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Late Quaternary cyclic aridity in tropical Australia

Patrick De Deckker*

Department of Geology, The Australian National University, Canberra ACT 0200, Australia

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Abstract

During the numerous Quaternary sea level fluctuations, the vast Gulf of Carpentaria, in northern Australia, was more often a large lacustrine basin than a shallow sea. Recovery of aeolian quartz particles in a core spanning the last 40,000 calibrated years of sedimentation identifies a ~2,600 year cyclic pattern of aridity. The most pronounced period peaks around 21,500 calibrated years BP, corresponding to the onstart of the period of lowest global sea level and glacial advance in New Zealand. The following peak of aeolian dust activity in Carpentaria just precedes the termination of the low sea level stand at 19,300 calibrated years BP.

The timing of aeolian activity in northern Australia does not coincide with Heinrich events HE 1 to 3 recognised in the Atlantic Ocean, nor with the cyclicity of Chilean glacial activity, thus suggesting that separate 'forces' engender those different phenomena.

Keywords: Aeolian; Dust; Late Quaternary; Cyclicity; Gulf of Carpentaria; Northern Australia; Tropics

1. Introduction

It has been pertinent to identify the timing and amplitude of the Last Glacial Maximum [= LGM], especially since there has been such a vast effort by the international scientific community to compare the ice-age Earth with present-day conditions (CLIMAP, 1976). Most glaciated regions retain little evidence of the amplitude of glaciation apart from the extent of moraines which, if dated adequately, can provide the timing and amplitude of glacial advances. Nevertheless, there is still difficulty when attempting to relate maximal glacial amplitude to maximal cold conditions in contrast to maximal supply of snow/ice as those phenomena are registered differently in glacier behaviour.

The aim of the present study is to determine the extent and timing of maximum aridity in northern Australia, knowing that during the LGM on this dry continent, 'glacial' conditions were translated into extreme arid conditions (Bowler, 1978). The Australian Alps in the Snowy Mountains only had a very small glaciated area [approximately 30–50 km^2] and Tasmania, located further south was covered by ~5,000 km^2 of ice (Galloway, 1973). Elsewhere in lowland Australia, a definite hydrological deficit occurred compared to today as there is substantial evidence of lakes being dry, nor have the major fluvial systems yielded water (Nanson et al., 1992). At the time, the dune fields of Australia had expanded substantially, especially for the large longitudinal dune fields (Wasson, 1986), and mean annual temperatures in central Australia were also considerably colder, having dropped by as much as 8°C (Miller

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* Corresponding author. Tel.: +61-2-6125-2070; fax: +61-2-6125-5544.

E-mail address: patrick.dedeckker@anu.edu.au (P. De Deckker).

