The long and the short of it: Archaeological approaches to determining when humans first colonised Australia and New Guinea

Jim Allen[1] and James F. O'Connell[2]

But Scientists, who ought to know,
Assure us that they must be so …
Oh! Let us never, never doubt
What nobody is sure about!
(Hilaire Belloc, cited as a preface to *A Prehistory of Australia, New Guinea and Sahul* [(White and O'Connell 1982])

…our own guesstimate is that human presence in Sahul is likely to be no older than 50-70,000 years. …. at present it seems the best bet: even occupation as old as 50,000 years has not been demonstrated.
(*A Prehistory of Australia, New Guinea and Sahul* (White and O'Connell 1982:42)

Abstract

Despite significant advances in radiometric dating technologies over the last 15 years, and concerted efforts in that time to locate and date new sites and redate known sites in Australia and New Guinea, there is yet little consensus on when humans first arrived in the Pleistocene continent. A majority of scientists now agree people were present at least by 45,000 years ago, but many still argue for dates up to and beyond 60,000 years ago. The long chronology continues to be driven by the five well-known sites of Nauwalabila, Malakunanja, Huon Peninsula, Lake Mungo and Devil's Lair. This paper reviews the data which have appeared for these sites over the last decade. It argues that uncertainty over much of the earliest data stems from questions of artefact context and site taphonomy rather than dating technologies. The problem is an archaeological one which has received insufficient attention.

Introduction

As a bet, Peter White was having a bit each way, but if *A Prehistory of Australia, New Guinea and Sahul* were revised today, even an editor with the critical acumen that White has brought to 23 years of journal editorship would likely force no change to this conclusion. Twenty-one years after this book disturbed the Canberra hegemony, scientists-who-ought-to-know still contest the date when humans first colonised Australia and New Guinea. While the physicists who do the dating seem mostly content with a chronology of ca. 60 ka (ka = 1,000 years B.P.; ky = 1,000 years) or beyond, archaeologists remain divided. In a recent straw poll 45 academic and museum archaeologists were asked to nominate the likely age of initial colonisation to the nearest 5000 year interval. Of 34 responses, estimates ranged between 35 ka and 100 ka. Ten people nominated 45 ka and a further ten 10 opted for 50 ka; eight preferred ages >50 ka and six supported ages <45 ka. Two of the non-respondents had previously published their support for 60 ka; including these, fewer than 28% favour a colonising date beyond 50 ka.

The difference between archaeologists and physicists on this matter can be viewed in different ways. A decade ago, the debate centred on a short chronology of ca. 40 ka versus a long chronology of ca. 60 ka, so at one level the gap between the two can now be seen to have narrowed. This is partly to do with improved techniques that now provide finite ^{14}C dates well beyond 40 ka (Bird et al. 1999), and partly to do with the wider application of other, particularly luminescence, techniques (Roberts 1997). Some archaeologists have been persuaded by the oldest claims, but more are happy that a number of claims beyond 40 ka are now substantiated, and some of both groups are willing to allow additional millennia for undiscovered older sites and the 'invisibility' of initial small populations of colonists. On the other hand, a difference of 10-15 millennia remains significant, not just for Australianists, but also for a global audience concerned with dating the ex-African spread of modern humans in general (e.g. Eswaran 2002; Klein 1995; McBrearty and Brooks 2000; Eswaran 2002).

Currently, the majority of views are accommodated within this 45-60 ka window. In recent years, support for older initial colonisation on archaeological grounds has appeared only rarely. Original claims for an age of ca. 116-176 ka for the Kimberley site of Jinmium (Fullagar et al. 1996) are now discounted as much younger (Roberts, Bird et al. 1998). Suggestions of older human colonisations from other Quaternary sciences still occasionally appear. Most recently, an increase in charcoal particles and an increase in grass pollen relative to *Eucalyptus* pollen in a tropical marine core collected between the Lesser Sunda Islands and northwestern Australia, and dated to ca. 185-200 ka, have been given an anthropogenic explanation (Wang et al. 1999). Jackson (1999) has used similar evidence to suggest human arrival in Tasmania ca. 130 ka. However, an increasing understanding of the El Niño-Southern Oscillation and other cyclical climatic events during the last 300 ka is now providing alternative natural explanations for such data (e.g., Haberle and Ledru 2001; Kershaw et al. in press).

The dating debate during the 1990s was frequently too narrowly focussed on techniques - a choice between radiocarbon and luminescence, the detection limits of radiocarbon and discussions about sample contamination. At one level such discussions were necessary, but at another they missed the fundamental point that establishing the time of initial colonisation was never just a question of dating technology, but was always primarily an archaeological problem. The foremost requirement for radiometrically dating any site, anywhere, is that dating samples relate directly to the human activity they purport to date. In our view too little attention has been given to the many taphonomic considerations surrounding early sites on this continent, especially in the vast arid and semi-arid sand regions.

Despite the reporting of new sites and widespread redating programs, all five sites in Australia and New

1 Department of Archaeology, La Trobe University, Bundoora, Victoria 3083, Australia. E-mail: jjallen@sci.net.au

2 Department of Anthropology, University of Utah, Salt Lake City, Utah, USA. E-mail: james.oconnell@csbs.utah.edu

Guinea where antiquities are currently claimed beyond 45 ka, are sites reported a decade ago by Smith and Sharp (1993). Three of them, Malakunanja, Nauwalabila and Fortification (a.k.a. Bobongara) Point on the Huon Peninsula, were the oldest sites listed then. The other two are Lake Mungo and Devil's Lair. All five have had at least some new chronological data published for them since 1993, and three have had substantial re-analysis. The implications of these new data for the likely date of initial colonisation now warrant further archaeological assessment.

In this review we do not pursue the advantages or limitations of different dating techniques or comparisons between them, except where these have been raised in discussion by other authors, nor do we enter into the separate question of the reliability of dating laboratories (Anderson 1998, 2000; Boaretto et al. 2003). The ^{14}C dates we cite are mostly uncalibrated because some have only been published this way, while elsewhere different calibrations may have been used. For example, Bowler (1998) adds between 3 ky and 5 ky to uncalibrated dates from the Willandra Lakes on the basis of comparisons between ^{14}C and U-Th dates published by Bard et al. (1990, 1993), using a formula devised by Miller et al. (1997), while Bird et al. (2002) use the Calib 4.1 program (Stuiver and Reimer 1993), the calibration set of Stuiver et al. (1998) for dates less than 22 ka, and an average of the calibration curves of Volker et al. (1998) and Kitagawa and van der Plicht (1998) for dates beyond 22 ka. Thus, we may refer, without further comment, to differently calibrated ages or age ranges so as to fairly represent authors cited. Readers wishing to pursue these matters will need to should return to the original sources. In general terms, calibrations for radiocarbon dates >30 ka remain uncertain. Recent syntheses by Beck et al. (2001) and Turney and Bird (2002) suggest that ^{14}C dates in the 30-40 ka range may fall short of calendar ages by as much as 7 ky, and those in the 40-50 ka range by 1-2 ky. Radiocarbon dates are cited at one standard deviation unless otherwise identified, and thermoluminescence (TL) and optically-stimulated luminescence (OSL) dates are given with the total uncertainty (Roberts et al. 1990b).

The Huon Peninsula

The Huon Peninsula is on the northern coast of Papua New Guinea. At Bobongara Point, it comprises a series of seven raised coral terraces, of which the uppermost is now ca. 400 m above sea level. Each coral terrace, some of which are hundreds of metres wide, was formed when glacio-eustatic rises of sea level overtook land, itself subjected to continual tectonic uplift. The unnamed excavated site is adjacent to an ephemeral stream called Jo's Creek. It is located within a more extensive area of surface finds of flaked stone artefacts, and more than 100 waisted and grooved flaked axes, regularly >20 cm long and frequently weighing >1 kg.

a) Tephras and terraces

Artefacts were found in the creek bed, cutting across terrace IIIa and the higher and older terrace IVb. A series of three tephras was trapped in the depression behind terrace IIIa and on the lower front to the rise to the older terrace IVb. Neither tephras nor artefacts were found on the younger, lower terraces, beginning with IIIb. This is taken to indicate that these terraces were yet to emerge from the sea when the artefacts and tephras were deposited. The ages for terraces IIIa and IIIb thus provide a general age range for the artefacts, if the reconstructed depositional events are accurate. Under these conditions, the artefacts are not younger than 44.5 ± 0.7 ka and not older than the oldest of several dates from terrace IIIa, 61.4 ± 0.6 ka (Chappell et al. 1996: Table 1; Chappell 2002: Table 1). These U-series dates are newer than those published in Groube et al. (1986) and increase the terrace ages cited there by ~10%.

b) Archaeology and dating the tephras

Excavations consisted of cleaning back a vertical section of creek bank, ca. 30 m long and cutting a trench ca. 10 m long at right-angles to the creek section (calculated from Groube et al. 1986: Fig. 2). The three superimposed tephras, with T1 the youngest and T3 the oldest, sit above bedded tuff and reef limestone. Artefacts were recovered from four findspots within the tephras. Findspots 1-3 each produced a single waisted axe, while a core and two flakes were recovered from findspot 4. Findspots 1 and 2 occur at the intersection of T3 and T2, findspot 4 is within T2 and findspot 3 is in the upper part of T1.

Tephra Unit	Minimum age (ka)	Maximum age (ka)
T1	31.3	42.1
T2	37.1	60.5
T3	36.2	59.8

Table 1 Huon Peninsula TL dates for tephras after Groube et al. (1986).

TL dates were obtained by Groube et al. (1986) for each of the three tephras (Table 1). There are uncertainties in the dose rate, and especially the concentrations of potassium, which may have been leached from the tephras. These, and assumptions about water content, are discussed by Groube et al. (1986:454) and Roberts (1997:867-68). Because the maximum ages were calculated using the measured potassium concentration, considered to be too low at 0.05-0.11%, these maxima are likely overestimates. The minimum ages were calculated using an assumed K_2O of 1.2%, which is the average for nearby Bismarck volcanics, but which is 'almost certainly' greater than the average value over the history of the tephras; thus the minima are likely underestimates. In addition, these ages were calculated assuming a zero water content in the tephras, itself an improbable assumption, which would act to reduce these ages. Groube et al. (1986) thus assumed a minimum age for these tephras, and the artefacts contained in them, of 40 ka.

Roberts (1997:868) recalculated a minimum age of ~47 ka using the assumed K_2O figure and a water content of 25%, using the figures provided by Groube et al. (1986). Roberts concluded that the lowest artefacts dated to between this age and ca. 61 ka (the oldest possible age for terrace IIIa), but did not discuss the basis for choosing a 25% water content.

Groube et al. (1986) remained cautious about post-depositional taphonomic events at the site. The cleaned section is steeply sloping (falling ca. 2 m for each ca. 3 m of horizontal distance) and the excavators identified slope wash and redeposition after each tephra fall as well as downslope creep. They also allowed that the absence of tephras on the younger terraces could indicate subsequent stripping.

