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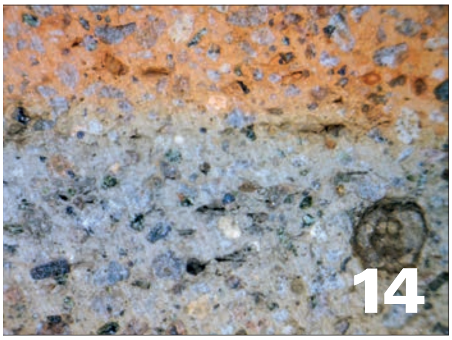

Articles

Thesis Abstracts - *Available online*

Book Reviews - *Available online*

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PUTTING WA ARCHAEOLOGY ON THE MAP:

THE INESTIMABLE CONTRIBUTION OF CHARLIE DORTCH

THEMED SECTION

GUEST EDITORS: SANDRA BOWDLER, JANE BALME AND JOE DORTCH

Image: Charlie Dortch at Devils Lair, southwest Australia.

Both half right:

Updating the evidence for dating first human arrivals in Sahul

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Abstract

This paper updates our previous analyses of the evidence for the timing of human arrival in Sahul. It reviews advances in dating technologies, summarises new data for sites published a decade ago or earlier, and examines the evidence from sites published since 2004. Extensions in time for first arrival can be attributed to improvements in both luminescence and radiocarbon dating techniques and especially the refinement of ^{14}*C calibration. The similarity of the ages of the earliest dates and their consistency with data from eastern Asia and Wallacea suggests that the discipline has now defined an event horizon that places first colonisation near but somewhere short of 50,000 years ago.*

> In 1995 one of us (JA) stayed with Charlie Dortch in Perth. At that time Charlie was seeing a charming woman; a few months later, speaking to Charlie on the phone, I enquired after her. 'It's finished,' said Charlie. 'She thought I was a rich American and I thought she was a rich Australian. We were both half right.'

Introduction

A decade ago we published two papers reviewing current knowledge on the timing of the initial colonisation of Sahul (Allen and O'Connell 2003; O'Connell and Allen 2004). Their purposes were to update the previous widespread review from a decade earlier (Smith and Sharp 1993) and also to continue to engage in the long and sometimes acrimonious debate on this subject that had begun with published claims for dates of 50–60 ka[1] for Malakunanja II [now Madjedbebe] (Roberts et al. 1990a) and that were subsequently extended to include Nauwalabila (Roberts et al. 1994). The claims brought an initial flurry of questions and responses (e.g. Bowdler 1990, 1991; Frankel 1990; Hiscock 1990; Roberts et al. 1990a, 1990b, 1990c) and we subsequently joined the discussion (e.g. Allen 1994; Allen and Holdaway 1995; O'Connell and Allen 1998).

It is not our purpose to revisit this debate here, except to note that three still-relevant themes emerged. On one side, proponents of luminescence argued that it allowed us to move past the technical limits of radiocarbon (e.g. Chappell et al. 1996a; Roberts et al. 1994), while on the other, questions of association between artefacts and dates in a landscape of bioturbation were emphasised by the startling implications that the new dates had for our understanding of world prehistory. Such problems were exacerbated by a poor understanding by archaeologists of both thermoluminescence (TL) and optically stimulated luminescence (OSL) and the assumptions underlying them in the 1990s; nor was any of this helped when TL-based claims for humans at Jinmium up to 176 ka emerged in 1996 (Fullagar et al. 1996) but were soon overturned (see below).

In this paper we revisit some of the sites that were in play ten years ago for which there are now new things to say; we also consider newer sites that contribute further information to the question of human antiquity in Sahul; and we assemble a list of acceptable and possibly acceptable sites of high antiquity as a basis for discussion. Before this we consider changes and improvements in both radiocarbon and luminescence technology, since these have been almost totally responsible for increases in acceptable first arrival dates over the last decade.

Advances in Radiometric Dating

Radiocarbon Contamination and Pre-Treatment

It was frequently noted in the early 1990s that the addition of 1% of modern carbon could convert a sample of infinite ^{14}C age to an apparent ^{14}C age of 35–40 kyr BP, when the real age might be as much as 100,000 years (e.g. Chappell 1991; Roberts et al. 1994), a problem that had been recognised for some time (e.g. Polach and Golson 1966). This hypothetical became a powerful driver in the dating debate, with researchers ignoring the fact that radiocarbon dates of 35–40 kyr BP might equally be correct (Allen 1992:245). Variations on this diversion occasionally still appear (Mellars 2006; O'Connor 2007; Oppenheimer 2012, 2014).

The problem of sample contamination had been previously addressed using different techniques depending on the material. Charcoal and wood samples were (and frequently still are) conventionally given ABA (acid-base-acid, also known as AAA, acid-alkali-acid) pre-treatment, where a hot acid wash with HCl, followed by a NaOH wash and a second HCl treatment removes contaminants. As noted below, there are several variations on this procedure.

As a direct result of the debate, Bird et al. (1999) developed and tested a different pre-treatment called ABOX-SC (acid-base-wet oxidation, followed by stepped combustion). It was found to remove contaminants both in the sample

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[1] Abbreviations used in this paper in conjunction with ^{14}C and luminescence ages are as follows: ka stands for thousand years ago, kyr BP equals thousand years before present (1950) and kyr cal. BP indicates that the ^{14}C date has been calibrated. Given the nature of the data and the purposes of this paper, most radiometric dates are cited to the nearest 100 years (one decimal point). The full dates are listed in the tables, with citations.

and in the laboratory that had previously not been removed by earlier pre-treatments. The technique was tested on charcoal samples from the northeast Queensland (Qld) site of Ngarrabullgan Cave (David et al. 1997) that had yielded a range of earlier ^{14}C dates from stratigraphic Units 3A-D from 28.8±1.1–36.1±0.8 kyr BP. The two samples with ABOX-SC pre-treatment were at the older end of the original range, suggesting that the Ngarrabullgan charcoal was largely uncontaminated; even so, ABOX-SC pre-treatment had refined these dates (Bird et al. 1999:139).

Subsequently, samples pre-treated using ABOX-SC were run for a number of sites that had been previously dated using conventional pre-treatment. From the Central Australian Puritjarra rockshelter, 31 ^{14}C dates conventionally pre-treated and nine luminescence ages assayed over a decade had increased the overall antiquity of the site from ca 22 ka (Smith 1987) to ca 35 ka (Smith et al. 1997). Even so the dates were uneven through the sequence, showing stratigraphic age reversals, consistent discrepancies between the radiocarbon and luminescence chronologies, and a wide range of dates for the earliest cultural deposits. The application of ABOX-SC removed the younger contaminants and significantly narrowed the chronological age range for the basal levels (Smith et al. 2001). However, as with Ngarrabullgan, the new technique did not extend the overall age of Puritjarra beyond that already determined for the site. New ^{14}C samples for Carpenters Gap and Riwi in the Kimberley of Western Australia (WA) and Cuddie Springs in northern New South Wales (NSW) were also run using the ABOX-SC pre-treatment. Again these refined previous ^{14}C ages from these sites but did not extend the chronologies (Fifield et al. 2001). The same team also re-dated the WA site of Devils Lair, where ABOX-SC pre-treatment extended the finite ^{14}C ages for human occupation from 32.5±1.3 kyr BP (Dortch and Dortch 1996) to somewhere between 41.5+1.4/-1.2 and 45.5+1.4/-1.2 kyr BP (O'Connell and Allen 2004; Turney et al. 2001a).

In practice, many radiocarbon laboratories continue to experiment and refine approaches to sample pre-treatment. For example, Hogg et al. (2013) outlined different protocols used at Waikato, Oxford and UC Irvine. At Waikato, the current pre-treatment for AMS dating employs an acid, multiple base and acid wash (acronym ABBA), where the sample is washed in hot HCl, rinsed and then treated with multiple hot NaOH washes. The NaOH insoluble fraction is treated with hot HCl, filtered, rinsed and dried (Fiona Petchey, pers. comm. March 2014). Most recently, Bird et al. (2014) compared the utility of ABOX-SC, ABA and hydrogen pyrolysis (hypy) pre-treatments, concluding that, in their laboratory experiments, ABOX-SC proved most efficient in removing contaminants, especially in older samples. It should be noted, however, that ABOX-SC pre-treatment may not be necessary in particular situations and may not work in others where the dating material is insufficient for this pre-treatment to be effectively applied.

Accelerator Mass Spectrometry

The increasingly common use of ABOX-SC pre-treatment complemented a further change in radiocarbon dating, namely the move towards accelerator mass spectrometry (AMS) dating and the gradual move away from gas proportional and liquid scintillation counting, although these remain in use. Both latter techniques detect and count the β particles in a sample over a set period of time and compare this activity to that in a modern standard. AMS follows a different procedure, directly counting the atoms of ^{14}C and ^{12}C and determining the ^{14}C/^{12}C ratio, also using a modern standard for comparison. This increases the sensitivity of the method and allows the measurement of much smaller samples, helping to avoid mixed samples and allowing a wider range of samples to be dated (but also increasing the problem of post-depositional movement of small organic dating targets).

As well, a recent inter-laboratory comparison test involving five reputable dating laboratories around the world identified small but unexplained differences in AMS measurements (Hogg et al. 2013). While these differences were small in the time range undertaken in this test (10–12 kyr BP), it is likely that differences would be greater at 40 kyr BP. Standard liquid scintillation assays may, in some situations, still be preferred to AMS, provided the sample size is sufficient (Fiona Petchey pers. comm. March 2014).

The combined use of modern pre-treatment and dating procedures means that finite radiometric dates to ca 55 ka are now being reported. As one example, five ABOX-SC AMS ^{14}C ages for the basal and culturally sterile deposits in the north Qld site of Nonda Rock yielded three finite ages with central tendencies >50 kyr BP and two infinite ages >55 ka (David et al. 2007). At the same time, few sites or samples are sufficiently studied to assert conclusively that finite dates of this age are necessarily reliable.

Calibration

Although the half-life of ^{14}C differs slightly from that measured by Libby last century, his original half-life is still used in reporting radiocarbon ages to maintain consistency. As well, the concentration of ^{14}C in the atmosphere has varied in the past. Both these complications are accommodated by calibrating radiocarbon dates against the tree-ring sequence up to ca 12.5 ka and now plant macrofossils up to ca 50 ka, as well as cross-dating, for example with U-series ages from corals (Reimer et al. 2013).

