundant rainforest vegetation. The larger open woodland area inland and to the south comprises the "dry tropics" with only moderate amounts of rainfall ($<1500\,mm\,yr^{-1}$)

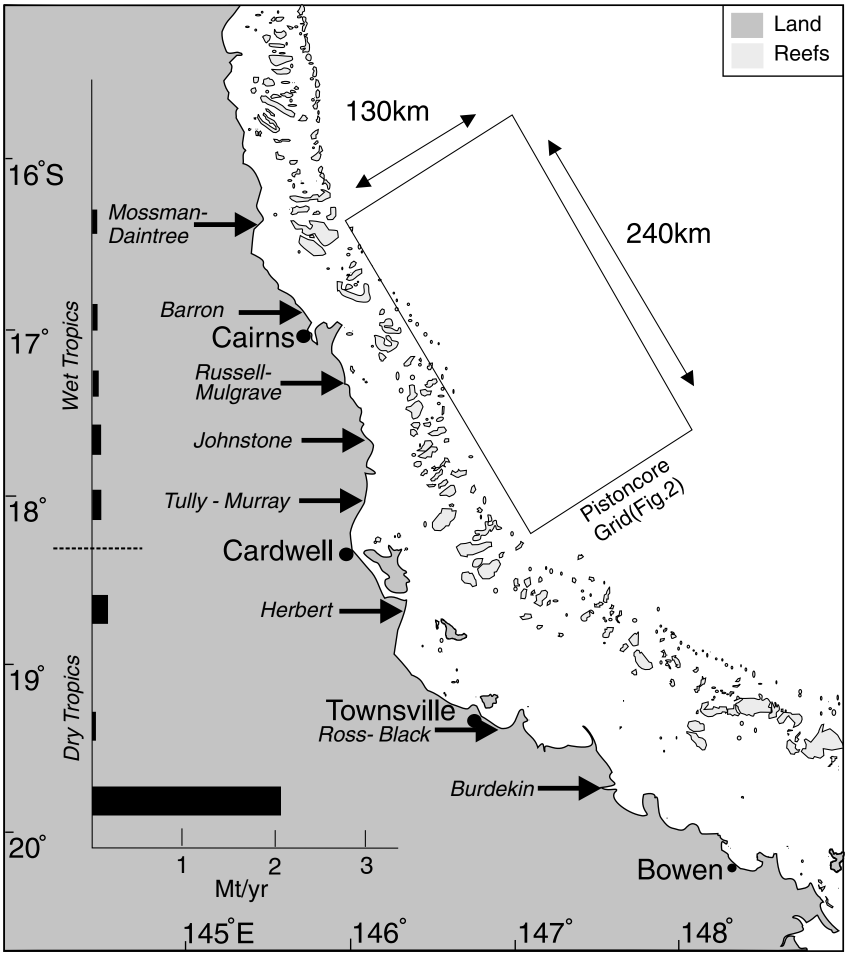


Fig. 3. Location (arrowed) and magnitude (bar graph) of the major discharge points of fluvial siliciclastic sediment to the central GBR continental shelf (values estimated for undisturbed catchments, after Neil and Yu, 1995). Note that most siliciclastic material added to the region comes from the Burdekin River, (i.e. is from the dry tropics). Also shown are the dimensions of the FR4/92 piston core grid (130 × 240 km) used to calculate the mass accumulation rate of siliciclastic and carbonate sediment in the Queensland Trough.

which falls mostly during the 3-month summer period.

Rainfall and vegetation have an important effect on fluvial sediment supply to the North Queensland margin. Eight river systems (Fig. 3) are significant in terms of siliciclastic supply to the eastern Queensland continental shelf between 16 and 20°S (Belperio, 1983; Neil and Yu, 1995; Woolfe et al., 1998). Five major rivers drain the wet tropics (Fig. 3) and have relatively steady water flow throughout the year. Conversely, three major rivers drain the dry tropics (Fig. 3) and are characterised by highly seasonal flow punctuated by major floods. Neil and Yu (1995) have estimated a collective natural sediment discharge from wet tropical rivers of approximately 0.4 MT yr^{-1}; Fig. 3), and from dry tropical rivers, approximately 2.2 MT yr^{-1} (mostly derived from the Burdekin; Figs. 1 and 3). Thus, a small but significant quantity of siliciclastic material is transferred annually from the Australian landmass to the north-central Queensland continental shelf, mostly during summer flood events (Belperio, 1983; Woolfe et al., 1998).

The central region of the Great Barrier Reef (GBR)

province, from approximately 15–18°S, (Maxwell and Swinchatt, 1970; Figs. 1–3) is of primary interest here because it is the area from which both siliciclastic and carbonate sediment is supplied to the Queensland Trough (Figs. 1–3). The shelf in this region varies in width from about 30 km north of Cairns to about 50 km off the coast of Cardwell (Fig. 1), and has been divided into shore parallel zones (Maxwell, 1968; Maxwell and Swinchatt, 1970; Belperio, 1983; Harris et al., 1990). The *inner shelf* slopes from the shoreline to approximately 20 m below sea level (mbsl), and is dominated by siliciclastic sand and mud (quartz, feldspar, and clay minerals) with a carbonate content less than 30%. This inner shelf siliciclastic material has accumulated preferentially in north facing bays near river sources (Belperio, 1983; Johnson and Searle, 1984; Carter et al., 1993). Material is also transported northwards by the prevailing southeast wind driven currents (Belperio, 1983), but the inner shelf zone is nonetheless relatively narrow (<5 km wide) away from coastal embayments. The *mid-shelf* grades gently from approximately 20–40 m in depth (Belperio, 1983), and is characterised by intermediate carbonate content (30–80%) because only minor amounts of terrigenous sediment are deposited there today. The thin, patchy Holocene sediment veneer (<2.5 m thick on the mid-shelf) consists of benthic foraminifera-rich gravelly carbonate sand (Johnson and Searle, 1984; Harris et al., 1990). Patches of pre-Holocene semi-indurated “relict” sediment also occur, especially in channels, and consist of alluvial, fluvio-deltaic or transgressive marine mud and sand (Maxwell and Swinchatt, 1970; Johnson and Searle, 1984; Harris et al., 1990; Carter et al., 1993). The *outer shelf* encompasses the main reef complex which is dissected by relatively deep (40–60 m) passages and channels that lie immediately landward of the shelf break, which is generally located at approximately 70 m depth. Sediment carbonate content is generally greater than 80%, except in outer reef passages (e.g. Trinity Opening and Grafton Passage; Fig. 2) where the siliciclastic content can exceed 30% (Maxwell, 1968; Maxwell and Swinchatt, 1970; Sims, 1980).

The sediment distribution on the continental shelf reflects two important features of the northeast Queensland margin. First, the separation of a siliciclastic inner shelf and a carbonate outer shelf by a sediment-starved zone of limited Holocene deposition suggests that little modern cross-shelf transport of siliciclastic material occurs (Maxwell, 1968; Maxwell and Swinchatt, 1970; Belperio, 1983). This inference is consistent with $\delta^{13}C$ analyses (Gagan et al., 1987), which show that terrestrial carbon from land plants is restricted to sediments which lie within 15 km of the shoreline. Second, the widths and depths of sediment zones correspond to a gentle cross-shelf gradient, especially beyond the inner shelf. Gradients between 0.4 and 0.8 m km^{-1} also often extend considerable distances inland from the coastline onto adjacent plains (>100 km; Woolfe et al., 1998).

The pattern of glacio-eustatic change in the late Quaternary includes a series of rapid rises in sea level, followed by gradual, step-like, falls (Fig. 4a; e.g. Chappell, 1994). The amplitude and dominant periodicity of these of glacial-interglacial sea level changes are ~120 m and ~100 ky. As a result, over the last 350 ky the continental shelf has been completely exposed for approximately 50% of the time and submerged at present-day levels for approximately 10% of the time (Fig. 4). Between 31 and 14.7 ka, the shoreline was located continuously below the shelf edge and sea level was ~100 m lower than today (Chappell, 1994). A rapid marine transgression occurred between 14.7 and 6.5 ka, as sea level rose to within 2 m of the present-day level (Fig. 4b; Larcombe et al., 1995).

2.2. Queensland Trough

The Queensland Trough is an 80,000 km^2 northwest–southeast trending rift basin (Symonds et al., 1983; Scott, 1993) which stretches from about 14–18°S, and separates the GBR platform (continental shelf and upper slope) to the west from the Queensland Plateau to the east (Fig. 1). The 550 km long Trough is wide (200 km) and deep (2800 m) in the north, where it opens into the Coral Sea Basin, but narrower (90 km) and shallower (900 m) to the south, where it terminates at a sill that separates the Queensland Trough from the Townsville Trough (Figs. 1 and 2). The sea-floor for most of the Queensland Trough lies between 1000 and 2000 mbsl (Figs. 1 and 2).

Bathymetric profiles across the Queensland Trough show a distinct asymmetry, with a steep slope on the western margin against the Australian continent and a

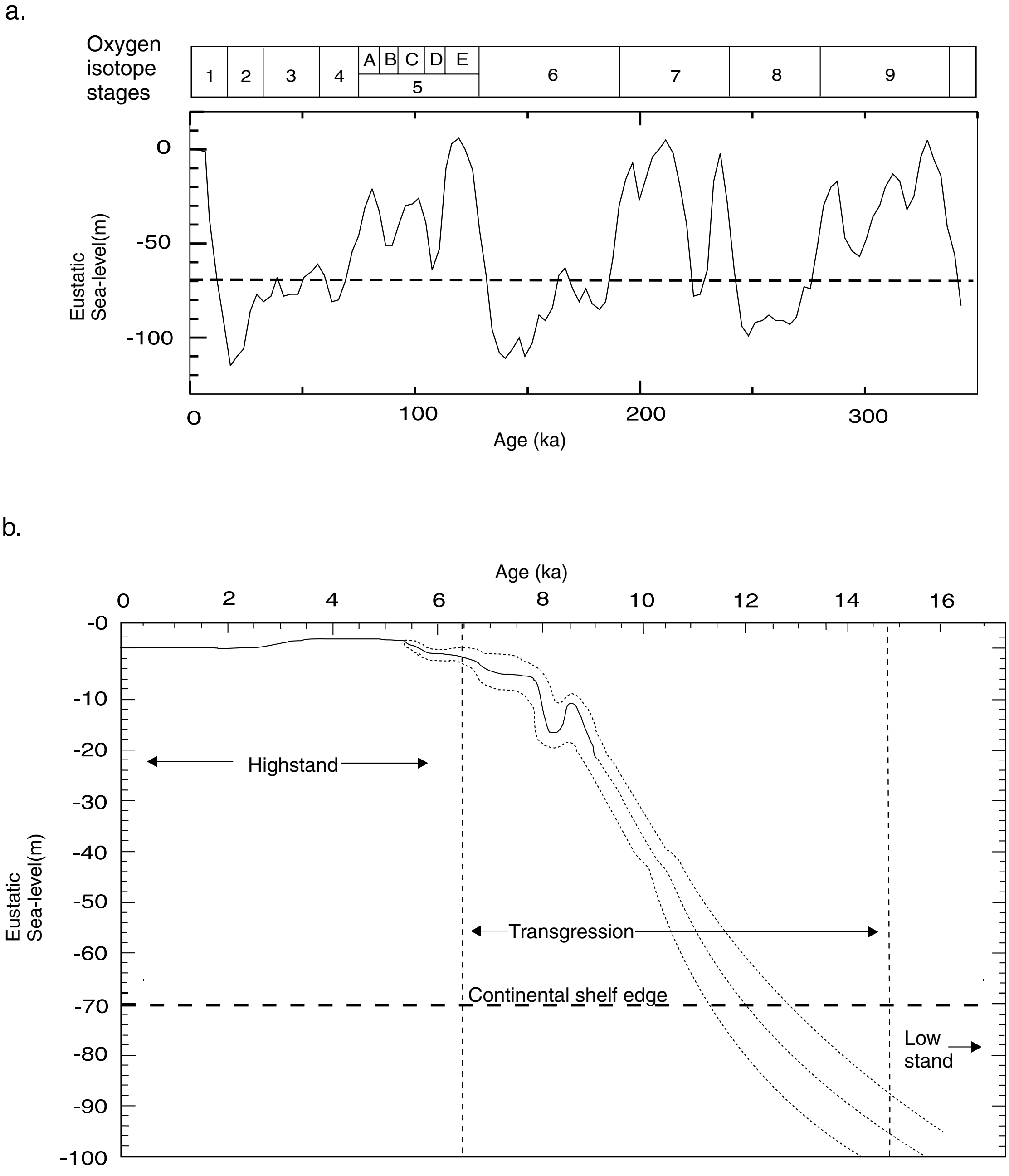


Fig. 4. Glacio-eustatic sea level changes applicable to the North Queensland margin (a) the last 350 ky (redrawn after Chappell, 1994) relative to the central GBR continental shelf edge (dashed line). The continental shelf has been exposed entirely, and comprised a fluvio-deltaic sedimentary environment (Johnson and Searle, 1984), for around 50% of this time. (b) Detailed sea level curve for the central GBR for the last 16 ky (modified after Larcombe et al., 1995). During transgression (14.7–6.5 ka), the sea rose above the shelf margin (dashed line) and rapidly crossed the shelf. Sea level and the position of the shoreline has remained relatively constant over the last 6.5 ky (highstand).

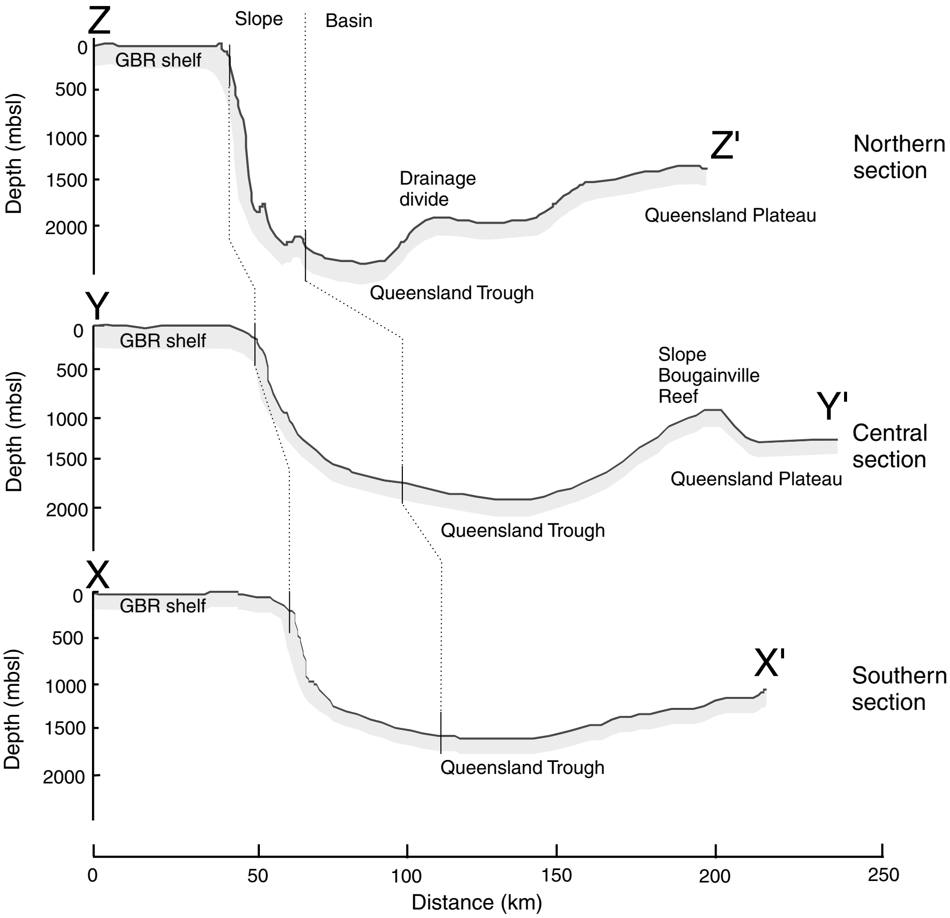


Fig. 5. Bathymetric profiles of the Queensland Trough across transects X–X′, Y–Y′ and Z–Z′ (Fig. 2) generated from the digital terrain model (DTM) of Lewis et al. (2000). Note the asymmetry of the trough with slope angles on the west margin that exceed 10° in the north. A drainage divide on the floor of the trough is also apparent in the north profile (Z–Z′). The division of the slope and basin is placed at 50 km perpendicular distance from the 200 m isobath for transects X–X′ and Y–Y′. The slope is much narrower (25 km) to the north (transect Z–Z′).

shallower slope on the eastern margin against the Queensland Plateau (Figs. 2 and 5). Continental slope angles on the eastern margin are typically about 2° toward the southern end of the trough but can exceed 10° in the north (Figs. 2 and 4). The floor of the Queensland Trough is relatively flat, with a shallow northward dip of $<1°$. However, the trough floor encompasses a distinct topographic high in the north. This key physiographic feature, presumably a basement fault block, divides the Queensland Trough into two northward trending channels at latitudes north of 16°S (Figs. 2 and 5).