However, the axe at findspot 2 was in several pieces, apparently buried 'after breakage with little subsequent displacement' (Groube et al. 1986:454). While both tephras and artefacts may have moved since initial deposition, the tephras were distinguishable from each other, and the excavated artefacts were clearly contained within them.

c) Conclusion

Unless these artefacts were discarded on an ancient tephra and then buried by an equally ancient redistributed tephra, the several lines of evidence reviewed here suggest that the Huon artefacts may date to more than 44 ka. Establishing a higher limit to this minimum age or indeed any meaningful maximum age less than the 61 ka limit imposed by the formation of the IIIa terrace, involves assumptions so far not justified.

Devil's Lair

Devil's Lair is a large limestone cave in the southwest of Western Australia. Central to claims for early occupation at this site are issues of stratigraphy, taphonomy and artefact distributions.

a) Stratigraphy and dating

The most recent dating program (Turney et al. 2001) has produced a coherent pattern of radiocarbon determinations, generally supported by related OSL dates. Turney et al. confine themselves to the new dating results and comparisons with earlier radiocarbon dating, clearly demonstrating the effectiveness of the ABOX-SC pretreatment for removing younger contaminants. They do not deal in any detail with the archaeological issues raised here, which are the subject of a forthcoming paper by the site's excavator, Charlie Dortch, and colleagues. Our summary draws freely upon an extensive, open and generous correspondence with Dortch over the last two years, in addition to earlier published accounts.

Table 2 lists the stratigraphic layers and related new dates relevant to this discussion. We include the electron spin resonance (ESR) dates although these are largely discounted in the discussion (Turney et al. 2001:11).

The lowest claimed *in situ* human feature in the Devil's Lair excavations is a series of four nested hearths referred to by Dortch and Dortch (1996:30) as the *hearth complex in layers 27-30 Upper*. The hearths in layer 27 and layer 30 Upper are described as much smaller than the layer 28 hearth and Porter's Hearth, sandwiched between the layer 28 hearth and layer 29, but not attributed to either layer. It is difficult to determine from which layer each of these hearths was initiated, since the uppermost and lowest hearths do not appear on any section drawing. It is unclear whether the hearth in layer 30 Upper is cut into layer 30 or contained in it. Working from the section drawing of the south face of the main excavation (Dortch 1984:27), it is possible that the upper three hearths may all have been initiated from layer 27.

At two standard deviations the radiocarbon age of the layer 28 hearth is 39.08 - 44.26 ka, which is supported by the OSL dates of 41.2 - 45.6 ka and 42.3 - 46.5 ka. When the radiocarbon date is calibrated, human occupation in Devil's Lair dates to beyond 40 ka and may be as old as ca. 46 ka.

Layer	Depth (cm)	ABOX-SC (ka)	OSL (ka)	ESR (ka)
27	329-334			42±3 - 52±4
				44±3 - 59±4
28	334-336	41.46+1.4,-1.19	43.4±2.2	
			44.4±2.1	
29	336-341			
30 Upper	341-355			
30 Lower	355-380	45.47+1.42,-1.21		
31	380-390			
32	390-395		47.1±2.6	
33	395-418	46.73+2.19,-1.72		
34-38	418-458			
39	458-530	48.13+2.59,-1.96	51.1±2.6	64±7 - 85±10
		>52.0		75±7 - 88±9

Table 2 Stratigraphy and current dating of the lowest artefact-bearing levels in Devils Lair; see text for wider discussion. The depths given here are approximate and derived from the section drawing of the east face of Trench 9, the one used by Turney et al. (2001) but better illustrated in Dortch (1984:26). The ^{14}C date for Layer 30 Lower is listed only as Layer 30 by Turney et al. (2001: table 1) but is ascribed here to Layer 30 Lower on the given depth of this sample (365 cm) and subsequently confirmed by Dortch (pers. comm.). Two ESR samples were processed for both Layer 27 and Layer 39 and results presented using both early uptake and linear uptake models. In each case the younger ages were produced using the EU model.

b) Deposits below layer 30 Upper

Claims for older human artefacts found deeper in the sequence remain problematic. Below 30 Upper and a discontinuous layer labelled 30 Middle, layer 30 Lower is a thick (25-30 cm) fan of inwashed soils, distinctly different from the brown sandy sediments comprising the layers above it. At two standard deviations it is dated between 43.05 ka and 48.31 ka. Below it, layers 31-38 reflect episodes of heavy erosion, marked by numerous erosion channels and convoluted scouring features. The matrix contains large amounts of limestone rubble and boulders, weathered to sub-rounded and sub-angular forms typical of entrance debris. Layers 28 to 30 Upper are also eroded in places, but not to the extent of layers 31-38. Layers 39-51 are devoid of any indications of human presence.

Stone artefact numbers for layers 31-38 have differed through time as examinations of them have continued. In 1984 Dortch (1984:56) claimed 14, with another 'half dozen' probables. Turney et al. (2001:5) claimed six artefacts, one each in layers 32-35, 37 and 38. Most recently Dortch (unpublished data) claims seven, including two halves of a limestone, probable root, concretion thought to have been used as a hammerstone. He now places the lowest artefact in layer 37.

Layer	Artefacts
19-27	55
28	34
29	14
30 Upper	8
30 Lower	0
31-38	7

Table 3 Stone artefacts from the lower levels of Devils Lair. Data from Dortch and Dortch (1996:31) and C. Dortch (pers. comm.).

Table 3 lists stone artefact numbers from the lower part of the site. It is possible that the artefacts in layers 29 and 30 Upper derive 'from small pits dug into these layers from layer 28' (Dortch 1984:56), but they may also reflect the first sporadic use of the cave. Turney et al. (2001:11) and Dortch (pers. comm.) accept that any artefacts in layers 31-38 are probably not in positions of primary deposition. Dortch offers several reasons why these artefacts have not filtered down from occupation layers above, including 1) that the thick layer 30 Lower is sterile, apart from a possible bone point within it, and thus forms an effective barrier; and 2) that four of the seven artefacts are made on calcrete while only two calcrete flakes occur among the layers 18-30 Upper artefacts, and that in those levels 126 of a totalout of 135 artefacts are quartz, whereas in layers 31-38 there are only two possible quartz artefacts. Instead, Dortch favours the idea that the artefacts were washed into these layers from older or contemporaneous deposits elsewhere in the cave or from sediments outside the now-blocked cave entrance. In support of this, Dortch points to the small but persistent presence in layers 31-38 of charred bone and bones with a distinctive carbonate cement coating.

Clearly, if these artefacts were inwashed from elsewhere, rather than having moved down the profile from above, they are overlain stratigraphically by layer 30 Lower, dated at two standard deviations to between 43.05 ka and 48.31 ka, and must be at least this old.

c) Continuing uncertainties for the lower deposits

Our uncertainty about age claims for Devil's Lair beyond ca. 42-45 ka rests on the following points.

The extreme turbidity associated with the formation and reformation of layers between 30 Upper and 39 is poorly understood. These layers reflect an apparently rapid distribution of large volumes of sediment, possibly associated with the formation of a new cave entrance and significant water flow, and/or the redistribution of materials from elsewhere in the cave, again presumably under the impetus of water. Site formation processes below layer 30 Upper require greater explication than is available from the excavation trenches so far opened. The notion that artefacts in layers 31-38 might derive from outside the now-blocked cave entrance is not supported by the excavations outside this entrance. These produced evidence of human occupation back only to 19.7 ± 0.4 ka (Dortch 1984:47).

Resolution is required on what are or are not artefacts in layers 31-38. This is currently under review by the excavator and colleagues. Six or seven artefacts scattered through 80 cm of disturbed and redeposited layers is a slender basis for the claims of great antiquity currently being made. While charred animal bones are present in small numbers in layers 31-38, they also occur, albeit more rarely and as fragments, in the earlier pre-human layers. This point is also under review. Charred bone is, in Dortch's words, 'not unequivocally associated with human activities.' Similarly, bones with distinctive carbonate cement coating are not found exclusively in layers below 30 Lower, occasionally occurring as high as layer 16 (Dortch 1984:18). Whether these bones were also washed in or worked upwards is unclear, although Dortch favours the former.

As discussed more fully for Nauwalabila, the displacement of a small number of artefacts over the distances involved here, and through seemingly unbroken stratigraphic layers remains possible, perhaps especially in a site which was wet at various times in its occupational history. The sample size is too small to test the proposed raw material differences statistically, and various idiosyncratic explanations could be adduced to explain the material grouping of these seven items.

d) Conclusion

While these reservations are not fatal to the claims of antiquity being made for Devil's Lair, they remain important points to be resolved. Excavations at the site much nearer the putative former entrance would likely clarify many of these issues. The newer dates from Devil''s Lair confirm human antiquity beyond 40 ka but claims beyond 45 ka are equivocal.

Lake Mungo and the Willandra region

Lake Mungo is one of 13 interconnected dry lake basins on the lower reaches of the Willandra Billabong Creek in western New South Wales. This area has been a focus of attention from geomorphologists and archaeologists since the late 1960s (Allen 1998; Bowler et al. 1970; Allen 1998). The Willandra archaeological record is rich by Pleistocene Australian standards: more than 300 sites have been identified, of which 20 or so have been given serious attention (Johnston and Clark 1998). Chronological data for the region are provided by well over one hundred radiocarbon, luminescence, U-series and ESR dates (Oyston 1996; Bowler 1998; Gillespie 1997, 1998, 2002; Bowler 1998; Bowler and Magee 2000; Bowler and Price 1998; Simpson and Grün 1998; Thorne et al. 1999; Bowler and Magee 2000; Bowler et al. 2003; Gillespie 1997, 1998, 2002; Gillespie and Roberts 2000; Grün et al. 2000; Bowler et al. 2003 Oyston 1996; Simpson and Grün 1998; Thorne et al. 1999).

