Late Pleistocene record of cyclic eolian activity from tropical Australia suggesting the Younger Dryas is not an unusual climatic event

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ABSTRACT

In the Gulf of Carpentaria, northeastern Australia, 30 ka of lacustrine sedimentation provides a record of cyclic deposition of eolian dust (>60 μm) just preceding the Holocene. Adjacent layers containing eolian particles >60 μm in a core from Carpentaria relate to (perhaps intermittent) periods of eolian activity involving sediment deflation, and thus aridity, in northern Australia, each spanning at least 600 yr; major peaks of dust deposition occurred about every 2.25 ka. Such amplitude of cyclicity has already been recognized elsewhere on the globe for other phenomena, including waxing and waning of North American and European mountain glaciers, oxygen-isotope records from Greenland and Antarctic ice cores, changes in deep-sea benthic foraminiferal composition, oxygen-isotope records of deep-sea foraminifera, and atmospheric ^{14}C variations. We propose that the cold Younger Dryas event that affected the Northern Hemisphere is matched by a significant dry event in the tropical region of northern Australia and that the timing of this event fits well into the ~2.25 ka cyclic pattern described here. Thus, the Younger Dryas is a phenomenon of global significance and is not an "odd" event, contrary to current belief. In addition, we propose that activation of dunes in northeastern Australia, over periods of ~600 yr, corresponds to, perhaps intermittently, stronger easterly trade winds. During such periods the Intertropical Convergence Zone may not have extended as far south as it does today.

INTRODUCTION

Like northern Africa, Australia today is a very dry continent characterized by a substantial hydrological deficit (Gentilli, 1986). The large desert part of the Australian interior is covered by a vast array of dunes characterized by a series of linear ridges (Mabbutt, 1986). During the late Quaternary, the desert regions of the Australian interior expanded outward, and linear dunes migrated over regions such as northeastern Tasmania, Kangaroo Island, and southern Victoria, which are now much wetter (Sprigg, 1979; Bowler and Wasson, 1984).

Because there are few accurate dates of the arid episodes (as reflected by the mobility of dunes and expansion of the arid zones) that affected Australia, we investigated the record of deposition of eolian dust in the large Gulf of Carpentaria in the northeastern tropical part of Australia. Deposits containing airborne particles provide information on the response of arid regions to climatic changes and on major atmospheric patterns through the reconstruction of paleowinds. Already, several studies of deep-sea cores obtained from offshore western Africa (Sarnthein and Koopman, 1980; Sarnthein et al., 1981) have unraveled in broad terms the timing and amplitude of eolian activity over part of the African continent during the Quaternary.

During the late Quaternary sea-level lowstands, which extended at least 53 m below the present level, the Gulf of Carpentaria became isolated from the ocean, and a vast lake (2.9–7.1 × 10^4 km^2; Torgersen et al., 1988), referred to as Lake Carpentaria (Fig. 1), remained fresh to slightly saline from ~40 to ~10 ka before being transgressed by rising sea level (Torgersen et al., 1985, 1988; De Deckker et al., 1988; McCulloch et al., 1989). There is no evidence of the lake having dried up; therefore it is possible to date some of the major events of eolian activity in northern Australia thought to be synchronous with periods of glacial expansion in the Northern Hemisphere. For example, elsewhere in Australia, most sites underwent deflation (with a loss of sedimentation record) around 18 ka, when aridity was considered to be at its maximum (Bowler and Wasson, 1984), coinciding with the glacial maximum in the Northern Hemisphere in the mid to high latitudes.

MATERIAL

We studied a 2.1-m-long core (GC-2) (see Fig. 1) from the deepest part of this shallow (<10 m) lake, ~60 km from its shoreline, to minimize any possible collection of fluviatile sediment coarser than 60 μm. Pollen evidence (Torgersen et al., 1988) suggests that there is no contribution of sediment from Papua New Guinea. Grain size was measured by using a Horiba Capa-300 (Gippel, 1988). Only the fraction >60 μm in diameter is thought to have been airborne before reaching the core site. Such a grain size would also relate only to significant events of eolian activity (Coudé-Gaussen, 1989) in the region adjacent to the Gulf of Carpentaria.

