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Rapid Communication

Redating the onset of burning at Lynch's Crater (North Queensland): implications for human settlement in Australia

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ABSTRACT: Lynch's Crater preserves a continuous, high-resolution record of environmental changes in north Queensland. This record suggests a marked increase in burning that appears to be independent of any known major climatic boundaries. This increase is accompanied, or closely followed, by the virtually complete replacement of rainforest by sclerophyll vegetation. The absence of any major climatic shift associated with this increase in fire frequency therefore has been interpreted as a result of early human impact in the area. The age for this increase in burning, on the basis of conventional radiocarbon dating, was previously thought to be approximately 38 000 ^{14}C yr BP, supporting the traditional model for human arrival in Australia at 40 000 ^{14}C yr BP Here we have applied a more rigorous pre-treatment and graphitisation procedure for radiocarbon dating samples from the Lynch's Crater sequence. These new dates suggest that the increase in fire frequency occurred at 45 000 ^{14}C yr BP, supporting the alternative view that human occupation of Australia occurred by at least 45 000–55 000 cal. yr BP. Copyright © 2001 John Wiley & Sons, Ltd.

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KEYWORDS: Radiocarbon dating; oxidation resistant elemental carbon; charcoal; environmental change; human impact; Australian archaeology.

Introduction

Human 'impact' has been invoked to explain significant changes in Australian landscapes during the late Pleistocene (Jones,1998). Such changes include megafaunal extinction (Flannery, 1990; Miller *et al.*, 1999; Roberts *et al.*, 2001) and modification of the Australian Summer Monsoon system by disruption of the vegetation cover through burning (Johnson *et al.*, 1999), although such views are fiercely contested (Bowman, 1998; Horton, 2000). A significant element of the debate concerns the actual timing of human arrival in Australia. The conventional radiocarbon chronology for Australian human colonisation suggests an arrival time of approximately 40 000 ^{14}C yr BP, as suggested from archaeological sites such as Upper Swan (Pearce and Barbetti, 1981), Carpenter's Gap (O'Connor, 1995) and Ngarrabullgan (David *et al.*, 1997) (Fig. 1). However, alternative dating techniques (such as luminescence and electron spin resonance) and recent developments in the pre-treatment and graphitisation of samples for radiocarbon dating, at Malakunanja II, Nauwalabilia I and Devil's Lair, have implied human arrival by 45 000–55 000 cal. yr BP (Fig. 1) (Roberts *et al.*, 1990, 1994, 1998; Turney *et al.*, 2001), and possibly as early as 56 000–68 000 cal. yr BP (e.g. Lake Mungo; Thorne *et al.*, 1999). This earlier age of arrival would be consistent with the timing of the loss of megafauna and disruption of the Australian Summer Monsoon (Johnson *et al.*, 1999; Miller *et al.*, 1999; Roberts *et al.*, 2001) being at least partly anthropogenic.

Lynch's Crater (17°37′S, 145°70′E) on the Atherton Tableland, north Queensland (Fig. 1) provides the main reference for late Quaternary environmental change in northeastern Australia, with one of the most complete environmental records of the last two glacial–interglacial cycles on the continent (Kershaw, 1974; 1976; 1978; 1986). The crater, which is of volcanic origin, contains at least 60 m of lake

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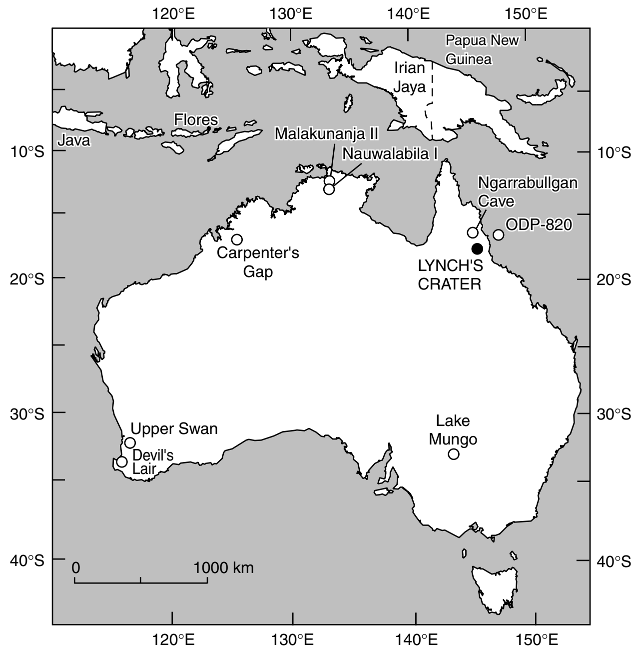