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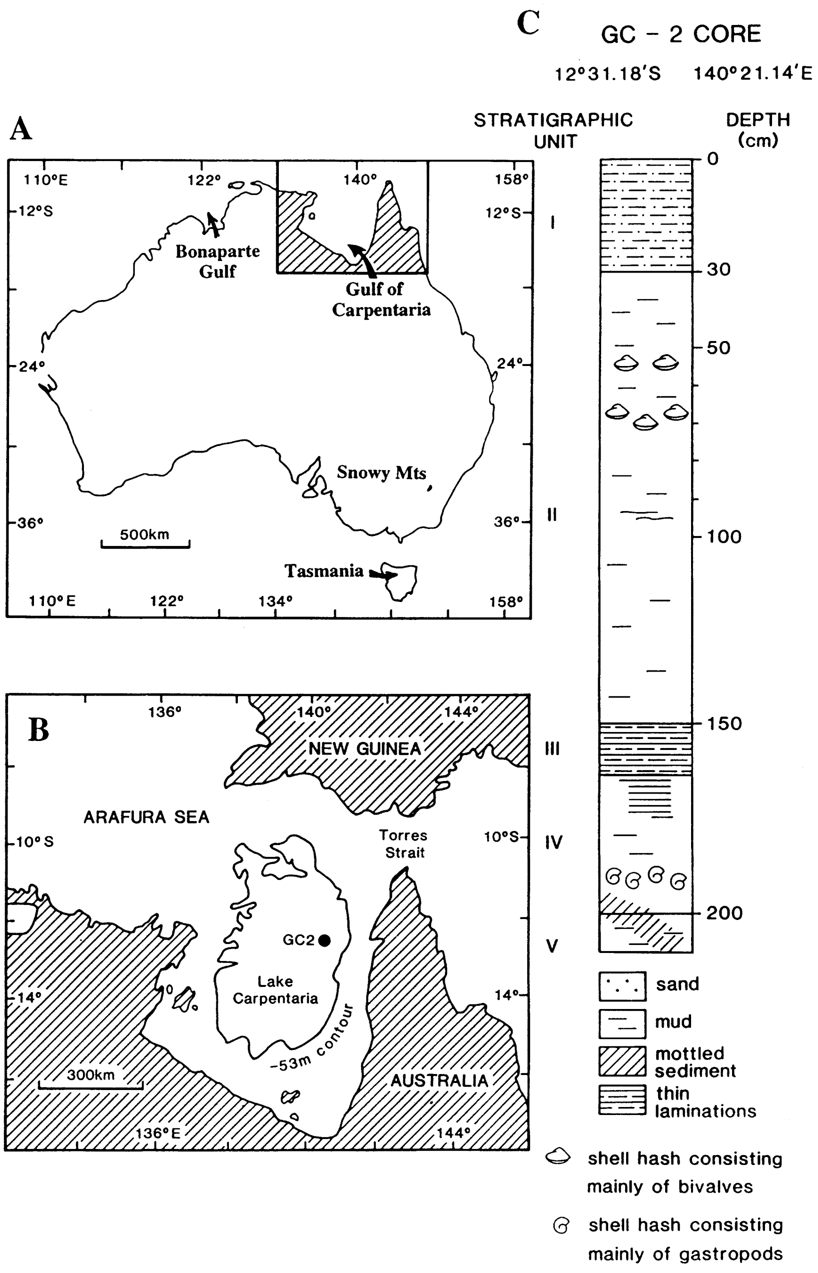

Fig. 1. (A) Map of the Gulf of Carpentaria showing the location of core GC2 and (B) also the extent of Lake Carpentaria that would have existed during periods of low sea levels. (C) shows a stratigraphic log of core GC 2.

et al., 1999). The latter is based on acid racemisation data from emu egg shells collected in a number of places in arid Australia. Unfortunately, except for the recent dating of numerous emu egg shells from a variety of locations in central Australia — mostly from transverse playa-marginal dunes (Miller et al., 1999) — there are too few dates relating to the maximum expansion of the Australian dune fields.

Table 1
List of samples from core GC-2 used for radiocarbon dating

Interval sampled (cm)	^{14}C age (years BP)	Error (1σ)	Laboratory number
0–7	5170	130	ANU 4800
26–31	7240	160	ANU 4801
31–35	9800	340	ANU 4802
68–70	13770	380	ANU 4804
113–117	18670	860	ANU 6633
146–150	21890	760	ANU 6634
155–156	19850	210	OZB 039U
163–167	26720	3040/2200	ANU 6635
192.5–197.5	36140	2900	ANU 6636

2. The Gulf of Carpentaria

The Gulf of Carpentaria (Fig. 1a) has been targeted for reconstructing palaeoenvironmental conditions in tropical Australia for a number of reasons. It lies in a vast depression that is now filled by oceanic water, but it was the site of a large lake (called Lake Carpentaria = LC) (Torgersen et al., 1988) during low sea levels because the topographically highest margins of the basin are bordered by two narrow and shallow sills (12 m depth in Torres Strait and 53 m for the Arafura Sill) (Torgersen et al., 1988). When full, LC was a huge lake, approximately 500 km by 300 km (Fig. 1b). Between ~10,000 cal. years and ~44,000 cal. years, it held mostly slightly saline water but was fresh at times, and it was up to 10 m deep. Prior to that lacustrine phase, LC was dry, and at about 10,000 cal. years the Arafura Sill was transgressed as sea level rose and the Gulf of Carpentaria remained an epeiric sea ever since (Torgersen et al., 1988; De Deckker et al., 1988, 1991; McCulloch et al., 1989).