Comprehensive review of this large body of information is hampered by incomplete publication of palaeo-environmental and archaeological data and uncertainty about the validity of many age determinations and their relationship with the general sedimentary sequence. For this reason, our discussion focusses on the two most fully reported data sets, those from the ca. 30 ka to 60 ka deposits in the Mungo and Arumpo Basins.

a) Deposits

Bowler (1998:125-26) divides the Mungo Unit deposits into two groups: the *Lower Mungo phase* (hereafter LM) components, defined in lake-bordering lunettes by a predominance of quartz sands, indicating relatively high lake levels; and the *Upper Mungo phase* (UM) components, marked by pelletal clay sands, indicating fluctuating, generally low lake levels (Fig. 1). At least six, possibly seven, calcareous soils are identified in LM components of the

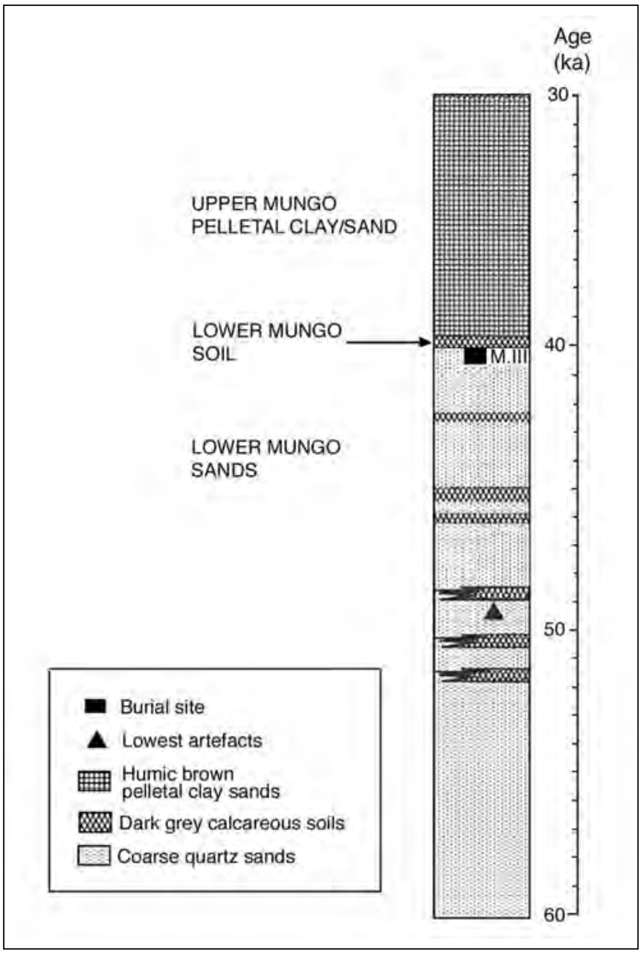

Figure 1 Simplified summary of mid-Upper Pleistocene stratigraphy at Joulni (Willandra Lakes site WOC-1), modified from Bowler et al. (2003). Note that the M-III burial and lowest artefacts were located several hundred metres apart.

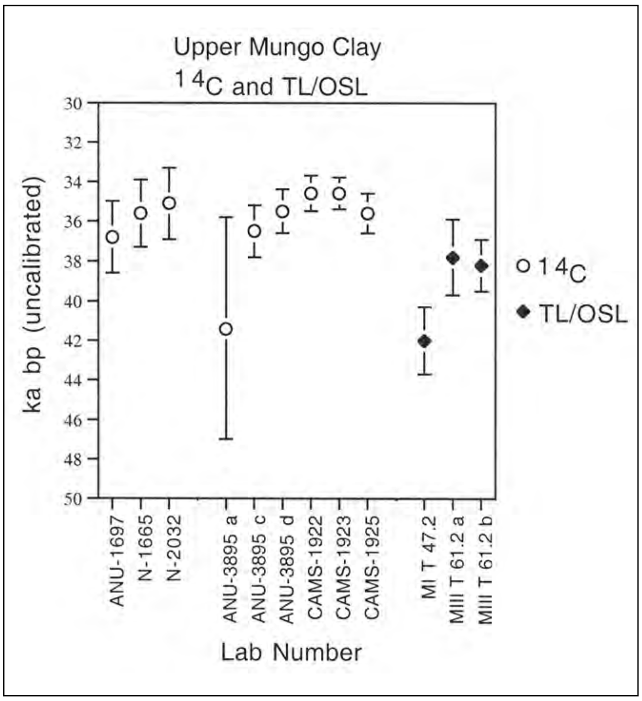

Figure 2 Selected ^{14}C, TL and OSL dates from the Upper Mungo clay/sand (data from Table 4). ^{14}C dates are uncalibrated.

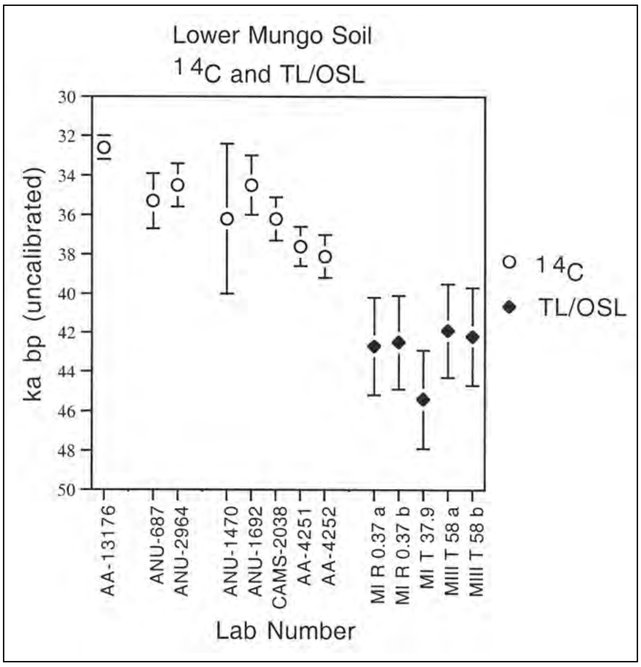

Figure 3 Selected ^{14}C, TL and OSL dates from the Lower Mungo soil (data from Table 4). ^{14}C dates are uncalibrated.

Mungo lunette, each reflecting some combination of regional drying, absence of sediment supply, and plant colonisation. The upper boundary of the LM phase is defined either by a particularly well-developed soil, sometimes called the Lower Mungo soil (hereafter LM soil), or by a sharp contact between LM quartz sands and UM pelletal clays, indicating that the LM soil has been removed by erosion. Wüstenquartz, silt-sized quartz with red clay skins that is an indicator of arid conditions west of the Willandra area, is present in small amounts intermittently through LM times, becoming much more common in the UM phase. Sediments in Arumpo basin display a similar sequence.

b) Dates

Chronometric control is provided by radiocarbon and luminescence data from six localities: the Joulni, Barbetti and Tourist sites on the Mungo lunette, Top Hut 1 and 3 on the Arumpo lunette, and Long Water Hole Gully on the Arumpo playa (Table 4). Some of these data are problematic. Gillespie's (1997, 1998) reviews of the radiocarbon record indicate frequent uncertainty about the nature of materials being dated, widespread humic acid contamination, and inconsistent, often inadequate sample pre-treatment. His rejection of 67 dates, from a total of 155 that he evaluated, shows the scale of the problem. As Bowler and others observe (e.g., Bowler and Price 1998; Gillespie and Roberts 2000), luminescence dates are open to question because of local differences in dose rate and degree of peri-depositional bleaching. Relationships between dates and key sedimentary features are also sometimes uncertain, especially where dates are published without adequate description of depositional context. Caution in the interpretations of all these data is definitely well advised.

Twenty-one dates for the UM phase range from 16 ka to 42 ka. Of these, nine ^{14}C dates on shell and charcoal are in excess of 34 ka (Fig. 2). Eight ^{14}C determinations are close to each other in age, overlapping at one standard deviation at

Location	Lab No.	^{14}C (ka)	TL/OSL (ka)	Material	Reference	Comment
Joulni site (WOC-1)	ANU-375A	20.3±0.3		Soil carbonate	Bowler et al. 1972	Hearth in LM soil, near locality M-I.
	ANU-375B	26.3±1.1		Charcoal	Bowler et al. 1972	Hearth in LM soil, near locality M-I.
	AA-13176	32.6±0.6		Otolith	Bowler 1998	LM soil, near M-I.
	W1801 a		48.6±8.2	LM sand	Bowler & Price 1998	TL samples collected near M-I, arrayed in stratigraphic order.
	W1801 b		47.4±7.9	LM sand	Bowler & Price 1998	
	W1971 a		50.3±9.3	LM sand	Bowler & Price 1998	
	W1971 b		49.0±8.9	LM sand	Bowler & Price 1998	
	W1802 a		44.0±6.3	LM sand	Bowler & Price 1998	
	W1802 b		44.7±6.4	LM sand	Bowler & Price 1998	
	W1803 a		34.0±4.8	LM sand	Bowler & Price 1998	
	W1803 b		35.3±5.0	LM sand	Bowler & Price 1998	
	W1804 a		57.8±10.4	LM sand	Bowler & Price 1998	
	W1804 b		64.1±12.4	LM sand	Bowler & Price 1998	
	W1805 a		40.3±5.4	LM sand	Bowler & Price 1998	
	W1805 b		43.2±5.9	LM sand	Bowler & Price 1998	
	W1806 a		48.6±6.0	LM sand	Bowler & Price 1998	
	W1806 b		51.3±6.4	LM sand	Bowler & Price 1998	
	M-I T 47.2		42.0±1.7	UM clay/sand	Bowler et al. 2003	OSL samples collected near M-I, arrayed in stratigraphic order.
	M-I R 0.37a		42.7±2.5	LM soil	Bowler et al. 2003	
	M-I R 0.37b		42.5±2.4	LM soil	Bowler et al. 2003	
	M-I T 37.9		45.4±2.5	LM soil	Bowler et al. 2003	
	M-I R 0.0		46.6±2.3	LM sand	Bowler et al. 2003	
	M-I T 35.2		44.9±2.4	LM sand	Bowler et al. 2003	
	MB T 1.6		50.1±2.4	LM sand	Bowler et al. 2003	
	MB T 1.95		49.1±2.7	LM sand	Bowler et al. 2003	
	MB T 2.4 a		47.9±2.4	LM sand	Bowler et al. 2003	
	MB T 2.4 b		45.7±2.3	LM sand	Bowler et al. 2003	
	M-I T 20.2		44.8±3.1	LM sand	Bowler et al. 2003	
	MB T 2.85		52.4±3.1	LM sand	Bowler et al. 2003	
	M-III T 61.2 a		37.8±1.9	UM clay/sand	Bowler et al. 2003	TL and OSL samples collected near M-III, arrayed in stratigraphic order.
	M-III T 61.2 b		38.2±1.3	UM clay/sand	Bowler et al. 2003	
	M-III T 58 a		41.9±2.4	LM soil	Bowler et al. 2003	
	M-III T 58 b		42.2±2.5	LM soil	Bowler et al. 2003	
	J3 a		43.3±3.8	LM sand	Oyston 1996	
	J3 b		43.1±6.7	LM sand	Oyston 1996	
	W1799		41.4±6.7	LM sand	Bowler & Price 1998	
	M-III T 56.4		48.1±3.2	LM sand	Bowler et al. 2003	
	M-III T 47.8		49.3±3.1	LM sand	Bowler et al. 2003	
	M-III T 36.3/35		42.1±1.7	LM sand	Bowler et al. 2003	
	M-III T 36/68		49.2±2.1	LM sand	Bowler et al. 2003	
	M-III T 29.4		42.8±3.1	LM sand	Bowler et al. 2003	
	M-III T 21/35		51.8±2.4	LM sand	Bowler et al. 2003	
	M-III T 21/80		62.2±1.8	LM sand	Bowler et al. 2003	
Barbetti site (WOC-3)	nnc/a		16.4±0.2	UM clay/sand	Bowler & Price 1998	^{14}C dates pertain to a hearth in UM clay/sand; Readhead's TL sample is from the same feature; Bowler's and Price's sample is from slightly higher in the same component. Bowler (1998: 126, fig. 4) puts both dates in the LM soil.
	ANU-680	30.8±0.5		Charcoal	Barbetti 1973	
	ANU-681	28.3±0.4		Charcoal	Barbetti 1973	
	ANU-682	27.5±0.3		Charcoal	Barbetti 1973	
	nnc/b		29.3±3.2	UM clay/sand	Readhead 1988	
Tourist site (WOC-4)	ANU-687	35.3±1.4		Charcoal	Barbetti 1973	
	ANU-2964	34.5±1.1		Charcoal	Clark 1987	
Top Hut 1	ANU-1470	36.2±3.8		Shell	Clark 1987	Bowler (1998:134, fig. 13) says the two AA dates are from just below the LM soil; others may be from the same context. Charcoal dates fall short of those on shell, and are rejected as contaminated.
	ANU-1471	25.1±0.8		Charcoal	Clark 1987	
	ANU-1472	30.8±3.0		Charcoal	Clark 1987	
	ANU-1473	16.0±0.8		Charcoal	Clark 1987	
	ANU-1692	34.5±1.5		Shell	Clark 1987	
	CAMS-2038	36.2±1.1		Shell	Gillespie 1997	
	AA-4251	37.6±1.0		Shell	Bowler 1998	
	AA-4252	38.1±1.1		Shell	Bowler 1998	