Much research effort has gone into refining calibration curves and extending their chronological range. As Table 1 indicates, recent and current calibrations of radiocarbon dates >30 ka, based on different sets of comparative evidence, show a general concordance; for each hypothetical date all comparisons are within one standard deviation of each other. Such differences are within limits acceptable to most (we are tempted to say all) archaeological enquiries, given the scales of resolution normally pertaining in archaeological sites (see below). Calibration curves now cover most of the effective range of the ^{14}C dating record (e.g. Bronk Ramsey et al. 2012).

Two General Remarks

It may seem trite to re-iterate that radiocarbon provides an age range where, at the probability given—one or two standard deviations—the real age of the sample has an equal chance of occurring anywhere within that range. Depending on the circumstance, it may be appropriate to generalise radiocarbon ages, but archaeologists using such data in specific terms should acknowledge this age range; in particular they should avoid the temptation of gravitating to the upper end of the range.

Our second observation is that, according to Williams (2012), almost half of the available radiocarbon data in Australia

Hypothetical Dates ^{14}C years BP	CalPal years cal. BP 1 sigma	IntCal09 years cal. BP 1 sigma	OxCal 4.2 years cal. BP 1 sigma
34,000±500	39,610±872	39,064±673	38,573±559
38,000±500	42,481±469	42,512±362	42,255±343
42,000±500	45,423±837	45,372±368	45,397±453
46,000±500	49,286±1827	49,505±496	No calculation

Table 1 A comparison of hypothetical dates >30 ka calibrated by CalPal2007-$_{\mathrm{HULU}}$ (Weninger and Jöris 2008), IntCal09 (Reimer et al. 2009) and OxCal 4.2 (Bronk Ramsey 2009).

derives from detrital charcoal rather than from clearly in situ features, such as hearths. Radiocarbon determinations from detrital charcoal should not be assumed to be automatically associated with the human behaviour being dated. Confidence is increased if the integrity of the deposit can be established on geomorphological or archaeological grounds and/or by assaying multiple age determinations. Both these matters are further addressed below.

Advances in Luminescence Dating

As with radiocarbon, the last decade has witnessed many technological improvements and advances in laboratory procedures that have enhanced confidence in various forms of luminescence dating. In Australia the early use of TL—for example at Madjedbebe (Roberts et al. 1990a) and Jinmium (Fullagar et al. 1996)—has almost entirely given way to the use of OSL. A principal reason for this is that, while TL works well in determining when previously heated materials, such as pottery and bricks, were originally fired, OSL is more appropriate for dating sediments, because sunlight on quartz grains will reset the OSL signal to virtual zero within two minutes, whereas part of the TL signal is insensitive to light (Duller 2008). This means, of course, that any residual TL signal present at the time of reburial will eventually result in a false and older estimate of age for that reburial.

Quartz is a preferred dating material, although other common minerals such as feldspars, calcite and zircons will also provide luminescence. However, OSL signals in quartz are more stable than those from feldspars, for example, where signals sometimes unexpectedly exhibit instability known as 'anomalous fading'.

The most important progression in OSL has been the move from larger aliquots (an undefined sub-sample of a sample) comprising perhaps several thousand grains, to smaller aliquots of tens or hundreds of grains and down to single grain measurements. These advances are important for several reasons. One is that measurements of the 'equivalent dose' (D_e) (see below), will yield more specific information, particularly if the sample contains grains of different ages that will be averaged if only measured as larger aliquots. Associated with this, it is now recognised that the luminescence signal may be dominated by only a small number of grains in the total sample. Both Duller (2008) and Wintle (2013) suggested that, in some samples, as few as 5–10% of grains may be providing 90–95% of the luminescence signal. Why this should be so is unclear, although heating in antiquity may sensitise the OSL signal in some grains. By isolating individual grains, the 'bright' ones can be analysed separately, offering more precise assessments of their potential ages. In addition, subject to evaluation using radial plot methods (Duller 2008) (see below), single grain analyses may be more appropriate when taking smaller samples from sites, reducing the risk of sampling strata separated in time as 'single' units, an important consideration in archaeological sites with very low deposition rates.

Equivalent Dose

Elsewhere, an anonymous reviewer observed 'The bottom line is that OSL and TL produce model age estimates, not dates. Archaeologists need to get this right.' The basic premise with luminescence dating, that age equals the total amount of radiation absorbed by the sample while buried (the D_e), divided by the annual amount of radiation that the sample receives from its surroundings (D_r), is deceptively simple. Much time and effort has been employed in refining the measurements of these inter-dependent components (see Duller 2008; Rhodes 2011; Wintle 2008, 2013).

The natural luminescence signal of a sample is measured in the laboratory, emptying the electron traps that give rise to the luminescence. The zeroed sample can then be irradiated with a series of increasing doses to determine a match between the natural luminescence and the equivalent induced level. For OSL dating, this procedure now normally incorporates the 'single aliquot regenerative dose' (SAR) protocol (Murray and Roberts 1998; Murray and Wintle 2000; Wintle and Murray 2006). This offers a solution to the problem of luminescence sensitivity (the amount of light an aliquot emits for each unit of radiation to which it is exposed), which can vary according to both laboratory procedures and sediment history. The protocol allows for corrections for any past changes in sensitivity, or changes during laboratory procedure, by using the OSL response to a small test dose after each OSL measurement. The SAR procedure has been shown to provide highly consistent D_e measurements for many, although not all, quartz samples (Duller 2008:11; Wintle 2013).

Because the SAR protocol can be easily applied to both large aliquot and single grain analyses, one advantage is that it can provide multiple D_e values for individual samples. These can be shown graphically in a radial plot of their dispersion, each point representing a measured D_e value whose precision is known. The plot defines a band that represents a standardised estimate indicating how different each D_e value is from the mean of all the D_e values. The width of the band represents two standard deviations from that mean. If 95% of the measured values fall inside this band, this reflects a single population, where the D_e uncertainties are sufficient to account for their scatter. If fewer than 95% fall within the band this is taken to mean that more than one population is present. Radial plots thus identify whether the sediments are mixed. In Australia it has sometimes been assumed that mixed sediments indicate a disturbed archaeological deposit (e.g. Roberts et al. 2001:1891 [cf. Field et al. 2008:102–103]; Robert Paton Archaeological Studies 2010), although this need not be so (see below).

Dose Rate

The important natural radioactive isotopes for luminescence dating are uranium (U), thorium (Th) and potassium (K). Both U and Th decay radioactively through a series of events, eventually to stable isotopes of lead, emitting α, β and γ radiation en route. ^{40}K decays to ^{40}Ca and ^{40}Ar with the emission of β and γ radiation. These emissions contribute to the total radiation absorbed by samples, together with cosmic rays that reach the earth's surface.

Dose rate (D_r) can be measured in the field or in the laboratory, and several techniques can be employed; these are reviewed by Duller (2008:16–17). Among them, an important assumption is often that the products in a decay chain are in secular equilibrium. This means that, within a decay chain, the descendent isotopes behave, in terms of their dose rate contributions, within normal ratios to their parent isotopes. This is not always the case. Disequilibrium occurs when members of the decay chains are enriched or depleted by in-site conditions, such as chemical leaching. Disequilibrium problems can be overcome by using laboratory emission counting techniques, like α or γ spectroscopy, and portable γ spectrometers for direct field measurements. While field measurements produce spectra of lesser quality than can be obtained in the laboratory, they accurately capture the γ dose rate from the surrounding sediments and thus allow for any lack of homogeneity at a scale of tens of centimetres. However, the assumption with field emission counting techniques is that the measured D_r has remained constant for the period for which the sample has been buried (Olley et al. 1997:434). As noted, where disequilibrium is recognised, the decay chains can be assessed using high resolution α or γ spectrometry, but if disequilibrium is not observed, previous equilibrium conditions cannot be further assessed.

Two other sources of potential error relevant here are water content in sediments and sediment composition. Water between mineral grains absorbs some of the radiation that would otherwise be absorbed by these grains. Since laboratory dose rate analyses are carried out on dried samples, water content has to be estimated and assumed to have been constant in the past. In deep-time sites that are today seasonally saturated but are traditionally excavated in the dry season when the seasonal water table is low, or sites that are dry today but in the past were wet, such as some Willandra Lakes sites, this assumption may be difficult to maintain. Field measurements in such situations may be of limited value. As Duller (2008:19) noted 'uncertainty in the water content is commonly one of the largest sources of uncertainty in the final age estimate derived using luminescence.'

Secondly, whereas natural sediments may be homogeneous and straightforward, some archaeological sites contain sediments mixed by human site use or mixed materials with different radioactive components. There may be low activity where there are high concentrations of carbonate or shell, or high activity where there is wood ash, rich in ^{40}K. These can result in different D_e values for contemporaneous grains (Wintle 2013). Where these problems are recognised, models can now be constructed to deal with such disparate data.

Despite these and further caveats identified by Wintle (2013), luminescence dating, properly applied and interpreted, is of particular importance in Australia, where the loss of datable organics in sites is widespread. It is instructive that there are increasing degrees of critical assessment being applied to this technique in this country, as three brief case studies indicate.