3. Methods

A gravity core (labelled GC 2; see Fig. 1c) from the central eastern part of the Gulf of Carpentaria has been extensively studied (Torgersen et al., 1988; De Deckker et al., 1988, 1991; McCulloch et al., 1989; Norman and De Deckker, 1990) and is ideally suited for the study of aeolian particles blown into LC. The core site was located some 60 km from the shore of LC when full, and there is no evidence that quartz grains coarser than 60 μm found at particular levels in the core would have been transported to the core site by fluvial activity. Pollen studies (see Luly in Torgersen et al., 1988) done on the same core failed to identify Papua New Guinean pollen that would otherwise have been transported by northern fluvial systems such as the Fly River which drains into the present-day Gulf.

The aeolian dust record from core GC2 has already been published (De Deckker et al., 1991). It is re-examined here since additional radiocarbon dates have been obtained on bulk carbonates (containing mainly ostracods, and a few non-marine foraminifers) from narrow intervals. In addition, one AMS date was done on biogenic carbonates (De Deckker et al., 1988; Head et al., 1999). Other previous radiocarbon dates have also been calibrated here into calendar years using INTCAL 98 program (Stuiver et al., 1998) and also using E. Bard's polynomial based on Stuiver et al.'s (1998) data. All dates reported here (Table 1) are in calendar years and are referred to as 'cal yBP'. Head et al. (1999) identified the validity of the dates obtained from biogenic as well as bulk carbonates, in contrast with the dates from organic material which indicate 'contamination by a non polar compound (or mixture) of yet unknown origin'.

4. Results

A stratigraphic log of core GC2 is presented in Fig. 1c. The fine laminations below 150 cm identify that the lake was stratified. This implies that no cyclonic activity would have occurred above the lake as mixing of bottom sediments would have occurred otherwise. This further implies that the