Core GC-2 was selected from about 30 cores taken in the gulf because it contains all the lacustrine facies (Fig. 1B) in the least-condensed form recognized in most cores (Torgersen et al., 1988). This permitted study of a high-resolution sequence. Laminations are found in parts of the core (see Fig. 1B), and these confirm the absence of bioturbation for those levels. Several other studies of core GC-2 (calcareous microfossils: De Deckker et al., 1988; pollen analyses: Torgersen et al., 1988; trace elements and Sr isotopes: McCulloch et al., 1989; ostracodes and metals: Norman and De Deckker, 1990) all confirm that there has been no reworking or substantial bioturbation in the pre-Holocene part of the core. From the absence of pollen carried by the southern rivers of Papua New Guinea (which otherwise could have supplied coarse sediment), we have established that none of the rivers contributed significantly to the hydrological and sediment budgets of the lake (palynological data [from core GC-2 from Carpentaria] of Luly, *in* Torgersen et al., 1988) (see also the geochemical evidence in McCulloch et al., 1989). Carbonate material (mostly of biogenic origin) from seven levels was also dated by ^{14}C (see Fig. 1B), permitting dating of the individual (0.5 cm diameter) cylindrical samples (<1 cm^3 in volume) taken for grain-size analysis (most at 3 cm intervals) (Table 1). We have not made any correction for secular changes in atmospheric ^{14}C for the dates presented here. Remarkable consistencies in $\delta^{13}C$ values for carbonates within this core and others in Carpentaria (18 measurements varying between +0.05‰ and −0.5‰) confirm that the radiocarbon dates are reliable (data in Torgersen et al., 1988, and unpublished).

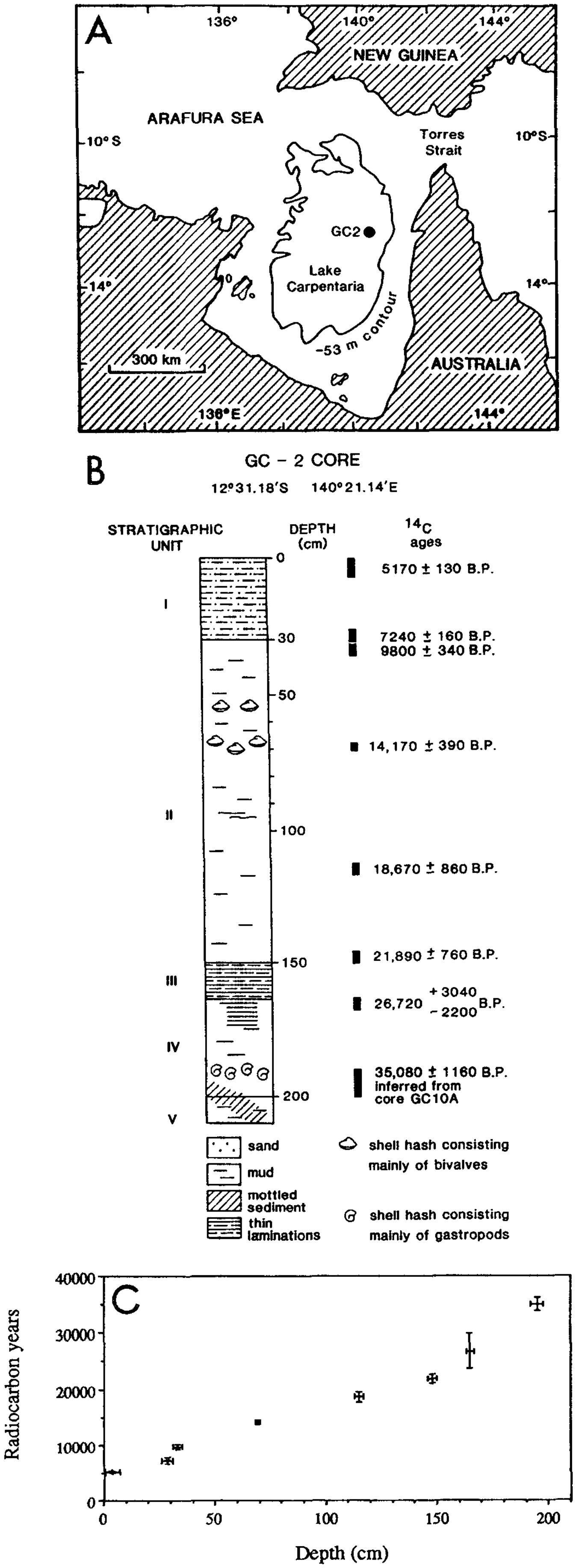

Figure 1. A: Extent of Lake Carpentaria during late Quaternary, when sea level was 53 m below that at present. Dot indicates location of core GC-2. B: Log of core GC-2 showing five recognized stratigraphic units (Torgersen et al., 1988; De Deckker et al., 1988), radiocarbon dates, and their position in core. C: Plot of radiocarbon dates for eight layers from core GC-2. Oldest date is extrapolated on facies equivalence with radiocarbon-dated layer from core GC-10A.