Case Studies

1. Claims for human occupation ages >100 ka for Jinmium (Fullagar et al. 1996), determined using TL, brought immediate responses. Spooner (1998) suggested that using the slowly bleached TL signal (the 375°C peak) rather than the rapidly bleached part of the signal (the 325°C peak) could mean that the measured sample carried residual TL at the time of burial. A similar response suggesting partial bleaching came from Roberts et al. (1998a), who proposed that decomposing soft sandstones in the deposit had released grains that had not been zeroed. This team re-dated the site using OSL (and radiocarbon) and suggested a basal date ca 22 ka and that much of the deposit above this date was Holocene. Jinmium has now dropped from the corpus of early Australian sites.
2. Allens Cave is an overhang at one end of a limestone doline in southern South Australia (SA), close to both the Great Australian Bight and the WA border. A preliminary OSL age of 39.8±3.1 ka from 3.9 m below surface (bs) was immediately below a claimed hearth and above an unknown number of stone artefacts that continued for a further 13 cm in depth (Roberts et al. 1996). A thorough testing of radioactive components at this site detected disequilibrium in the U decay chain (Olley et al. 1997) but mainly in the upper 10 cm of deposit which was thought to have a different origin to the lower sediments, themselves derived from the surrounding plain. It was concluded that, since the dose rate was deduced from high-resolution α and γ spectrometry, deviation of the calculated dose rate from the true dose rate was <2%. Newer values of D_e were subsequently calculated that marginally altered the original OSL age to 39.6±2.6 ka. A further OSL age estimate of 47.0±3.5 ka, 67 cm below any artefacts, was also announced (Murray and Roberts 1997; see also Turney et al. 2001b). So, while analysis of Allens Cave luminescence and radiocarbon dating identified disequilibrium in the upper part of the site, it also verified the accuracy of the 39.8±3.1 ka age of human occupation. A projected radiocarbon date for the hearth was never published (Bert Roberts pers. comm. August 2013).
3. Nonda Rock is a rockshelter on the plateau of Ngarrabullgan Mountain in northeast Qld. Nearby Ngarrabullgan Cave is dated to 40.1±1.4 kyr cal BP (David 2002; David et al. 1997; our calibration using OxCal 4.2). An intensive radiocarbon and OSL dating program was carried out on the sparse cultural deposits of Nonda Rock (David et al. 2007), where the lowest artefact-bearing layer is dated by radiocarbon to 31.7±0.3 kyr BP (ca 36 kyr cal BP). In the ca 14–16 cm of culturally sterile deposit below this, five AMS radiocarbon dates with ABOX-SC pre-treatment yielded three finite ages with central tendencies >50 kyr BP and two infinite ages >55 ka, suggesting a hiatus in deposition or missing deposit. A detailed OSL analysis was undertaken,

> where three samples straddling the cultural/non-cultural boundary were divided into 24 small aliquots which yielded a wide range of OSL ages between 10±2 and 80±7 ka. The eight ages from the samples considered most reliable only slightly reduced this spread to between 19±2 and 70±9 ka (David et al. 2007: Table 5). Various tests carried out during these analyses excluded disequilibrium in the decay chains and partial bleaching as explanations for these results. Instead, wide dispersions of ages in the small aliquot samples suggested mixing in the sediments (David et al. 2007).

These case studies indicate three of the more common problems that critical use of OSL now routinely eliminates by detailed testing within the analyses. However, little progress has been made on the long-standing problem of certainty in associating artefacts and radiometric ages, whether assayed by TL, OSL or radiocarbon. As noted, the ability to date single quartz grains can identify sediment mixing, but does sediment mixing disqualify archaeological deposits as disturbed?

Associating the Sedimentology and the Archaeology

It has long been a common circumstance that ^{14}C dates, especially those assayed on detrital charcoal, can be in stratigraphic sequence but not perfect chronological order. Frequently aberrant dates are explained as unsatisfactory for technical reasons (sample size, low carbon content, etc.) but equally frequently they remain unexplained. However, unless there is no coherent chronological pattern at all, it is rare for such date inversions to be taken as a sufficient reason to overturn the archaeological integrity of a site; while it is assumed that the sample had been displaced, the quality of the associated archaeological record is rarely questioned.

Single grain OSL ages allow a finer resolution to be applied to the problem by allowing the systematic measurement of post-depositional movement of sand grains down (or up) a section on the assumption that grains with similar ages were once adjacent. Nonda Rock is an example of a site where this strategy has been employed (David et al. 2007).

In Australia the demonstration that artefacts can move after initial discard was first made by Stockton (1973:116) in a 'scuffage and treadage' experiment at the Shaws Creek shelter that showed that one day's trampling of artefacts covered by 5 cm of unconsolidated sand redistributed them up to the surface and down to 16 cm below it. Conjoining flaked stone artefacts remains the most direct demonstration that archaeological deposits are disturbed, when it can be shown that items that were part of a single flaking episode are separated both vertically (moving both higher and/or lower in a deposit) and/or horizontally. Unfortunately the corollary, that conjoining items that show little vertical separation reflect an undisturbed deposit, does not hold, since artefacts can move in unison after discard.

An important critical review of this general field was recently undertaken by Richardson (2010:16–41), who examined 19 conjoining studies worldwide, together with an additional 22 studies involving experimentation and other research designed to elucidate taphonomic processes; these included only five Australian studies (Hughes 1977; Hughes and Lampert 1977; Shawcross 1998; Stern 1980; Stockton 1973). Listed causes for these processes include occupational disturbances (pits, post-holes) and artefact re-use and removal; together with a range of non-cultural processes, such as erosion, surface cracking in wet/dry sediments, fluvial action and bioturbation. Richardson identified a range of artefact and assemblage features associated with these taphonomic processes.

Previously, Richardson (1992, 1996) had identified significant vertical movement of artefacts in Kenniff Cave, central Qld, over minimal distances of 54–64 cm and possibly >90 cm (1996:85, 88). In this more recent study of the same site, Richardson (2010:243) adduced evidence to support two relevant, if surprising, conclusions:

- There is no relationship between rates of sedimentation and artefact breakage, artefact size or artefact displacement in any level in the site; and,
- There is also no relationship between rates of sedimentation and artefact abundance measured either by density, weight or time interval; or between either of these and stratigraphic units defined by sediment colour.

Prima facie this suggests that, at this site, deposition of artefacts and their post-depositional movements were independent of sedimentation rates, whether or not those sediments contain grains of different ages (which is not known for Kenniff Cave). A comparable case came from the open sand sheet site of Bend Road, near Melbourne. There Hewitt and Allen (2010) identified bioturbation and three large scale erosional events within the cultural layers. In addition, the multiple OSL samples showed wide dispersion ratios, indicating mixing of different aged grains. This is consistent with their morphology, being highly rounded and abraded, suggesting that they have been recycled as wind-blown sand perhaps for hundreds of thousands of years (Allen et al. 2008:25). Such movement is also consistent with the fact that all minerals except quartz had been removed from these sands, although these could equally have been leached.

Despite this, Bend Road exhibits both integrity and coherence in its archaeology. This paradox might be explained by the different processes acting on the taphonomies of artefacts, charcoal and sand grains. This is not to say that disturbed archaeological sites will not have mixed sediments; one might predict that they most frequently will. The point is that sediment mixing should not be taken as an indication of archaeological disturbance without further review.

Further Comments on Previously Assessed Sites

The previous review section of this paper used radiometric ages as reported. In the remainder of this paper, where we turn to analysis, all calibrated dates have been re-calculated for comparison using OxCal 4.2 (78), which employs the IntCal 13 curve (Bronk Ramsey 2009; see also *Radiocarbon* (2013) 55[4]). Neither the Southern Hemisphere offset SHCal 13, nor any offset for the marine reservoir effect have been applied, because with the age ranges discussed here such offsets make no significant difference to the data.

For convenience, in the following sections we consider the sites geographically, starting with East Asia and Wallacea and then dividing Sahul into a far northern section, consisting of Papua New Guinea and associated off-shore islands, a mid-northern section, comprising north Australia to approximately 25°S, a mid-southern section that includes the southern half of the mainland, and a far southern section that accommodates Tasmania.

Wallacea

Lene Hara

Lene Hara, a rockshelter in East Timor, was previously reported with the uncalibrated ^{14}C age of 34.7±0.6 kyr BP (O'Connor et al. 2002), which now calibrates to 39.3±1.5 kyr cal BP. O'Connor and colleagues returned to the site in 2009, where they uncovered older cultural deposits in breccia (O'Connor et al. 2010). Two dates, both on trochus shell, gave virtually identical uncalibrated AMS ^{14}C ages of 38.0±0.5 and 38.2±0.6 kyr BP. This latter date now calibrates to 42.4±0.9 kyr cal BP. This date is considered secure, both on the internal evidence from the site and by comparison with the first occupation date for a nearby site, Jerimalai (see below).

Far Northern Sahul

Bobongara

The open site of Bobongara (also known as Fortification Point) is located on the Huon Peninsula, northeast New Guinea, where a series of coral terraces rise to about 1000 m above sea level. The terraces record the interaction between glacio-eustatic sea level changes and ongoing tectonic uplift of the Huon Peninsula. A coral terrace was formed each time a glacio-eustatic rise in sea level overtook the rising land; the widest terraces correspond to glacial termination, when sea level rose about 120–130 m. Since their description by Chappell (1974), the terraces have been the subject of a series of studies, including the report by Groube et al. (1986) of the archaeological site at Bobongara, located on a late Pleistocene terrace labelled 'IIIa' in Chappell's (1974) terrace numbering scheme.

The Bobongara site was discovered following the surface collection of scores of large, coarse stone artefacts in small creeks cut into the late Pleistocene terraces. The site lies in a depression, thought to have originated as a small lagoon but incised by a creek after emergence from the sea, on terrace IIIa. Excavation revealed a series of three tephras, clay-rich and pedogenically altered. Several apparently in situ artefacts were recovered from beneath the middle tephra, including two described as waisted axes. Despite this, Groube et al. (1986) were cautious about the possibility of post-depositional disturbance at the site and considered that it was occupied at least 40,000 ka. Dating rested on three lines of evidence: (i) the tephras on terrace IIIa appeared not to be present on younger terraces IIIb and IIa; (ii) U-series ages of 45–53 ka had previously been reported from the reef comprising terrace IIIa; and (iii) TL determinations from the site indicated ages of 36–60 ka for the two lower tephras and 31–42 ka for the upper tephra. The D_e were well defined, but dose rate estimates were complicated by post-depositional leaching, possible U-series disequilibrium, and uncertain water content, giving rise to these wide age ranges.

Subsequent studies suggested that the site may be somewhat older than 40 ka. Roberts (1997:868) pointed out that the minimum TL age estimates in Groube et al. (1986) rested on dose rates unrealistically based on zero water content. Instead, he suggested a minimum age of 47 ka for the lower two tephras; however, Roberts' estimate was based on Groube's TL data and could not account for the uncertainties in it.