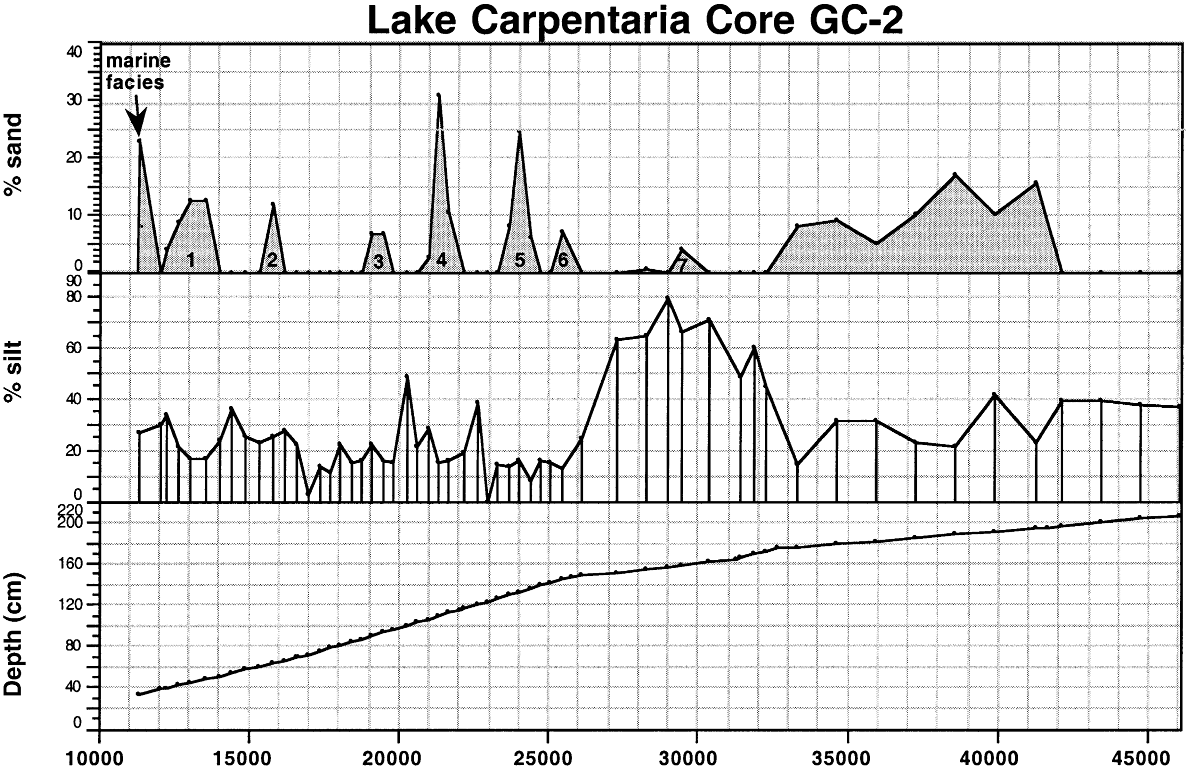

Fig. 2. Diagram to show the percentage of the sand-sized (top) and silt-sized (middle) particles recovered from Core GC2 against time in calibrated years BP. The seven aeolian peaks discussed in the text are labelled in the top diagram. The levels examined in the core (see Table 2) are represented by vertical bars in the middle diagram. The bottom diagram illustrates the change in sedimentation rate in the core and thus helps justify that the bottom portion of the core cannot be used to determine any evidence of cyclicity with certainty. Note that the sand peak younger than peak 1 was deposited during the marine transgression and is not used when discussing cyclic aeolian events in the lacustrine phase of Carpentaria.

Intertropical Convergence Zone was not located above LC at least between 26,000 and 31,000 cal yBP during low sea level stands. It is not surprising that cyclones were absent from the Carpentaria region during periods of low sea level as it would have been located far away from the open ocean where cyclones normally form.

The upper 30 cm of the core, on the other hand, yield marine sediments deposited in a shallow sea. Nevertheless, some lacustrine sediments (and related biogenic remains) from the previous phase have been mixed with the marine sediments (and related biogenic remains), and this is likely to have occurred during the transgression, and also during cyclonic activity. Bottom mixing and turbulence should commonly occur in the Gulf during cyclones as the Gulf today is less than 60 m deep.

The quartz grains are not considered to have been deposited as part of a shoreline environment during lake level fluctuations as trace-element studies carried out on ostracod shell chemistry from core GC2 indicate only minor salinity and temperature fluctuations for adjacent to, or the same level as the horizons with >60 μm quartz grains (De Deckker et al., 1988). The postulated maximum salinity recognised in GC2 corresponds to aeolian peak 4 in Fig. 2.

The dated occurrence of sand-sized [>60 μm] aeolian particles in GC2 is presented in Fig. 2, which shows the calibrated ages or the mean heights for the seven peaks of aeolian particles recovered in that core. The correlation coefficient ($r^2 = 0.991$) gives a re-occurrence of the peaks every ~2,600 calibrated years (Fig. 3).

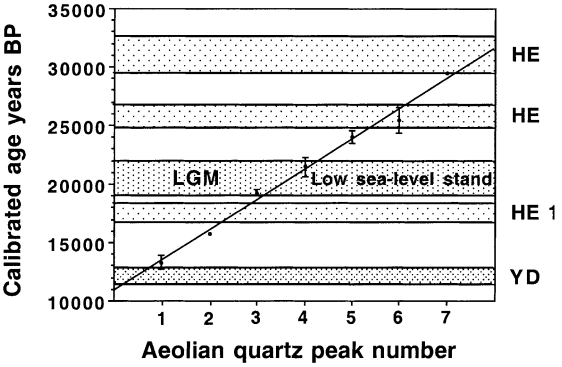

Fig. 3. Diagram showing the calibrated ages of the mean heights for the seven peaks of aeolian particles [squares showing also error bars] recovered in core GC2. The correlation coefficient ($r^2 = 0.991$) gives a re-occurrence of the peaks every ~2,600 calibrated years. Superimposed on this are the timings of the three Heinrich events [HE 1–3] as well as the timing of the Younger Dryas [YD]. Note that the timing of the three HE does not coincide with the arid events recorded in Carpentaria, and also that LC aeolian peaks 4 and 3 coincide exactly with the onset (peak 4) and the end (peak 3) of the period of lowest sea level recorded from the tectonically-stable Bonaparte Gulf.