Long Water	W1792		29.6±3.0	UM clay/sand	Bowler & Price 1998	Bowler (1998:132-6) assigns the ^{14}C
Hole Gully	ANU-1491A	23.4±0.4		Charcoal	Clark 1987	dates to UM times and rejects charcoal
	ANU-1491B	32.7±1.0		Charcoal	Clark 1987	dates as contaminated. The TL date
	ANU-1697	36.8±1.8		Shell	Clark 1987	overlies the shell midden dated by
	N-1665	35.6±1.7		Shell	Clark 1987	the ^{14}C samples.
	N-2032	35.1±1.8		Shell	Clark 1987	
Top Hut 3	ANU-3895 a	41.4±5.6		NaOH soluble	Bowler 1998	^{14}C dates reported by Bowler pertain
	ANU-3895 b	32.7±0.9		NaOH insoluble	Bowler 1998	to different sediment fractions from a
	ANU-3895 c	36.5±1.3		NaOH insoluble	Bowler 1998	hearth at base of UM component.
	ANU-3895 d	35.5±1.1		NaOH soluble	Bowler 1998	Gillespie's dates are from the same
	CAMS-1922	34.6±0.9		Humic acid	Gillespie 1997	location. The TL date is from the next
	CAMS-1923	34.6±0.8		Humic acid	Gillespie 1997	lowest component.
	CAMS-1925	35.6±1.9		Shell	Gillespie 1997	
	W1796		41.7±5.6	LM sand	Bowler & Price 1998	

Table 4 Selected radiocarbon, TL and OSL dates from Lake Mungo and Lake Arumpo. WOC-1, WOC-3 and WOC-4 are on the southern and eastern margins of the Mungo locality; Top Hut 1 and 3 and Long Water Hole Gully are on or near the eastern side of the Arumpo locality (see Bowler 1998; Johnston and Clark 1998 for additional details). Lower case letters have been added to some laboratory numbers to distinguish multiple analyses of the same samples. All radiocarbon dates are uncalibrated. UM refers to the Upper Mungo component or its stratigraphic equivalents, LM to various Lower Mungo components or their equivalents. M-I is the Mungo 1 cremation site, M-III the Mungo 3 burial site. 'nnc' means no laboratory number was cited in the source listed.

ca. 35 ka. The ninth is older in its central tendency, but has a large error range which means it also overlaps with six of these eight dates. Assuming, following Bowler (1998), a plus 3-5 ky calibration range, the base of these deposits thus dates to 38-40 ka. Two of three luminescence dates from the base of the UM component at the Joulni locality also overlap with this calibrated ^{14}C chronology. Bowler et al. (2003) use these data to peg the LM/UM transition to ca. 38-40 ka.

Eighteen dates on the LM soil range from 16 ka to 45 ka. Many have been rejected as contaminated, but seven of eight ^{14}C dates on shell and charcoal from Top Hut 1 and the Tourist Site, identified by Bowler and/or Gillespie as acceptable, are >34 ka (Fig. 3). At one standard deviation, six overlap between 36 ka and 37 ka. Again, assuming a plus 3-5 ky offset, the base of these deposits thus falls in the 39-42 ka range. Four of five luminescence dates on the LM soil at Joulni are almost identical in age, with central tendencies at ca. 42 ka and similar error ranges, and these overlap with the fifth luminescence date at ca. 43 ka. Bowler et al. (2003) appeal to both ^{14}C and luminescence dates in placing the LM soil at ca. 40-42 ka.

Thirty-three luminescence dates come from below the LM soil (Fig. 4). Fourteen TL dates from the Joulni locality range in their central tendencies between 34 ka and 64 ka; 18 OSL dates from the same site range in their central tendencies between 41 ka and 62 ka; neither set shows any clear relationship between age and stratigraphic depth. One additional LM date from Top Hut 1 falls in the 36-47 ka range. Given that the Joulni dates show no clear depth/age relationship, they invite skepticism about their precise validity. Primarily on the basis of the OSL dates, Bowler et al. (2003) put the bottom of the LM component at ca . 60 ka.

c) Artefactual evidence

Archaeological materials from Willandra have not been published in much detail, but are reportedly present in some quantity in the LM soil on the Mungo lunette and in the quartz sands immediately underlying it (e.g., Allen 1972; Bowler 1998; Bowler et al. 1970; Johnston 1993; Bowler 1998). Items mentioned most frequently include lithics, hearths, roasting pits, and small, shallow middens containing fish, shellfish and mammal remains. At least some of these materials must have remained at the point of initial deposition, implying ages equivalent to that of the LM soil or slightly older, roughly 40-

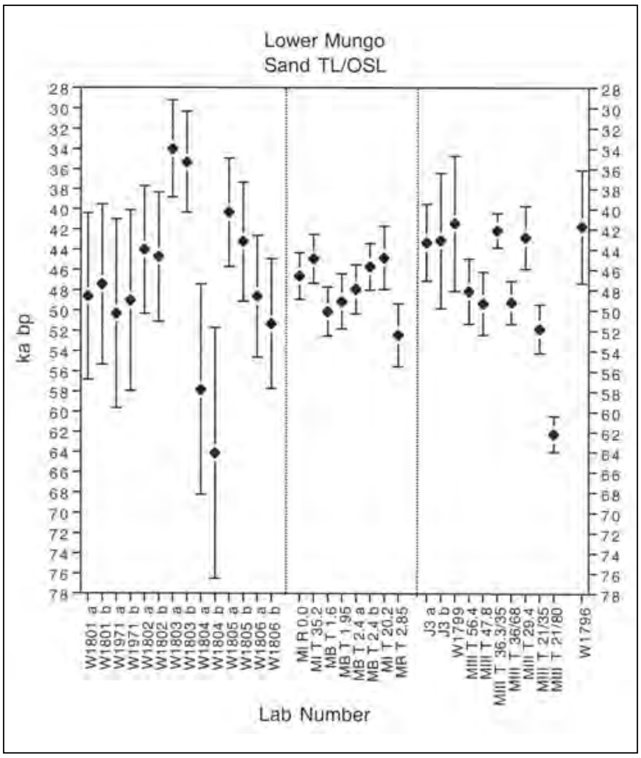

Figure 4 TL and OSL dates from Lower Mungo sand (data from Table 4). The figure is divided into three sections: W-series dates reported by Bowler and Price (1998) from augered samples adjacent to the Shawcross excavation; MI/MB dates on samples collected near the M-I burial location (Bowler et al. 2003); J3/M-III dates on samples collected near the M-III burial location. Within each section samples are arranged in descending stratigraphic order, uppermost at left.

45 ka. Similar remains are associated with the LM soil, but not the underlying sands, at Top Hut 1 and 3 on the Arumpo lunette (Bowler 1998:133, 147).

Arguments for earlier dates on the archaeology appeal to two data sets. One is the M-III burial, discussed below. The second is a collection of eleven silcrete flakes found well down in the LM component at Joulni (Fig. 1). Illustrations of these pieces have not been published, but excavators express no uncertainty about their human authorship (Shawcross 1998; Bowler et al. 2003; Shawcross 1998). Stratigraphic position and roughly bracketing OSL dates of 50.1 ± 2.4 ka and 49.1 ± 2.7 ka (above the artefacts) and 47.9 ± 2.4 ka and 45.7 ± 2.3 ka (below the artefacts) are read by some to indicate a date in the 46-50 ka range; but we are skeptical, partly because of the small size of the assemblage, partly because of its sedimentary context. Bowler (1998) notes that LM sands are typically marked by 'steep avalanche bedding' and 'cross sets', indicating erosional and depositional processes likely to facilitate the movement of artefacts well below the original point of deposition. The lack of a strong age-depth relationship in the Joulni dates (already discussed, also see Fig. 4) emphasises this point. While conjoining exercises involving these eleven flakes have apparently not been attempted, Shawcross sees this as a 'powerful test' for the locational integrity of artefacts. He reports (1998:193-95) conjoining efforts from higher in the Joulni deposits where some flakes in one conjoining set are up to 20 cm higher than the core, while one is ca. 40 cm below it. It is unclear which, if any, of the pieces in this conjoin set are *in situ*. At present, the case for a pre-45 ka date for these eleven items must be considered unproven.

d) The M-III burial

The second argument involves the human burial known as M-III (a.k.a. Mungo III, LM-3 or WLH-3). Recent discussions of these remains are complex, requiring a brief review of their history.

The skeleton was found partly exposed on an eroded surface in LM sediments; thus the surface of origin for the pit in which it was placed could not be observed directly. Its stratigraphic position has been inferred from a comparison of the grave pit contents with surrounding sediments:

1. Excavators Bowler and Thorne (1976:134) argued that the burial was in place before the LM soil was formed because a) dark humic sands from the soil were absent from the grave fill, and b) soil-related carbonate cementation of the bones was comparable with that of adjacent sediments.
2. Citing a personal communication from Bowler, Oyston (1996) reported that Wüstenquartz was more common in the M-III grave fill than in the surrounding sediments, suggesting that the burial occurred after the deposition of most of the LM sands, but just before the overlying LM soil was formed, during a period of increased aridity that foreshadowed the pattern typical of later UM times.
3. In contrast, Bowler himself (1998:150, Ffig. 9) claimed that both the grave fill and surrounding quartz sands were *almost entirely free* of both Wüstenquartz and pelletal clay, with the 'very small percentage' of Wüstenquartz having sifted down from overlying UM sediments through bioturbation.
4. More recently, Bowler and Magee (2000: Fig. 2) published a stratigraphic diagram indicating that pelletal clay and Wüstenquartz were found in sediments *below* the level of the grave pit.
5. Finally, Bowler et al. (2003:840) report that the grave pit contained 'traces of pelletal clay and *dark, reworked soil*' [our emphasis].

These inconsistencies in data and opinion notwithstanding, we are led to infer that M-III was interred late in LM times, just before (or perhaps coincident with) the formation of the LM soil. Given the dates reviewed above (see Table 4 and text) for the LM soil and the LM sands immediately underlying it, a date of 42-43 ka for the interment of M-III seems plausible. That said, the difficulty of determining the surface from which the grave was dug and changing observations on its content maintain the possibility of a significantly younger age for this individual.