In addition, according to Chappell (2002), reef IIIa comprises three down-stepping members that formed during successive sea level rises that culminated around 60 ka (reef IIIa-upper), 52 ka (IIIa-middle) and 49 ka (IIIa-lower), respectively. The Bobongara site lies in a depression partly eroded into IIIa-upper and must be <60 ka in age. It should be noted that this assigning of the Bobongara site to IIIa-upper is not affected by variations in Huon terrace nomenclature reviewed by Chappell (2002). Terrace IIIb, comprising a substantial reef lower and younger than the IIIa group, formed during a sea level rise that culminated at 45 ka (Chappell 2002). Thus, given that Groube et al. found no trace on terrace IIIb of the tephras that bury the critical artefacts on terrace IIIa, the Bobongara site could well be as old as 47 ka, as Roberts (1997) suggested.

As a further comment concerning this and other comparable coastal sites, we have argued elsewhere (Allen and O'Connell 2008; O'Connell et al. 2010) that occupation was most likely near the culmination of a substantial sea level rise, when reef ecosystems and resources were maximal (Chappell 1993). In this light, occupation at Bobongara may well have coincided with the development of reef IIIb about 45 ka (Chappell 2002). However, both the testing of this speculation and a more precise age for occupation will require further dating of the site itself, if possible.

The matter is further complicated by wider debates on associating dates and terraces (e.g. Chappell et al. 1996b; Chappell and Shackleton 1986; Esat and Yokoyama 2006; Lambeck and Chappell 2002; Yokoyama et al. 2001) that are partly relevant to the Bobongara site. On the data available, we are unable to resolve the age of Bobongara beyond concluding that the axes date somewhere in the range 38–<60 ka.

Buang Merabak

Previous ^{14}C dates from four shells from the earliest cultural level of Buang Merabak cave, on the northern coast of New Ireland, initially provided an age range of ca 7–8 (39.1±0.6, 40.1±0.6, 33.3±0.6 and 32.4±0.6 kyr BP) (Leavesley et al. 2002). Subsequently, seven further shell samples were dated, all *Turbo argyrostomus*, six of them opercula. Two samples were assayed conventionally in a liquid scintillation counter and gave 'young' ages (ca 27 and 32 kyr BP). The remaining five were crushed, cleaned and digested to produce CO_2, which was reduced with granulated iron and hydrogen to graphite. Made into targets they were then assayed by AMS and provided as wide a range of ages as the first four samples, between 30.2±0.1 and 38.8±0.1 kyr BP.

Microscopic thin-section examination of these samples indicated that three were significantly altered by the uptake of secondary calcite, while the remaining two showed little indication of diagenesis. The ^{14}C dates for the former groups were pronounced unreliable, leaving ANU-11556-2 (34.1±0.1 kyr BP) and ANU-11556-6 (38.8±0.1 kyr BP) as acceptable radiometric ages (Leavesley and Chappell 2004).

The discrepancy between these reliable ^{14}C ages was argued to reflect a very low level of deposition in the earliest layer of the site, and the older of these ages was seen as sufficient confirmation of the two older dates in the first set of assays. Leavesley et al. (2002) had combined these first two older ages to offer a mean age of 39.6±0.6 kyr BP (43.5±0.9 kyr cal. BP) for earliest occupation. While we could wish for more certain dating, infrequent site occupancy in the early levels of Matenkupkum, another New Ireland cave site dated to 40.7±0.4 kyr cal. BP (O'Connell et al. 2010), offers support for the Leavesley et al. explanation, as well as the general age obtained.

Mid-Northern Sahul

Carpenters Gap 1

Frawley and O'Connor (2010) offered a maximum age estimate of 42.8±1.85 kyr BP (OZD 161) for this site in the Kimberley of WA. This date was not included in the discussion of dates in O'Connor (1995). The cited source, McConnell and O'Connor (1999), is concerned with another topic and reports this date in text without further information. It also appears in their Figure 5 (but with a different standard error, ±2.05 kyr BP). On this diagram OZD 161 derives from Spit 48. Nearby ^{14}C dates include Spit 40 = 39.7±1.0 kyr BP, Spit 45 = 30.7±0.65 kyr BP and Spit 49 = 39.22±0.87 kyr BP.

It is not known what this dating inversion might mean. There are numerous stone artefacts in these lower levels, although their distribution is unusual given that the site was excavated in 2 cm units: Spit 45 = 78, Spit 46 = 879, Spit 47 = 177, Spit 48 = 28, Spit 49 = 0, Spit 50 = 98, Spit 51 = 75 and Spit 52 = 0.

In their ABOX re-dating exercise for Carpenters Gap 1, Fifield et al. (2001) imprecisely claimed that the previous dates offered ages ca 40 ka. These researchers ran five ABOX-AMS ^{14}C dates, two for Spit 45 and three for Spit 48. The two former dates were divided into two sub-samples for one, and three for the other. These five ages all overlapped at 1 sd, with the 'oldest' age being 33.6±0.5 kyr BP. The three dates from Spit 48 also overlapped at 1 sd, with the 'oldest' age being 40.6±0.8 kyr BP (ANUA 7616).

OZD 161 calibrates to a statistically identical age to Nawarla Gabarnmang, currently the oldest acceptable site in Australia. However, given that it lacks a published history, here we continue to use ANUA 7616, calibrated to 44.3±1.4 kyr cal. BP.

Madjedbebe

Assessments of Madjedbebe (Malakunanja II) (e.g. Allen and O'Connell 2003; Hiscock 2008:35–36, 42–44; Mulvaney and Kamminga 1999:140 ff.) have been hindered by the lack of any detailed archaeological report or the illustration of any of the artefacts. Despite this, initial occupation before 50 ka is still accepted by some (e.g. Hiscock 2013; Oppenheimer 2014; Smith 2013:71). Crucial to this antiquity is a claimed pit, which is taken to be an in situ human artefact. The pit is straddled by single grain OSL ages of 44.2±4.7 ka (KTL164) above, and 55.5±8.2 ka (KTL162) (Roberts et al. 1998b) below. This pit has not been described or illustrated in any detail. The excavators make three brief references to it, noting the 'presence of artefacts in a small pit' overlain by KTL164 which thus provides a *terminus ante quem* for this feature (Roberts et al. 1990a:153); 'a well-defined pit or depression containing numerous artefacts' (Roberts et al. 1990b:125) and again 'a small pit containing artefacts' (Roberts et al. 1994:19). The stratigraphic drawings accompanying these articles include a representation of the pit only in Roberts et al. (1990b).

Further description was supplied by Hiscock (2008:36, 43). The pit was ca 20 cm deep, 'a fragile feature, preserved only as a subtle and delicate difference in the sediments; it was not disturbed or displaced.' Hiscock's stratigraphic drawing (2008:36) included the pit as shown by Roberts et al. (1990b), but the source of the description was not identified. What is clear is that the pit occurred in a zone containing the lowest artefacts: 'there is a marked peak in artefact density from 2.3 to 2.5 m depth with occupation starting abruptly at 2.6 m depth.' (Roberts et al. 1990a:153). Leaving aside our view that this zone of artefacts represents a post-depositional 'stone line' (Allen and O'Connell 2003 and references therein), the excavators commented, 'we cannot exclude the possibility that the lowest artefacts may have been trodden into unconsolidated older sediments … a conservative estimate places initial occupation at 2.4 m depth' (Roberts et al. 1990a:153).

Aware of the folly of talking in centimetres in a site of this nature, we are nonetheless left with no other evidence to review. If we assume, for the sake of argument, that KTL164 dates legitimate occupation in the site, this sample, taken from a depth of 230–236 cm is immediately (0–2 cm) above the surface from which the pit is said to have been dug (Roberts et al. 1990b:Fig. 1). KTL162, taken from 254–259 cm bs, dates the lowest artefacts, if they are in situ. These single-grain OSL ages are separated by an original TL sample from 241–254 cm bs, KTL158. This sample is dated at 52±7.1 ka, which predates the pit, being ca 10 cm below its surface. If we take the excavators' conservative line, it is difficult to see that the pit could be much older than KTL164 (44.2±4.7 ka). Hiscock (2008:43) noted that the pit could be younger than 40 kyr or substantially older than 50 kyr, but we do not see this on the evidence.

A lack of data precludes any consideration of whether any of the dense lower band of artefacts are in situ, or even whether the pit could be a natural depression (Roberts et al. 1990b:125). As observed by Kamminga, who first excavated the site in 1973 (Mulvaney and Kamminga 1999:142), the deposits at these levels show no stratification. Kamminga is of the opinion that the lowermost artefacts might even derive from the Holocene shell midden at the top of the site (Mulvaney and Kamminga 1999:141).

Our own view is less extreme, but there is no compelling evidence from Madjedbebe to indicate that it dates beyond the known general range of ages from other sites in northern Australia. In 2012 we were fortunate to be invited by Mike Smith to visit Madjedbebe during its extensive re-excavation. The new excavation encountered the same dense layer of early artefacts previously described and a very large suite of samples for OSL dating were taken. It is to be hoped that this new analysis will help to clarify the status of this site.

Mid-Southern Sahul

Willandra/Menindee

In our previous review of Lake Mungo (O'Connell and Allen 2004) we concluded that neither the M-III burial nor the local archaeological record provided strong support for human occupation before ca 43 ka.

There have been only a few significant additions to the Willandra/Menindee Lakes data base since 2004. Cupper and Duncan (2006) reported a re-investigation of the Tedford megafaunal site on the northern edge of Lake Menindee. In particular they reported paired ^{14}C and OSL dates for an in situ and stratified hearth (Cupper and Duncan 2006: Figure 6). Charcoal given AAA pre-treatment yielded an AMS radiocarbon age of 41.5±1.6 kyr BP (45.9±3.1 kyr cal. BP) and a small aliquot OSL age of 43.1±3.7 ka. Using a 2006 CalPal calibration these authors arrived at a weighted mean for the OSL and calibrated radiocarbon ages of 45.1±1.4 kyr BP for human activity at the site. This is the oldest secure date for humans along the Darling River.