Of importance also is the peak representing the highest percentage of sand-sized particles (see Table 1) with mean peak height around 21,500 cal yBP. It is here considered to represent the peak of maximum aridity in the Carpentaria region. The second highest peak is older and is dated at 24,000 cal yBP. Prior to that episode, there are two other peaks, which represent only a small percentage of quartz sand. However, very high values of silt-size particles, all being greater than 60% of the total of the grains measured, were recorded for those two horizons (Table 2, Fig. 2). These are considered to represent additional arid events. Resolution for these two peaks [6 and 7 in Fig. 2 with the following ages: ~25,500 and ~29,500 cal yBP] should be looked at with caution compared with the younger-aged peaks due to the larger errors attributed to the dates. Several additional peaks of quartz-sand particles were recognised in the lower (older) portion of the core, but will not be discussed here for several reasons; they occur in low-sedimentation rate intervals (Fig. 2), and uncertainty due to proximity to the detection limit of the radiocarbon method. Three other peaks [1–3 in Fig. 2 with the following ages: 13,300, 15,800 and 19,300 cal yBP] represent moderate percentages of aeolian quartz. The youngest peak *had* previously been considered to have coincided with the timing of the Younger Dryas period (De Deckker et al., 1991), thus pointing out to the synchroneity of this arid phase in northern Australia with a cold episode in many parts of the northern hemisphere, as well as the equatorial Indian Ocean (Bard et al., 1997). The Younger Dryas has not been found in other parts of Australia because most lacustrine sites with the potential of recording this event were dry.

5. Discussion

Peak 1 in GC2 can no longer be claimed to be synchronous with Younger Dryas which is an interval considered to have commenced between 12,900 and 12,500 cal yBP and ended between 11,600 and 11,000 cal yBP (Bard and Kromer, 1995). Peak 1 here is centred around 13,300 cal yBP but extends until 12,230 cal yBP. So, it may still overlap with a part of the Younger Dryas, but this cannot be reconciled until additional dates on a new core would solve this enigma. Note that new, and longer, cores have been taken under the IMAGES program using the *RV Marion Dufresne* and are currently being analysed by A.R. Chivas and colleagues at the University of Wollongong (Chivas et al., submitted).

A regression line through all 7 peaks identifies a ~2,600 year cyclicity for aeolian sand deposition in Carpentaria. This differs from the previous attempt at examining cyclicity in northern Australia (De Deckker et al., 1991), but this time the data rely on calibrated ages. A recent review of Quaternary climatic oscillations identifies a 2.83 ky periodicity related to other reported ones at ~2.5, 2.6, 2.7 and 3 ky (Gauthier, 1999). Nevertheless, before discussing cyclic patterns any further, all these reported cycles will eventually have to be re-examined because many of the reported chronologies are not in calendar years, or were done on marine carbonates for which a 400-year reservoir correction is subtracted for the radiocarbon record. At this stage, one cannot assume such a constant marine reservoir effect, especially for periods when the aragonite compensation depth or the calcite compensation depth have been known to have changed dramatically in the oceans during the Late

Table 2

List of levels sampled in core GC2 and for which the respective percentages of the sand and silt fractions were recovered. All levels are given a calibrated age obtained from the radiocarbon dates presented in Table 1 with sedimentation rates adjusted accordingly between dated horizons. Peak numbers of the sandy (aeolian) layers are listed nearest to the most prominent sandy level (shown in bold) with the respective standard deviation values given for all the adjacent (if present) sandy layers together