Figure 1 Location of Lynch's Crater and sites discussed in text

and peat sediments, and records sustained changes in taxon and community distributions as well as a significant increase in burning in the catchment (as recorded by high charcoal concentration), considered to result from Aboriginal activity in the area (Kershaw, 1986). The original chronology for the sequence was based upon 10 bulk radiocarbon ages derived from the uppermost 9 m of sediments. This chronology placed a major change in charcoal distribution at ca. 38 000 ^{14}C yr BP, which was very close to the presumed limit of the method at the time, but consistent with the traditional radiocarbon chronology for human arrival. Owing to the potential that such an age might be a minimum age, reflecting the 'radiocarbon barrier' of the time, a subsequent attempt was made to corroborate the result with an oxygen isotope and radiocarbon dated marine palynological record (ODP-820) from the continental slope adjacent to the Atherton Tableland (Fig. 1) (Moss and Kershaw, 2000). The results of this exercise suggested an age for the increase in charcoal of ca. 45 000 cal. yr BP, although the possibility of significant hiatuses in the ocean core made the correlation uncertain.

In an attempt to test these different age models, a rigorous redating and palaeoenvironmental programme was undertaken at Lynch's Crater, applying the latest developments in the pre-treatment and graphitisation of samples for radiocarbon dating. Here we present results relating to the timing of the onset of burning at Lynch's Crater and discuss the wider implications of this event with regard to environmental change and human arrival in Australia.

Methods

Little core material remained from the original work undertaken in the 1970s and it was therefore necessary to recore the site (as close as possible to the original coring locations). Coring was carried out using a modified Livingstone sampler in November 1998. Sections 1 m long were extracted and wrapped individually in the field and stored at 4 °C. A detailed lithostratigraphy, using a modified Troels-Smith system (Kershaw, 1997), was undertaken in the laboratory and a summarised version is shown in Fig. 2.

To aid comparison with the original chronology, organic carbon content was determined and pollen analysis undertaken at 10 cm intervals throughout the entire core. Carbon content was measured using an elemental analyser and all samples were acid washed with 10% HCl prior to measurement. For pollen analysis, 1 cm^3 samples were prepared using standard KOH and HF digestion and acetolysis, with the residue suspended in silicon oil. One hundred grains of dry land woody taxa formed the pollen sum on which percentages of major taxa groups were calculated.

The determination of charcoal concentration as an indicator of fire activity was undertaken using two techniques. The first method quantified the mass of chemically resistant charcoal (oxidation resistant elemental carbon or OREC) as described in detail by Bird and Gröcke (1997). The technique involves the sequential pre-treatment of samples with HCl, HF and NaOH followed by a $K_2Cr_2O_7/H_2SO_4$ oxidation at 60 °C. Samples were left in the oxidation stage for 72 h. Owing to the high organic carbon content of the sediments (up to 60% weight mass), samples subsequently were treated with a 1 : 1 mix of 6 M KOH and 32% H_2O_2 solution for a further 12 h (Bird and Gröcke, 1997). Carbon content was determined on the remaining material using an elemental analyser and the percentage OREC calculated by the difference between mass of sample prior and subsequent to treatment. The second method involved counting of charcoal particles greater than 10 μm maximum diameter within the prepared pollen samples and expressed as particles per cubic centimetre. A ratio of charcoal to pollen concentration also was calculated to account for possible variations in sedimentation rate.