Thorne et al. (1999) have developed a very different chronology for M-III, based on ten U-series and ESR analyses of the skeleton itself, one U-series analysis of the attached calcite matrix, and two OSL determinations on LM sediments they claim are stratigraphically equivalent to the position of the burial (Table 5). Ages range from 50 ka to 79 ka, excluding the mass spectrometry date on sediment adhering to M-III bone, which at 82.0 ± 21.0 ka, extends the range at one standard deviation to 103 ka. The authors' preferred estimate is 62.0 ± 6.0 ka. They agree that the burial was interred just prior to the formation of the LM soil, but contend that the soil itself formed over a much longer period than suggested by Bowler and, in particular, by the closely associated luminescence dates reported by Oyston (1996) and Bowler et al. (2003).

Method	Sample	Age (ka)
Mass spectrometry	Bone (M-III)	69.8±2.1
		58.3±1.2
		50.7±0.9
		54.5±0.7
Mass spectrometry	Sediments adhering to M-III	82.0±21.0
Gamma spectrometry	Bone (M-III)	69.5±2.9
		64.1±3.7
		74.0±7.0
		60.0±5.0
Electron spin resonance	Tooth enamel (M-III)	63.0±6.0
		78.0±7.0
OSL	Sediment	59.0±3.0
		63.0±3.0

Table 5 Dates on M-III burial from Thorne et al. (1999). All determinations except OSL pertain either to the skeleton itself or immediately adjacent sediments; OSL dates relate to Lower Mungo sands collected several hundred metres away from that location. See Bowler and Magee (2000), Gillespie and Roberts (2000), Grün et al. (2000) for additional discussion.

Detailed critique of the U-series and ESR methodology is beyond us, but the obvious complexity and experimental nature of the techniques, the assumptions required in controlling uranium uptake and loss, the wide variation in dates obtained by the same or similar analyses on the same or similar materials (e.g. the 20 kyr spread of dates produced from the mass spectrometric analyses of M-III bone), and especially the wide mismatch with the luminescence- and radiocarbon-based chronology outlined by Bowler and associates (Table 4), make us skeptical of its results (see Gillespie 2002, Gillespie and Roberts 2000, Gillespie 2002 for detailed critiques). The luminescence dates reported by Thorne et al. offer general support for their own argument; but the fact that the samples they analysed were collected several hundred metres away from the M-III site, in association with a soil that *may or may not* be the LM soil claimed to seal the M-III burial, must be seen to undercut their position.

e) Conclusion

Currently, neither the M-III burial nor the local archaeological record provide any solid support for humans being in the Willandra Lakes region before ca. 43 ka.

Nauwalabila

Nauwalabila is a rockshelter formed by an outlier of the Arnhem Land escarpment in the Northern Territory, ca. 200 km east of Darwin. Ground surface consists of level sandsheet inside and beyond the shelter, but within its dripline, artefacts are found through 2.5 m of sand deposits and into 30-40 cm of underlying sandstone rubble, itself resting on sand and bedrock. Fourteen radiocarbon and five luminescence dates (Roberts et al. 1994) indicated fairly steady sand accumulation from ca. 60 ka, with the lowest artefacts between two OSL dates of 53.4 ± 5.4 ka and 60.3 ± 6.7 ka. A recent paper by Bird et al. (2002) offers a set of complex and interlocking arguments and new data in support of this antiquity.

a) New dates

In a previous review (O'Connell and Allen 1998), we suggested that the positions of both the rubble and the lowest artefacts might be secondary, with settling resulting from post-depositional termite bioturbation. To test this idea, Michael Bird looked at the sediment particle size distribution in the profile to see whether there was an impoverishment of fine particles at depth, which he predicted would be the expected result if this material was being selectively carried to the surface by termites (Bird et al. 2002:1070). The results were inconclusive. Bird et al. found no decrease in the proportion of fine material at depth, but offered several mechanisms by which the observed constant ratio of materials could be maintained in the face of termite infestation. Even so, Bird et al. proposed that disturbance by termite activity had not been intense over recent millennia, a conclusion based on the consistency of increasing age with depth for the ^{14}C samples for the upper part of the site. Whether particle size analysis is the most appropriate way of identifying termite activity over a sequence spanning 40 or 50 millennia is uncertain, given that termites cause 'continuous disturbance and homogenization' at rates for some species up to 1000 kg ha^{-1} year^{-1} of soil translocated to the surface and subsequently reburied in this ongoing process (Holt and Lepage 2000:391).

What Bird et al. did find were small charcoal particles down to the base of the section, some 60 cm deeper than the deepest charcoal reported by Jones and Johnson (1985:179-80) and ca. about 1 m below the previous lowest radiocarbon date. The number of new samples dated is not stated; from cited laboratory numbers it appears >30 samples between 75 cm and 293 cm below surface were tested, using ABOX-SC and other pretreatment techniques and AMS and conventional dating. The results from 110 cm and below are shown in Table 6, together with the OSL dates previously reported by Roberts et al. (1994:579). An additional 13 ^{14}C dates from higher in the sequence do not bear on the immediate argument and have been commented on elsewhere (O'Connell and Allen 1998).

Obviously, these radiocarbon dates show neither a coherent pattern of increasing age with depth, nor any close relationship to the OSL dates. *Prima facie*, they might be seen to reflect the random pattern of charcoal particles displaced down the profile through bioturbation. Bird et al. (2002) reject this interpretation.

b) An alternative hypothesis

Bird et al. (2002:1070) argue that the presence in the site of pisolites (a.k.a. pisoliths), occurring from ca. 110 cm below surface to the base of the deposit, formed as a result of a fluctuating groundwater table (2002:1070), which was at or near the palaeosurface of Nauwalabila at the Pleistocene-Holocene transition. Explanations offered for a raised water table include increased rainfall at this time, coupled with higher river base levels accompanying higher sea levels, and wet season water draining from the escarpment behind the site (2002:1071).

In turn, these climatic effects reduced the transport of sand and the intensity of occupation, reflected in a gap in the calibrated radiocarbon dates between ca. 12.5 ka and 9.2 ka (Bird et al. 2002: Table 1, samples ANU-8653, ANU-8654). Subsequently, the site was no longer subjected to seasonal wetting, occupation was more intensive, and sediments accumulated more rapidly. The maximum water table fell to ~200 cm below the modern surface by 6.65 ka or younger.

The purpose of this reconstruction by Bird et al. is to support their view that the dated charcoal samples below 110 cm have had their carbon composition altered by the proposed high water table. Bird et al. (2002:1069) report that above this level, hard black fragments of charcoal retain their internal structure, whereas below 110-130 cm and especially below 180 cm charcoal fragments have been subjected to variable degrees of pervasive alteration — large charcoal fragments are sparse, heavily coated by clays and iron oxides, soft and brown. Their internal structures are degraded, and their carbon contents range from 3.9% up to ~42%, but mostly below 25%, compared with 36-47% for unaltered samples. Microbial activity is suggested as the vector of carbon replacement. Thus the radiocarbon ages below ~180 cm reflect the age of this alteration rather than the age of the sediments from which they were recovered.

c) Comments on this hypothesis

While we cannot contradict the view that these samples are contaminated beyond the ability of the ABOX-SC, or other pretreatments to rectify, problems remain.

1. Bird et al. (2002:1064, 1067, 1069) argue that any bioturbation would have originated from the modern surface and would necessarily have mixed the upper units as well as the sediments below 110 cm. To refute this, they point to a coherence in the age/depth relationship of the radiocarbon dates above 110 cm below surface and argue that bioturbation is thus not a major concern. While this age/depth coherence

Depth below surface (cm)	Sample	ABOX-SC AMS (ka)	Other ^{14}C dates (ka)	^{14}C calibrated (BP)	OSL (ka)
104-10	OXODK172				13.5±0.9
107	ANU-8653		8.18±0.07	9140-9028	
111	ANU-8654		10.53±0.24	12877-12105	
115	ANU-8677		9.81±0.12	11345-11081	
118	ANU-8676		11.09±0.24	13213-12892	
123	ANU-8678		10.92±0.11	13044-12871	
127	SUA-236		13.19±0.18	16222-15500	
139	ANU-10929		12.33±0.12	14423-14102	
151	ANUA-9513	18.33±0.28		22230-21314	
151	ANUA-9905	13.29±0.18		16315-15624	
151	ANUA-9906	13.89±0.34		17121-16204	
152	ANU-10928		19.99±0.36	24196-23138	
164	ANU-10927		12.00±0.25	14336-13500	
164	ANUA-9514	17.12±0.30		20840-19919	
164	ANUA-9907	16.45±0.32		20078-19139	
170-75	OXODK166				30.0±2.4
176	ANU-3177		22.84±0.52	26660-25420	
176	ANU-3182B		12.00±0.60	14457-13405	
176	ANUA-9512	8.75±0.1		9895-9599	
176	ANUA-9908	14.6±0.34		17938-17022	
180	SUA-237		19.97±0.365	24179-23122	
189	ANUA-8131	5.88±0.15		6805-6498	
189	ANUA-8223	7.05±0.14		7973-7724	
236	ANUA-6906		27.35±0.44	31500-29700	
236	ANUA-9902	12.73±0.14		15634-15148	
236	ANUA-9909	6.96±0.14		7871-7673	
228-40	OXODK168				53.4±5.4
241	ANUA-10317		8.21±0.12	9298-9025	
241	ANUA-10318		9.106±0.12	10426-10174	
256	ANUA-9903	9.28±0.18		10688-10236	
293	ANUA-7618		7.51±0.23	8483-8107	
293	ANUA-7619		6.92±0.14	7862-7657	
293	ANUA-9904	7.56±0.14		8454-8182	
293	ANUA-9912	9.45±0.18		10878-10493	
285-301	OXODK169				60.3±6.7

Table 6 Nauwalabila ^{14}C dates below 110 cm, separated into ABOX-SC/AMS dates and other 14C dates, which include a variety of pretreatments. Where other ^{14}C dates carry an ANUA sample code, these have been measured using AMS. We assume the remainder are conventional dates. Data, including calibrated ages, extracted from Bird et al. (2002: Table 1). Calibrated age for ANUA-6906 from Bird et al. (2002:1066). Where multiple calibrated ages occur, we have only listed the one with the highest probability. Readers wanting the full details should consult Bird et al. (2002: Table 1). OSL dates from similar depths are from Roberts et al. (1994: Table 2), with cited ± representing the total uncertainty provided there.

relies on the relocation of several reported dates and the exclusion of others (O'Connell and Allen 1998:135-36), we are more concerned here by the static view of site formation processes that suggests bioturbation necessarily originated from the existing surface. If bioturbation has been ongoing during the formation of the site, if there has been a continuous recycling of the deposit by termites, potentially disruptive processes have had more time to operate on deeper parts of the deposit, with potentially greater effect.