Locations in the Queensland Trough can be classified as upper slope, lower slope or basin depending on bathymetry and distance from the GBR platform. Prior to our study, the best information concerning regional sediment deposition in the Queensland Trough came from a detailed sidescan sonar survey in 1989 by *HMAS Cook* using the GLORIA Mk II sonar array and a Seabeam multibeam echosounder (D.P Johnson, unpublished data). The resulting acoustic response of the sea floor, in conjunction with bathymetry, suggests the slope and basin can be divided into six different acoustic facies (Fig. 6; D.P. Johnson, pers. comm.). Intense backscattering occurs in regions along the western margin of the continental shelf south of 16°S; these are areas of exposed bedrock. Similar levels of backscattering

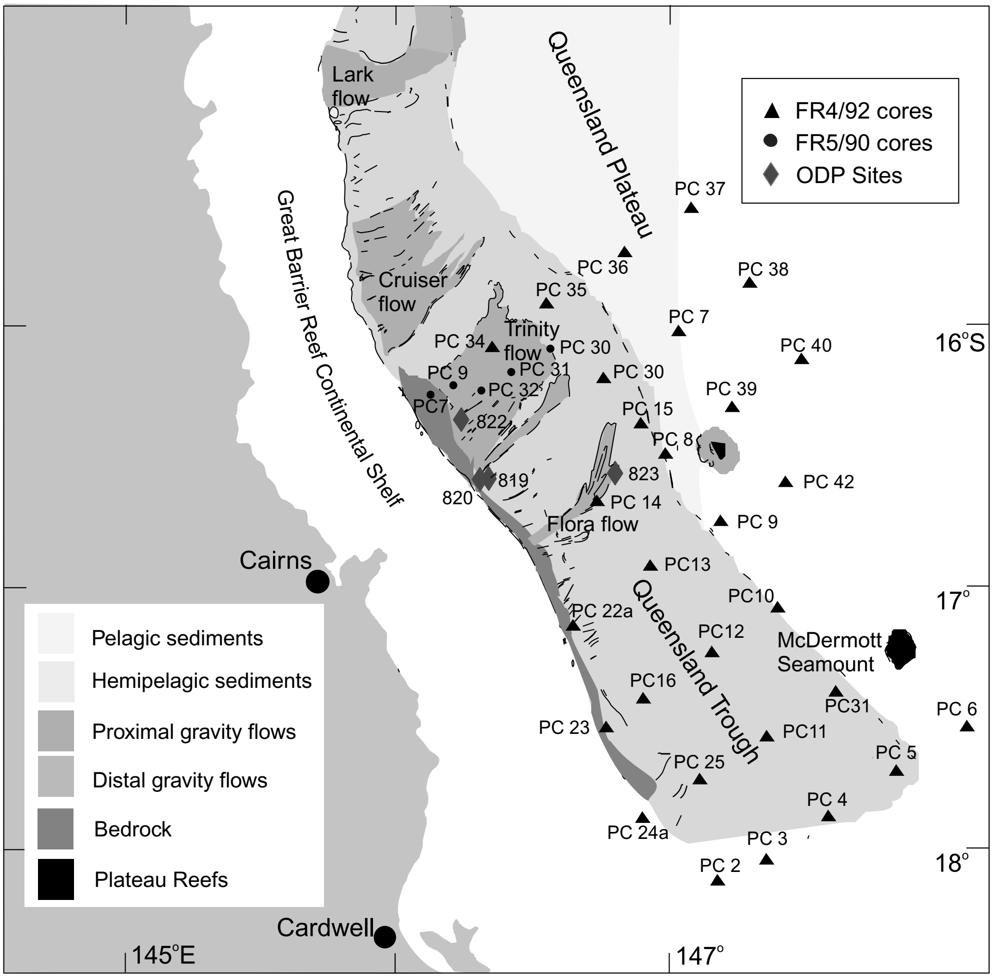


Fig. 6. Geological interpretation of the GLORIA sidescan sonar mosaic based on the acoustic response of the sea floor (modified after D. Johnson, unpublished map). Four large proximal sediment gravity flows (Lark, Cruiser, Trinity, Flora) originate on the continental margin and extend towards the basin axis, feeding distal gravity flows which curve northwards, into the trough axis. Cores from such regions contain a chaotic stratigraphy (slumps and turbidites) that precludes regional correlation (Fig. 9H, I). Other cores studied lie in zones of hemipelagic and pelagic sediments and correlation between sites is excellent.

occur on the outer edge of the GBR and above reef topped seamounts, areas where there is a high proportion of cemented framework coral. Medium to high backscattering exists for lobate or digitate patterns on the slope that are oriented perpendicular to the edge of the continental shelf. These features probably represent proximal gravity flows, of which four prominent flows are here given names: Flora, Grafton, Trinity, and Lark (Fig. 6). A medium to high level of acoustic response was also observed for elongate features along the trough axis, which parallel the continental shelf. These features correspond to an axial sediment transport path to the north, and probably represent distal gravity flows. The lowest levels of backscatter occur in regions that are largely free of bathymetric features, and represent hemipelagic drape of layered sediment over underlying topography. There is no evidence for submarine fans on the continental slope of the Queensland Trough (D.P. Johnson, pers. comm.). A further key point is that there is little evidence for gravity flow activity

over most of the area between 16°30′ and 18°S, i.e. over the central GBR slope.

2.3. Sediment accumulation in the Queensland Trough through time

Ocean Drilling Program (ODP) Leg 133 cored five locations in the Queensland Trough (Sites 819 through 823; Fig. 2) to evaluate the sedimentary response of the adjacent margin to changes in sea level (Davies et al., 1991). Glenn et al. (1993) examined changes in the petrology of sediment packages (sequences) over time at Sites 819, 820 and 821 on the upper slope, and Peerdeman and Davies (1993) constructed a high-resolution record of sedimentation at Site 820. Both of these studies indicate that maximum and minimum siliciclastic sediment abundance occurred during transgression and lowstand respectively.

Glenn et al. (1993) suggested that the siliciclastic-rich sediment intervals represented times of carbonate/pelagic sediment starvation. However, such an interpretation is inconsistent with results reported by Peerdeman and Davies (1993), which indicate that both the flux and concentration of siliciclastic material to Site 820 increased during transgression. In order to explain low siliciclastic accumulation during sea level lowstand, Peerdeman and Davies (1993) suggested that sediment bypasses the slope during such periods. However, a specific process was not offered to explain the high fluxes of siliciclastic sediment that occur during transgression. Here, we examine a suite of piston cores from the Queensland Trough to test and expand upon the ideas presented by Peerdeman and Davies (1993).

3. Samples and methods

The nature of siliciclastic and carbonate deposition on the east Queensland margin has been evaluated by: (1) collecting sediment cores on the slope and basin; (2) describing their sediment composition; (3) correlating their stratigraphy; (4) constructing age models; and (5) determining variations in sediment type through time. Thirty-five piston cores (up to 5.5 m in length) recovered from *RV Franklin* cruises FR4/92 (30 cores) and FR5/90 (5 cores) are discussed in this study (Table 1; Figs. 2 and 6). Throughout the text cores identified only with the prefix "PC" are from cruise FR4/92. These cores define a 130 by 240 km grid from the slope to the basin of the Queensland Trough, and range from depths of 166–1857 mbsl (Appendix A; Figs. 2 and 3). In addition to the *RV Franklin* piston cores, we use results from ODP Sites 819, 820 and 822, and from theses by Blakeway (1991); Grace (1993); Dunbar (2000).

Other work has shown that sediment in these cores is primarily composed of terrigenous siliciclastic sediments (mainly quartz, feldspar and clay minerals) and biogenic carbonate material (Belperio, 1983; Scoffin and Tudhope, 1985; Davies et al., 1991; Hudson, 1998). Most of the material was deposited by pelagic or hemipelagic sedimentation, although some turbidites are present. We have measured high resolution (sampling intervals <1 cm) physical property logs for the cores, including, magnetic susceptibility and greyscale (Appendix A). In addition we have determined 16 radiocarbon ages from four cores (Table A1), and the oxygen isotope composition of 233 planktonic foraminiferal samples from six cores (Table A2). Bulk carbonate content was determined by acid digestion for 167 samples from five cores (Appendix A).

4. Stratigraphy

4.1. Age models

Age models are constructed for six cores (PC 6, PC 14, PC 35, PC 36, PC 39 and PC 42), based on oxygen isotope data and comparison with the SPECMAP δ^{18}O record of Martinson et al. (1987). Correlation of the Queensland Trough isotope records to the SPECMAP timescale was performed using the public domain software package "Analyseries" (Paillard et al., 1996). Resulting age scales for the six cores are shown in Figs. 7 and 8.

Age models for other cores were determined through correlation of their physical property logs with a composite log described below. Magnetic susceptibility (MS) and greyscale records for cores with δ^{18}O records were converted from depth to age based on spline interpolation between isotope control points. The similarity of physical property logs between cores (Fig. 9A–G) suggests strongly that such measurements can be used to correlate sediment

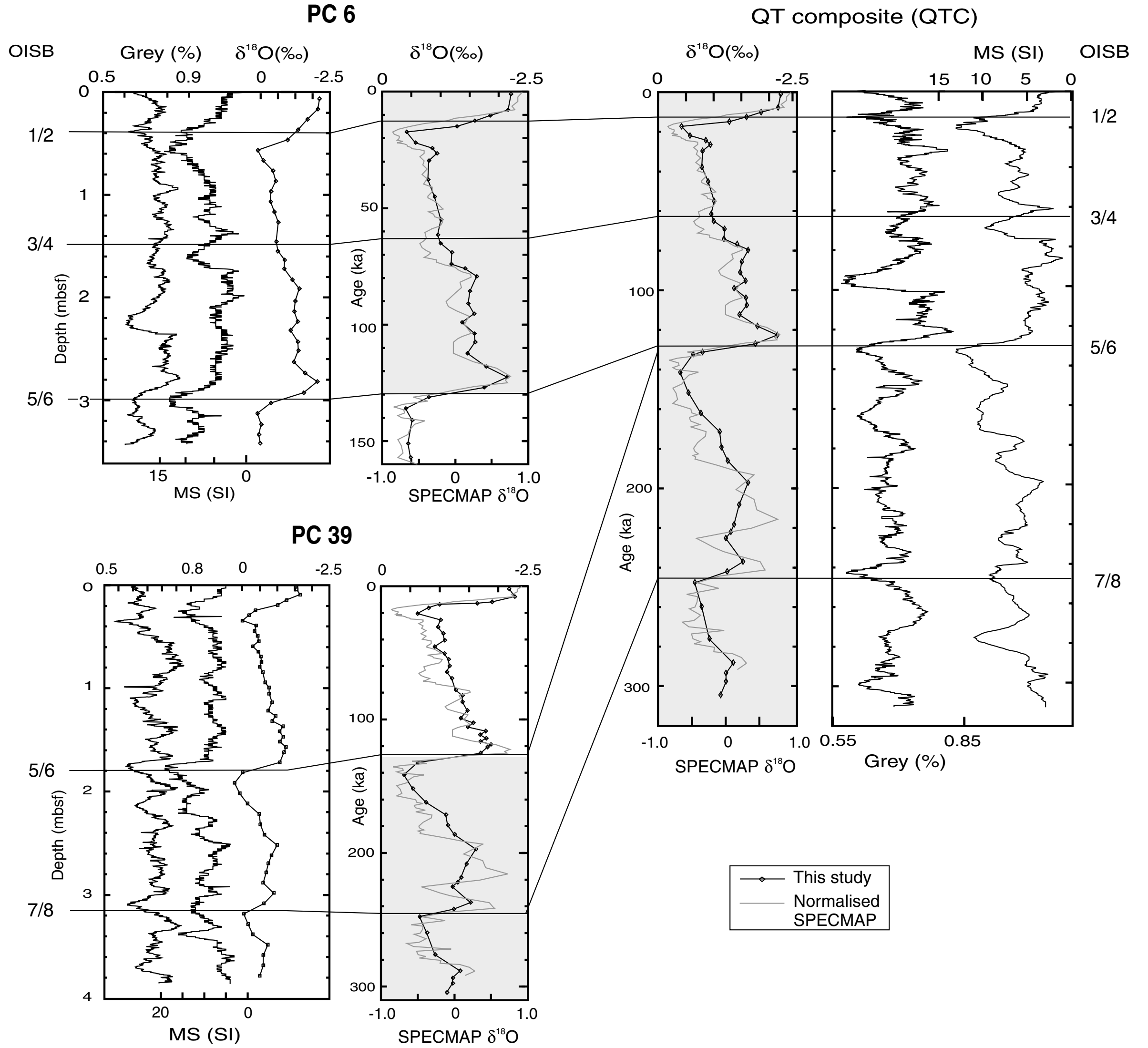
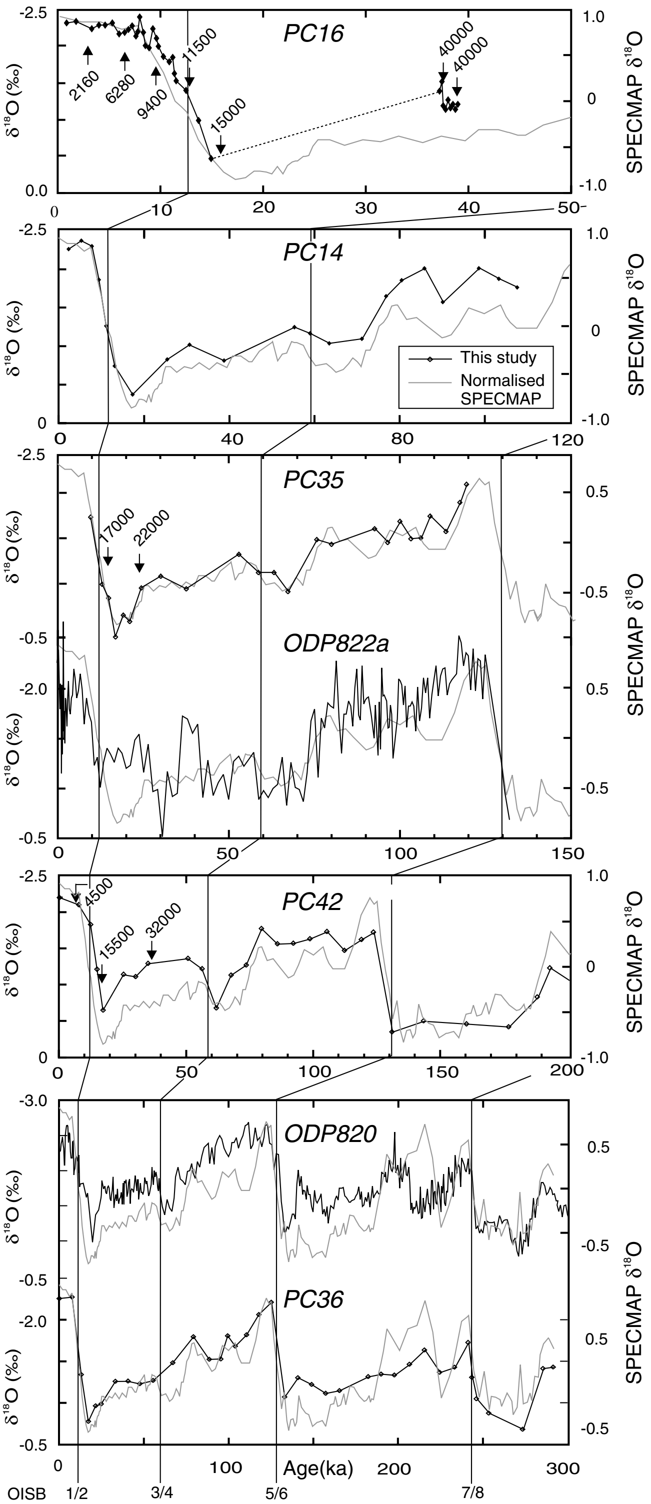


Fig. 7. Downcore records of oxygen isotopes (Appendix A), magnetic susceptibility and greyscale for cores PC 6 and PC 39. The isotope stratigraphy for these cores is by correlation to the SPECMAP reference curve (Martinson et al., 1987). The two cores were spliced together (grey shaded sections) to create the Queensland Trough Composite (QTC). Ages assigned to the QTC were transferred to variations in magnetic susceptibility and greyscale using a spline interpolation between tie points. The resulting MS and grey records were used to assign ages to other cores in the study area. OISB = oxygen isotope stage boundary.

sequences across the Queensland Trough. Core PC 6 has the highest resolution δ^{18}O record for the last 150 ky, and Core PC 39 has the longest δ^{18}O record with good resolution older than 150 ka (Fig. 7). Thus, the MS logs for these two cores were combined to generate a single "master" MS curve (here called the Queensland Trough Composite—QTC) that has been used to convert depths on different MS logs to age (Fig. 7). Age models for 24 other cores were determined by correlating their downcore MS records to the QTC. The correlation of the physical property logs is best shown by plotting transects across the Queensland Trough (Figs. 2 and 9A–G). It is immediately apparent that distances between horizons are


PC16
2160
6280
9400
11500
15000
40000
40000
PC14
This study
Normalised SPECMAP
PC35
17000
22000
ODP822a
PC42
4500
15500
32000
ODP820
PC36
δ18O (‰)
SPECMAP δ18O
Age(ka)
OISB
1/2
3/4
5/6
7/8

much greater on the slope than in the basin (Fig. 9G), i.e. that the slope sedimentation rates exceed the basinal sedimentation rate by an order of magnitude.

4.2. Uncertainty in age models

The accuracy of ages derived through oxygen isotope correlation depends on two factors. First, age estimates for SPECMAP are ±5000 years, although this error is not evenly distributed between 0 and 300 ka (Martinson et al., 1987). Second, some of the high frequency, low amplitude features apparent in SPECMAP cannot be resolved in Queensland Trough cores because of their relatively low sedimentation rate and bioturbated nature. The most reliable tie points are the short duration, high amplitude $\delta^{18}O$ variations that occur at the isotope stage 1/2, 5/6, and 7/8, boundaries at 12, 130, and 244 ka, respectively. Age estimates for the stage 2/3, 4/5 and 6/7 boundaries at 24, 74, and 190 ka, respectively, are less reliable. Ages for depths within isotope stages 3, 5, 7 and 8 contain the greatest uncertainty.

Radiocarbon ages and biostratigraphy provide important independent verification of our age models determined through oxygen isotope stratigraphy. Cores PC 35 and PC 42 have ages determined by both oxygen isotope stratigraphy and radiocarbon dating (Table 1). For a given depth, ages match within error (Fig. 8). Radiocarbon ages for samples from cores without $\delta^{18}O$ records are consistent with ages derived through correlation of MS logs (Fig. 9). In addition the last appearance of the pink form of *G. ruber* occurs at 120 ka in the Indian and Pacific Oceans (Thompson et al. 1979). At locations examined for biostratigraphy (Table 1), the last appearance of pink *G. ruber* was found at the position of the 5/6 boundary as estimated from oxygen isotopes and physical properties.

4.3. Physical property deviations

Some MS logs show significant deviations from the QTC (Fig. 9H, I). There are two general causes for these deviations. First, cores contain intervals of partial recovery, differential sediment compaction, and surface cracking, especially at their tops or at section breaks. For all cores with gaps, physical property data from intervals of no sediment recovery were deleted, and the remaining record was concatenated. Second, turbidites introduce “instantaneous” and localised pulses of sediment (Appendix A). These turbidites are identified by a sharp erosional contact, which is overlain by well-sorted fine to medium sand. For the purpose of generating core age models, data representing turbidite intervals were removed, and the remaining core segments were again concatenated (Fig. 9).