The original radiocarbon chronology reported for the sequence was based upon untreated bulk organic peat and lake sediments. Here we applied two pre-treatment methods to paired samples selected for radiocarbon dating: an acid-base-wet oxidation followed by step-combustion (ABOX-SC; Bird *et al.*, 1999), and a conventional acid-base-acid pre-treatment followed by stepped combustion (ABA-SC) (Turney *et al.*, 2001). It was anticipated that the stringent ABOX-SC pre-treatment regime would eliminate virtually all contamination and provide reliable dating of this material to at least 50 000 ^{14}C yr BP (Bird *et al.*, 1999; Turney *et al.*, 2001). However, the scarcity of 'charcoal' in several of the Lynch's Crater samples (particularly below the depth marking the onset of sustained burning) has raised questions regarding the application of ABOX-SC to these lake or swamp sediments. Several of the 'ages' prepared by ABOX-SC were not in stratigraphical order (Turney *et al.*, 2001) and suggest contributions from younger, bacterial carbon to fine 'charcoal' that are resistant to the chemical pre-treatment and/stepped combustion method. The extent to which this phenomenon is significant appears to be sample specific, and probably is dependent upon the length of the wet oxidation step in the pre-treatment. We therefore have used the ages obtained from ABA-SC on bulk sediment samples, for the establishment of the most reliable chronology for Lynch's Crater (Turney *et al.*, 2001). Samples were wet sieved through mesh size 2 mm to remove extraneous root material and then sequentially pre-treated with HCl, HF, NaOH and HCl. Results from macroscopic charcoal have shown that consistent, reproducible ages can be obtained from the 850 °C combustion fraction, and that the lower temperature fractions may still contain younger contaminant carbon (Bird *et al.*, 1999). Therefore, graphite