For Lake Mungo, Olley et al. (2006) reported the OSL dating of blocks of sediment from the grave fill of the M-III burial that had been stored in a cupboard for 30 years. The application of single-grain LM-OSL (linearly modulated OSL) facilitated separating grains that had not been exposed to light during excavation and subsequent analysis. Just those grains were dated. These produced an OSL age of 40.9±4.5 ka. This analysis provided the first direct dating of sediments immediately associated with this burial, earlier estimates being determined from sediments into which the grave was dug and stratigraphically younger sediments nearby (Bowler et al. 2003). The estimate of Bowler et al. of 40±2 kyr for the M-III burial is confirmed by the Olley et al. LM-OSL date.

Bowler et al. (2012:Table 1) list all shell and otolith dates from various named localities within the Willandra Lakes, arguing that organic carbon has frequently not provided consistent and reliable radiocarbon ages for the region, whereas freshwater mussel shell carbonate has (see Bowler 1998; Gillespie 1998). The authors note that many of the shell dates employed hand-scraping with weak acid etching as pre-treatment, and the oldest results were close to maximum age limits for the liquid scintillation counting that was used. By comparison, all otolith dates were measured using AMS on single otolith samples, often with better decontamination procedures, stable isotope correction and smaller uncertainties (Bowler et al. 2012:282).

Of 88 listed dates, prior to calibration only three exceed 40 ka, while an additional nine exceed this age when calibrated. Shells from the same middens dated by both LS counting and AMS produce ages that all overlap at one standard deviation. A shell from Prungle South Lakebed returned a conventional age of 44.1±1.4 kyr BP, this date being beyond calibration; this sample is probably non-cultural because Bowler et al. (2012:283) refer to it only in the context of demonstrating the presence of water. An otolith labelled LAC-9002 from Locality 969660 on the Mungo lunette has a conventional age of 41.7±0.7 kyr BP (43.7±0.3 kyr cal. BP). This sample was collected by Nicola Stern, who considered it to be of non-cultural derivation (pers. comm. November 2013). Finally, a shell from Leaghur Peninsula produced a conventional age of 41.1±1.2 kyr BP (45.1±2.3 kyr cal. BP). The status of this sample is unknown. Unfortunately, the specific references for any of these dates/samples were not supplied by Bowler et al. (2012); thus it is not possible to judge whether the contexts of any of these determinations are cultural or non-cultural.

Lastly, Fitzsimmons et al. (2014) reported a new survey of the central part of the Mungo lunette (most previous work has concentrated on the southern area). The Lower Mungo Unit with the earliest traces of human activity elsewhere is sparse in this region and only two age determinations amongst those so far assessed exceed 40 ka. The relevant determinations are EVA1010, 51.0±2.7 ka and EVA1012, 40.0±1.8 ka, although neither of these dates are immediately associated with cultural material; instead they bracket the Lower Mungo Unit (Nicola Stern pers. comm. November 2013). As elsewhere, this unit contains some sparse cultural remains at this location, but they are yet to be directly dated. It seems clear from various reports (especially Bowler 1998) that the oldest cultural remains in the Willandra area likely to be in situ pertain to the uppermost part of the Lower Mungo Unit in the Mungo lunette. OSL age estimates of roughly 40 ka noted above for the M-III burial probably post-date these remains. A radiocarbon date of 38.1±1.1 kyr BP (AA 4252) (42.6±1.9 kyr cal. BP) reported for a shell midden at the top of the Lower Mungo Unit may do so as well (Bowler and Price 1998: 166). Gifford Miller (pers. comm. 2014), who processed this sample, advises us that the limited acid pre-treatment applied may mean that this date itself underestimates the true age of the sample. The oldest age estimate for the Lower/Upper Mungo interface is an OSL determination of 45.4±2.5 ka reported by Bowler et al. 2003 (Fig. 2, Column 2, Mungo I transect) but no direct archaeological relationship is apparent. Collectively, current data from western NSW indicate a human presence there not earlier than ca 46 ka, with the vast bulk of cultural material being associated with the Upper Mungo Unit and more recent deposits, all <42 ka.

Cranebrook Terrace

Thirty years ago Stockton and Holland (1974) drew attention to what they thought was a range of core tools in alluvial gravels at the base of the Cranebrook Terrace along the Nepean River, on the eastern side of the Great Dividing Range ca 50 km west of Sydney and provided an infinite ^{14}C date of >31.8 ka for the gravels. Thirteen years later, Nanson et al. (1987) provided a more detailed account of the stratigraphy and chronology of the basal gravels using both ^{14}C to date logs buried in the gravels and two TL samples to date the gravels themselves. The authors considered the logs to be contaminated by younger carbon and intensive pre-treatment eventually produced multiple ^{14}C dates ca 40 kyr BP, plus two TL dates of 43.1±4.7 and 47.0±5.2 ka. At the same time the authors carried out a more detailed analysis of the five artefacts claimed by Stockton and Holland (1974) and determined that two items were definitely cultural, with another a possibility. In a short postscript a further five possible artefacts from subsequent work at the site were added. Given the unprepossessing context, the site was treated with some scepticism (e.g. Mulvaney and Kamminga 1999:138).

Most recently Stockton and Nanson (2004:60) offered four more TL dates for the gravels that range between 41.9±5.5 and 50.4±8.9 ka, noting that the 'original in situ pebble chopper would be dated at or near this last date.' Apart from the wide standard deviation of this date, the question of whether the claimed tools are of human origin remains open and their recovery from a fluvial bed not encouraging. If these artefacts are humanly derived and in situ, their ages now fall into the range of old dates from elsewhere in Sahul and the site would rank amongst the oldest on the eastern seaboard.

Nauwalabila and Devils Lair

While no new data have appeared for Nauwalabila or Devils Lair in the last decade, we summarise the problems we see to be associated with claims of antiquity back to, and beyond, ca 50 ka for these two sites. In 2003 we offered extensive analysis of both sites (Allen and O'Connell 2003:13–16 for Nauwalabila and 2003:7–8 for Devils Lair).

For Nauwalibila, O'Connell and Allen (1998) suggested that the positions of the lowest artefacts and the rubble containing them might be secondary, resulting from post-depositional termite bioturbation. Bird et al. (2002) tested this idea by examining the sediment particle size distribution, but the results were inconclusive. However, this re-examination identified charcoal particles down to the base of the section, beyond the depth previously thought to mark the depth of detrital charcoal. Thus, multiple new samples were dated using ABOX-SC and other pre-treatments and employing both AMS and conventional radiocarbon dating. Stratigraphically, between OSL ages of 30.0±2.4 and 53.4±5.4 ka, ten charcoal samples returned conventional ^{14}C ages between 5.9±0.2 and 27.4±0.4 kyr BP; and between OSL ages of 53.4±5.4 and 60.3±6.7 ka, seven charcoal samples returned conventional ^{14}C ages between 6.9±0.1 and 9.5±0.2 kyr BP. These 17 ^{14}C samples showed no indication of chronological sequence.

Bird et al. (2002) rejected the suggestion that these detrital charcoal fragments had been displaced down the deposit through bioturbation. Instead, these authors argued that a fluctuating groundwater table had degraded the charcoal and reduced the carbon content, with microbial activity being the vector of carbon replacement. We had, and continue to have, problems with this and supplementary explanations, including the claimed coherence of ^{14}C dates from the upper part of the sequence, the offered scenario for groundwater fluctuation, and the question of carbon replacement. Most telling in our view is that not all of the lower charcoal fragments are degraded and the non-degraded set is explained as having travelled down termite tunnels; even so they show the same approximate ages as the degraded charcoal fragments. Further arguments were canvassed in Allen and O'Connell (2003). Here it is sufficient to say that it would be valuable to have new single grain and small aliquot OSL data from the site to re-address these issues, after the new results from Madjedbebe are assessed.

For Devils Lair, Turney et al. (2001a) published the results of a re-dating program that included 27 ^{14}C and lesser numbers of OSL, ESR and U-series dates. An age for human occupation at 50 ka was claimed. All ^{14}C dates were processed using AMS and either ABA-BC (bulk combustion) or ABOX-SC pre-treatment.

The earliest claimed in situ feature is a set of nested hearths in Layers 27–30 Upper dated in Layer 28 by ^{14}C to 41.5+1.4/1.2 kyr BP (45.4±2.6 kyr cal. BP). Two OSL dates from the same layer are 43.4±2.2 and 44.4±2.1 ka, offering close support. Layer 30 Lower is a sterile layer of in-washed soils up to 30 cm thick, dated by ^{14}C to 45.5+1.4–1.2 kyr BP (beyond calibration). 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. Six or seven stone items in Layers 31–38 (if seven, one in each layer, except Layer 36) are accepted by us and other archaeologists as artefacts. Layer 32 has an OSL date of 47.1±2.6 ka and Layer 33 has a ^{14}C date of 46.7+2.2 /1.7 kyr BP (beyond calibration). Layers 39–51 are devoid of any indications of human presence. A conventional ^{14}C date of 48.1+2.6/2 kyr BP and an OSL date of 51.1±2.6 ka derive from Layer 39. Charlie Dortch, who spent much of his professional career excavating, analysing and publishing Devils Lair, accepts that the artefacts in Layers 31–38 are likely to be in secondary position but argues that, even so, Layer 30 Lower sealed these few artefacts and that the age of this layer is a minimum age for these few flakes. It is a strong argument.

Our uncertainty about Devils Lair involves several related issues. The source(s) and deposition of layers between 30 Upper and 39 are not well understood, but they reflect the water movement of vast amounts of soil over potentially thousands of years, and the subsequent re-working of these deposits in situ. Since Layer 30 Lower is itself in-washed, the charcoal within it that provides the ^{14}C age for this layer might also be in-washed. If so, it would be older, and possibly much older, than the time of its arrival in Layer 30 Lower. The seven artefacts below it are scattered through 80 cm of equally disturbed deposits. If truly sealed by Layer 30 Lower, and if the charcoal sample truly dates this layer, the artefacts must be at least this age, although, as discussed above, Richardson has shown at Kenniff Cave that under the right conditions artefacts can move significant distances through apparently unbroken strata.

Our reservations about Devils Lair are not fatal to the claims of antiquity that have been made for this site, but they require better substantiation and preferably corroboration from other local sites. If the date for Layer 30 Lower is accepted, its conventional age central tendency is more than 2500 years older than the conventional age central tendency of the oldest ^{14}C date from Nawarla Gabarnmang, currently the next oldest published site in Australia. This date would make humans at Devils Lair as old as the earliest humans in Niah Cave in Borneo (see below). Given the slender data base for the Devils Lair claim, the site's geographical location in the south-west corner of the Australian mainland, and the lack of any similarly aged human presence between it and Borneo, accepting this age is difficult—it would make Devils Lair a distinct outlier in the present data set.