2. Explanations for a fluctuating groundwater table involving higher rainfall and higher river base levels accompanying the sea level rise are arguable. Nauwalabila is more than 40 km in a straight line from the South Alligator River, into which Deaf Adder and other ephemeral creeks near the site empty. At ca. 9 ka, by which time the claimed high groundwater table was in decline, sea level was still rising, and was at that time at minus 20 metres to present sea levels (Chappell and Grindrod 1983:87), so that it is improbable that river base levels were raising the water table at Nauwalabila. While the Pleistocene-Holocene transition may have been wetter, this wetter period may barely overlap with the period 12.5 ka to 9.2 ka (Taçon and Brockwell 1995:680 and refs) or not overlap at all (Kershaw 1995:672). The modern pattern of wet seasons is thought to date from the formation of Torres Strait, ca. 6-7 ka (Kershaw 1995:672). We are unaware of other climatic events sufficient to raise the groundwater table a significant amount at this time and subsequently lower it ~1 m in a little over 2 ky.

3. Contra Bird et al. (2002:1067-68), higher sedimentation rates in the upper metre of Nauwalabila imply higher

sedimentation rates on the surrounding sandy plain as well, since the plain is at the same level as the shelter floor. If this topographical uniformity is the result of redistribution of escarpment sand by large quantities of surface water from the modern yearly wet seasons, it is pertinent to ask what effects the seasonal wetting and drying of the site may have had? It did not degrade charcoal in the upper part of the site, but may have facilitated the post-depositional movement of artefacts by flooding and collapsing disused termite tunnels.

4. Bird et al. (2002:1069-70) demonstrate that charcoal samples below 110 cm and especially below 180 cm are altered in physical form, but it is less evident that these samples are necessarily *in situ*, or that younger carbon in them is of microbial origin. As they point out, while charcoal can absorb dissolved organic compounds, making it an attractive habitat for micro-organisms to colonise, there is no clear evidence that they did so.

The introduction of extraneous younger carbon into older charcoal will alter the $^{14}C/^{12}C$ ratio. On our behalf, Mike Barbetti (University of Sydney) calculated that the $^{14}C/^{12}C$ ratio of unaltered carbon samples aged between 30 ka and 50 ka would be somewhere between about 4% and 0.2% of the ^{14}C modern standard. This calculation depends on past atmospheric levels of ^{14}C, for which Barbetti conservatively allowed up to ~2 x the modern level.

Samples with apparent ages of 6 ka to 10 ka have an equivalent $^{14}C/^{12}C$ ratio of roughly 50% to 30% of the modern standard. This means that the altered samples from Nauwalabila are *almost entirely* composed of carbon which is, on average, much younger than both the assumed ages of >30 ka, and the supposed time of the high groundwater table of 12.5 ka to 9.2 ka. If the assumption that these samples are *in situ* and contaminated is correct, what remains unknown is what happened to the original carbon in the charcoal and how so much young material has been introduced into the samples in a form that would withstand the ABOX-SC pretreatment, which is designed to remove humic acids and other soil organic substances.

d) New evidence of bioturbation

Detracting from their own argument, Bird et al. acknowledge that not all charcoal from the deeper levels of Nauwalabila is either degraded or *in situ*. Since it is not unknown which dates listed in our Table 6 are from degraded or intact samples, we quote from their paper (Bird et al. 2002:1070-71):

> … small quantities of sand-sized (125-500µm), apparently unaltered charcoal of <10,000 years in age have moved to the deepest levels of the deposit from original positions at 100 cm or above. Small quantities of black and vitreous charcoal fragments, with well preserved woody structures and generally 125-500µm in size, *are found in most samples throughout the sequence*. … Regardless of pretreatment, these samples yielded dates which are too young to represent the age of sedimentation, ranging between 8300 and 15,400 cal. BP for samples below 200 cm, when radiocarbon dates from other samples from similar levels yielded much older ages. *These fragments have most likely fallen down termite or ant galleries from high in the sequence* [our emphases].

This statement clearly suggests that termite or ant bioturbation has affected all of the lower deposit to some unknown degree.

e) Comment on the ^{14}C dates

Given that some younger charcoal has reached the bottom of the site, plus the apparent approximate coincidence of the ages of the altered and the unaltered charcoal, plus the related points raised here, we think it premature to discard the possibility that altered charcoal, in addition to unaltered charcoal, has also been displaced downwards. Required are alternative explanations for why some of these samples at depth are altered and others not. Whether these lower charcoal samples are in different stages of decay, under soil conditions that have removed other organics from these levels, is beyond our competence to judge.

f) Post-depositional artefact movement

Bird et al. (2002) adduce a range of reasons why post-depositional artefact movement is minimal. We briefly summarise these and offer responses.

1. Contra to the oft-cited paper of Richardson (1992) on the vertical movement of artefacts in Kenniff Cave, demonstrated by conjoining artefacts, Bird et al. (2002:1071) claim that Richardson (1996) found 'no evidence of large scale vertical movement of artefacts' in a 'more sophisticated subsequent analysis.'

Response. Richardson's 1996 Kenniff analysis actually *increased* the maximum vertical separation of 30.4 cm established in 1992 (Richardson 1992:417). Conjoin set 12 has a minimum upward vertical separation of 54-64 cm for one flake from the core onto which it directly fits (Richardson 1996:88). Set 18 has a maximum vertical separation of 38.4 cm between several groups of artefacts (Richardson 1996:91). Maximum possible separation distances in the wider collection are on occasion >90 cm (Richardson 1996:85). All these movements in Kenniff occurred in only the last three millennia. Their significance can be judged by noting that 30 cm displacement in Nauwalabila would reduce the age of the lowest artefacts to <50 ka, while 70 cm displacement would make them <40 ka (Bird et al. 2002:1072).

2. The depth of significant disturbance by termites in sandy soils in the Northern Territory, defined by the presence of subsurface stonelines, is, according to Bird et al. (2002:1072) generally limited to less than 0.5 m from the surface. In their view, the period of most intense termite activity was most likely the post-mid-Holocene, where disturbance in the site is not evident and the radiocarbon chronology most coherent. Therefore termite bioturbation was minimal.

Response. There is no evidence that stonelines in the Northern Territory are limited to 0.5 m from the surface. While this depth can be extrapolated from Williams (1978: Fig. 5.4a), this article and Williams (1968), cited by Bird et al., report the same *single* exposure from a *single* site. Termites can operate at much greater depths – up to 50 *metres* in one report (Holt and Lepage 2000:393), so that stonelines deeper than 0.5 m can be anticipated in the Northern Territory. Since termites have been there since the Tertiary (Williams 1978:139), we can assume they have been inhabiting the sand layers of Deaf Adder Gorge since their formation and are not merely a late Holocene phenomenon in the Nauwalabila shelter.

However, we ask again whether the rubble band at the base of Nauwalabila might itself be a stoneline? It rests mostly on a boulder base and contains ‘the lowest artefact’, but it also overlies pockets of sand. It is not decayed bedrock (Jones and Johnson 1985:175) and it is 30-40 cm thick. No explanation for its formation has been advanced, apart from our suggestion (O’Connell and Allen 1998) that its appearance is similar to the sorts of stonelines resulting from termite bioturbation.

3. Artefact densities in Nauwalabila form distinct peaks at different levels in the site, which argue against large-scale redistribution of artefacts (Bird et al. 2002:1072-73). In particular, groups of quartz crystals previously unreported by Jones and Johnston (1985) occur exclusively at only two places in the sequence. The upper group has 37 items separated vertically through 12 cm of deposit at 104-116 cm depth, while the lower group has three pieces separated vertically by 9 cm at 185-194 cm depth (Bird et al. 2002:1073).

Response. Contra Bird et al. (2002:1072), Jones and Johnson do report quartz crystals in the site, although the distributions and numbers now offered by Bird et al. are different from those originally reported. Jones and Johnson (1985:191) noted that the ‘large quartz crystals from which flakes had been struck’ mainly derived from units between 143 cm and 175 cm below surface, a vertical distribution of 32 cm. Jones and Johnson (1985: Table 9.6) listed all the retouched quartz crystals recovered from Pits K28, K29, L28 and L29, which, together, form the 1m byx 1m excavation trench - Bird et al. (2002:1073) apparently limit their remarks to the 0.5 m xby 0.5 m L29 pit. However, this latter pit now contains more quartz crystals than originally reported for the total excavation by Jones and Johnson, who listed 35 pieces, mostly randomly distributed between depths of 31 cm and 264 cm. Thirteen were clustered between 143 cm and 152 cm, and a further six occurred between 213 cm and 228 cm. The remainder are single occurrences across a depth of 233 cm.

4. Bird et al. (2002:1073) suggest that four artefact peaks in the sequence contain artefacts of different raw materials and combinations of raw materials - at 40 cm (quartzite), at ~90 cm (chert), at ~150 cm (quartz) and at 240 cm (quartz and quartzite, with low numbers of chert). They argue that ‘[f]or quartzite to be more common than chert in the peak at 240 cm, the quartzite artefacts would have had to have been selectively “settled” not only through the sand matrix but through the abundant chert artefacts at ~90 cm as well.’

Response. The argument here is that if quartzite has moved at all in the site, then the quartzite at 240 cm necessarily derives from 40 cm. This is self-evidently a *non sequitur*. As conjoining exercises routinely demonstrate, most pieces produced in a flaking episode may stay close to their points of production while many fewer pieces may be moved up or down the deposits by incidental forces. Movement distances may be small or large, but rarely uniformly the same. For Nauwalabila it is not necessary that stone artefacts moved from top to bottom in this site, even if charcoal did. Bird et al. (2002:1072) suggest small charcoal pieces may have fallen down termite tunnels; downward artefact movement attributed to termites mostly occurs as abandoned galleries collapse, as previously described (O’Connell and Allen 1998:138-39). In the particular case of the Nauwalabila artefacts, all major raw material classes occur in all levels in the sequence, except at the very base of the deposit (Jones and Johnson 1985: Table 9.4).

g) Conclusion

The scrutiny afforded Nauwalabila is concomitant with the extreme antiquity claimed for it. We agree with Bird et al. (2002:1073) that the luminescence chronology cannot be questioned by the irregular radiocarbon ages in the lower deposits, but are less sanguine that available evidence rules out the possibility of post-depositional movement of the contaminated charcoal samples or stone artefacts, especially given that in-site termite activity is suggested by Bird et al. for the post-depositional movement of non-degraded charcoal. Claims that any translocation distances of artefacts are necessarily small and in keeping with what might be expected of scuffage and treadage are unconvincing in the absence of Shawcross’ ‘powerful test.’ Assessing these propositions by conjoining exercises is a daunting enterprise, but one that is warranted if the tag of ‘oldest site’ is to be substantiated.

Depth below surface (cm)	Sample	ABOX-SC AMS (ka)	^{14}C (ka)	TL (ka)	OSL (ka)
146	ANU-7006		13.39±0.40		
149	ANUA-9913	10.33±0.15			
149	ANUA-9914	13.05±0.21			
152	KTL 165			15±2	
192-216	KTL 97			24±4	
202	SUA-265		18.04±0.30		
232	KTL 164			45±7	a) 45.7±4.1
					b) 44.2±4.7
250	KTL 158			52±8	
254	ANUA-9915	10.81±0.20			
260	KTL 162			61±10	a) 60.7±7.5
					b) 55.5±8.2

Table 7 Malakunanja ABOX-SC/AMS and conventional radiocarbon dates (Bird et al. 2002: Table 1) compared to TL and OSL dates from similar or nearby depths after Roberts et al. (1990a, 1994, 1998), with cited ± representing the total uncertainties provided there. For OSL dates, a = the single aliquot measure, b = single grain measure.