Other cores have a stratigraphy which does not correlate at all with the QTC (Fig. 9H, I). Six of these cores are located on (or adjacent to) the Trinity Flow (Figs. 6 and 9H), and it is likely that significant hiatuses and disturbed intervals are present in these records. For example the last appearance of pink *G. ruber* in Core FR5/90 PC 30 occurs at 0.40 mbsf, Fig. 9H). Three more of these cores contain prominent turbidites (Fig. 9I), which makes correlation problematic. Finally, it is unclear why the MS logs for Cores PC 15 and PC 25 do not align to the QTC.

5. Rates of sediment accumulation

The linear sedimentation rate (LSR) is a measure of the compacted thickness of sediment which has accumulated over a given interval of time. Calculation of LSRs represents the first step to quantifying the input of siliciclastic and carbonate sediment into the Queensland Trough. In this study, bulk LSRs have been calculated for concatenated cores with good MS logs over three time intervals: 31–14.7 ka (lowstand), 14.7–6.5 ka (transgression), 6.5–0 ka (highstand). These three time intervals were chosen because their boundaries correspond to major inflections in the regional sea level curve constructed for the eastern Queensland margin (Fig. 4b). The short length of available piston cores (<6 m) means that in areas of rapid sediment accumulation (>40 cm ky^{-1}) only the most recent time interval (6.5–0 ka) is available

Fig. 8. Oxygen isotope curves for cores from the Queensland Trough (Table A2) compared to the SPECMAP reference curve (in grey) of Martinson et al. (1987). Radiocarbon ages for samples from cores PC 35 and 42 are also indicated (Table A1). The age model for core PC 16 is based on linear interpolation between radiocarbon ages. Data for cores PC 35 and PC 42 are from Grace (1993), for ODP Site 820 from Peerdeman et al. (1993), and for ODP Site 822 from Corrège (1993).

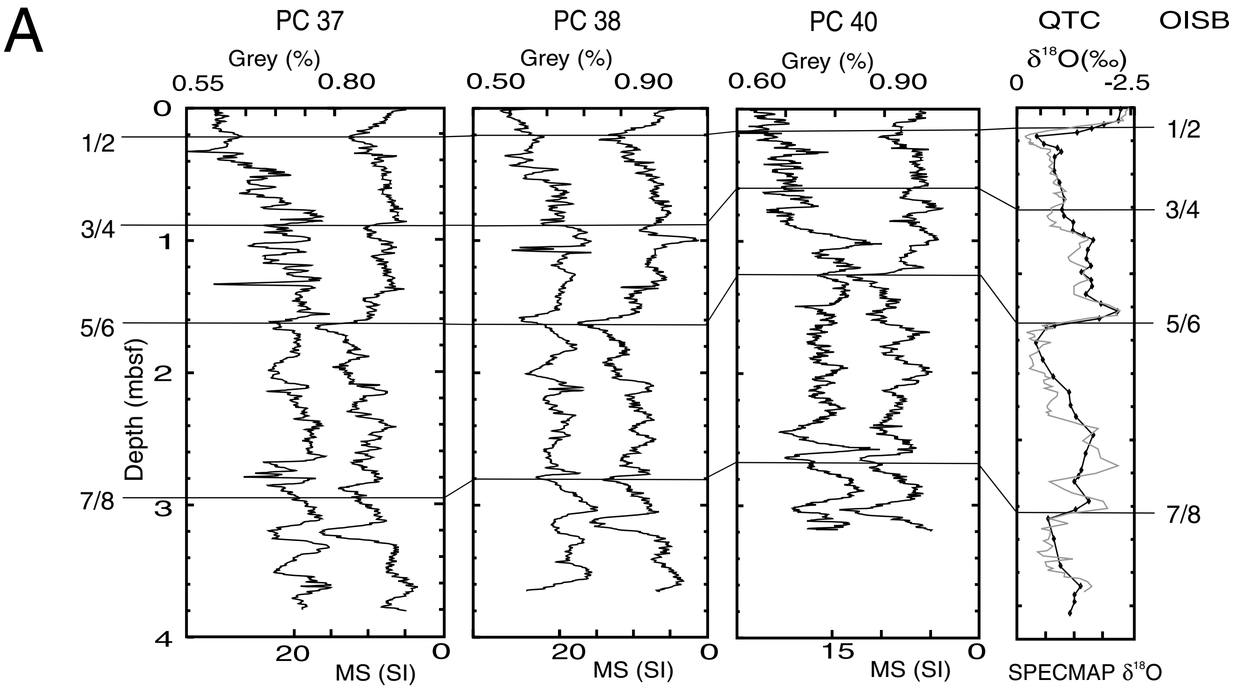


Fig. 9. 9A–G. Down core logs of MS (Magnetic Susceptibility in IS units) and Greyscale (or $CaCO_3$ data for ODP 820, Peerdeman and Davies, 1993; Peerdeman, 1993) along transects “A” through “G” in the study area (Fig. 2). Correlation between cores is based on matching prominent features in the physical properties logs. Ages of the isotope stage boundaries are from Martinson et al. (1987). Sandy turbidites are shaded grey. Cores from areas identified as major gravity slides (H) and in some cases other areas (I), contain abundant slumps and soft sediment deformation which preclude correlation with the regional stratigraphy. OISB = oxygen isotope stage boundary.

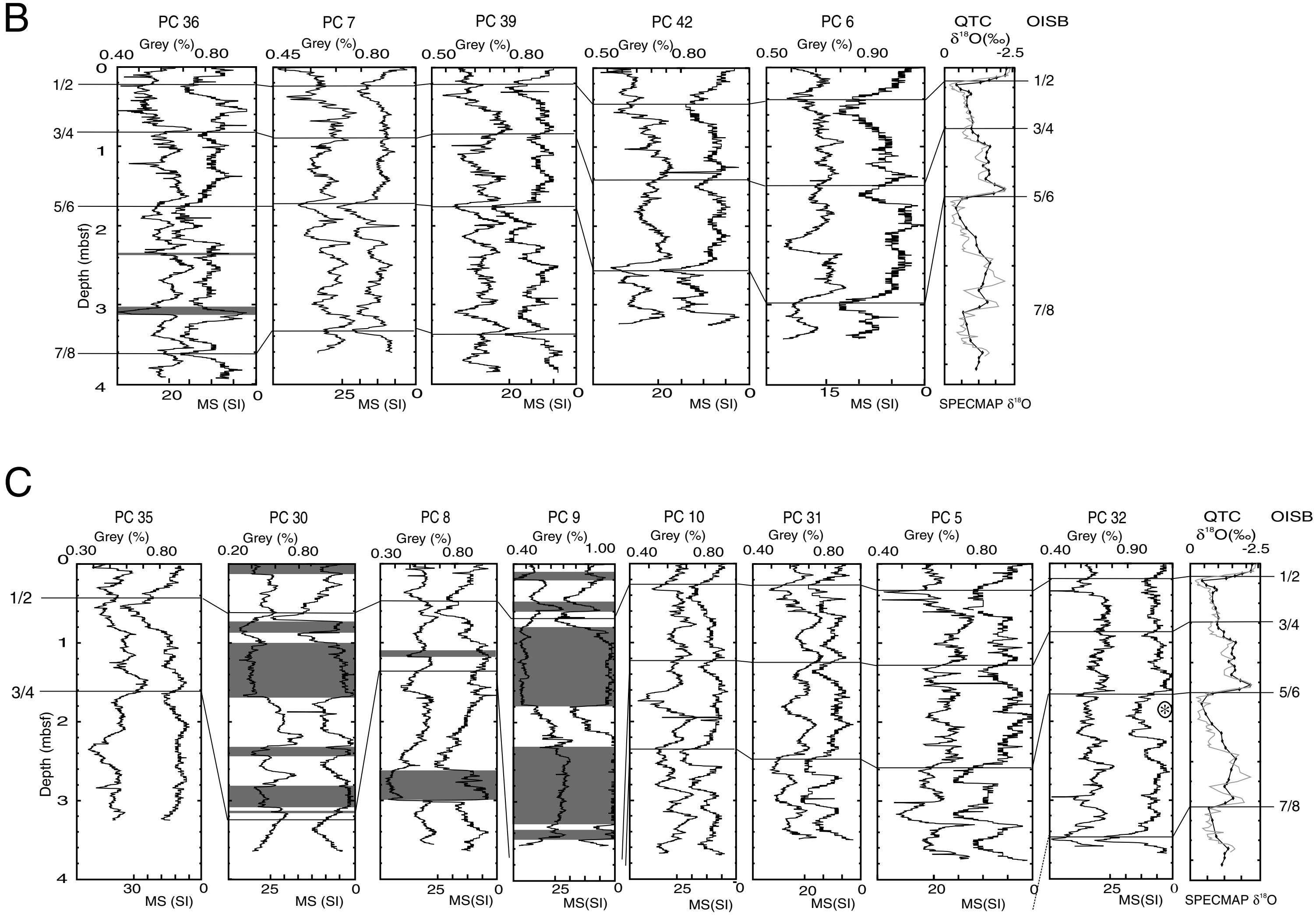


Fig. 9. (*continued*)

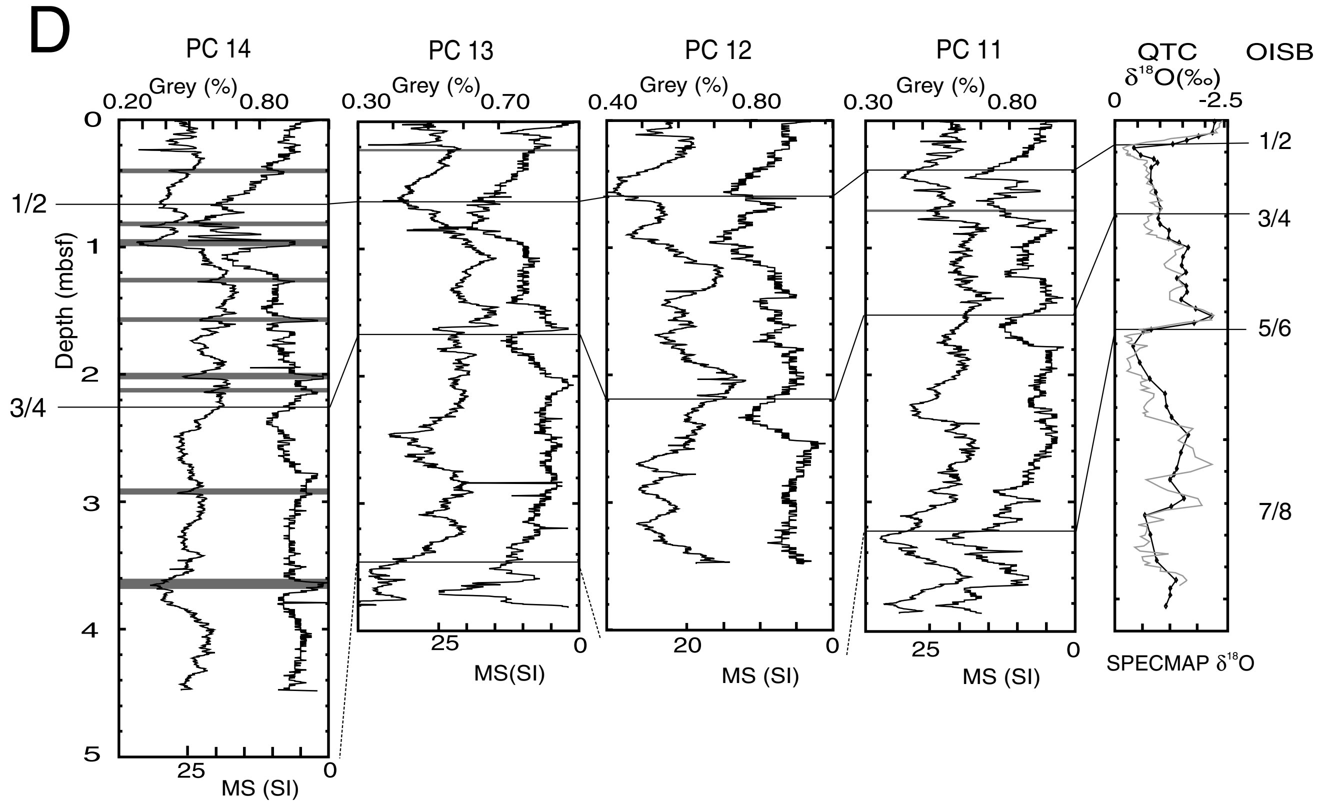
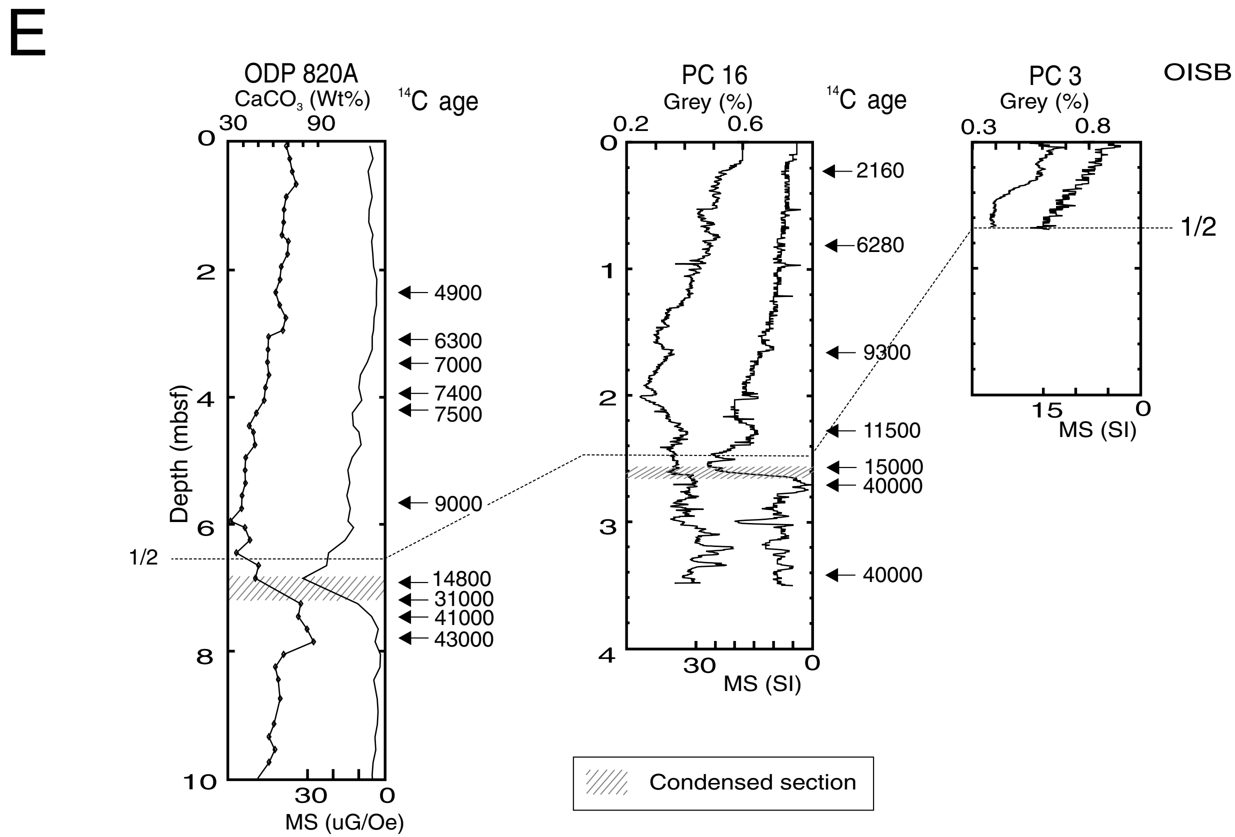


Fig. 9. (*continued*)



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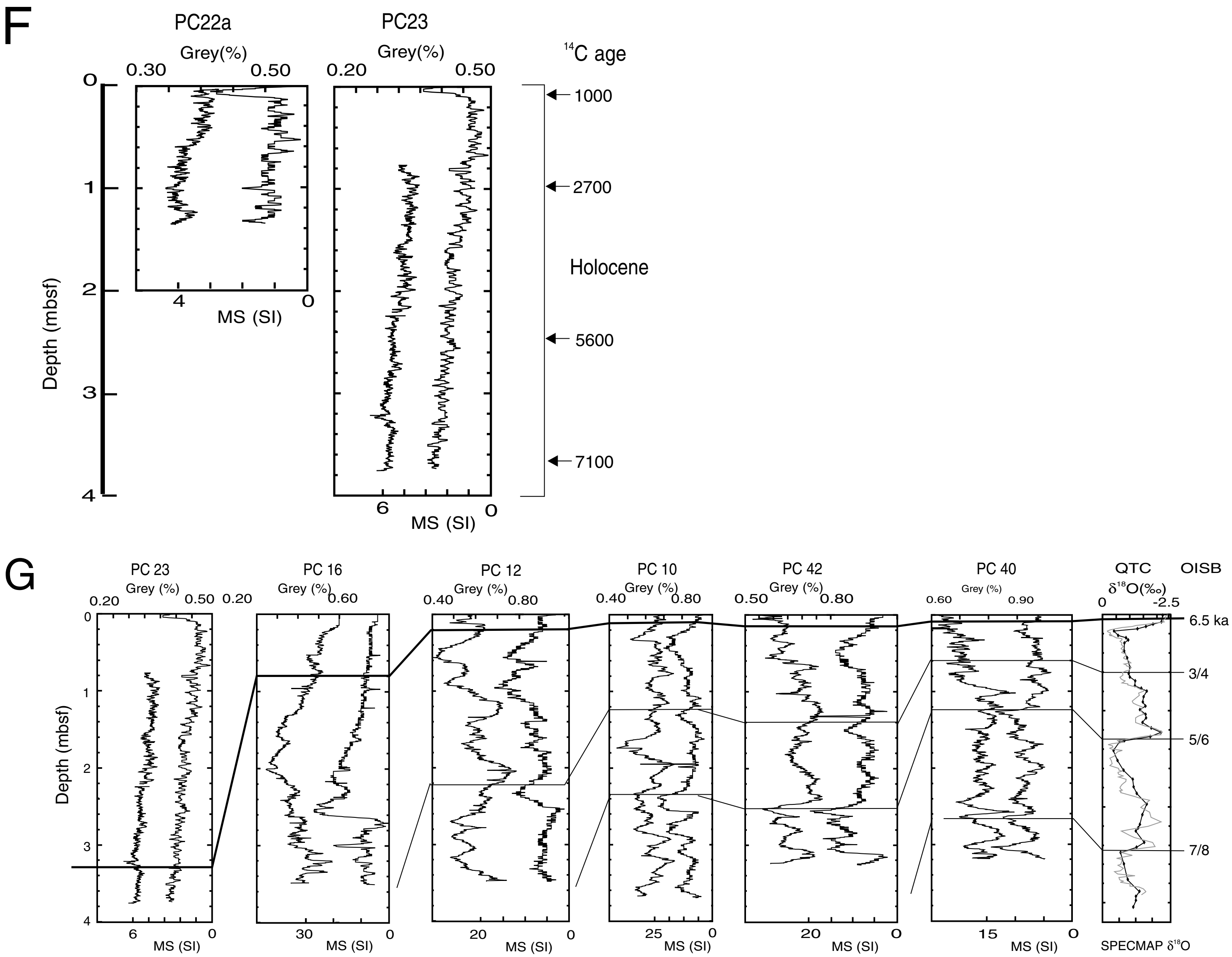