Sites Reported since 2003 (Figure 1)

East Asia

A full review of this region is beyond our present scope (but see Bellwood 2013). The data frequently remain difficult to assess and often comprise human skeletal remains rather than archaeological sites. Norton and Jin (2009:256, 258) suggested that, for East Asia, archaeological correlates for modern human behaviour occur mostly after ca 50 ka, but that a growing amount of evidence indicates that anatomically modern humans may have been there before this date. Various late archaic human fossils carrying more modern morphological attributes are claimed before 100 ka (Demeter et al. 2012a), such as the partial mandible from Zhirendong in southern China (Liu et al. 2010).

Tianyuan Cave

The partial skeleton of a modern human from Tianyuan Cave in northern China (Shang et al. 2007) was directly dated using AMS ^{14}C to ca 39 kyr cal. BP, considered to be a reliable date because it comes from a layer where five calibrated AMS ^{14}C dates for other animal bones run between ca 36–44 kyr cal. BP, although no stone artefacts or other cultural material were in association.

Tam Pa Ling Cave

Additionally, a modern human cranium from Tam Pa Ling Cave in Laos was directly dated using U/Th to a maximum age of 63.6±6 ka (Demeter et al. 2012a), although the age claimed in the title of this paper was 46 ka. The deposits in the cave contained no artefacts or other evidence of human occupation and the human fossil is considered not to be in

Figure 1 Locations for sites listed in Table 2.

situ, possibly washed in from outside the cave. The cranium was found at 2.35 m bs and is bracketted by an OSL date of 46.4±4 ka from 0–20 cm below it and an uncalibrated AMS ^{14}C date of 51.4±3.3 kyr BP from 25 cm above it. The OSL sample was a small aliquot analysed using the SAR protocol; the ^{14}C sample was given ABA pre-treatment. This age inversion was questioned by Pierret et al. (2012) but defended by Demeter et al. (2012b). Because no model of U uptake could be determined the U-series age is taken to be a maximum age for the fossil and it is thus dated in the range 46–63 ka.

Niah Cave

The iconic site of Niah Cave in Sarawak, Borneo, was excavated in the 1950s and 1960s by Tom and Barbara Harrisson and is famous for the modern human skull originally dated to ca 40 ka. A re-investigation of the site began in 2000 that assessed the early excavations and offered a new chronostratigraphy for the site. The stratigraphy is complex, made more so by the post-depositional movement of sediments, water incision and bioturbation. Despite this, an extensive radiometric dating program, coupled with geomorphological and sedimentological studies, offers confidence in an initial occupation of Niah by modern humans before 46 ka. The oldest ^{14}C date, 45.9±0.8 kyr BP, is beyond calibration, with the oldest calibrated date being 47.6±1.6 kyr cal. BP. There are some indications of a human presence below these dates. Direct dating of the skull using U-series produced two ages. The error-weighted mean of these, 35.2±2.6 kyr, is considered suspect on technical grounds; instead the authors offer an age range of 39–45 ka for this fossil (Barker et al. 2007).

Tabon Cave

From Tabon Cave, on Palawan Island, the diaphysis of a right tibia of *H. sapiens* has been directly dated by U-series to 47.0+11/-10 ka (Détroit et al. 2004). Given the wide error margin, disturbed stratigraphy and different, much younger ages for two other human bones in the deposit, the authors are properly cautious about an age for this fossil in the upper end of the possible range. The date for human occupation in Tabon thus remains uncertain.

Wallacea

Callao Cave

Two U-series ages have been reported from the direct dating of *Homo* skeletal remains from the Philippines. Mijares et al. (2010) described the dating of an almost complete third metatarsal from a breccia bed in Callao Cave. While provisionally attributing it to a small *H.sapiens*, these researchers concede that the bone's 'peculiar proportions' make this attribution tentative. Other bones in the breccia bed include deer, pig and an extinct bovid, thought to reflect human predation. Two deer bones date younger (52–54 ka) than the human metatarsal, for which an age of 66.7±1 ka was assayed. This is considered a minimum age. No stone artefacts were associated with the breccia layer, although they occur higher in the deposits. However, one deer bone carries three parallel cut marks. It is thought that the bones in this layer, including the metatarsal, were originally deposited elsewhere in the cave. Collectively, the evidence suggests that any claim for modern humans in Callao Cave at 67 ka remains, at best, unproven.

Jerimalai

In Timor dates from Jerimalai shelter (O'Connor 2007) initially extended the previous date of ca 39 kyr cal. BP for the nearby cave site of Lene Hara (O'Connor et al. 2002). As noted above, newer dates of ca 42 kyr cal. BP are now available for this latter site (O'Connor et al. 2010). In Jerimalai, two 1 x 1 m test pits were excavated; the earliest dates in each pit were on marine shell and provided ages of 42.5±0.9 and 41.7±0.7 kyr cal. BP. Although details of stratigraphy and dating procedures are still awaited, these ages are accepted as secure because of the corroborative evidence from Lene Hara.

Far Northern Sahul

Ivane Valley

Table 2 lists radiocarbon ages for four sites in the Ivane Valley in the eastern highlands of Papua New Guinea. Work done in the 1960s (White et al. 1970) had identified Pleistocene occupation at Kosipe Mission in the valley and all the listed sites are within ca 2 km of each other and Kosipe; indeed AER Trench 2 is a further excavation at Kosipe. All sites sit close to the 2000 m asl contour, along a ridge overlooking a swamp, and give the impression of ephemeral camp sites that might occur more-or-less continuously along this ridge. The stratigraphy is very similar at each site and a suite of 22 uncalibrated AMS ^{14}C Pleistocene dates are stratigraphically consistent and range from 22.2±1.1–42.0±1.6 kyr BP (Ford 2012; Summerhayes et al. 2010). The oldest calibrated date, 46.1±3kyr cal. BP, we take to be among the oldest secure dates for humans in Sahul despite the wide error margin, because of the corroborative dates from the nearby sites.

Mid-Northern Sahul

Nawarla Gabarnmang

Nawarla Gabarnmang is a large painted sandstone/orthoquartzite rockshelter on the plateau above the Arnhem Land escarpment first excavated in 2010, with excavations continuing. David et al. (2011) reported 25 AMS ^{14}C dates from Square A, while David et al. (2013) reported an additional 18 AMS ^{14}C dates from Square E. Minor inversions of dates in both squares appear not to impact on the chronology of the oldest units; for both squares the stratigraphically and chronologically oldest samples all fall within 1σ of each other. The oldest date is 42.9±1.5 kyr BP (46.9±2.7 kyr cal. BP). This age is very similar to the oldest date from the Ivane Valley. Nawarla Gabarnmang is currently the oldest securely dated site in Australia.

GRE 8

GRE 8 is a rockshelter situated in a limestone escarpment near the Gregory River in the Carpentaria region of Qld, south of Lawn Hill National Park, where a small test pit was excavated in 2002 (Slack et al. 2004). An unreported number of chert artefacts at the base of the 65 cm deep deposit were dated using freshwater mussel shell, present throughout the deposit and abundant at the base. Pre-treatment consisted of scraping the shell surface and the sample was assayed in a liquid scintillation counter to 37.1±3 kyr BP (43.1±6.1 kyr cal. BP). Although only a single sample was run from the lowest level, three further ^{14}C dates from above are in stratigraphic order, being approximately 28, 16 and 4 kyr BP. Although more extensive excavation and dating of this site would be desirable, there is no basis for questioning this date.

Parnkupirti

Parnkupirti is an open site on a feeder creek to Lake Gregory, on the edge of the Great Sandy Desert in WA (Veth et al. 2009). Four stratigraphic units occur, with Unit D, the surface unit, and Unit C below it being of archaeological interest. The landscape is eroded and artefacts in Unit D are of uncertain provenance, having been subject to probable post-depositional disturbances, including the swelling and cracking of lake muds and termite bioturbation. Although associated with an OSL date of ca 37 ka, some artefact types, such as tulas, are seen by the excavators to be Holocene tools in a secondary position, while others may be in situ. Unit C is a unit of well-rounded cobbles and gravels, indicating high velocity fluvial activity. A flaked core was recovered from this unit, with the flaking argued to reflect human activity.

Eleven OSL samples indicated sediment mixing in their dose distributions; however, three samples were considered reliable. For Unit C, two of these samples from the same depth gave ages of 52.4±3.0 and 45.0±2.9 ka, statistically the same age at 2σ. From the younger Unit D the third reliable sample gave an age of 37.2±5.8 ka. As the authors acknowledge, more work is required at Parnkupirti to identify earliest human occupation. A date of >45 ka was accepted by Hiscock (2013), but at present such an antiquity is at best uncertain.

Ganga Maya

Morse et al. (2014) reported two early sites recently excavated in the northeast Pilbara region of WA. Kariyarra Rockshelter produced an oldest conventional ^{14}C age of 34.0±0.4 kyr BP (Wk 35955), while the large cave site of Ganga Maya produced two similar ^{14}C ages, from excavation unit (XU) 20, 39.8±0.7 kyr BP (Wk 37321), (43.7±0.6 kyr cal. BP) and from XU 23, 40.4±0.9 kyr BP (Wk 38073), (44.2±0.8 kyr cal. BP). Both these latter samples were given ABBA pre-treatment and were run as AMS dates.

The square that produced these samples has a further five Pleistocene aged ^{14}C dates above them, all in temporal order.