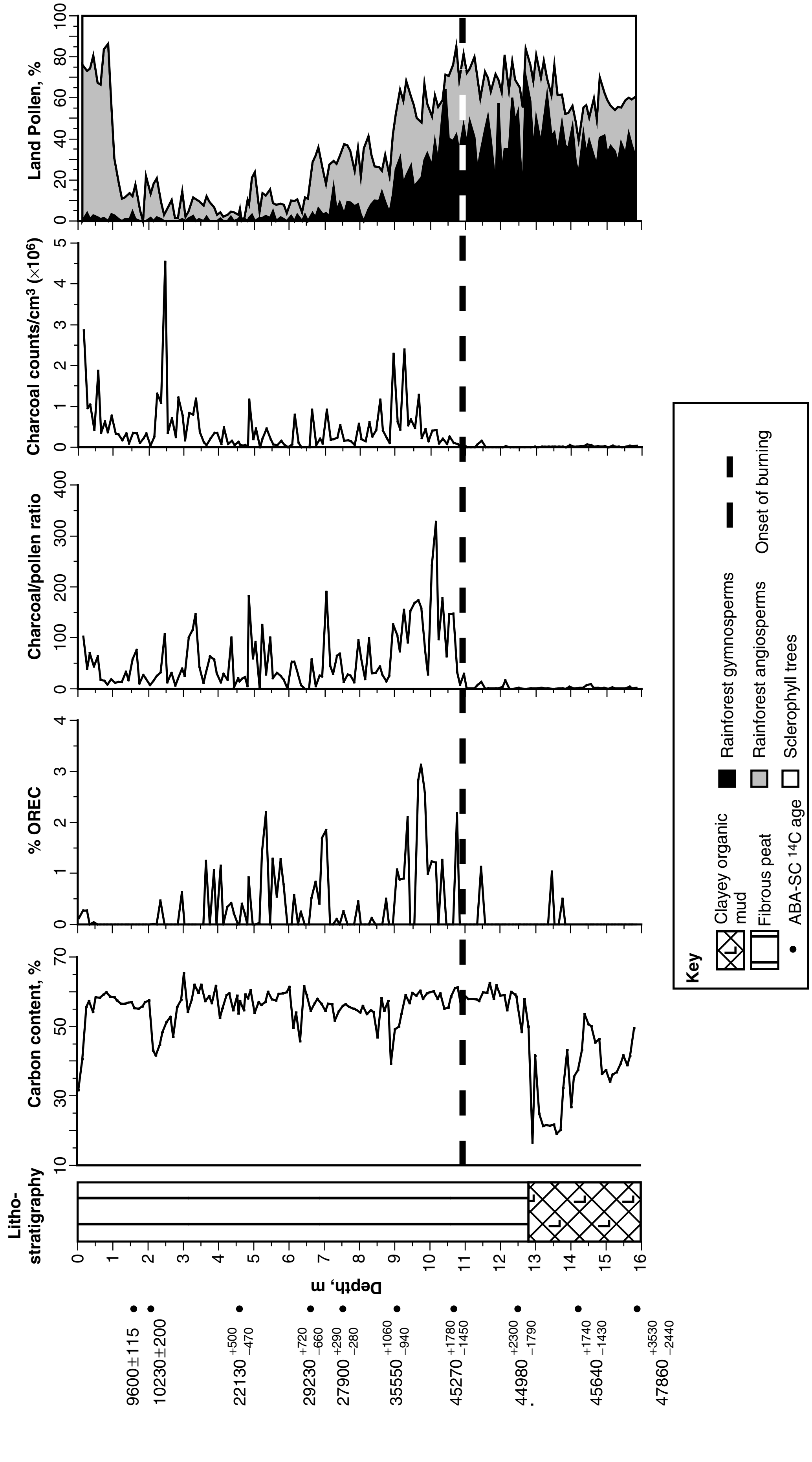

Figure 2 Lithostratigraphy, carbon content, OREC content, charcoal concentration, charcoal/pollen ratio and principle pollen taxa changes recorded in the uppermost 16 m of Lynch's Crater

Table 1 The ABA-SC ^{14}C ages obtained from Lynch's Crater. A $\delta^{13}C$ value of −25‰ is assumed

Depth, m	Laboratory code (ANUA-)	Uncorrected %M ($\pm 1\sigma$)	^{14}C yr BP ($\pm 1\sigma$)
1.55	15508	30.47 ± 0.43	9600 ± 115
2.05	11524	28.22 ± 0.69	$10\,230 \pm 200$
4.60	11523	6.56 ± 0.38	$22\,130 + 500 - 470$
6.75	11522	2.83 ± 0.22	$29\,230 + 720 - 660$
7.55	11509	3.30 ± 0.10	$27\,900 + 290 - 280$
8.95	11525	1.40 ± 0.14	$35\,550 + 1060 - 940$
10.85	14120	0.56 ± 0.05	$45\,270 + 1780 - 1450$
12.50	11520	0.57 ± 0.07	$44\,980 + 2300 - 1790$
14.45	15506	0.54 ± 0.04	$45\,640 + 1740 - 1430$
15.90	11519	0.46 ± 0.07	$47\,860 + 3530 - 2440$
20.00	12306	0.20 ± 0.06	'Background'

targets for accelerator mass spectrometry (AMS) were produced from the CO_2 evolved at the 850 °C step. The radiocarbon contents of the graphite targets were measured by AMS using the 14UD ANU accelerator in the Department of Nuclear Physics at the Australian National University (laboratory code ANUA-) (Table 1). In order to determine our ^{14}C backgrounds for this procedure, a sample from a depth of 20 m in the original core (considered to be '^{14}C dead') were processed in the same way as above. However, owing to the small sample sizes resulting from the pre-treatment method it was necessary to combine the CO_2 evolved at the 630 and 850 °C steps for graphitisation of the 20 m sample. The background determined is 0.2% Modern Carbon, equivalent to 50 000 yr BP (Table 1).

Results and discussion

There is a clear increase in fire activity at Lynch's Crater as recorded by the OREC, charcoal particle concentration and charcoal/pollen ratio at approximately 10.8 m. The values of OREC and charcoal/pollen ratios rise abruptly, whereas charcoal concentrations increase more gradually. A marked response in the pollen is recorded shortly after the charcoal increase, with a sustained decline in rainforest gymnosperms from 10.4 m and substantial replacement of the rainforest components by sclerophyll pollen by 9 m depth. This point corresponds with a peak in charcoal concentrations and the end of the phase of highest levels in OREC and charcoal/pollen values.