Fig. 9. (*continued*)

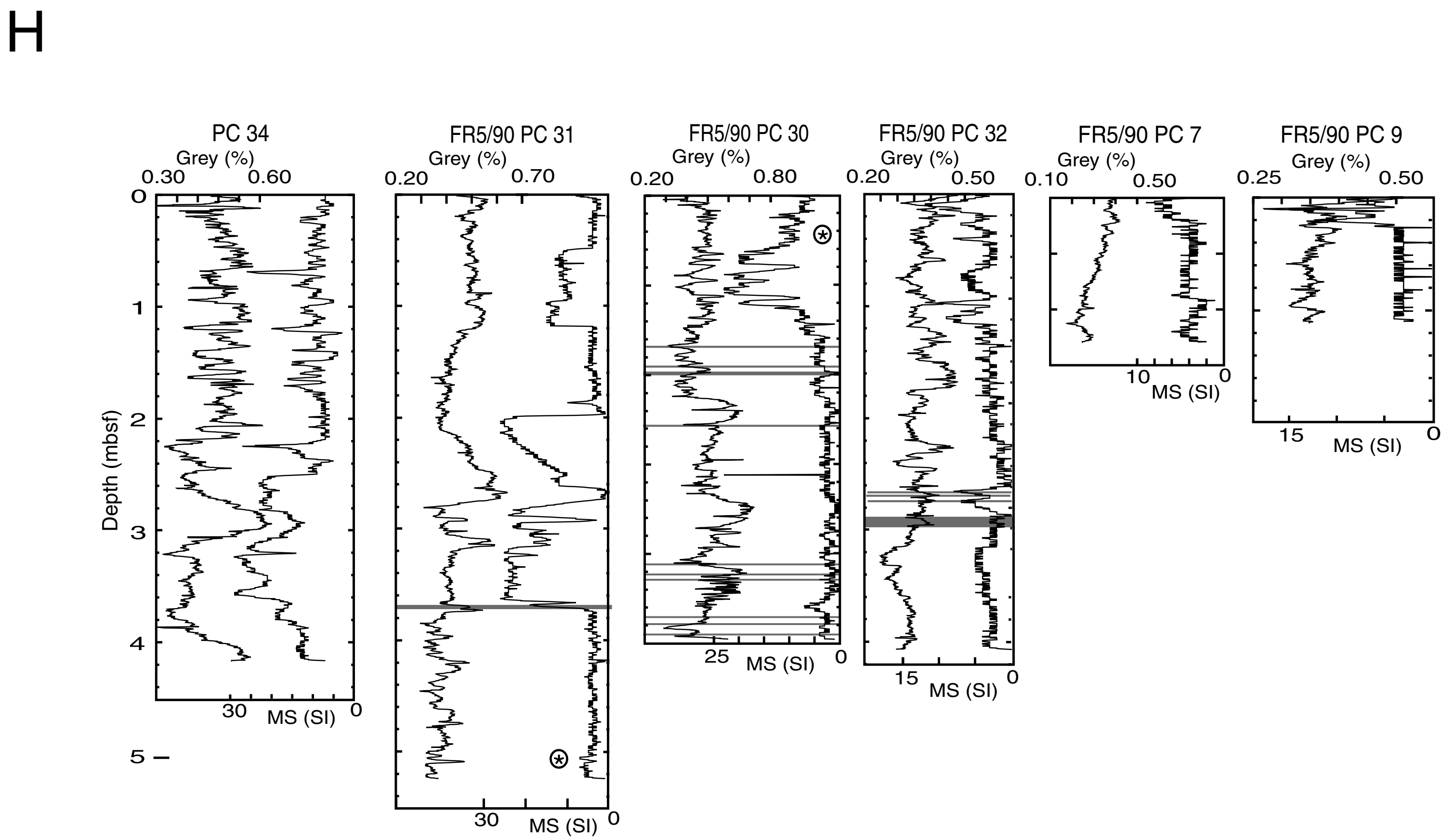


Fig. 9. (*continued*)

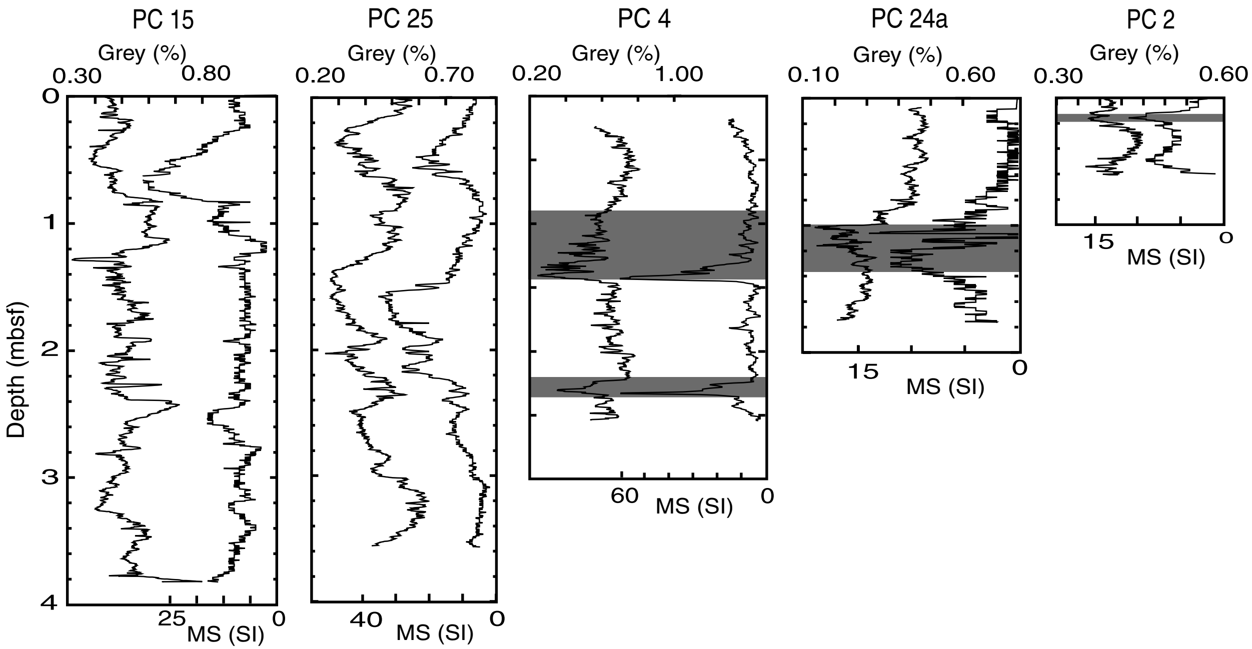


Fig. 9. (*continued*)

for examination. We therefore discuss first the spatial trends in the LSR across the Queensland Trough for the Holocene highstand interval.

Linear sedimentation rates for locations in the Queensland Trough over the last 6500 years range from 55 cm ky^{-1} to less than 1 cm ky^{-1} (Table 2; Fig. 10). The highest LSRs occur on the upper slope in less than 300 m water depth. Values decrease nearly exponentially with respect to distance from the GBR platform (defined here as the perpendicular distance to the 200 m isobath) until background levels of less than 3 cm ky^{-1} are reached at a distance of approximately 50 km from the continental shelf edge (Fig. 11). The lowest LSRs (~1 cm ky^{-1}) are found on the northeast margin of the Queensland Trough (Figs. 5 and 10). The west side of the drainage divide, in the northern trough adjacent to the GBR platform, shows markedly higher sedimentation rates (in excess of 2.2 cm ky^{-1}) than those immediately east of the divide (Fig. 10), confirming that the GBR platform is an important sediment source. The high LSRs for slope locations decrease over time during highstand (Fig. 12).

Between 6.5 and 14.7 ka, i.e. during transgression, LSRs for locations across the Queensland Trough were fairly similar to those during the highstand period (Fig. 11). There is an exponential decrease in LSRs from the upper slope (>40 cm ky^{-1}) to the basin (<4.5 cm ky^{-1}), with the lowest LSRs (<2.0 cm ky^{-1}) along the northeast margin (Table 2; Fig. 2). Interestingly, LSRs in the basin were consistently slightly higher during transgression than during highstand (Table 2; Fig. 2). High LSRs for slope locations appear to peak during middle to late transgression, between 8 and 12 ka (Fig. 12).

Bulk sedimentation in the Queensland Trough is markedly different during lowstand than during highstand and transgression. Although LSRs in the basin are similar to those during subsequent time intervals, LSRs on the slope are lower by nearly two orders of magnitude (Table 2; Fig. 11). This major change in sediment accumulation between 15 and 31–40 ka is well-constrained by radiocarbon ages at ODP Site 820 and in PC 16 (Table 1; Fig. 9E), and effectively marks the presence of a condensed interval on the slope during lowstand (Fig. 12). Correlation of the magnetic susceptibility curves between Sites 820 and 819 shows the condensed interval extends to Site 819. The overall effect of this condensed interval is to make slope and basin LSRs similar during lowstand (Fig. 11).

The existing oxygen isotope record at ODP Site 822 on the slope (Fig. 8; Corrège, 1993) shows a high degree of scatter. However, two aspects of this record support the presence of a lowstand condensed interval. First, only three data points between 2.95 and 3.05 mbsf yield δ^{18}O values greater than −1.0‰. This is similar to the above cores with condensed sections, but contrasts with isotope records from cores with a fuller stratigraphy from the Queensland Trough that have a complete lowstand interval (e.g. Cores PC 14, PC 35, PC 36, PC 42; Fig. 8). Second, using the isotope stage boundaries suggested by Corrège (1993), the overall bulk LSR between 12 and 74 ka is much lower (~3 cm ky^{-1}) than the LSR during the Holocene (~20 cm ky^{-1}) or between 74 and 125 ka (~9 cm ky^{-1}).

Long-term average bulk LSRs in the Queensland Trough (Table 2; Fig. 13) show a similar pattern to that for the highstand period (Fig. 10), with two notable exceptions. First, LSRs are significantly lower on the slope for cores that contain sediment older than 14.7 ka. This observation is consistent with (and emphasises) the presence of a condensed interval on the slope during lowstand. Second, overall LSRs are higher for cores with turbidites. The LSRs for concatenated cores are fairly uniform across the basin (Fig. 10). Thus, the presence of turbidites in some cores results in large and spatially heterogeneous deviations in LSRs. Turbidites clearly provide an additional supply of sediment that is superimposed on the regional accumulation of siliciclastic and carbonate components. The additional turbidite component can increase the LSR at a particular location by as much as three times (e.g. Core PC 9).

Excluding cores with turbidites, LSRs are relatively constant (within a factor of two) across the basin over the last 31 ky (Table 2). Because of low LSRs, several cores in the basin extend past the isotope stage 7/8 boundary at 244 ka (e.g. Fig. 9A). Thus, the similarity of the bulk LSRs for these cores (Fig. 13) and LSR rates derived for the Holocene (Fig. 10) suggests that sedimentation in the basin has remained fairly uniform throughout several major sea level oscillations.

Table 2
Sediment thickness and sedimentation rates for lowstand, transgression and highstand phases of sea level

Core	Age Interval		0–6.5 ka		6.5–14.7 ka		14.7–31.0 ka		Overall		
	Distance to 200 m isobath (km)	Depth (mbsl)	Thickness (m)	Rate (cm/ky)	Thickness (m)	Rate (cm/ky)	Thickness (m)	Rate (cm/ky)	Thickness[a] (m)	Oldest Age (ka)	Rate (cm/ky)
Slope											
PC 23	1	225	3.36	51.7	n/a	n/a	n/a	n/a	3.74	7.1	51.3
ODP 820	2	278	3.55	54.6	3.48	42.4	0.32	2.0	271.7	1270	21.4
ODP 819	5	565	2.82	41.6	3.28	42.1	1.00	5.9	189.2	1270	14.9
ODP 822	11	955	1.40	21.7	1.60	19.3	0.40	2.3	411	2420	17.0
PC 16	18	1043	0.86	13.2	1.70	20.7	0.06	0.4	3.5	36.8	9.0
PC 3	19	870	0.30	4.6	n/a	n/a	n/a	n/a	n/a	n/a	n/a
PC 14	32	1574	0.40	6.2	0.48	5.8	0.46	2.8	4.48	109	4.1
PC 13	37	1507	0.32	5.0	0.29	3.5	0.51	3.1	3.81	137	2.8
PC 12	48	1443	0.23	3.5	0.45	5.5	0.60	3.7	3.48	103	3.4
Basin											
PC 32	58	1134	0.10	1.6	0.21	2.5	0.16	1.0	3.68	287	1.3
PC 11	59	1320	0.17	2.6	0.28	3.4	0.49	3.0	3.88	167	2.3
PC 35	63	1857	0.14	2.2	0.28	3.4	0.64	4.0	3.25	118	2.8
PC 30	65	1797	0.18	2.8	0.21	2.6	0.40	2.5	3.64	74	4.9
PC 9	69	1616	0.18	2.7	0.36	4.4	n/a	n/a	3.56	29	12.5
PC 5	75	1193	0.11	1.7	0.38	4.6	0.27	1.6	3.76	197	1.9
PC 10	78	1334	0.09	1.4	0.26	3.2	0.42	2.6	3.69	235	1.6
PC 31	92	1308	0.11	1.7	0.24	3.0	0.40	2.4	3.50	197	1.8
PC 39	96	1334	0.08	1.2	0.18	2.2	0.18	1.1	3.86	310	1.2
PC 7	98	1488	0.10	1.5	0.17	2.0	0.34	2.1	3.60	297	1.2
PC 36	99	1824	0.06	1.0	0.13	1.6	0.29	1.8	3.92	300	1.3
PC 42	101	1389	0.17	2.6	0.27	3.2	0.34	2.1	3.26	207	1.6
PC 6	103	1193	0.15	2.3	0.30	3.6	0.51	3.1	3.43	161	2.1
PC 40	129	1168	0.05	0.7	0.10	1.2	0.20	1.2	3.20	293	1.1
PC 37	131	1458	0.06	1.0	0.13	1.6	0.27	1.6	3.80	321	1.2
PC 38	132	1340	0.07	1.0	0.10	1.3	0.25	1.5	3.65	309	1.2

[a] Thickness to lowest age horizon. Thickness does not include turbidites, except for "Overall" rates and ODP Sites 819, 820 and 822. Biohorizons from ODP Sites 819, 820 and 822 are from Gartner and Wei (1993).

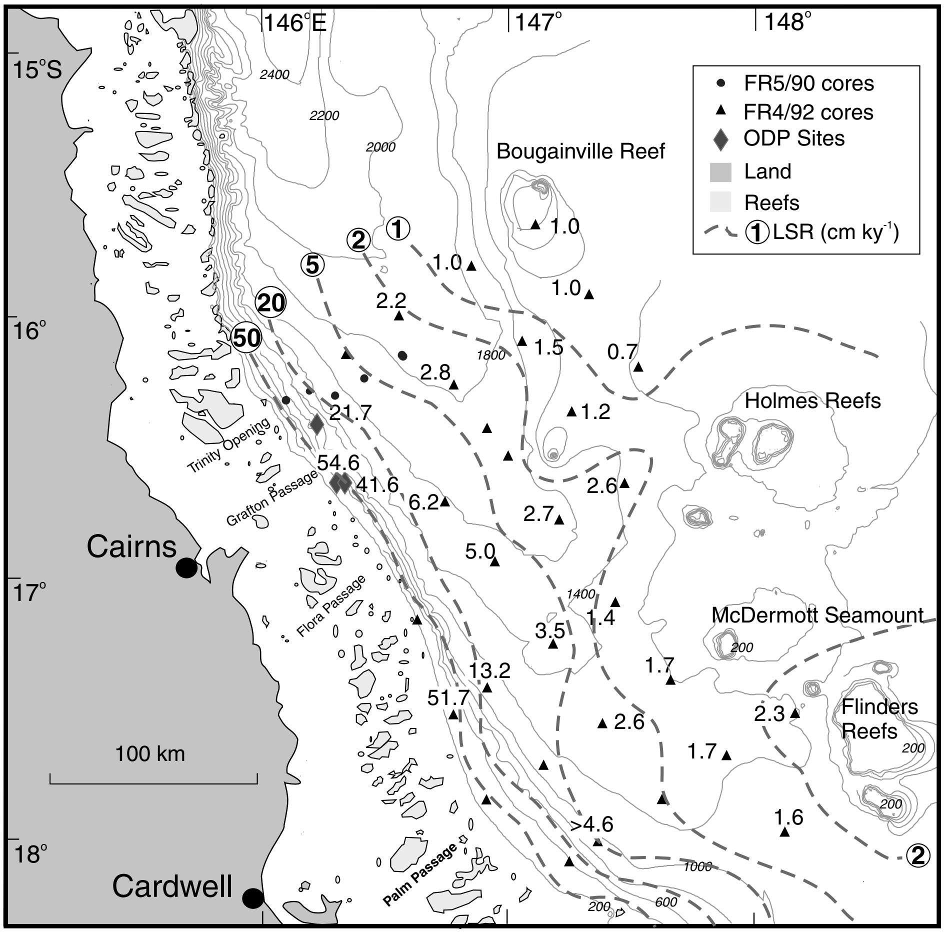


Fig. 10. Linear sedimentation rates (cm ky^{-1}) since 6.5 ka (highstand) for the Queensland Trough, based on radiocarbon and oxygen isotope age models. LSRs do not include turbidite deposition. Locations without reliable LSRs are shown without data.