Region/Site Name	Location	Technique (Where Known)	Sample Number	^{14}C ka	Calibrated ^{14}C ka OxCal 4.2 (1σ)	Calibrated Range ka (2σ)	OSL/TL (ka)	U-Series (ka)	Reference
East Asia									
Tianyuan Cave	China	AMS ^{14}C	BA 03227	34.43±0.51	39.01±1.25	41.50–36.52			1
Tam Pa Ling	Laos	ABA-AMS ^{14}C, U-series, TL, OSL	A1291	51.4±3.3	Beyond calibration				2
			TPL1/DEM				46.0±4.0	63.6±6.0	
Sunda									
Niah Cave	Borneo	ABOX-AMS ^{14}C	OxA-V-2057-31	45.9±0.8	Beyond calibration				3
		U-series	APNIAH2					35.2±2.6	
Tabon Cave	Palawan	U-series	IV-2000-T-197					47+11/-10	4
Wallacea									
Callao Cave	Philippines	U-series						66.7±1	5
Jerimalai	Timor	AMS ^{14}C	Wk 17831	38.26±0.60	42.45±0.85	44.12–40.76			6
Lene Hara		AMS ^{14}C	Wk 26405	38.21±0.61	42.41±0.86	44.14–40.69			7
Far North Sahul									
Ivane -Vilakauv	Eastern Highlands, PNG	ABA-AMS ^{14}C	Wk 27072	41.95±1.57	46.13±3.01	52.15–40.10			8
Ivane-South Kov		ABA-AMS ^{14}C	Wk 23354	40.3±0.96	44.16±1.59	47.34–40.97			
Ivane-Airport Mound		ABA-AMS ^{14}C	Wk 23356	39.84±0.91	43.81±1.47	46.75–40.87			
Ivane-AER Trench 2		ABA-AMS ^{14}C	Wk 17901	35.05±0.67	39.80±1.41	42.61–36.98			
Buang Merabak	New Ireland	AMS ^{14}C	ANU 8179	39.59±0.55	43.46±0.92	45.30–41.63			9
Mid-North Sahul									
GRE 8	Carpenteria, Qld	Liquid scintillation ^{14}C	Wk 11429	37.11±2.95	43.10±6.12	55.33–30.87			10
Nawarla Gabarnmang	Arnhem Land, NT	ABBA-AMS ^{14}C	Wk 32126	42.87±1.45	46.91±2.72	52.34–41.48			11
Parnkupirti	Lake Gregory, WA	OSL	K2007/K1528				45.0±2.9/52.4±3.0		12
Jansz	Cape Range, WA	Acid wash (shell)-AMS ^{14}C	Wk 8919	35.23±0.45	39.84±1.04	41.92–37.76			13
Ganga Maya	Pilbara, WA	ABBA-AMS ^{14}C	Wk 38073	40.44±0.91	44.22±0.76	45.74–42.71			14
Djadjiling		ABBA-AMS ^{14}C	Wk 23313	35.75±0.55	40.37±1.16	42.69–38.04			15
YIN09-002		ABA-AMS ^{14}C	Beta 323638	?	45.25±0.83				16
Kakutungutanta		ABBA-AMS ^{14}C	Wk 33656	36.04±0.27	40.59±1.46	43.51–37.67			17

Table 2 Radiometric ages for sites published since 2003 and for sites published before 2003 where newer data are available (see text for details). Sites in bold are considered secure, the remainder are uncertain. Key to references: [1] Shang et al. 2007; [2] Demeter et al. 2012a; [3] Barker et al. 2007; [4] Détroit et al. 2004; [5] Mijares et al. 2010; [6] O'Connor 2007; [7] O'Connor et al. 2010; [8] Summerhayes et al. 2010; [9] Leavesley and Chappell 2004; [10] Slack et al. 2004; [11] David et al. 2011; [12] Veth et al. 2009; [13] Smith 2013; [14] Morse et al. 2014; [15] Law et al. 2010; [16] Rowland and Timms 2012; [17] Sinclair and Wright 2012; [18] Koettig 1987; [19] Cupper and Duncan 2006; [20] Stockton and Nanson 2004; [21] Richards et al. 2007; [22] Walshe 2012; and [23] Robert Paton Archaeological Studies 2010. Continued overleaf.

Region/Site Name	Location	Technique (Where Known)	Sample Number	^{14}C ka	Calibrated ^{14}C ka OxCal 4.2 (1σ)	Calibrated Range ka (2σ)	OSL/TL (ka)	U-Series (ka)	Reference
Mid-South Sahul									
Fal Brook	Hunter Valley, NSW	AMS ^{14}C	Beta 17009	34.58±0.65	39.20±1.61	42.43–35.98			18
Menindee	Western NSW	ABA-AMS ^{14}C, OSL	NZA 23736	41.53±1.63	45.86±3.10	52.06–39.67	43.1±3.7		19
Cranebrook Terrace	Nepean River, NSW	TL	W935				50.4±8.9		20
Box Gully	Lake Tyrell, Vic.	ABA-AMS ^{14}C	Wk 171	40.38±0.77	44.11±1.29	46.69–41.53			21
PACD H1	Port Augusta, SA	AMS ^{14}C, OSL	GNS NZA 34976	40.5±0.95	44.29±1.60	47.50–41.09			22
Far South Sahul									
Jordan River Levee	Eastern Tasmania	OSL	JR05				37.5±3.8		23

Table 2 continued.

Age increases with depth in satisfactory order, suggesting no hiatus in deposition, although the deposition rate is low. Bone refuse is present in the upper half of the ca 1.4 m of deposit only, reflecting the acidic nature of the lower deposit, but charcoal is present throughout. Stone artefacts are present in only small amounts throughout the deposit and occur mostly in the middle of the site. There are only 22 artefacts in the bottom 12 XUs, covering approximately 25–45 ka. While a stronger archaeological indication of human presence would be reassuring, there is no basis on which to question this age for humans at the site.

Djadjiling

Djadjiling is a rockshelter on the Hamersley Plateau, also in the Pilbara region (Law et al. 2010). Sandy deposits containing exfoliated material from the shelter ceiling and walls extend to ca 1.8 m bs, with evidence for occupation beginning at ca 1.45 m bs. Stone artefacts are plentiful in the pre-LGM deposits and 12 radiocarbon dates are in general stratigraphic order, although two anomalous dates derive from the deepest, non-cultural deposits. These are said to reflect charcoal possibly falling in from higher in the section. The report does not identify the pre-treatment or measurement procedures for these samples. Three ^{14}C ages from the earliest cultural unit provide almost identical ages, the oldest being 35.8±0.6 kyr BP (40.4±1.2 kyr cal. BP). The similar ages of all three samples offer support for the reliability for the timing of initial human occupation of Djadjiling.

Jansz and C99

Jansz and C99 are rockshelters at the northern end of Cape Range on the North West Cape in WA. Undertaken as doctoral research, the published account of this work provides few details on the radiometric dates (even, inexplicably, omitting the standard errors for the dates provided) (Przywolnik 2005). Since we have not accessed the Przywolnik thesis, pre-treatment and dating procedures are unknown to us. However, according to Smith (2013:86), seven ^{14}C dates on shell from Jansz are in stratigraphic order, with the oldest date being 35.2±0.5 kyr BP (39.8±1kyr cal. BP). The nearby site of C99 has sequences of ^{14}C dates from two squares, again on shell; excluding the uppermost age determination from each square there are six ^{14}C dates from each square in stratigraphic order. The oldest date is 33.9±0.3 kyr BP (Smith 2013:86), calibrated to 38.3±0.9 kyr cal BP. The oldest dates from the two squares overlap at two standard deviations and are statistically identical. As well, they overlap with the oldest ^{14}C date, 34.2±1.1 kyr BP (38.7±2.4 kyr cal. BP) from Mandu Mandu, a rockshelter in the same range but 50 km to the south (Morse 1993). There is, however, some uncertainty about this latter date in that it sits above a basal ^{14}C date on shell of 30.0±0.9 kyr BP and is thought to be contaminated with groundwater carbon dioxide, making it possibly 1000 years too old. Despite these problems, this group of sites is important because they each contain evidence of Pleistocene marine foraging, and are only 10–12 km inland from the edge of the continental shelf.

Mid-Southern Sahul

Box Gully

Box Gully is located in a clay lunette on the northern side of Lake Tyrell in the Victorian Mallee (Richards et al. 2007). A Pleistocene presence here was recognised more than 20 years ago (Macumber 1991). Most cultural material recovered from the 2001 excavation resided in Stratum 4, where four AMS ^{14}C dates and one conventional ^{14}C date group between 22.0±0.1 and 27.7±0.2 kyr BP. All samples were given standard ABA pre-treatment. A single stone artefact was recovered from Stratum 5, together with a further AMS ^{14}C date of 40.4±0.8 kyr BP (44.1±1.3 kyr cal. BP). Richards et al. (2007:4) suggested this artefact might derive from Stratum 4, but note that the raw material of this artefact differs from those above it. Thus, while human presence at Lake Tyrell before 40 ka remains unproven, occupation there at the older date would be unsurprising, given the use of the Willandra Lakes at this time.

PACD H1

PACD H1 is a hearth of burnt sandy sediment exposed in 2010 and sitting on the hard pan on Coopers Dune, bordering Dempsey Lake near Port Augusta in SA (Walshe 2012). Two ^{14}C dates (assumed to be AMS dates) on the burnt sediment, assayed in two different laboratories, produced (again assumed) conventional ^{14}C ages of 38.3±1.0 and 40.5±1 kyr BP. Sediments judged to be above and certainly below the hearth were then dated using OSL, in order to accommodate possible problems with dating hearths that have no visible charcoal but abundant humic acids, as previously observed in Willandra hearths (Gillespie 1998). The results, 32.1±2.4 and 36.6±2.6 ka above, and 44.5±3.7 and 48.1±3.3 ka below support the calibrated ^{14}C age of 44.3±1.6 kyr cal. BP for this feature.

Further support for this age may soon be available from apparently very old human occupation in Warratyi rockshelter in the Flinders Ranges, currently being subjected to additional chronological assessment (Giles Hamm pers. comm. May 2014).

Far Southern Sahul

Jordan River Levee Site

Some attention has been given to claims for an open site in eastern Tasmania on the Jordan River Levee (Robert Paton Archaeological Studies 2010), where three OSL dates overlap at 2σ (26.6±2.6, 34.0±2.8 and 37.5±3.8 ka). In our view this site, formed by the frequent flooding of the river, has been so far insufficiently sampled and claims for an in situ deposit have not been demonstrated. Elsewhere, Olley (undated [2010]) has seriously questioned the dating of this site.