Malakunanja

Since the excavation and analysis of this site remains unpublished except for the original and subsequent announcements of the TL and OSL dates (Roberts et al. 1990a; Roberts 1997; Roberts, Yoshida et al. 1998) little can be made of its claimed antiquity. Roberts (1997:856) allowed the possibility of downward displacement of the lowest artefacts, but argued for the *in situ* status of artefacts in 'a small pit feature' overlain by a TL date of 45 ± 7 ka and OSL dates of 45.7 ± 4.1 ka (single -aliquot) and 44.2 ± 4.7 ka (single grain).

Although they provide no discussion of the data, Bird et al. (2002: Table 1) have also published three new ABOX-SC/AMS dates for Malakunanja. These are reproduced here (Table 7) along with relevant conventional radiocarbon, TL and OSL dates. We do not know if these samples are degraded or non-degraded in the fashion of the Nauwalabila samples discussed above.

The two ABOX-SC dates from 149 cm below surface fail to overlap at two standard deviations, although the older one is in general agreement with the associated radiocarbon and luminescence dates. The third of these dates, from 254 cm below surface, is clearly too young at 10.81 ± 0.20 ka, sandwiched between TL dates of 52 ± 8 ka and 61 ± 10 ka. The general similarity in age between this sample, the younger ABOX-SC date from 149 cm below surface, and the suite of aberrant ABOX-SC dates from Nauwalabila may point to a common problem between these sites.

Discussion and Conclusion

While radiometric dating techniques able to extend the range of conventional ^{14}C ages have resulted in useful amendments to previous chronologies for some sites, there has been no uniform or significant increase in basal dates from the oldest sites in the region in the last decade. At the same time, advances in dating technologies in that time have been significant; optically stimulated luminescence and infrared-stimulated luminescence have offered improvements over thermoluminescence (Roberts 1997:824 ff.) and allowed the development of single aliquot and single grain sampling (e.g. Roberts, Yoshida et al. 1998). Similar advances have been made with radiocarbon, firstly in the development of the acid-base-wet oxidation pretreatment with stepped combustion (ABOX-SC) used in conjunction with AMS radiocarbon dating (Bird et al. 1999), and secondly in refinements to calibration curves and the delineation of radiocarbon plateaux, like the one around 33-34 ka radiocarbon years, that produces ^{14}C ages statistically indistinguishable for the 6000 calendar years from 35 ka to 41 ka (Turney and Bird 2002:3 and *passim*), a period vital in early Australian archaeology.

Dating technology has not, however, freed us from the inherent limitations of archaeological site contexts, formation processes and taphonomies. Levels of resolution in radiometric dates, constrained by their error ranges, are at least equally constrained by the levels of archaeological resolution available in sites subjected to subsequent human use, bioturbation and other forces of nature. If these processes are not recognised and controlled in the field evidence, the ability to date single sand grains from these sites is meaningless.

The so-called 'radiocarbon barrier', the point beyond which existing technology cannot accurately measure residual radioactive carbon in a sample, has its equivalent in archaeology. An initial counter to this 'archaeology barrier', the reduction in size of excavation units, implemented in the last several decades, has now passed its effective limits. Even if it were feasible to excavate the grains of site matrices individually, this would not aid in more closely identifying the behavioural relationships of artefacts to each other or to the various materials used to date them. We now recognise that many Pleistocene sites in Australia may have depositional rates as low as a one or a few centimetres per millennium, and we need to confront the issue that the archaeological resolution in such sites may never be better than a few millennia. At a Perth conference several years ago, a visiting dating scientist dismissed the Cape York site, Ngnarrabulgan, as disturbed because ^{14}C dates from a single hearth differed as much as six or seven millennia. At this site, first occupied 35 ka (David 2002), the deposit is so shallow and deposition rates so low, that this hearth would likely have remained visible on the surface, even if the site had been abandoned for hundreds or possibly thousands of years. Its re-use in such circumstances is unremarkable.

The evidence in this paper suggests that renewed efforts should be directed at refining our understanding of post-depositional taphonomic events, the intellectual antithesis of dating the lowest artefact. Artefact conjoining is an obvious technique which should be more commonly employed, with its use extended to bone as well as stone (Leavesley and Allen 1998). Soil analyses like those attempted by Bird et al. (2002) should be further researched. Radiometric dates might be more creatively used to detect site disturbances, or to detect phases of site activity and abandonment (Holdaway and Porch 1996).

As for identifying the date of initial colonisation in Australia and New Guinea, a decade has elapsed since claims were made for human settlement between 50 ka and 60 ka at Nauwalabila and Malakunanja. Despite new site discoveries and a concerted re-dating program in potentially older known sites, there are currently no claims for initial occupation beyond 50 ka in any other site in Australia, New Guinea or in modern human sites in Southeast Asia (O'Connell and Allen n.d.). The single exception is the Thorne et al. (1999) interpretation of the M-III burial at Lake Mungo, subsequently contested.

By our assessment, the two sites that fired the debate in the 1990s, Nauwalabila and Malakunanja, remain sequestered by it. Not only do internal data from these sites continue to raise questions about stratigraphic integrity within them, but also the body of related external data, bolstered by improved dating technology and concerted research effort, continues to emphasise their isolation in the data set.

Acknowledgments

For information, assistance and comments we thank Atholl Anderson, Mike Barbetti, Jim Bowler, John Chappell, Charlie Dortch, Jennifer Graves, Don Grayson, Rainer Grün, Richard Klein, Nigel Spooner and Marjorie Sullivan.

References

Allen, H. 1972 Where the Crow flies Backwards: Man and lLand in the Darling Basin. Unpublished Ph.D. thesis, Australian National University, Canberra.

Allen, H. 1998 Reinterpreting the 1969-72 Willandra Lakes archaeological surveys. *Archaeology in Oceania* 33:207-220.

Anderson, A.J. 1998 Reply to comments on 'A production trend in AMS ages on *Rattus exulans* bone.' *Archaeology in New Zealand* 41:231-234.

Anderson, A.J. 2000 Differential reliability of ^{14}C AMS ages of *Rattus* *exulans* bone gelatin in south Pacific prehistory. *Journal of the Royal Society of New Zealand* 30:246-261.

Barbetti, M. 1973 Archaeomagnetic and Radiocarbon Studies of Aboriginal Fireplaces. Unpublished Ph.D. thesis, Australian National University, Canberra.

Bard, E., Hamelin, B., Fairbanks, R.G. and Zindler, A. 1990 Calibration of the ^{14}C timescale over the last 30,000 years using mass spectrometric U-Th ages from the Barbados corals. *Nature* 345:587-592.

Bard, E., Arnold, M., Fairbanks, R.G. and Hamelin, B. 1993 ^{230}Th - ^{234}U and ^{14}C ages obtained by mass spectrometry on corals. *Radiocarbon* 35:191-199.

Beck, J. W., Richards, D.A., Edwards, R.L., Silverman, B.W., Smart, P.L., Donahue, D.J., Hererra-Osterheld, S., Burr, G.S., Calsyas, L., Jull, A.J.T. and Biddulph, D. 2001 Extremely large variations of atmospheric ^{14}C concentration during the last glacial period. *Science* 292:2453-2458.

Bird, M.I., Ayliffe, L.K., Fifield, L.K., Turney, C.S.M., Cresswell, R.G., Barrows, T.T., and David, B. 1999 Radiocarbon dating of 'old' charcoal using a wet oxidation, stepped-combustion procedure. *Radiocarbon* 41:127-140.

Bird, M.I., Turney, C.S.M., Fifield, L.K., Jones, R., Ayliffe, L.K., Palmer, A., Cresswell, R.G., and Robertson, S. 2002 Radiocarbon analysis of the early archaeological site of Nauwalabila 1, Arnhem Land, Australia: Iimplications for sample suitability and stratigraphic integrity. *Quaternary Science Reviews* 21:1061-1075.

Boaretto, E., Bryant, C., Carmi, I., Cook, G., Gulliksen, S., Harkness, D., Heinemeier, J., McClure, J., McGee, E., Naysmith, P., Possnert, G., Scott, M., van der Plicht, J. and van Strydonck, M. 2003 How reliable are radiocarbon laboratories? A report on the Fourth International Radiocarbon Inter-comparison (FIRI) 1998-2001. *Antiquity* 77:146-154.

Bowler, J.M. 1998 Willandra Lakes revisited: Eenvironmental framework for human occupation. *Archaeology in Oceania* 33:120-155.

Bowler, J. and Magee, J. 2000 Redating Australia's oldest human remains: Aa skeptic's view. *Journal of Human Evolution* 38:719-726.

Bowler, J. and Price, D. 1998 Luminescence dates and stratigraphic analyses at Lake Mungo: Review and new perspectives. *Archaeology in Oceania* 33:156-168.

Bowler, J.M. and Thorne, A.G. 1976 Human remains from Lake Mungo: Discovery and excavation of Lake Mungo III. In R.L. Kirk and A.G. Thorne (eds) *The Origin of the Australians*, pp. 127-38. Canberra: Australian Institute of Aboriginal Studies.

Bowler, J.M., Jones. R., Allen, H. and Thorne, A. 1970 Pleistocene human remains from Australia: Aa living site and human cremation from Lake Mungo, western New South Wales. *World Archaeology* 2:39-60.

Bowler J., Thorne, A., and Polach, H. 1972 Pleistocene man in Australia: Age and significance of the Mungo skeleton. *Nature* 240:48-50.

Bowler, J.M., Johnston, H., Olley, J.M., Prescott, J.R., Roberts, R.G., Shawcross, W. and Spooner, N.A. 2003 New ages for human occupation and climatic change at Lake Mungo, Australia. *Nature* 421:837-840.

Chappell, J. 2002 Sea level changes forced ice breakouts in the Last Glacial cycle: Nnew results from coral terraces. *Quaternary Science Reviews* 21:1229-1240.

Chappell, J. and Grindrod, A. 1983 7±2ka 'spike' review. In J. Chappell and A. Grindrod (eds) *CLIMANZ*, pp.87-88. Canberra: Department of Biogeography and Geomorphology, Research School of Pacific Studies, Australian National University.

Chappell, J., Omura, A., Esat, T., McCulloch, M., Pandolfi, J., Ota, Y. and Pillans, B. 1996 Reconciliation of late Quaternary sea levels derived from coral terraces at Huon Peninsula with deep sea oxygen isotope records. *Earth and Planetary Science Letters* 141:227-236.

Clark, P.M. 1987 Willandra Lakes World Heritage Area Archaeological Resource Study. RUnpublished report to the NSW Department of Planning, Sydney, and to the Western Lands Commission of NSW, Sydney.

David, B. 2002 *Landscapes, Rock Art and the Dreaming: An Archaeology of Pre-understanding*. London: Leicester University Press.

Dortch, C. 1984 *Devil's Lair. A Study in Prehistory*. Perth: Western Australian Museum.

Dortch, C.E. and Dortch, J. 1996 Review of Devil's Lair artefact classification and radiocarbon chronology. *Australian Archaeology* 43:28-32.