6. Sediment variability over time

6.1. Carbonate (and siliciclastic) components

Sediments in the Queensland Trough are predominantly composed of two components: siliciclastic (quartz, feldspar and clay minerals) and carbonate material. Terrigenous material is derived largely from northern Australia, either suspended in the water column or by aeolian transport. Carbonate material is derived from both the reef tract and from plankton. Determining the carbonate content of the sediment therefore provides information on the combined abundance of the two main components, but does not differentiate between reefal and pelagic carbonate sources.

Carbonate content of Queensland margin sediments ranges between 29 and 94 wt% (Table 3). The highest values occur in core PC 42 from the east part of the basin, and the lowest values occur at 2 mbsf in core PC 16 on the slope (Fig. 2). This comparison highlights two important facts (Fig. 14): (1) carbonate content generally increases from the slope to the basin; and (2) pronounced temporal variations in carbonate content that occur on the slope are not apparent in the basin.

Cores from the slope (PC 16 and PC 23, and ODP Sites 819 and 820) possess highstand intervals that are

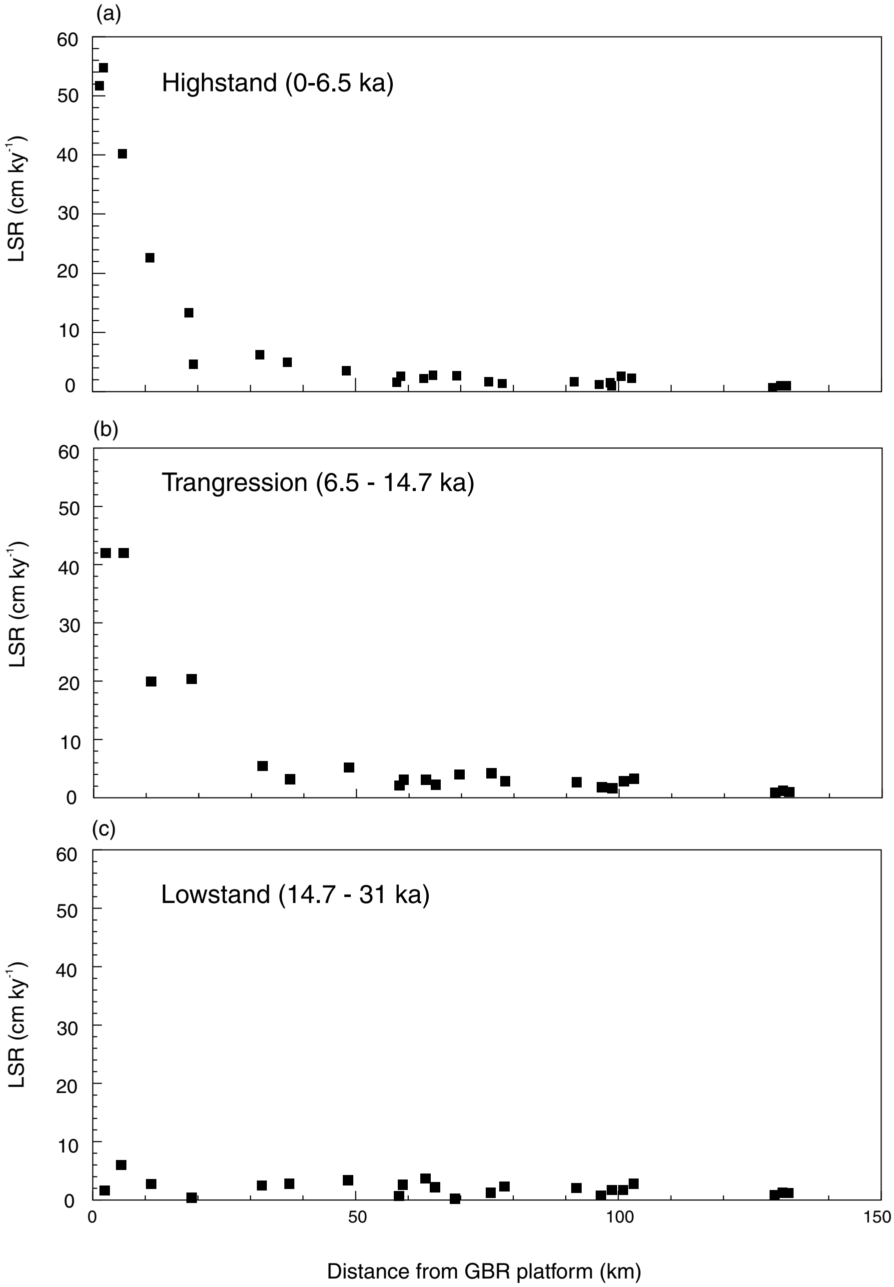


Fig. 11. Linear sedimentation rates (cm ky^{-1}) plotted against perpendicular distance from the 200 m isobath for cores in the study area. For (a) the present highstand (6.5–0 ka), (b) the post-glacial marine transgression (14.7–6.5 ka), and (c) the last sea level lowstand (31–14.7 ka). During highstand and transgression most sediment accumulated on the continental slope: conversely, during lowstand sediment accumulates more evenly across the Queensland Trough.

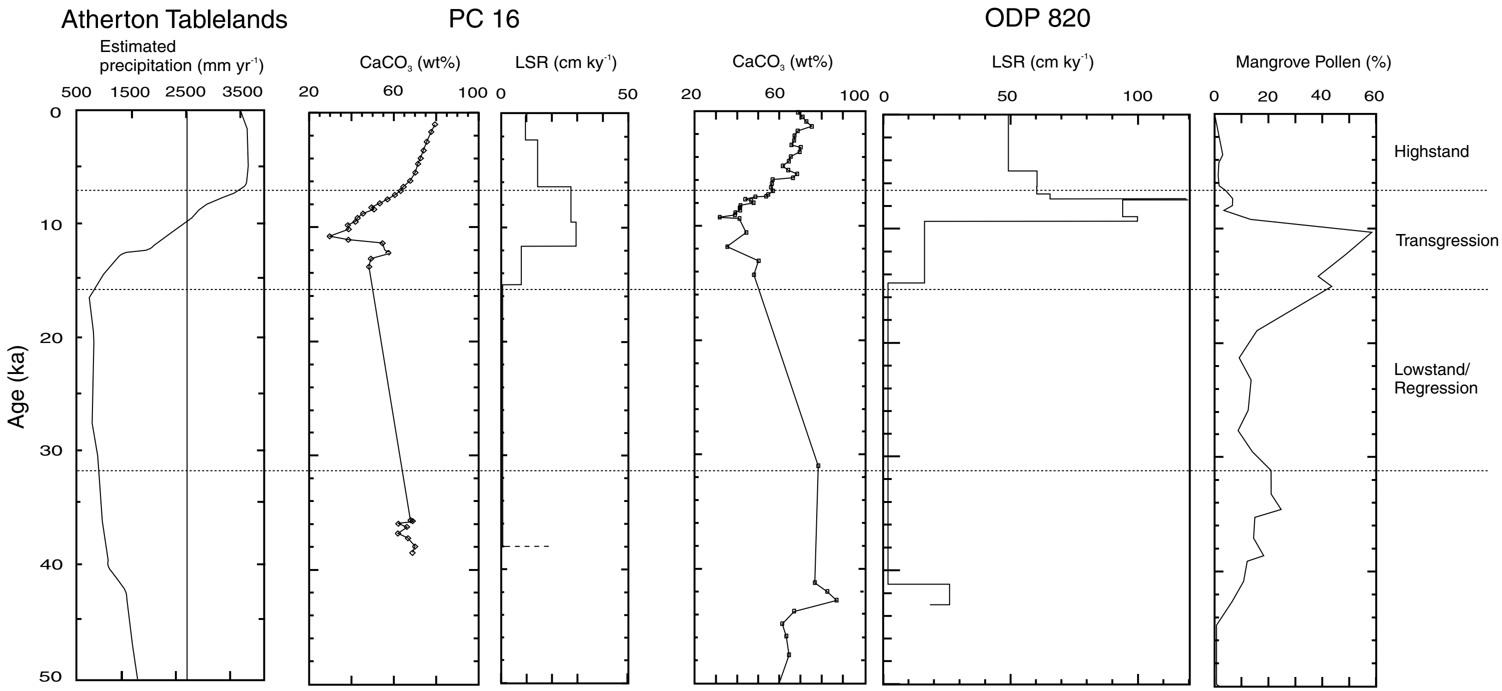


Fig. 12. LSRs, carbonate and mangrove pollen abundance (redrawn after Moss and Kershaw, 1999) on the continental slope. LSRs are based on linear interpolation between radiocarbon ages (Table A1). Although LSRs at Site 820 are higher than at PC 16, the general trends are very similar, including an antithetic relationship between carbonate content and LSR. Radiocarbon ages and carbonate data from ODP Site 820 are from Peerdeman and Davies (1993); Peerdeman (1993).

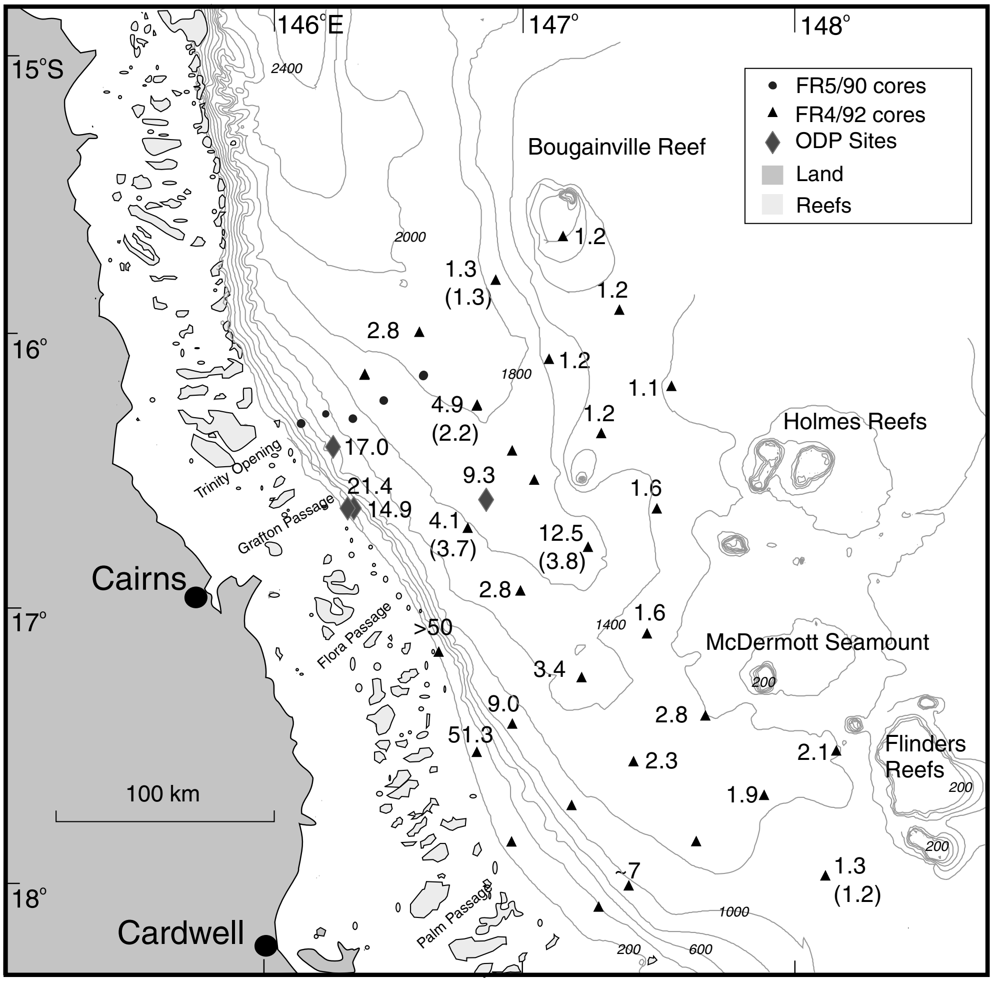


Fig. 13. Overall linear sedimentation rates (cm ky^{-1}) for each site using the lowest reliable age marker (Table 2) with, and (in brackets) without, turbidites. Note the marked difference between overall LSRs and Holocene LSRs (Fig. 10) on the continental slope but not in the basin. Age horizons for ODP sites were taken from Gartner and Wei (1993). Interestingly, Sadler (1981) has shown that for most sediment sequences, the LSR decreases over an increasing time of sedimentation. However, because of the condensed intervals during lowstand, long-term average LSRs on the slope of the Queensland Trough are considerably greater than short-term LSRs for the last lowstand (Table 2; Fig. 11).

characterised by high carbonate contents which steadily increase from 60–70% at 6.5 ka to 70–85% at present-day (Table 3; Fig. 14). In contrast, transgressive intervals contain lower carbonate contents (<70%) that reach minimum values between 9 and 11 ka (Fig. 14). Lowstand intervals also have relatively high carbonate contents (60–80%), although there is a paucity of information because this interval is very condensed on the slope (Fig. 12). There is an antithetical relationship between carbonate content and bulk LSR for locations on the slope between 14.7 ka and present-day (Fig. 12), i.e. high LSRs on the slope during transgression are accompanied by low carbonate content and high siliciclastic content.

Long-term trends in carbonate content are only available from the two ODP Sites on the slope and from a few piston cores on the Queensland Plateau where LSRs are less than 2 cm ky^{-1} (Fig. 14). At the slope locations, bulk carbonate varies over the last 200 ky by >40%, and a prominent carbonate minimum is observed at the isotope stage 5/6 boundary (Fig. 14). In contrast, at the basin locations, bulk

Table 3
Down core carbonate content (wt%) of bulk sediment samples

PC 6		PC 7		PC 16		PC 23		PC 42	
Depth (mbsf)	$CaCO_3$ (%)	Depth (mbsf)	$CaCO_3$ (%)	Depth (mbsf)	$CaCO_3$ (%)	Depth (mbsf)	$CaCO_3$ (%)	Depth (mbsf)	$CaCO_3$ (%)
0.12	90.4	0.02	82.6	0.10	79.5	0.04	83.1	0.10	89.0
0.20	92.3	0.13	80.2	0.17	77.7	0.10	83.2	0.20	86.2
0.35	80.0	0.23	75.5	0.27	75.6	0.16	84.4	0.30	80.6
0.50	83.8	0.33	84.0	0.37	74.0	0.21	84.2	0.40	87.4
0.55	80.0	0.37	85.3	0.47	72.6	0.27	83.2	0.50	86.4
0.67	88.1	0.43	89.6	0.55	71.4	0.33	81.9	0.60	90.1
0.80	94.5	0.53	90.0	0.65	70.2	0.39	82.5	0.70	91.6
0.93	93.5	0.63	87.5	0.75	67.7	0.45	82.1	0.80	93.3
1.24	81.5	0.73	88.3	0.85	64.6	0.51	82.9	0.90	92.4
1.30	92.2	0.83	85.9	0.95	63.2	0.57	82.1	1.00	92.6
1.41	92.0	0.98	84.3	1.05	60.5	0.63	82.8	1.10	87.9
1.62	81.9	1.08	80.7	1.15	57.0	0.69	81.3	1.20	93.5
1.90	92.6	1.18	72.0	1.25	53.4	0.74	80.7	1.30	93.1
2.22	78.3	1.26	75.6	1.35	49.5	0.84	80.9	1.40	89.6
2.40	91.4	1.36	78.7	1.40	50.7	0.94	79.5	1.50	83.6
2.50	91.8	1.46	82.8	1.50	45.5	1.04	79.5	1.60	85.3
2.72	87.2	1.56	77.6	1.60	42.9	1.14	79.6	1.70	88.7
2.81	87.7	1.66	78.2	1.70	41.9	1.24	79.6	1.80	85.0
2.92	73.7	1.76	66.9	1.80	38.3	1.44	78.9	1.90	80.6
3.02	76.6	1.86	75.8	1.90	38.7	1.54	77.7	2.00	80.4
3.12	69.5	1.96	86.4	2.07	29.8	1.64	77.1	2.10	89.0
3.20	77.9	2.06	78.6	2.17	38.6	1.74	75.7	2.20	88.5
3.26	79.3	2.16	82.0	2.27	54.7	1.84	75.2	2.30	88.5
3.32	83.2	2.31	81.5	2.37	56.5	1.94	75.7	2.40	92.4
3.42	77.1	2.41	78.2	2.47	49.2	2.04	74.7	2.50	73.5
		2.51	85.4	2.57	48.3	2.14	75.2	2.60	86.8
		2.61	76.1	2.67	67.9	2.26	73.8	2.70	78.5
		2.71	81.5	2.77	67.6	2.36	73.6	2.80	86.1
		2.81	77.3	2.87	62.3	2.46	73.4	2.90	87.6
		2.96	73.6	3.02	64.8	2.56	73.1	3.00	83.5
		3.06	78.0	3.12	61.2	2.66	73.1	3.10	88.6
		3.16	85.4	3.22	66.7	2.76	69.2	3.20	90.8
		3.26	87.9	3.32	70.1	2.86	73.1		
		3.36	80.1	3.42	68.7	2.96	73.0		
		3.46	84.8			3.06	71.2		
		3.56	77.8			3.21	70.9		
						3.31	72.1		
						3.41	70.1		
						3.51	69.3		
						3.61	68.3		
						3.70	66.6		

carbonate varies over the last 200–300 ky by <15% and a distinct carbonate minimum occurs at the stage 5/6 boundary. Evidently, earlier transgressions across the North Queensland margin were also associated with low rates of carbonate sedimentation.

A carbonate minimum is also observed during isotope substage 5b, and possibly continued through the transgression into substage 5a (Fig. 14). The regional nature of this event is evident from greyscale logs (where greyscale is generally correlated with $CaCO_3$ content) in Fig. 9.