TABLE 1. GRAIN SIZES RECOVERED IN CORE GC-2, GULF OF CARPENTARIA

Depth (cm)	Age * (yr B.P.)	Sand (vol %)	Silt (vol %)	Clay (vol %)
1.0	4963	20.0	29.9	50.1
6.0	5378	33.5	37.3	29.2
9.0	5627	27.7	29.0	43.3
12.0	5876	14.4	38.1	47.5
15.0	6125	28.6	30.0	41.4
18.0	6374	25.6	30.2	44.2
21.0	6623	30.9	19.8	49.3
24.0	6872	18.0	23.1	58.9
27.0	7121	29.1	21.5	49.4
30.0	8094	26.5	18.4	55.1
33.0	9800	22.8	26.5	50.7
36.0	10115	0.0	30.1	69.9
39.0	10430	4.0	33.9	62.1
42.0	10745	8.7	21.0	70.3
44.5	11007	12.6	16.8	70.6
48.0	11375	12.6	17.0	70.4
51.0	11690	0.0	23.4	76.6
54.0	12005	0.0	35.9	64.1
57.0	12320	0.0	25.3	74.7
60.0	12635	0.0	23.2	76.8
63.0	12950	11.8	24.9	63.3
66.0	13265	0.0	27.9	72.1
68.5	13530	0.0	21.9	78.1
72.0	13895	0.0	2.9	97.1
75.0	14210	0.0	13.4	86.6
78.0	14525	0.0	11.4	88.6
81.0	14840	0.0	22.0	78.0
84.0	15155	0.0	15.2	84.8
87.0	15470	0.0	15.7	84.3
90.0	15785	6.6	22.1	71.3
93.0	16100	6.8	15.7	77.5
96.0	16415	0.0	15.4	84.6
100.0	16835	0.0	48.8	51.2
103.0	17150	0.0	21.6	78.4
106.0	17465	2.6	28.7	68.7
109.0	17780	31.0	15.1	53.9
112.0	18095	10.4	15.8	73.8
116.0	18515	0.0	19.2	80.8
120.0	18935	0.0	38.3	61.7
123.0	19250	0.0	0.0	100.0
126.0	19565	0.0	14.2	85.8
129.0	19880	8.1	13.4	78.5
132.0	20195	24.5	15.9	59.6
136.0	20615	6.0	8.2	85.8
139.0	20930	0.0	15.9	84.1
142.0	21245	0.0	14.8	85.2
145.0	21575	7.1	13.1	79.8
148.0	21890	0.0	24.2	75.8
151.0	22748	0.0	63.5	36.5
154.0	23606	0.6	65.0	34.4
157.0	24464	0.0	79.9	20.1
159.0	25036	4.1	66.6	29.3
162.0	25894	0.0	71.1	28.9
166.0	27038	0.0	48.2	51.8
169.0	27896	0.0	60.4	39.6
172.0	28754	0.0	44.5	55.5
176.0	29898	8.0	14.6	77.4
179.0	30756	9.1	31.3	59.6
182.0	31614	5.0	31.3	63.7
185.0	32472	10.0	22.7	67.3
188.0	33330	17.1	21.2	61.7
191.0	34188	10.0	41.7	48.3
194.0	35046	15.7	22.7	61.6
197.0	35904	0.0	39.2	60.8
200.0	36762	0.0	39.0	61.0
203.0	37620	0.0	37.6	62.4
206.0	38478	0.0	36.6	63.4

* Calculated ^{14}C ages (uncorrected) for each sediment depth analyzed for their grain size, based on the ^{14}C chronology obtained for core GC-2 (see dates in Fig. 1B).

RESULTS: THE DUST RECORD

All the samples containing particles >60 μm were recorded, and the percentage of this material compared to that of the other smaller grains for the 67 samples is presented in Figure 2 and Table 1. The fine-sand–sized grains are predominantly quartz with minor amounts of zircon, K-feldspar, and sphene. Minor amounts of siliceous diatoms were recorded, and each level with particles >60 μm was checked for any biogenic silica remains.