Depth (cm)	Years BP calibrated	% Sand fraction	% Silt fraction	Peak number	Mean age of peak	Standard deviation
1	5666	20.0	29.9			
6	6114	33.5	37.3			
9	6412	27.7	29.0			
12	6680	14.4	38.1			
15	6948	28.6	30.0			
18	7217	25.6	30.2			
21	7486	30.9	19.8			
24	7754	18.0	23.1			
27	8022	29.1	21.5			
30	9199	26.5	18.4			
33	11344	22.8	26.5			
38	12083	0.0	30.1			
39	12231	4.0	33.9			
42	12674	8.7	21.0			
45	**13043**	**12.6**	**16.8**	**1**	**13302**	**564**
48	**13560**	**12.6**	**17.0**			
51	14003	0.0	23.4			
54	14446	0.0	35.9			
57	14890	0.0	25.3			
60	15333	0.0	23.2			
63	**15777**	**11.8**	**24.9**	**2**	**15777**	**0**
66	16220	0.0	27.9			
69	16590	0.0	21.9			
72	17013	0.0	2.9			
75	17356	0.0	13.4			
78	17706	0.0	11.4			
81	18055	0.0	22.0			
84	18404	0.0	15.2			
87	18754	0.0	15.7			
90	**19103**	**6.6**	**22.1**	**3**	**19278**	**247**
93	**19453**	**6.8**	**15.7**			
96	19802	0.0	15.4			
96	19802	0.0	15.4			
100	20268	0.0	48.8			
103	20618	0.0	21.6			
106	20967	2.6	28.7			
109	**21316**	**31.0**	**15.1**	**4**	**21491**	**501**
112	**21666**	**10.4**	**15.8**			
116	22139	0.0	19.2			
120	22609	0.0	38.3			
123	22962	0.0	0.0			
126	23314	0.0	14.2			
129	23667	8.1	13.4			
132	**24019**	**24.5**	**15.9**	**5**	**24019**	**352**
136	24371	6.0	8.2			
139	24724	0.0	15.9			
142	25076	0.0	14.8			
145	**25428**	**7.1**	**13.1**	**6**	**25428**	**0**
148	26087	0.0	24.2			

Table 2 (*continued*)

Depth (cm)	Years BP calibrated	% Sand fraction	% Silt fraction	Peak number	Mean age of peak	Standard deviation
151	27314	0.0	63.5			
154	28234	0.6	65.0			
157	28971	0.0	79.9			
159	29462	4.1	66.6	**7**	**29462**	**0**
162	30381	0.0	71.1			
166	31442	0.0	48.2			
169	31861	0.0	60.4			
172	32280	0.0	44.5			
176	33290	8.0	14.6			
179	34613	9.1	31.3			
182	35935	5.0	31.3			
185	37258	10.0	22.7			
188	38580	17.1	21.3			
191	39903	10.0	41.7			
194	41225	15.7	22.7			
197	42107	0.0	39.2			
200	43429	0.0	39.0			
203	44752	0.0	37.6			
206	46074	0.0	36.6			