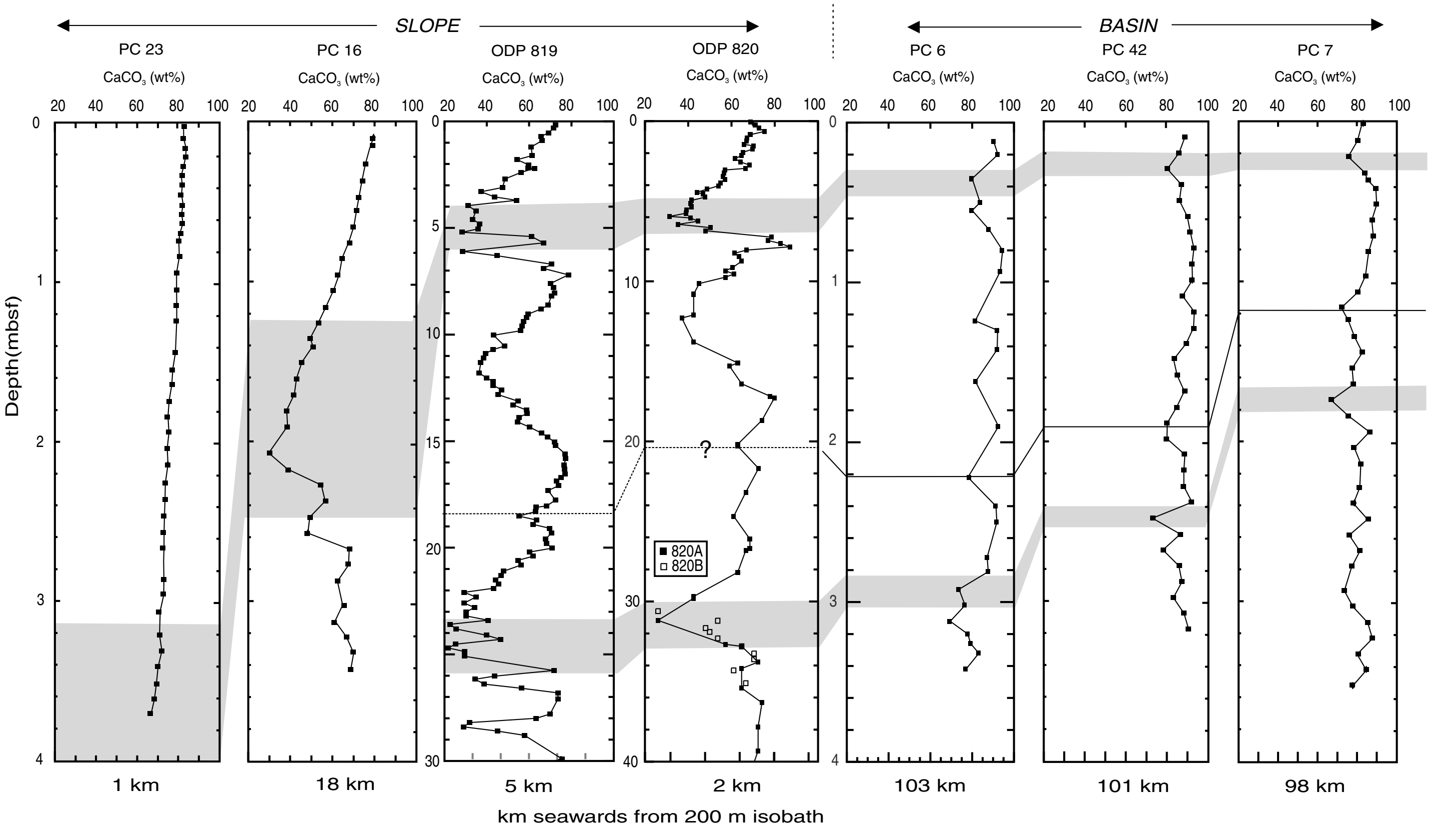


Fig. 14. Downcore $CaCO_3$ profiles for sites on the continental slope and the basin. Note $CaCO_3$ minima during transgressions (isotope stage boundaries 1/2 and 5/6), and greater range in $CaCO_3$ content on the slope. Data for ODP Sites 819 and 820 are from Alexander et al. (1993); Peerdeman and Davies (1993) respectively.

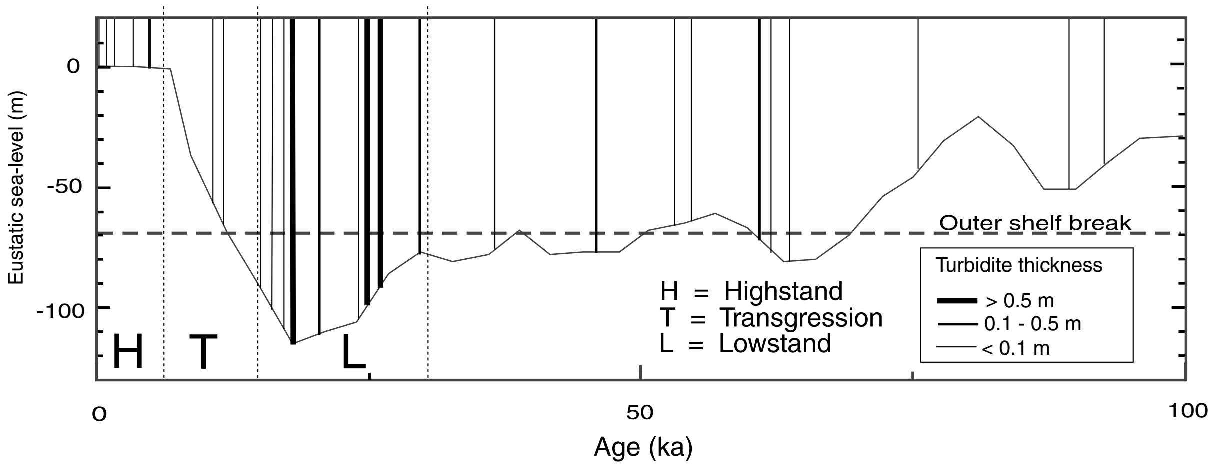


Fig. 15. Timing of sandy turbidites (vertical lines) relative to the sea level history of the Queensland Trough. The decreasing density of turbidites with depth is partly a sampling artefact, because many cores are short.

6.2. Turbidites

The age of turbidites in a core can be estimated by comparing a concatenated MS log with the QTC model (e.g. Fig. 9C). Over the past 100 ky, and for all cores, 26 sandy turbidites can be dated to within ~5 ky (Fig. 15). Though there is a steady decrease in the number of turbidites deposited in older sediment, this trend largely reflects the absence of older age datums in most cores. In detail, there is a limited correspondence between turbidite frequency and the relative position of sea level (Fig. 15), with turbidite frequency probably highest during lowstands Watts et al. (1993), and Blakeway (1991) have reached similar conclusions from analyses of cores in the Queensland Trough.

7. Sediment mass accumulation

7.1. General approach

The study area comprises a rectangle with a northeast–southwest dimension of 130 km and a northwest–southeast dimension of 240 km (Figs. 2 and 3). The mass accumulation rate (MAR) of sediment in this 31,200 km^2 rectangle over a given time interval can be determined from sediment volume and dry bulk density (DBD) estimates as follows. The LSRs for individual locations during highstand, transgression, and lowstand (Table 2; Fig. 11) were multiplied by the duration of each interval (6.5, 8.2, and 16.3 ky, respectively). This calculation gives curves that summarise the relationship between sediment thickness and distance from the GBR platform for three different time intervals (Fig. 16). Each of these relationships can be approximated by a simple exponential or linear function (Fig. 16). The area under these distance-thickness curves is then integrated and multiplied by the dimensions of the study area (Table 4). The DBD was assumed to be 1.0 g cm^{-3} for all sediment in the Queensland Trough (Table 4). This value is within 15% of most sediment deposited on continental margins, including the Quaternary sediment at ODP Site 820 (Davies et al., 1991, p. 538). Sediment MARs can be partitioned for different areas between the slope and basin by integrating distance–thickness curves (Fig. 16) at prescribed limits for distance. We have taken a distance of 50 km from the 200 m isobath as the boundary between the slope and basin because this is the point where the bathymetric gradient levels out in the study area (Figs. 2 and 5).

The individual MARs of siliciclastic and carbonate sediment components can be estimated by multiplying the total sediment MAR by the weight fraction of each component. After performing this calculation to derive carbonate MARs, siliciclastic MARs over time can be determined by subtracting carbonate

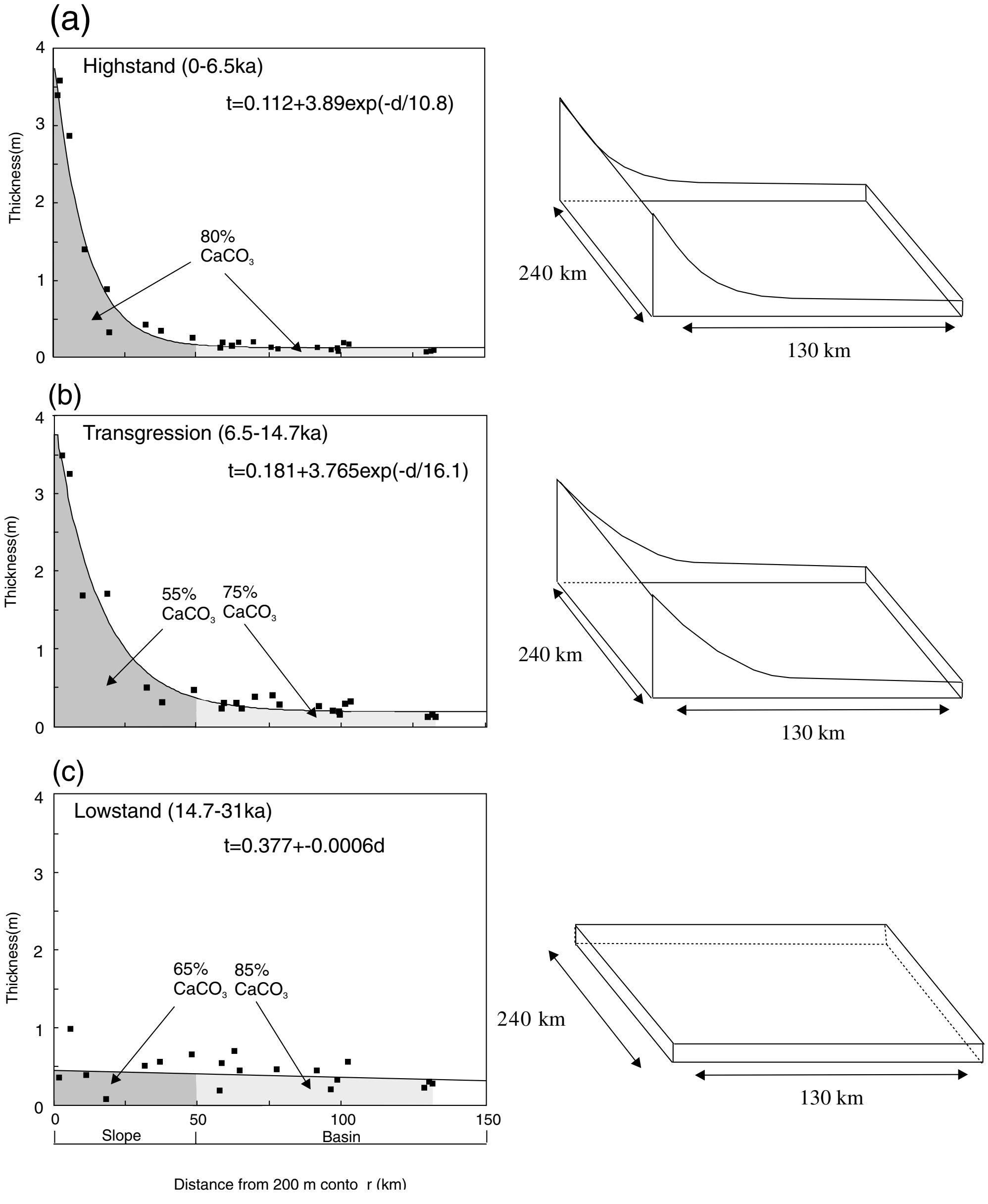


Fig. 16. Sediment volume calculations for the study area (Fig. 3) over three different phases of sea level (a) highstand (6.5–0 ka) (b) transgression (14.7–6.5 ka) and (c) lowstand (31.0–14.7 ka). Curves have been fitted to thickness (Table 2) and perpendicular distance from the 200 m isobath to the Queensland Plateau (Table 1). The area under each curve was estimated by integrating between limits of 0–50 km (slope) and 50–130 km (basin).

MARs from total MARs (Table 4). Note that our derivation of MAR differs from that presented in many other papers. MARs are more usually expressed in units of mass divided by time *and* area (e.g. MT yr^{-1} km^{-2}). In many cases (and unlike the data set presented here), this choice is one of necessity and reflects a lack of the spatial coverage necessary to integrate over an area.

Table 4
Mass accumulation rates for sediment in the Queensland Trough

Time period		Sediment Volume (km^3)	Sediment Mass (MT)	DBD ($g\ cm^{-3}$)	$CaCO_3$ (wt%)	Total MAR[a] ($MT\ yr^{-1}$)	Siliciclastic MAR[a] ($MT\ yr^{-1}$)	Carbonate MAR[a] ($MT\ yr^{-1}$)
0–6.5 ka	Slope	11	11000	1.0	80	1.7	0.3	1.4
	Basin	2	2000	1.0	80	0.3	0.1	0.2
	Total	13	13000			2.0	0.4	1.6
6.5–14.7 ka	Slope	16	16000	1.0	55	2.0	1.0	1.1
	Basin	4	4000	1.0	75	0.5	0.1	0.4
	Total	20	20000			2.5	1.1	1.4
14.7–31.0 ka	Slope	5	5000	1.0	65	0.3	0.0(7)	0.2
	Basin	6	6000	1.0	85	0.4	0.0(8)	0.3
	Total	11	11000			0.7	0.1(5)	0.5

[a] MAR = Mass accumulation rate. These rates have been integrated over the 31,200 km^2 of the study area.

7.2. Highstand (0–6.5 ka)

Approximately 13,000 MT of sediment accumulated in the study area over the last 6.5 ky (Table 4). Of this total sediment ~11,000 MT (85%) accumulated on the slope at an average rate of 1.7 $MT\ yr^{-1}$, and 2000 MT of sediment (~15%) accumulated in the basin at an average rate of 0.3 $MT\ yr^{-1}$ (Table 4). The average carbonate content of sediment deposited during highstand is about 80%, both on the slope and in the basin (Fig. 14). Thus, during highstand, there were average annual accumulations of approximately 0.3 $MT\ yr^{-1}$ of siliciclastic material on the slope, 0.1 $MT\ yr^{-1}$ of siliciclastic material in the basin, 1.4 $MT\ yr^{-1}$ of carbonate on the slope, and 0.2 $MT\ yr^{-1}$ of carbonate in the basin (Table 4). Downcore plots of carbonate content (Fig. 14) and LSR (Fig. 12) for locations on the slope show that the amount of carbonate increases steadily over the interval of decreasing LSR. This observation shows that the supply of siliciclastic material to the slope decreased steadily throughout the post-glacial sea level highstand.

7.3. Transgression (6.5–14.7 ka)

Approximately 20,000 MT of sediment accumulated in the study area between 14.7 and 6.5 ka (Table 4). As for the highstand period, 16,000 MT (80%) of sediment accumulated on the slope at an average rate of 2.0 $MT\ yr^{-1}$, and 4000 MT accumulated in the basin at an average rate of 0.5 $MT\ yr^{-1}$ (Table 4). There is a potentially large error in the estimate for the slope MAR during transgression because the distance–thickness curve used for integration of slope sedimentation (Fig. 16) is loosely defined by only seven points. Nevertheless, it is an inescapable conclusion that large amounts of sediment were deposited on the slope of the Queensland Trough during transgression.

Although distance–LSR curves (Fig. 11) and MARs for the slope display similar patterns during highstand and transgression, the average carbonate contents of sediment deposited during transgression are about 55% for the slope and 75% for the basin (Fig. 14). Thus, during transgression, there were average annual accumulations of approximately 1.0 $MT\ yr^{-1}$ of siliciclastic material on the slope, 0.1 $MT\ yr^{-1}$ of siliciclastic material in the basin, 1.1 $MT\ yr^{-1}$ of carbonate on the slope, and 0.4 $MT\ yr^{-1}$ of carbonate in the basin (Table 4). The massive quantity of sediment deposited on the slope during transgression reflects an order of magnitude increase in siliciclastic MARs relative to lowstand. Because slope LSRs reach pronounced peaks between 12 and 8 ka that are at least 150% higher than average transgression values (Fig. 12), the maximum flux of siliciclastic material to the entire Queensland Trough during transgression was about 2.5 $MT\ yr^{-1}$, i.e. similar to the estimated rate of pre-industrial terrigenous input to the entire north–central GBR platform by rivers (Neil and Yu, 1995; Fig. 3).

7.4. Lowstand (14.7–31.0 ka)

Approximately 11,000 MT of sediment were deposited in the study area between 31.0 and 14.7 ka (Table 4). In striking contrast to the patterns for highstand and transgression, only about 45% of this accumulation occurred on the slope. Thus, during lowstand, approximately 5000 MT of sediment accumulated on the slope at an average rate of 0.3 MT yr^{-1}, and 6000 MT of sediment accumulated in the basin at an average rate of 0.4 MT yr^{-1} (Table 4). The average carbonate content of lowstand sediment is about 65% for the slope and 85% for the basin (Fig. 14), although we have limited information about lowstand deposition on the slope. Thus, during lowstand, there were average annual accumulations of less than 0.1 MT yr^{-1} of siliciclastic material both on the slope and in the basin, approximately 0.2 MT yr^{-1} of carbonate on the slope, and 0.3 MT yr^{-1} of carbonate in the basin (Table 4). Sediment accumulation on the slope was very low during lowstand (Figs. 11 and 12).

7.5. Turbidites

The above calculations do not include turbidites. Given their spatial variability, it is inherently difficult to evaluate the lateral extent and thickness of individual turbidite layers. Hence, any estimate of turbidite contribution to overall sediment MARs is somewhat speculative. We have estimated turbidite accumulation by expressing the total thickness of turbidite deposits as a fraction of the total sediment recovered for all *RV Franklin* FR4/92 cores in the study area regardless of age. Thus calculated, turbidites represent approximately 7% of the core recovered.