Using the ^{14}C chronology (Fig. 1B) and after consideration of the different sedimentation rates for the various parts of the core (Fig. 1C), we can assign an age to every sample analyzed. Times of peak deposition of sand-sized particles >60 μm can be well defined. Particles >60 μm in the core representing the first part of the Holocene are disregarded because they represent material reworked during the marine transgression (Torgersen et al., 1988; De Deckker et al., 1988).

Examination of Figures 2 and 3 indicates that the largest peak of dust occurs at 17.8 ka. This date coincides with the glacial maximum in the Northern Hemisphere and that of nearby Papua New Guinea glaciers (Hope, 1981). This date also corresponds to the maximum aridity event postulated for Australia (Bowler, 1978; Sprigg, 1979; Bowler and Wasson, 1984).

There are ten peaks of eolian dust in core GC-2. Plotted against time, it is evident that the first seven (11–25 ka) lie on a line (Fig. 3) and thus recur in a regular cycle every ~2.265 ka. Peaks 8–10 (27–35 ka) lie below this line, which we attribute to (1) the large uncertainties in assigning the 35 ka control date from nearby core GC-10A to core GC-2 (De Deckker et al., 1988) and (2) poor resolution of the peaks in the core because of lower sedimentation rates before 25 ka. These sources of uncertainty are greater than any effects of differential sediment compaction unaccounted for in a depth-age curve that can be constructed by using data in Figure 1B. Regression to all ten peaks gives an average recurrence interval of 2760 yr (r = 0.99), but we accept the above interval, ~2265 yr, for the cyclicity of the eolian dust peaks.

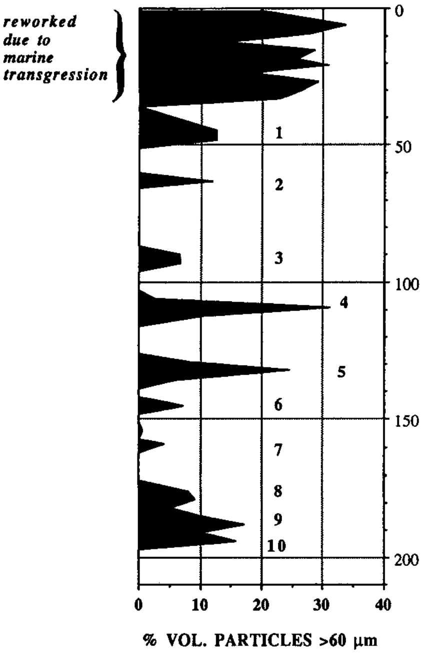

Figure 2. Percentages by volume of particles >60 μm recovered in 67 layers sampled in Carpentaria core GC-2. All major peaks are numbered and referred to as such in Figure 3. Upper seven peaks reflect higher sedimentation rates recorded in upper part of core. Note that upper part of core contains sand reworked during marine transgressive phase.

DISCUSSION

Several important conclusions can be drawn from the results presented above.

1. Eolian-dust activity over the Gulf of Carpentaria was cyclic between 35 and 10 ka. We adopt a 2.25 ka period from the best available data set.

2. The well-defined peak between 11,375 and 10,430 B.P. appears to have coincided with the Younger Dryas event, as recognized in the Northern Hemisphere (Berger and Labeyrie, 1987; Mangerud, 1987). This event represents a cold spell of ~1000 yr, matched by glacial readvance, and is equivalent to a period of aridity over northeastern Australia and glacial readvance in New Zealand (Chin, 1981; Salinger, 1990). This event also coincided with the arid interval found in the Levant (northern Negev and Judean Desert of Israel; Magaritz and Goodfriend, 1987). Such synchroneity suggests a worldwide phenomenon, so far only recognized in climatically sensitive areas (Magaritz and Goodfriend, 1987).

3. If we are correct in assuming that peak 1 coincided with the Younger Dryas event of the Northern Hemisphere, we can no longer assume that the Younger Dryas is an "odd" event in the sense of Berger and Labeyrie (1987, p. 13), Broecker et al. (1989), and Broecker and Denton (1990). Our peak 1 (synchronous with the Younger Dryas) appears to be part of a cycle of dry events in Australia and cooler events in the Northern Hemisphere.