Eswaran, V. 2002 A diffusion wave out of Africa: the mechanism of the modern human revolution? *Current Anthropology* 43:749-774.

Fullagar R.L.K., Price, D.M. and Head, L.M. 1996 Early human occupation of northern Australia: Aarchaeology and thermoluminescence dating of Jinmium rockshelter, northern Australia. *Antiquity* 70:751-773.

Gillespie, R. 1997 Burnt and unburnt carbon: Ddating charcoal and bone from the Willandra Lakes, Australia. *Radiocarbon* 39:239-250.

Gillespie, R. 1998 Alternative time scales: Aa critical review of Willandra Lakes dating. *Archaeology in Oceania* 33:169-182.

Gillespie, R. 2002 Dating the first Australians. *Radiocarbon* 44:455-472.

Gillespie, R. and Roberts, R. 2000 On the reliability of age estimates for human remains at Lake Mungo. *Journal of Human Evolution* 38:727-732.

Groube, L.M., Chappell, J., Muke, J. and Price, D. 1986 A 40,000 year-old human occupation site at Huon Peninsula, Papua New Guinea. *Nature* 324:453-455.

Grün, R., Spooner, N., Thorne, A., Mortimer, G., Simpson, J.J., McCullough M.T., Taylor, L. and Curnoe, D. 2000 Age of the Lake Mungo 3 skeleton: Aa reply to Bowler and Magee and to Gillespie and Roberts. *Journal of Human Evolution* 38:733-741.

Haberle, S.G. and Ledru, M-P. 2001 Correlations among charcoal records of fires from the past 16,000 years in Indonesia, Papua New Guinea, and Central and South America. *Quaternary Research* 55:97-104.

Holdaway, S. and Porch, N. 1996 Dates as data: Chronostratigraphy and lithostratigraphy as a basis for analytical unit formation. In J. Allen (ed.) *Report of the Southern Forests Archaeological Project.* Vol. 1: *Site Descriptions, Stratigraphies and Chronologies*, pp.251-77. Bundoora: Archaeology Publications, School of Archaeology, La Trobe University.

Holt, J. A. and Lepage, M. 2000 Termites and soil properties. In T. Abe et al. (eds) *Termites: Evolution, Sociality, Symbioses, Ecology*, pp.389-407. Dordrecht: Kluwer Academic Publishers.

Jackson, W.D. 1999 Palaeohistory of vegetation change: Tthe last 2 million years. In J.B. Reid, R.S. Hill, M.J. Brown and M.J. Hovenden (eds) *Vegetation of Tasmania*, pp.64-88. *Flora of Australia Supplementary Series* 8. Hobart: University of Tasmania, Forestry Tasmania, and Cooperative Research Centre for Sustainable Production Forestry. *Flora of Australia Supplementary Series* 8.

Johnston, H. 1993 Pleistocene shell middens of the Willandra Lakes. In M.A. Smith, M. Spriggs and B. Fankhauser (eds) *Sahul in Review: Pleistocene Archaeology in Australia, New Guinea and I iIsland Melanesia*, pp.197-203. Canberra: Department of Prehistory, Research School of Pacific Studies, Australian National University. *Occasional Papers in Prehistory* 24.

Johnston, H. and Clark, P. 1998 Willandra Lakes archaeological investigations 1968-98. *Archaeology in Oceania* 33:105-119.

Jones, R and Johnson, I. 1985 Deaf Adder Gorge: Lindner Site, Nauwalabila I. In R. Jones (ed.) *Archaeological Research in Kakadu National Park*, pp.165-227. Canberra: Australian National Parks and Wildlife Service. *Special Publication* 13.

Kershaw, A. P. 1995 Environmental Change in Greater Australia. In J. Allen and J. F. O'Connell (eds) *Transitions: Pleistocene to Holocene in Australia and Papua New Guinea*, pp.656-75. *Antiquity* 69, *Special Number* 265.

Kershaw, A.P., van der Kaars, S. and Moss, P.T. in press Late Quaternary Milankovitch-scale climatic change and variability and its impact on monsoonal Australasia. *Marine Geology*, forthcoming.

Kitagawa, H. and van der Plicht, J. 1998 Atmospheric radiocarbon calibration to 45,000 yr BP: Llate Glacial fluctuations and cosmogenic isotopic production. *Science* 279:1187-1190.

Klein, R.G. 1995 Anatomy, behaviour and modern human origins. *Journal of World Prehistory* 9:167-241.

Leavesley, M. and Allen, J. 1998 Dates, disturbance and artefact distributions: Aanother analysis of Buang Merabak, a Pleistocene site on New Ireland, Papua New Guinea. *Archaeology in Oceania* 33:63-82.

McBrearty, S. and Brooks, A.S. 2000 The revolution that wasn't: A new interpretation of the origin of modern human behaviour. *Journal of Human Evolution* 39:453-563.

Miller, G.H., Magee, J.W. and Jull, A.J.T. 1997 Low-latitude cooling in the southern hemisphere from amino acid racemization in emu eggshells. *Nature* 385:241-244.

O'Connell, J.F. and Allen, J. 1998 When did humans first arrive in Greater Australia, and why is it important to know? *Evolutionary Anthropology* 6:132-146.

O'Connell, J.F. and Allen, J. n.d. Dating the initial human colonization of Australia and New Guinea: Aa review of recent research. Manuscripts in. under review.

Oyston, B. 1996 Thermoluminescence age determinations for the Mungo III human burial. *Quaternary Science Reviews* 15:739-749.

Readhead, M.L. 1988 Thermoluminescence dating study of quartz on aeolian sediments from southeastern Australia. *Quaternary Science Reviews* 7:257-264.

Richardson, N. 1992 Conjoin sets and stratigraphic integrity in a sandstone rockshelter: Kenniff Cave (Queensland, Australia). *Antiquity* 66:408-418.

Richardson, N. 1996 Seeing is believing: a graphical illustration of the vertical and horizontal distribution of conjoined artefacts using DesignCAD 3D. In S. Ulm, I. Lilley and A. Ross (eds) *Australian Archaeology '95: Proceedings of the 1995 Australian Archaeological Association Annual Conference*, pp. 81-95. St. Lucia: Anthropology Museum, Department of Anthropology and Sociology, University of Queensland. *Tempus* 6.

Roberts, R.G. 1997 Luminescence dating in archaeology: From origins to optical. *Radiation Measurements* 27(5/6):819-892.

Roberts, R.G., Bird, M., Olley, J., Galbraith, R., Lawson, E., Laslett, G., Yoshida, H., Jones, R., Fullagar, R., Jacobsen, G. and Hua, Q. 1998 Optical and radiocarbon dating at Jinmium rock shelter in northern Australia. *Nature* 395:358-362.

Roberts, R.G., Jones, R. and Smith, M.A. 1990a Thermoluminescence dating of a 50,000 year old human occupation site in northern Australia. *Nature* 345:153-156.

Roberts, R.G., Jones, R. and Smith, M.A. 1990b Stratigraphy and statistics at Malakunanja II: Reply to Hiscock. *Archaeology in Oceania* 25:125-129.

Roberts, R.G., Jones, R., Spooner, N.A., Head, M.J., Murray, A.S. and Smith, M.A. 1994 The human colonization of Australia: Optical dates of 53,000 and 60,000 bracket human arrival at Deaf Adder Gorge, Northern Territory. *Quaternary Science Reviews* 13:575-583.

Roberts, R.G., Yoshida, H., Gailbraith R., Laslett, G., Jones, R. and Smith, M. 1998 Single aliquot and single grain optical dating confirm thermoluminescence age estimates at Malakunanja II rock shelter in northern Australia. *Ancient TL* 16:19-24.

Shawcross, W. 1998 Archaeological excavations at Mungo. *Archaeology in Oceania* 33:183-200.

Simpson, J.J. and Grün, R. 1998 Non-destructive gamma spectrometric U-series dating. *Quaternary Geochronology* 17:1009-1022.

Smith, M.A. and Sharp, N. 1993 Pleistocene sites in Australia, New Guinea and island Melanesia: Geographic and temporal structure of the archaeological record. In M. Smith, M. Spriggs and B. Fankhauser (eds) *Sahul in Review: Pleistocene AaArchaeology in Australia, New Guinea and Island Melanesia*, pp.37-59. Canberra: Department of Prehistory, Research School of Pacific Studies, Australian National University. *Occasional Papers in Prehistory* 24.

Stuiver, M. and Reimer, P.J. 1993 Extended ^{14}C database and revised Calib 3.0 ^{14}C age calibration program. *Radiocarbon* 35:215-230.

Stuiver, M., Reimer, P.J., Bard, E., Beck, J.W., Burr, G.S., Hughen, K.A., Kromer, B., McCormac, F.G., van der Plicht, J. and Spurk, M. 1998 INTERCAL 98: radiocarbon age calibration 24,000-0 cal BP. *Radiocarbon* 40:1041-1083.

Taçon, P.S.C. and Brockwell, S. 1995 Arnhem Land prehistory in landscape, stone and paint. In J. Allen and J.F. O'Connell (eds) *Transitions: Pleistocene to Holocene in Australia and Papua New Guinea*, pp.676-95. *Antiquity* 69, *Special Number* 265.

Thorne, A., Grün, R., Mortimer, G., Spooner, N.A., Simpson, J.J., McCulloch, M., Taylor, L. and Curnoe, D. 1999 Australia's oldest human remains: Aage of the Lake Mungo 3 skeleton. *Journal of Human Evolution* 36:591-612.

Turney, C.S.M. and Bird, M.I. 2002 Determining the timing and pattern of human colonization in Australia: Pproposals for radiocarbon dating 'early' sequences. *Australian Archaeology* 54:1-5.

Turney, C.S.M., Bird, M., Fifield, L.K., Roberts, R.G., Smith, M., Dortch, C.E., Grün, R., Lawson, E., Ayliffe, L.K., Miller, G.H., Dortch, J. and Cresswell, R.G. 2001 Early human occupation at Devil's Lair, southwestern Australia, 50,000 years ago. *Quaternary Research* 55:3-13.

Volker, A.H.L., Sarnthein, M., Grootes, P.M., Erlenkeuser, H., Laj, C., Mazaud, A., Nadeau, M-J. and Schleicher, M. 1998 Correlation of marine ^{14}C ages from the Nordic Sea with the GISP2 isotope record: Iimplications for ^{14}C calibration beyond 25 ka BP. *Radiocarbon* 40:517-534.

Wang, X., van der Kaars, S., Kershaw, P., Bird, M. and Jansen, F. 1999 A record of fire, vegetation and climate through the last three glacial cycles from Lombok Ridge core G6-4, eastern Indian Ocean, Indonesia. *Palaeogeography, Palaeoclimatology, Palaeoecology* 147:241-256.

Williams, M.A.J. 1968 Termites and soil development near Brock's Creek, Northern Territory. *Australian Journal of Science* 31:153-154.

Williams, M.A.J. 1978 Termites, soils and landscape equilibrium in the Northern Territory of Australia. In J.L. Davies and M.A.J. Williams (eds) *Landform Evolution in Australasia*, pp.128-41. Canberra: Australian National University Press.