Turbidites therefore provide a small but significant amount of siliciclastic sediment (~0.1 MT yr^{-1}) to the study area. Two general types of sandy turbidites occur in sediment cores of the Queensland Trough, and these are distinguished on the basis of sediment composition and texture. Mixed siliciclastic/carbonate (or sandy) turbidites are predominantly composed of quartz ((50%) with subordinate feldspar and carbonate minerals. High carbonate turbidites are most prominent in core PC 9 (Table 1).

8. Sequence stratigraphic models

8.1. Models of carbonate and siliciclastic sedimentation

Sequence stratigraphic models (SSMs) are based on an underlying assumption that the deposition of sediment packages on the shelf and slope is controlled by relative changes in sea level (Vail, 1987; Miall, 1997). Siliciclastic and tropical carbonate depositional systems respond, to relative sea level change, differently (Eberli, 1991; James and Kendall, 1992), and end-member models have been proposed to describe each system.

In siliciclastic systems, maximum and minimum slopes to basin sediment fluxes occur during sea level lowstand and transgression, respectively (Van Wagoner et al., 1988). The shelf and upper slope may be exposed during lowstand. Thus, rivers attempt to re-establish grade, leading to river channel incision and subaerial erosion (Posamentier and Vail, 1988). Under these conditions, sediments bypass the continental shelf and are deposited directly on the continental slope and basin as submarine fan and channel levee complexes. Toward the end of lowstand, sea level rises, valley incision ceases, and a lowstand sediment “wedge” develops on the upper slope. As sea level rises and transgresses the shelf, rapid landward migration of sediment depocentres leaves the outer continental shelf, slope and basin starved of sediment. This results in a “condensed section” that is characterised by very low LSRs (Van Wagoner et al., 1988; Posamentier and Vail, 1988). Deposition on the shelf during sea level highstand is generally widespread with progradation of the shoreline and its associated sediment wedge (Van Wagoner et al., 1988). Slope and basin sedimentation progressively increases during highstand and early regression as the sediment wedge progrades to the shelf edge (Posamentier and Vail, 1988).

In pure tropical carbonate systems, maximum and minimum offshore sediment fluxes occur during sea level highstand and lowstand, respectively (James and Kendall, 1992), because the supply of available carbonate sediment is controlled by shallow water biogenic carbonate production (e.g. Boardman and Neumann, 1984). During periods of low sea level, the shelf is exposed, and total carbonate production is low (James

and Kendall, 1992). As sea level rises above the shelf margin, corals and other carbonate secreting organisms (e.g. calcareous algae, benthic foraminifera, sponges and molluscs) on a widening shelf increase overall volumes of carbonate production. The amount of material transported off the shelf during transgression varies and is dependent on rates of production (James and Kendall, 1992). During highstand, shelf production of carbonate slows as accommodation space becomes limited, but export of carbonate off the shelf continues to be high.

8.2. The GBR mixed depositional system

Relatively few mixed siliciclastic/carbonate systems have been described from a dynamic perspective, which includes sediment flux through time (cf. Mount, 1984; Dolan, 1989). The available evidence (summarised by Cant, 1992) suggests that such systems respond as “siliciclastic” during lowstand, and as “carbonate” during highstand. That is, a significant volume of siliciclastic sediment is transported across the continental shelf and deposited in adjacent marine basins during lowstand, and massive quantities of carbonate are exported to the basin during highstand. This alternating highstand deposition of carbonates and lowstand deposition of siliciclastics has been termed “reciprocal” sedimentation (Wilson, 1967; Cant, 1992). Although outcrop examples of inferred reciprocal sedimentation are numerous (e.g. Silver and Todd, 1969; Borer and Harris, 1991; Rankey and Lehrmann, 1996), examples constrained by independently derived sea level curves and detailed chronologies are rare.

The sediment record at ODP Site 820 on the slope of the Queensland Trough (Figs. 9, 12 and 14) cannot be explained by the simple “reciprocal” model, because the maximum and minimum bulk sediment LSRs occurred during transgression and lowstand, respectively. The main cause of discrepancy between the observed record and the model expectation is the behaviour of the siliciclastic component (Peerdeman and Davies, 1993). Carbonate accumulation over time at Site 820 is similar to that predicted by SSMs for pure tropical carbonate margins. However, the maximum and minimum siliciclastic deposition during transgression and lowstand, respectively, is not predicted by end-member siliciclastic SSMs. Our results from piston cores on the slope of the Queensland Trough, especially core PC 16 (Figs. 9, 12 and 14), are closely similar to those from ODP Site 820. We conclude that the eastern Queensland margin, an outstanding modern example of a mixed tropical siliciclastic/carbonate system, behaves differently than current models would predict.

Peerdeman and Davies (1993) have provided a partial explanation for the stratigraphy encountered at ODP Site 820 and suggested that the condensed sediment interval at lowstand results from the bypassing of siliciclastic material via canyons on the slope, and from a marked drop in the amount of shallow water carbonate production. Similarly the increasing carbonate content throughout highstand was attributed to trapping of siliciclastic sediment on the inner shelf, and increased shedding of carbonate detritus from growing reefs. The large influx of siliciclastic mud, which occurred during transgression, has not been explained. Assuming a constant siliciclastic source over time, if significant quantities of siliciclastic material bypassed the slope during lowstand, then we might expect to see an increase in the accumulation of this material in the Queensland Trough. However, an increase in siliciclastic MAR during lowstand is not observed (Table 4), and the MAR of siliciclastic sediment in the basin during lowstand (0.08 MT yr^{-1}) is similar to that during transgression (0.1 MT yr^{-1}) and highstand (0.1 MT yr^{-1}).

Two additional factors bear on sediment accumulation in the Queensland Trough. First, the maximum siliciclastic MAR to the Queensland Trough between 12 and 8 ka ($\sim$2.5 MT yr^{-1}) is similar to the total riverine input to the entire central GBR platform at present-day (2.6 MT yr^{-1}, Neil and Yu, 1995). Much of the fluvial sediment discharged on to the GBR platform at present-day is transported and deposited along the coast (e.g. Belperio, 1983). Presumably such transport and deposition also occurred throughout transgression. Thus, unless riverine terrigenous inputs increased several fold between 14 and 6 ka, simple mass balance considerations preclude direct fluvial input as having been the dominant source of siliciclastic material during transgression. Second, the current siliciclastic MAR in the Queensland Trough (0.4 MT yr^{-1}) represents a significant fraction (15%) of the total riverine input to the central GBR platform, including discharge from the Burdekin River (Neil

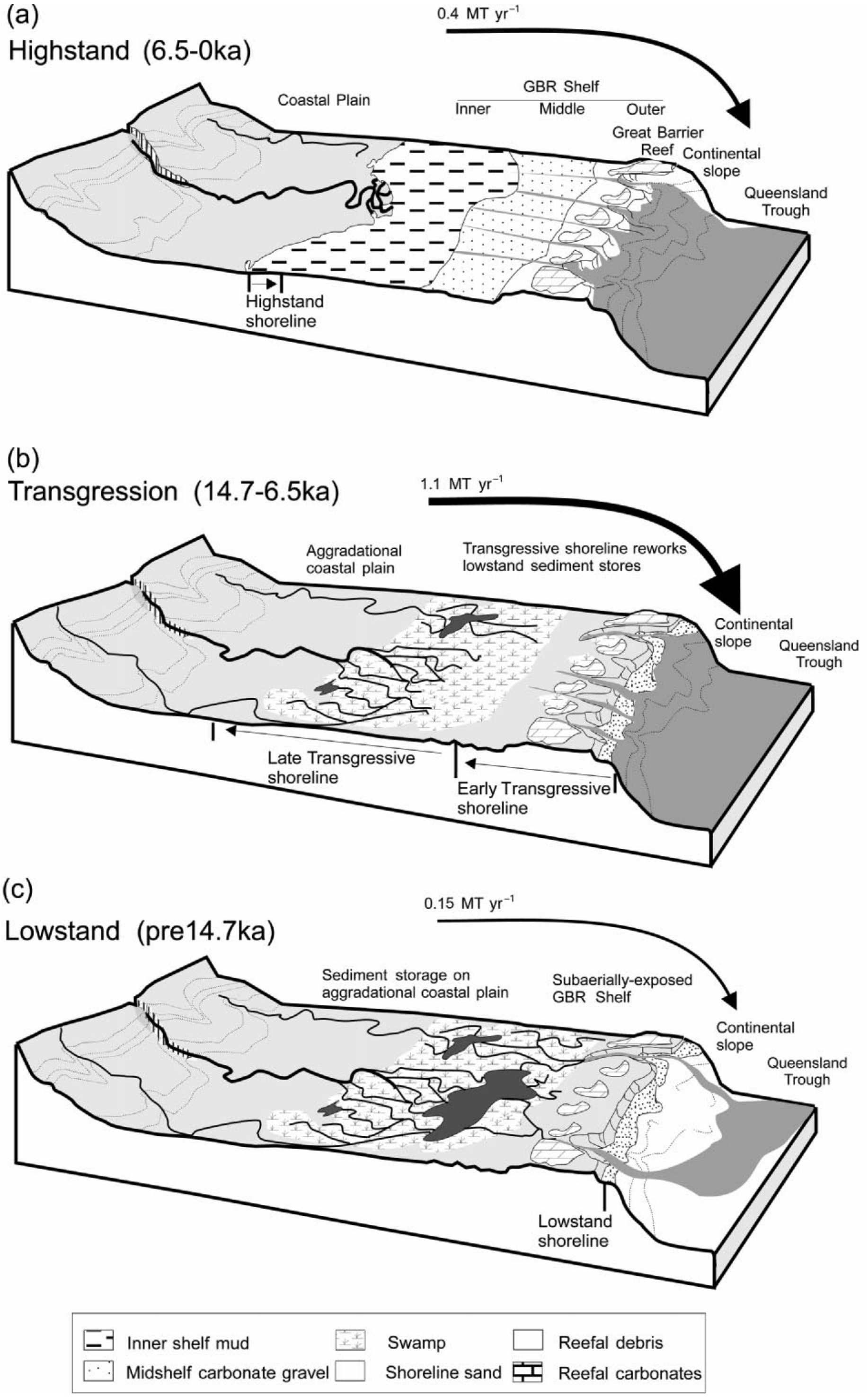
and Yu, 1995). This quantity of terrigenous sediment greatly exceeds the cross-shelf transport which is predicted by models of sediment movement on the GBR shelf at the present day (e.g. Larcombe et al., 1996).

Regional variations in parameters such as climate, oceanographic circulation, shelf and basin physiography, tectonism and sediment supply can modify the general relationships between lithofacies and eustatic sea level (e.g. Karner and Marra, 1998; Rankey, 1997; Galloway, 1998). Palynological studies show that pollen over the last glacial cycle at ODP Site 820 is derived from the Atherton Tablelands of North Queensland (Moss and Kershaw, 2000). Preliminary geochemical work also indicates that siliciclastic sediment in our cores has a chemical composition identical to siliciclastic material on the nearby shelf. Available information therefore suggests that terrigenous sediment deposited in the Queensland Trough is derived from nearby coastal sources rather than from distant sources. This assumption is inherent in the following discussion.

Recent work (Woolfe et al., 1998; Talling, 1998) has highlighted the importance of shelf gradient and sediment consolidation as controls on fluvial processes during lowstand. Continuous seismic profiling on the GBR platform shows numerous channels incised into a sub-aerially exposed surface (reflector A) which corresponds to sea level lowstand (Orme et al., 1978; Johnson et al., 1982; Johnson and Searle, 1984; Carr, 1988; Harris et al., 1990). Johnson and Searle (1984) suggested these channels were formed by fluvial incision during lowstand or by tidal channel downcutting during transgression. Although Johnson and Searle (1984) favoured a fluvial origin for these channels, Woolfe et al. (1998) have argued for the alternative explanation. These latter authors suggest that significant fluvial incision did not occur during lowstand because of the very low gradient across the GBR platform, and because of low rainfall in river catchments. Woolfe et al. (1998) suggest mainly "floodout" type deposition occurred during lowstand, whereby raised avulsive river channels drain into a broad mid-shelf swamp (Fig. 17). In such a system, the continental shelf acts as a store for sediment during falls in sea level and lowstand, in contrast to the off-shelf terrigenous discharge predicted by conventional SSMs (cf. Posamentier and Vail, 1988). This interpretation is supported by deep and intermediate penetration seismic reflection studies of the GBR platform which show the GBR shelf itself is formed from sigmoidal prograding units characteristic of lowstand fluvial and deltaic sedimentation (Symonds et al., 1983; Davies et al., 1991). Shallow boomer profiles across the shelf adjacent to Townsville (Fig. 1) show that Pleistocene sediments underlying reflector "A" are primarily of fluvial origin and that such sediments extend to the outer shelf where they are replaced by eastward prograding units interpreted as lowstand deltaic sedimentation (Davies et al., 1983; Harris et al., 1990). In addition, sediment starvation on the continental slope during glacial periods could also be enhanced by the winnowing effects of slope parallel currents (e.g. Pickard et al., 1977; Burrage, 1993; Hughes, 1993) although relevant data are limited.

Accumulation rates, terrigenous content and mangrove pollen content all increase on the central GBR slope during the 15–11 ka transgression (Fig. 12). During this period, the shoreline would have passed through a geomorphologically complex zone consisting of Pleistocene reef "islands", channels, and sheltered bays with mangrove swamps (Fig. 17). The presence of early post-glacial mangrove swamps on the outer shelf has been verified by coring (Larcombe et al., 1995; Grindrod and Kershaw, 1996). Presumably, some of the sediment in the mangroves would be exported off the shelf and the observed increase in organic carbon and terrigenous mud during early transgression (Peerdeman and Davies, 1993) probably represents seawards leakage from these established mangrove tracts. As the shoreline transgressed landwards, away from the reef island structures, the coast would have become more linear (Harris et al., 1990). The reduced number of sheltered bays precluded the formation of widespread mangrove swamps or the accumulation of substantial bodies of fine-grained sediment. During this time of mid-transgression,

Fig. 17. Conceptual model for the behaviour of the siliciclastic sediment component of the northeast Queensland margin (during) (a) highstand, (b) transgression, and (c) lowstand time respectively. Diagrams modified after Woolfe et al. (1998). Also shown are our estimated annual siliciclastic sediment fluxes into the Queensland Trough.


(a)
Highstand (6.5-0ka)
0.4 MT yr^{-1}
Coastal Plain
GBR Shelf
Inner
Middle
Outer
Great Barrier Reef
Continental slope
Queensland Trough
Highstand shoreline
(b)
Transgression (14.7-6.5ka)
1.1 MT yr^{-1}
Aggradational coastal plain
Transgressive shoreline reworks lowstand sediment stores
Continental slope
Queensland Trough
Late Transgressive shoreline
Early Transgressive shoreline
(c)
Lowstand (pre14.7ka)
0.15 MT yr^{-1}
Sediment storage on aggradational coastal plain
Subaerially-exposed GBR Shelf
Continental slope
Queensland Trough
Lowstand shoreline
Inner shelf mud
Swamp
Reefal debris
Midshelf carbonate gravel
Shoreline sand
Reefal carbonates

sediment that had accumulated on the middle shelf during lowstand and early transgression would lie at depths of 30–50 m, within the reach of storm wave-base, and hence would be easily resuspended and transported seawards (downslope). Such a mechanism can account for the massive accumulation of siliciclastic sediment, which occurred on the slope during late transgression.

Climate change could also have been a significant control on sediment flux during late transgression. Kershaw (1975, 1985, 1994) estimated from palynological evidence that rainfall on the Atherton Tablelands (Fig. 2) increased from approximately 600 mm yr^{-1} to >3000 mm yr^{-1} over the period from 11 to 7 ka (Fig. 12). The dramatic increase in siliciclastic MAR in the Queensland Trough is synchronous with this elevated precipitation. However, it does not necessarily follow that increased precipitation in the tablelands would result in a greater sediment discharge to the North Queensland margin. First, an increase in precipitation would probably increase vegetation cover, and thereby might instead reduce sediment supply to river channels. This effect is especially prevalent in areas where mean annual precipitation is ~1000 mm (e.g. Schumm, 1968), as is the case for the dry tropics of North Queensland. Second, paleoclimate reconstructions for the Atherton Tablelands are possibly not generally applicable to most of North Queensland (Ash, 1983). We consider it unlikely, therefore, that elevated precipitation in the wet tropics was the main cause of increased siliciclastic flux to the Queensland Trough, because the peak flux during late transgression (~2.5 MT yr^{-1}) is almost an order of magnitude greater than the total estimated discharge from wet tropical rivers at the present-day (Neil and Yu, 1995). A shelf sediment reservoir that stores siliciclastic material during lowstand, and releases this material during transgression, is the most satisfactory explanation for the observed pattern of sediment accumulation in the Queensland Trough.

There is an additional argument for the storage of significant amounts of siliciclastic material on the shelf during lowstand. A wide variety of evidence suggests that most modern sediment discharged on to the GBR platform does not reach the outer shelf at present-day (Maxwell and Swinchatt, 1970; Belperio, 1983; Johnson and Searle, 1984; Gagan et al., 1987). Throughout the Holocene highstand, however, a large mass of siliciclastic sediment has accumulated in the central sector of the Queensland Trough. This siliciclastic flux has averaged about 0.4 MT yr^{-1}, although both LSRs and the percentage of siliciclastic material indicate a systematic decline from 6.5 ka to the present day (Figs. 12 and 14). Given the current best estimates of present-day discharge from the mainland, a seemingly unrealistic percentage of sediment must be transported across the continental shelf unless sediment stored during lowstand is currently being reworked. We acknowledge, however, that this argument depends on our understanding of cross-shelf sediment transport, a process that is poorly constrained for the Queensland margin (e.g. Orpin et al., 1999).