4. The mechanisms causing the 2.25 ka cyclicity of these events remain unexplained; however, a cyclicity of the same order (2.5 ka) for other phenomena during the late Quaternary has already been recognized elsewhere. The phenomena include glacial advances in the Northern Hemisphere (Denton and Karlen, 1973), oxygen isotopic records from Greenland (Dansgaard et al., 1984) and Antarctic ice cores (Benoist et al., 1982), changes in deep-sea benthic foraminiferal composition (Pisias, 1983), oxygen isotopic records of deep-sea foraminifera (Pestiaux et al., 1988), and atmospheric ^{14}C variations (Suess, 1980).

5. The data permit calculation of the regression to the present. This allows correlation with cyclic events, also of about 2.25 ka, recognized by Holocene lake-level changes and δ^{18}O fluctuations in the Great Salt Lake, Utah (McKenzie and Eberli, 1987), events that lasted ~750 yr. Note that the two meltwater pulses (mwp-IA and mwp-IB) recognized by Fairbanks (1989) from δ^{18}O analyses of coral reefs drilled offshore Barbados are separated by an interval of 2535 (calendar) yr. There is also a cyclicity of 2.5 ka of lake-level changes in the Ziway-Shala basin (Ethiopia), documented by Gillespie et al. (1983).

6. The cycles of eolian-dust deposition do not necessarily represent periods of constant aridity over northern Australia. We believe that these cycles (as calculated from Table 1) represent substantial (but perhaps intermittent) periods of drought and dune reactivation that lasted an average of 600 yr and were separated by wetter periods lasting ~1500 yr. The drier periods are thought to represent the intensification of the eastern trade winds over northern Australia that would engender the transport of coarse eolian material over parts of northern Australia, including the Gulf of Carpentaria. This change in atmospheric circulation, in turn, would force the Intertropical Convergence Zone (ITCZ) to re-

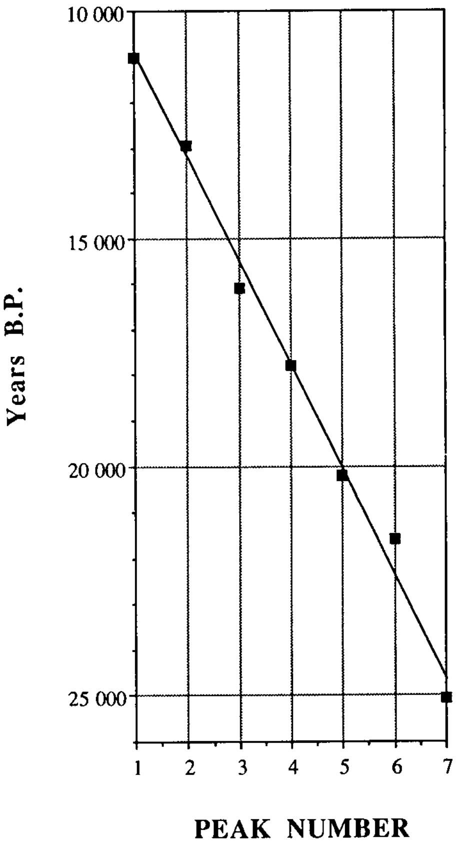

Figure 3. Regression line indicating average cyclic recurrence of 2.265 ka (y = −8744 − 2265x) for upper seven peaks from Carpentaria core GC-2.

main farther north (compared to today), implying a temporary failure of the monsoon over the Gulf of Carpentaria and an intensification of the Southern Oscillation over the Pacific region during the same time.

CONCLUSIONS

A high-resolution record of eolian activity has been recovered for the late Quaternary in Australia. That this is the first is explained by the fact that most lakes where such a record could be found were dry during arid events and thus commonly underwent deflation. Lake Carpentaria was sufficiently large so that any fluviatile sediment (>60 μm) brought into the lake would not reach its depocenter where core GC-2 was taken.

An accurate period for the cyclicity recognized at all the above-mentioned sites obviously cannot be determined within the limits of uncertainty of dating. Thus, at present, we can only assume a cyclicity of events of the order of >2 ka.

The causes and mechanisms for the >2 ka cyclicity recognized here and in other parts of the world remain unclear, although Anderson et al. (1990) discussed an ~2.4 ka cycle that may reflect changes in solar activity. Nevertheless, the >2 ka cyclic changes discussed here appear to be global in expression and affect the oceans, the atmosphere, and the cryosphere.

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Reviewer's comment

Important information about an important global climatic cycle.

Roger Y. Anderson