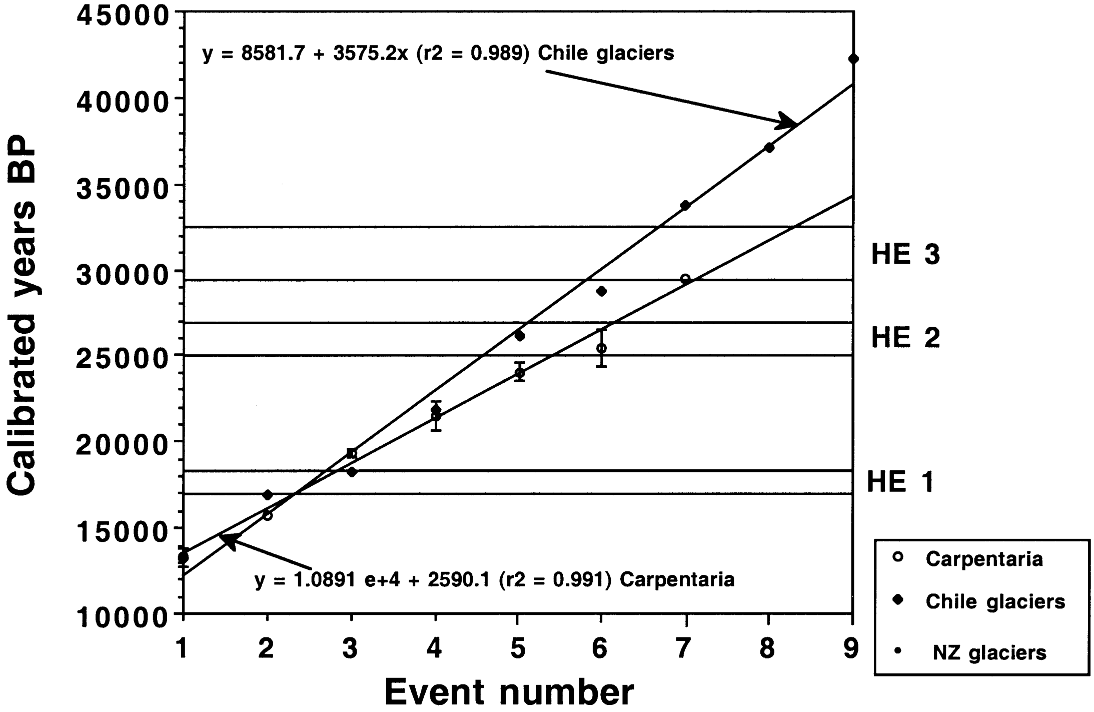

Fig. 4. Comparison in ages between the Carpentaria aeolian dust peaks (open circles), the Chilean glaciations (black diamonds) (Lowell et al., 1995) and the 2 New Zealand glaciations (black circles) (Denton and Hendy, 1994). Note that the timing of New Zealand glaciations coincides with LC aeolian peaks 1 and 4. The Chilean glaciations are out of phase with the Carpentaria aeolian record, but several of them instead coincide with Heinrich Events.

Quaternary (Berger, 1973), thus potentially affecting the recycling of older carbon at times.

It is noteworthy that those LC arid events presented in Fig. 2 do not coincide with the last three Heinrich events [HE 1–3] recognised in the North Atlantic which were documented by Bond and Lotti (1995) but which were recently redated by Elliot et al. (1998). Similarly, comparison of the Carpentaria aeolian record with the chronology reported for southern hemisphere glaciers in Chile (Lowell et al., 1995) again identifies a lack of synchroneity (Fig. 4) between those aeolian and glacial events in the southern hemisphere. The Chilean glacier cyclicity, combined with the New Zealand glacial advances, is somewhat longer (~3,575 years). Nevertheless, the most arid event in Carpentaria (21,666–21,316 cal yBP) is coeval with the maximum extent of the New Zealand Taramaku 2_2 glacier at 21,850 cal yBP (Lowell et al., 1995). This applies also for peak 1 in LC and the youngest glacial advance in New Zealand (Fig. 4) (Denton and Hendy, 1994). This coincidence between peaks 1 and 4 in LC with the New Zealand glacial advances implies that aridity, in association with cold temperature, was a broad climatic feature for the entire Australasian region, and also coincided with a glacial scenario for the northern hemisphere, and the lowest global sea level drop (Yokoyama et al., 2000a, b). In fact, the period of lowest sea level identified from the tectonically-stable Bonaparte Gulf in northern Australia [Fig. 1] between 22,000 and 19,500 cal yBP (Yokoyama et al., 2000a,b) fits very well on either sides of the two peaks of aridity in Carpentaria (see Fig. 2). The most prominent event of dust commenced ~21,700 cal yBP and peaked at ~21,500 cal yBP when sea level was at its lowest (Yokoyama et al., 2000a,b) and remained as such until the following period of aeolian activity peaking at ~19,300 cal yBP. This occurred just prior to the onset of sea-level rise recognised in Bonaparte Gulf at 19,000 cal yBP.

6. Conclusions

Comparison of the timing of arid events recorded in tropical Australia with the last three Heinrich Events reported in the north Atlantic Ocean identifies an obvious asynchroneity of events. It appears that what triggered the last three Heinrich Events may also have induced the glacial advances on land adjacent to the southern Atlantic Ocean in Chile. Aridity in Australia, on the other hand, was triggered by different ‘forces’, apparently not engendered in the North Atlantic Ocean.

The Chilean glaciations are out of phase with the Carpentaria aridity record. Nevertheless, several of the Chilean peaks coincide with the ending of the last three Heinrich Events, thus suggesting that there may have been a controlling factor of glacial advances in the Chilean Andes even if they are not bordering the South Atlantic Ocean. The New Zealand glaciations coincide with the dry, and presumably cold, phases in northern Australia. Forces outside the North Atlantic Ocean will have to be sought to explain the ~2,600 year cyclicity of aridity in Australia.

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