Around 6.5 m depth, the pollen values indicate that sclerophyll vegetation has almost totally replaced rainforest around Lynch's Crater, and gymnosperm-dominated araucarian rainforest had virtually disappeared. This pattern of burning and replacement of fire-sensitive rainforest by fire-tolerant sclerophyll vegetation is very similar to that recorded in the original pollen diagram and reinforces the interpretation of the change as being driven by a change in fire frequency (Kershaw, 1976, 1986). Such a change is unlikely to be climate driven. During the penultimate dry glaciation (MIS 6) such an overwhelming change from fire-sensitive to fire-promoting vegetation is not recorded, nor is there evidence of significant levels of burning (Kershaw, 1986). This change clearly occurs within the fibrous peat sediments, approximately 1.6 m above the transition from clayey organic lake muds, indicating the shift is not related to a change in depositional environment or indirectly to changes in water levels at the site or in the catchment. Also, the nature of the change associated with burning, in that it takes place over some 20 000 yr is very different from other abrupt major changes in the record for which a climatic mechanism is invoked. Small increases in charcoal accompany many of these other changes, suggesting a role of fire in facilitating the climatically controlled transition from one vegetation state to another (Kershaw, 1986).

The uppermost 11 m of peat sediments record a linear, relatively slow sedimentation rate (ca. 0.3 m kyr^{-1}) back to at least 45 000 ^{14}C yr BP. Below this depth to 16 m (approximately 48 000 ^{14}C yr BP), the sedimentation rate appears to be significantly more rapid, although the ages derived using ABA-SC are statistically indistinguishable, and therefore problematic to determine as an absolute rate. Nevertheless, the basal ages are statistically distinguishable from the background value of 0.2 pMC and therefore are real and provide a significantly older age estimate than previously obtained for the increase in burning (approximately 38 000 ^{14}C yr BP).

The calibration of radiocarbon ages at the limit of the radiocarbon time-scale is problematic. Few records exist with sufficient accuracy and precision beyond 40 000 ^{14}C yr BP to allow calibration. Preliminary data-sets from the Nordic Sea (Voelker *et al.*, 1998) suggest that the long-term offset between radiocarbon and calendar years during the period 40 000–50 000 ^{14}C yr BP generally is of the order of 1000–2000 yr. It therefore seems likely that the increase in burning could be a maximum of 47 000 cal. ^{14}C yr BP. Such an age is in excellent agreement with other ages that suggest human colonisation substantially earlier than 40 000 cal. yr BP. The newly determined age for this event in Lynch's Crater is statistically indistinguishable from the same event as recorded in ODP-820, which is based on an independently derived chronology, indicating that the onset of burning at this time is a regional signal (Moss and Kershaw, 2000). Single grain luminescence dating of the Malakunanja II sequence (Roberts *et al.*, 1998), multi-dating (including radiocarbon) of the Devil's Lair sequence (Turney *et al.*, 2001), and the extinction of the megafauna *Genyornis newtonii* (Miller *et al.*, 1999) and other species (Roberts *et al.*, 2001) point to age of arrival of approximately 45 000–55 000 cal. yr BP (although some studies suggest an even earlier arrival, e.g. Thorne *et al.*, 1999).

Conclusions

A new robust radiocarbon chronology has been developed for the uppermost 16 m of Lynch's Crater. At approximately 45 000 ^{14}C yr BP, a significant increase in burning is recorded in increases in the OREC content of the sediments and the ratio of charcoal particles to pollen grains. Such a shift is accompanied by a marked shift in the vegetation, with the almost complete replacement of rainforest angiosperms and gymnosperms by sclerophyll vegetation beginning about 45 000 and continuing to 28 000 ^{14}C yr BP, a period of generally stable climate. This new age for the initiation of substantial burning in the area is in strong agreement with other records of earlier human arrival and impact in Australia than believed previously.

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