Carbonate records from several locations in the Queensland Trough display a carbonate minimum at the isotope stage 5/6 boundary at 130 ka (Fig. 14). This observation suggests a great flux of terrigenous sediment to the Queensland Trough during the penultimate transgression. A further interesting observation concerns the small sea level rise (30 m) and transgression that occurred at the substage 5a/b boundary at ~85 ka. Several cores from the Queensland Trough show a conspicuous carbonate minimum at this time (Fig. 14), and this sediment change is probably a regional feature because it is readily identified on many greyscale logs (Figs. 9A–C). At this time the shoreline would have been about 40–50 m below present-day. Thus, this drop in carbonate content may also signify increased siliciclastic accumulation during another transgression across the middle and inner shelves. Sediment storage during lowstand, and sediment release during transgression, may be a general phenomenon for the central North Queensland margin, and has been probably repeated through time at different scales.

Sediment accumulation in the Queensland Trough is different from that predicted by the siliciclastic SSM, probably because of climate and basin physiography controls. The low and variable input of siliciclastic sediment onto a broad low angle shelf, silled at its basinward edge by coral reefs, would favour “floodout” deposition on a lowstand shelf. Quantitative studies are needed on other margins to test whether the central north Queensland margin is a general paradigm for mixed siliciclastic

carbonate systems, or alternatively represents a special case.

Several special factors apply to the central Great Barrier Reef margin. First, the central section is characterised by a broad, (40–70 km wide) shelf and a gentle 2–4° upper slope. To the north, however, the shelf narrows and the slope steepens (Fig. 5). The steeper basin physiography in the north might have favoured increased siliciclastic accumulation on the slope during lowstand and decreased siliciclastic accumulation on the slope during transgression. Second, the central area generally lacks large gravity flows, except to the north (Fig. 6).

The locations of the cores that have been used for calculating MARs may also have influenced our interpretation. The GLORIA survey shows a series of large gravity flows at the north end of our study area and beyond (Fig. 6). Although we tried to determine the stratigraphy of piston cores from these flows (Figs. 5 and 9H), the sedimentary record is chaotic, and the age of the flows therefore remains unknown. Thus, we have studied only the accumulation of sediment deposited by pelagic and hemipelagic processes and it remains possible that significant quantities of siliciclastic sediment were emplaced on the slope and in the basin during lowstand by gravity flows.

We also note that our approach for calculating MARs over the Queensland Trough (Fig. 16) is necessarily simple and, assumes a line source of sediment to the slope and basin. Bulk carbonate concentrations have been determined for core top sediment across the Queensland Trough (Dunbar, 2000), and show that carbonate contents are lower in the northern part of the Trough. This observation is consistent with an increased dilution, by siliciclastic sediment, at the northern end of our study area at the present-day. However, during transgression, when sediment stored on the continental shelf would have been reworked by waves, siliciclastic sediment supply to the Trough would probably have been more linear. In contrast, and as discussed earlier, the supply of siliciclastic sediment to the slope and basin during lowstand may have approximated a series of point sources (e.g. Carr, 1988; Harris et al., 1990). Given the limited number of cores that were available to us to study lowstand sediment accumulation on the slope (Fig. 11), it is possible that coincidentally all were distal from a lowstand point source.

9. Conclusions

Sediment accumulating in the Queensland Trough is mainly composed of varying combinations of terrigenous and marine carbonate material. Variations in MS and greyscale logs for at least 24 piston cores (as well as ODP sites) can be correlated over a 31,200 km^2 area of the Trough. The physical property measurements in these cores can be assigned ages from oxygen isotope measurements, radiocarbon ages and biostratigraphic analyses. Using these age models, we have quantified the mass accumulation rates (MARs) for siliciclastic and carbonate components of the central GBR platform over three time intervals: lowstand (31–14.7 ka), transgression (14.7–6.5 ka), and highstand (6.5–0 ka). We conclude:

1. Maximum bulk accumulation (2.5 MT yr^{-1} MAR) occurred during the postglacial transgression, and minimum bulk accumulation (~0.7 MT yr^{-1} MAR) may have occurred during the last glacial lowstand.
2. Maximum and minimum siliciclastic accumulation also occurred during transgression (1.1 MT yr^{-1} MAR), lowstand (0.15 MT yr^{-1} MAR), respectively; and
3. Maximum and minimum carbonate accumulation occurred during highstand and transgression (1.6–1.4 MT yr^{-1} MAR), and lowstand (0.5 MT yr^{-1} MAR), respectively.

Although rates of carbonate sediment accumulation are similar to those predicted by current models for carbonate systems, siliciclastic sediment accumulation on the Queensland margin departs from the model. High siliciclastic accumulation during occurred during transgression, reflecting enhanced input of material to the slope then, and low siliciclastic accumulation occurred during lowstand indicating a lack of sediment supply or erosion then. The volume of siliciclastic sediment deposited during transgression and highstand precludes models that link high rates of sediment accumulation directly to high rainfall in adjacent river catchments.

We propose the following scenario for siliciclastic sediment accumulation in the Queensland Trough:

1. Terrigenous sediment supplied during the last

glacial lowstand was sequestered on the middle GBR shelf as a result of reduced fluvial discharge and stream power (Woolfe et al., 1998). This sediment storage prevented most siliciclastic material from entering the Queensland Trough.
2. During the early post-glacial transgression, some siliciclastic sediment was supplied to the Queensland Trough, and some was again stored on the outer shelf. However, during late transgression, reworking of the sediment stored on the middle shelf, possibly combined with a higher riverine sediment input, resulted in a large offshore flux of siliciclastic material.
3. The MARs of siliciclastic sediment have decreased systematically during highstand, because limited amounts of sediment could cross the shelf and because sediment reservoirs on the shelf were becoming progressively depleted.

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Appendix A. Analytical methods

A.1. Volume magnetic susceptibility

Magnetic susceptibility was measured on all split cores of the Queensland Trough using a GEOTEK multi-sensor track system. Split sediment cores were equilibrated at ~25°C, and sediment MS was measured at a spacing of 4 mm using a Bartington Instruments MS2 meter connected to a Bartington “F” type point sensor unit with a spatial resolution of approximately 20 mm (Bartington, 1995). The MS2 meter measures susceptibility using a tuned oscillator circuit. Variations in the frequency of the AC waveform caused by placing the sensor on magnetically susceptible sediment are directly proportional to the MS of the sample (Robinson, 1990). Our system was operated with an AC field strength of 80 A/m rms, and at a frequency of 0.58 kHz (1 second integration time). The MS meter is controlled by a microprocessor that raises the sensor 20 mm above the core surface and re-zeros the meter between readings to minimise drift. Volume MS data for all cores are reported in arbitrary Bartington Meter IS scale units.

Two hundred and nine measurements from Section-1, core PC 6, were repeated to estimate reproducibility. The mean difference between the two data sets was 0.25 ± 1.53 SI (one standard deviation). Volume susceptibility data for all cores are reported in arbitrary Bartington Meter SI scale units.

A.2. Visual reflectance (greyscale)

Core sections were scraped to remove surface water and to smooth exposed core surfaces. Images of each core were acquired using a Kodak DC-40 digital camera with four GEC-Osram 150 W Quartz-Iodine bulbs containing tungsten filaments for lighting. Colour temperature was corrected to “daylight” using an 80A colour correction filter.

Sediment greyscale was determined from these images. Each photographed core section included a background white calibration strip and a Kodak greyscale reference chart (Kodak publication number Q-14). Images were down-loaded to a PC for processing, and numerical greyscale values were obtained from the digital images using the public domain

Table A1
Radiocarbon ages of mixed planktonic foraminifera (OZ) and bulk carbonate (Wk) from the Queensland Trough

Core	Depth (mbsf)	Age (ka)	Error (±)	ANSTO (OZ) and Waikato (Wk) #
PC 16	0.21	2160[a]	50	OZC 967
PC 16	0.80	6280[a]	70	OZC 968
PC 16	1.65	9370[a]	110	OZC 969
PC 16	2.30	11550[a]	150	OZC 970
PC 16	2.59	15050[a]	150	OZD 811
PC 16	2.64	40400[a]	3500	OZD 812
PC 16	3.44	36800[a]	2000	OZD 813
PC 23	0.07	1010[a]	50	OZE 162
PC 23	0.99	2660[a]	50	OZE 163
PC 23	2.47	5590[a]	60	OZE 164
PC 23	3.65	7130[a]	80	OZC 971
PC 35	0.50	17020	300	Wk 2729[b]
PC 35	0.80	22010	400	Wk 2730[b]
PC 42	0.10	4440	220	Wk 2724[b]
PC 42	0.50	15420	340	Wk 2725[b]
PC 42	1.00	32000	1200	Wk 2726[b]

[a] Age is reported in conventional ^{14}C years.
[b] Unpublished data (T. Grace).

software package "NIH Image v 1.60". Greyscale measurements were averaged across a width of 30 pixels (4.5 mm) from the centre of the core. The position of core sections, camera, and lights was kept constant for all images, and variations in illumination along the length of the core were eliminated as much as possible by normalising image greyscale intensity to variations in the intensity measured along the uniform white calibration strip. Greyscale values were then scaled to calibrated "100% white" and "100% black" values on the greyscale reference chart.

Reproducibility of greyscale was evaluated by repeating measurements for cores PC†16 and PC 42 after 22 months. Absolute values show some variation over time, with the greatest change in greyscale intensity over the first and last 10 cm of each core section. The cause of this greyscale change over time is unclear, but does not detract from the use of greyscale values as a correlative tool. Even after intensity changes over time, over all trends in greyscale are reliably reproduced.

A.3. Radiocarbon ages

Radiocarbon ages were determined on 11 samples of planktonic foraminifers from two piston cores (Table A1) by accelerator mass spectrometry (AMS) at the Australian Nuclear Science and Technology Organisation (ANSTO). Samples were washed through a 125 mm wet sieve and dried at room temperature. The largest planktonic foraminifera (mainly *Globigerinoides ruber, G. sacculifer, G. conglobatus, Globorotalia* sp.) in the >125 μm fraction were hand picked. Submitted sample weights ranged from 11 to 23 mg. Errors (1σ) associated with ages are reported in Table A1.

Radiocarbon ages also were determined on five bulk sediment samples from two piston cores (Table A1) by use of a proportional gas counter at the University of Waikato Radiocarbon dating laboratory in New Zealand. These samples were prepared by Grace (1993).

A.4. Oxygen isotopes

Oxygen isotope analyses were made on foraminifera specimens from discrete sediment samples from five cores using a Finnigan MAT 251 mass spectrometer coupled to a Kiel "individual acid on sample" carbonate device at the Australian National University (ANU). Individual samples for these analyses came from cores PC 6, PC 14, PC 16, PC 36, and PC 39, and were typically spaced at 5–10 cm depth intervals in each core (Table A2). The cores were chosen because as a set they are distributed across the slope and basin of the Queensland Trough. Actual isotope analyses were determined on approximately 160 μg collections (about 11 tests) of white *G. ruber* extracted from a sediment fraction sieved at 250–355 μm. Samples were picked and subsequently cleaned in an ultrasonic bath with alcohol to remove fine fraction contamination. The species and size range were chosen to maintain consistency with data published for ODP Site 820 (Peerdeman et al., 1993).

Oxygen isotope results (Table A2) are expressed in delta notation ($\delta^{18}O$) with PDB as a reference standard. The standard deviation of 70 analyses of NBS-19 was 0.036‰.

Oxygen isotope data from cores PC 35 and PC 42 are taken from Grace (1993).

Table A2
Oxygen isotopic composition of white *G.ruber* 250–355 μm tests, and *G. sacculifer* (PC 35 and PC 42, T. Grace, unpublished data)

PC 6		PC 14		PC 16		PC 35		PC 36		PC 39		PC 42	
Depth (mbsf)	δ^{18}O (PDB)	Depth (mbsf)	δ^{18}O (PDB)	Depth (mbsf)	δ^{18}O (PDB)	Depth (mbsf)	δ^{18}O (PDB)	Depth (mbsf)	δ^{18}O (PDB)	Depth (mbsf)	δ^{18}O (PDB)	Depth (mbsf)	δ^{18}O (PDB)
0.06	−2.21	0.07	−2.26	0.08	−2.31	0.39	−1.84	0.00	−2.26	0.04	−2.19	0.10	−2.20
0.16	−2.16	0.27	−2.37	0.17	−2.33	0.49	−1.10	0.10	−2.27	0.09	−2.28	0.20	−2.10
0.26	−1.86	0.47	−2.30	0.37	−2.23	0.59	−0.95	0.20	−1.34	0.14	−1.90	0.30	−1.83
0.36	−1.59	0.63	−1.86	0.47	−2.28	0.69	−0.52	0.30	−0.78	0.19	−1.64	0.40	−1.21
0.46	−1.28	0.76	−1.26	0.55	−2.28	0.89	−0.76	0.40	−0.97	0.24	−1.00	0.50	−0.65
0.56	−0.42	0.85	−0.74	0.65	−2.31	0.99	−0.69	0.46	−0.99	0.29	−0.81	0.70	−1.14
0.66	−0.57	0.99	−0.37	0.75	−2.16	1.09	−1.06	0.60	−1.26	0.34	−0.63	0.80	−1.11
0.76	−0.86	1.16	−0.83	0.85	−2.18	1.19	−1.19	0.70	−1.26	0.39	−1.02	0.90	−1.29
0.86	−0.94	1.26	−1.02	0.95	−2.22	1.29	−1.05	0.78	−1.23	0.44	−0.97	1.20	−1.36
0.96	−0.80	1.42	−0.81	1.05	−2.27	1.49	−1.43	0.86	−1.27	0.49	−1.06	1.30	−1.22
1.06	−0.79	1.78	−1.25	1.15	−2.13	1.59	−1.23	0.96	−1.48	0.54	−1.09	1.40	−0.68
1.16	−0.90	1.88	−1.16	1.20	−2.19	1.69	−1.23	1.06	−1.80	0.59	−0.92	1.50	−1.13
1.26	−1.01	2.02	−1.04	1.25	−2.39	1.79	−1.02	1.16	−1.52	0.64	−1.08	1.60	−1.27
1.44	−0.96	2.34	−1.10	1.35	−2.18	1.99	−1.59	1.26	−1.53	0.69	−1.15	1.70	−1.77
1.54	−1.00	2.61	−1.65	1.40	−2.00	2.09	−1.54	1.34	−1.81	0.74	−1.17	1.80	−1.56
1.62	−1.20	2.79	−1.86	1.50	−1.97	2.39	−1.71	1.41	−1.68	0.79	−1.12	1.90	−1.57
1.71	−1.18	3.06	−2.01	1.60	−2.23	2.49	−1.56	1.51	−1.82	0.84	−1.21	2.00	−1.63
1.82	−1.42	3.26	−1.57	1.70	−2.10	2.59	−1.79	1.61	−2.06	0.94	−1.27	2.10	−1.73
1.90	−1.62	3.66	−2.01	1.80	−1.99	2.69	−1.6	1.71	−2.21	0.99	−1.39	2.20	−1.47
2.02	−1.51	3.87	−1.87	1.90	−1.85	2.79	−1.61	1.81	−1.07	1.05	−1.39	2.30	−1.62
2.12	−1.48	4.06	−1.76	2.07	−1.78	2.89	−1.85	1.91	−1.30	1.14	−1.48	2.40	−1.72
2.22	−1.58			2.17	−1.84	3.09	−1.68	2.01	−1.22	1.22	−1.36	2.60	−0.35
2.31	−1.37			2.22	−1.62	3.29	−2.00	2.11	−1.12	1.27	−1.58	2.70	−0.50
2.42	−1.58			2.27	−1.52	3.69	−2.20	2.21	−1.15	1.32	−1.48	2.80	−0.46
2.50	−1.60			2.37	−1.39			2.41	−1.32	1.37	−1.79	2.90	−0.42
2.62	−1.46			2.47	−0.98			2.50	−1.35	1.42	−1.69	3.00	−0.83
2.72	−1.79			2.57	−0.46			2.59	−1.33	1.47	−1.80	3.10	−1.23
2.81	−2.14			2.67	−1.38			2.69	−1.46	1.52	−1.70	3.20	−1.06
2.92	−1.75			2.77	−1.51			2.79	−1.64	1.57	−1.88		
3.02	−0.80			2.82	−1.18			2.89	−1.37	1.62	−1.82		
3.12	−0.41			2.92	−1.13			3.00	−1.43	1.72	−1.70		
3.22	−0.52			3.02	−1.26			3.17	−1.73	1.82	−0.63		
3.32	−0.45			3.12	−1.15			3.28	−1.31	1.92	−0.40		
3.41	−0.49			3.22	−1.20			3.37	−1.05	2.02	−0.55		
				3.32	−1.13			3.47	−0.88	2.12	−0.77		
				3.42	−1.20			3.62	−0.68	2.22	−1.11		
								3.74	−1.41	2.32	−1.14		
								3.86	−1.43	2.42	−1.25		
										2.52	−1.62		
										2.62	−1.46		
										2.69	−1.37		
										2.78	−1.31		
										2.88	−1.22		
										2.98	−1.53		
										3.08	−1.24		
										3.18	−0.66		
										3.28	−0.79		
										3.38	−0.92		
										3.48	−1.35		
										3.58	−1.22		
										3.68	−1.22		
										3.78	−1.12		

A.5. Biostratigraphy

The position of the last occurrence (LO) of the pink form of the planktonic foraminfera *Globigerinoides ruber* was determined for certain cores (Table 1). The LO of pink *G. ruber* in the Pacific and Indian Oceans occurred near the stage 5/6 boundary ca. 120 ka (Thompson et al., 1979). For a sequence of samples near the isotope stage 5/6 boundary, approximately 2–3 g of each sample was wet-sieved at 125 μm, and examined for the presence or absence pink *G. ruber* under a binocular microscope.

A.6. Carbonate content

Selected sediment samples from five cores (Table 1) were examined for carbonate content using an acid digestion technique (Table 3). Approximately 5 g of sediment was oven dried at 60°C for at least 24 h, removed from the oven, and equilibrated at room temperature and humidity. The mass of the sample was determined. Approximately 70 ml of dilute (10%) HCl was added to each sample and allowed to react. Samples were rinsed twice with distilled water, and after the supernatant liquid was decanted, the sample was dried and reweighed. The resulting loss of mass from this procedure was assumed to represent removal of carbonate.

The accuracy and reproducibility of the acid digestion method was evaluated with analyses of prepared mixtures of ground quartz and analytical grade $CaCO_3$. The mean difference between known and measured carbonate content for 11 samples was 0.2% with a standard deviation of 0.36%.

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