The Grey Literature

The Jordan River Levee site is part of an ever-increasing amount of unpublished literature associated with commercial archaeology across six Australian states and two territories and in Papua New Guinea. It is inevitable that some early sites have gone undetected in excavations where radiometric dating has not been attempted and that others will be overlooked in reviews like ours. This is especially true of WA, with the expansion of mining. This is not the place to discuss this problem, but it requires urgent critical review by the discipline, especially if the scientific importance of archaeological sites still has any value.

We are grateful to colleagues who have drawn our attention to sites listed here. We are also aware of other early sites from the Pilbara not yet available for citation. To our knowledge these do not change the overall picture we present.

Fal Brook

Excavations along a pipeline at Fal Brook, near Singleton in the Hunter Valley in 1986, located stone artefacts in the B-horizon (generally thought to be of Pleistocene age). Three disparate Pleistocene ^{14}C dates were obtained at site SCGD 16: 1) ca 13 kyr BP, stratigraphically below artefacts in the B-horizon; 2) >20 kyr BP from charcoal associated with a stone hearth; and 3) 34.58±0.65 kyr BP, dated by AMS from within the B-horizon and again associated with artefacts (Koettig 1987). This date calibrates to 39.2±1.6 kyr cal. BP. The site was assessed for possible post-depositional movement. Sub-surface erosion gullies within the B-horizon were noted, as were surface cracks and minor bioturbation. Koettig systematically deleted any of the 43 artefacts in this horizon where doubt existed for original deposition, and concluded that nine of the artefacts could be accepted as in situ. Again, conservatively, Koettig suggested that occupation commenced at some time prior to 20 ka. On this basis Fal Brook is a potentially early site, but the calibrated date remains uncertain. Apart from Koettig's conservative stance, Hughes et al. (2014) questioned how the charcoal might have survived in the B-horizon. At the same time, Hughes et al. argued the possibility that several artefacts in Pleistocene sands at Warkworth in the Hunter Valley are in situ and date to ca 45 ka by OSL, despite their dismissal by Scarp Archaeology (2009:91). We note but do not engage this dispute here, although the relevance of the data is further briefly considered in the discussion section.

YIN09-002

YIN09-002 is a western Pilbara rockshelter. A 1 x 1 m test pit yielded 19 artefacts between the surface and 40 cm bs, together with frequent large charcoal pieces. Two Pleistocene age samples are reported (Rowland and Timms 2012): one from 30 cm bs with a date of 41.7±0.5 kyr cal. BP and one from 34 cm bs with a date of 45.3±0.8 kyr cal. BP. The dates were assayed by Beta-Analytic P/L as AMS ^{14}C dates with ABA pre-treatment. The conventional ages are not provided, nor the calibration identified; the dates are given as age ranges and whether these ages are at one or two standard deviations is unknown. Without any description of the sediments or other necessary analysis these dates are considered uncertain; if they are accurate, YIN09-002 is the oldest yet reported site in the Pilbara.

Kakutungutanta

Kakutungutanta (also known as CB10-93) is a small rockshelter in the Chichester Ranges in the Pilbara reported by Sinclair and Wright (2012). We are yet to sight this report. Hook and Veth (2013) noted a radiocarbon date of 36±0.3 kyr BP (40.6±1.5 kyr cal. BP). This sample is said to come from 27 cm bs, with stone artefacts continuing to 81 cm bs. We understand that further investigation, including OSL dating, is scheduled. Without further information we cannot assess this site.

Discussion

Terrell (1986:4–5) observed that science must confront the possible with the actual. Claims made almost a quarter of a century ago for human arrival before 50 ka and possibly at 60 ka still linger. Hiscock (2013) proposed dates to 55 ka, still relying mostly on the 'famous four' (Lake Mungo, Devils Lair, Nauwalabila and Madjedbebe), despite questions about all of them. As outlined here, we see no new evidence from these sites to persuade us from our critiques of a decade ago. Nor are we persuaded that attrition rates will have obliterated most traces of the earliest sites. Hiscock's appeal to modelling the disappearance of short-term megafaunal kill sites (Surovell and Grund 2012) as a measure of the disappearance of ancient habitation sites, especially those protected in rockshelters and caves, has no equivalence; as Surovell et al. (2009) argued, rockshelter deposits are relatively free from post-depositional loss of the deposits, although loss of organic components within them frequently occurs. Equally, Hiscock's continued appeal to sea level rise obliterating the earliest sites and providing a period of invisibility ignores the existing data for Timor, the Huon Peninsula, New Ireland and North West Cape, where sites were within walking distance of the Pleistocene coastline. These sites mostly reflect the exploitation of coastal resources and show initial settlement dates no older than inland sites. The invisibility argument was credible when coastal colonisation models (e.g. Bowdler 1977) held sway; today it is more plausible to assume that inland dispersion occurred very soon after initial arrival and that the earliest human landfall occurred within the standard deviations of the known oldest dates from Sahul.

Here, following Terrell's dictum, currently available undisputed dates, either OSL or ^{14}C, do not exceed ca 47 ka in their central tendencies (Table 3). Six calibrated ^{14}C date ranges set at 2σ reach 50 ka, but in every case this is attributable to a large standard error (between 5.14 kyr [Devils Lair] and 12.24 kyr [GRE 8]).

Table 3 shows 23 Sahul sites older than 40 ka at 1σ (none of these exceed 50 ka) that few dispute; this number would increase significantly if the uncertain very old sites discussed here were to be verified as true records. If sites >35 ka were included, we estimate site numbers would easily increase to >50. For us this is not a pattern that reflects the chance remnants of some larger number of early sites. Such a pattern might be expected to show a long tail of dispersed sites of widely variable ages preceding multiple sites of similar ages increasing in numbers over time. The famous four do not represent such dispersed sites, since each contains, or can be suspected to contain, evidence of disturbance that calls into question the relationships of artefacts to dated sediments. What we see as acceptable dates for Devils Lair and the Willandra have been argued here only on their internal site evidence; that these ages, younger than the extreme ages sometimes claimed for these sites, fit into the wider database we take as confirmation of our position.

The 22 sites dated by ^{14}C in Table 3 (see also Figure 3) span in their central tendencies less than 9000 years; the ten oldest of these sites are contained in their central tendencies by a span of only 2800 years. Figure 3 shows remarkably similar patterns and similar ages for sites in far north, mid-north and mid-south Sahul, attesting to the speed of colonisation (almost instantaneous at the resolution available to us) and the reliability of the data set as a whole. As well, the two Timor sites can be added to this set without altering these parameters. This suggests that we are looking at a genuine 'event horizon'[2]. While technology and further discoveries may modify this pattern and marginally expand it, our view is that 50 years of archaeological exploration has determined, within the current limits of the discipline, when humans arrived in Sahul.

As noted, relatively small increases of a few thousand years in earliest colonisation dates over the last decade are primarily attributable to greater precision in the technologies of measurement, and to better calibration curves, rather than older sites continuing to be discovered. This has had two related outcomes. The first is that we can now rid ourselves of the 'radiocarbon barrier' arguments. Neither the re-dating of previously dated sites, nor the dating of new sites over the last decade, has produced ^{14}C dates that approach the present-day upper limits of the technique. The second aspect is the increasing concordance between calibrated ^{14}C ages and luminescence ages, where both are employed on individual sites. Apart from the added confidence that such correspondences bring, any discrepancies between these techniques no longer result in choices between one or the other technique. Instead, they lead to more thorough re-assessments of both dating techniques and site formation processes. The application of luminescence dating techniques has not led to a dramatic change in the absolute antiquity of human arrival in Sahul, as was once predicted. Indeed, while multiple sites where both luminescence and ^{14}C techniques have been employed yield statistically identical ages when considering absolute antiquity, it is of interest that the oldest central tendencies of the radiometric dates listed in Table 3 rest predominantly with ^{14}C. Whether there are technical or other implications in this trend is beyond our capacity to judge.

Demonstrating certain association between artefacts and dates remains an intractable problem that many Sahul archaeologists continue to ignore, especially in contract archaeology. We applaud signs that university-based researchers are confronting the issue more directly (i.e. Langley et al. 2011; Richardson 2010; Venn 2008) as part of their research agenda.

An initial Sahul colonisation date ca 47–48 ka finds good support in the archaeological evidence for South East Asia and Wallacea, in climate and sea-level studies, and in non-chronological analyses of mitochondrial, non-recombinant Y-chromosome and nuclear DNA, previously reviewed by us (Allen and O'Connell 2008; O'Connell and Allen 2007, 2012; O'Connell et al. 2010). (The chronological frameworks applied to these genetic studies are in large part derived from the archaeology and thus lead to circularity in the argument.) The genetic evidence is now the subject of a more extensive examination we are undertaking elsewhere.

The initial occupation of the Japanese Islands is an interesting parallel case of colonisation involving open sea crossing. Current views suggest this event did not occur much before 40 ka, with entry through the Korean Peninsula (Kudo and Kumon 2012; Takashi 2012). The Korea Strait is ca 200 km wide, but stepping stone islands might have reduced the maximum crossings to ca 40 km. A similar argument has been developed for a crossing from Taiwan to Luzon in the northern Philippines (Davidson 2013); the equivocal evidence for early human occupation in Callao Cave has been reviewed earlier in this paper.

What emerges from these reviews is the real possibility that the conjunction of environmental, biological and historical opportunities that led to the human colonisation of Sahul may have existed for only a few thousand years before climate changed and sea level began its long descent towards the LGM low sea stand. Following Chappell (1993), falling sea levels would have promoted steep shorelines and pronounced lowering of the productivity of the coastal ecotones of the Wallacean islands. It is logical that populations on these islands diminished under these conditions. So if, as the available human genetic data indicate (e.g. Friedlaender et

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[2] An event horizon is the boundary in space and time dictated by the available data (and the quality of that data) for the occurrence of an event. The term, originally borrowed from the theory of general relativity has been used previously in Australian archaeology by Chappell et al. (1996a) in respect of the 'radiocarbon barrier' and by Gillespie (2002) in much the same sense as used here. It allows that new data might modify the horizon (or boundary) but that 'there is now such a large dataset built into the literature that deviations from established wisdom require stringent scrutiny' (Gillespie 2002:455).

Site Name	Location	Sample Number	^{14}C ka	Calibrated ^{14}C ka OxCal 4.2 (1σ)	Calibrated Range ka (2σ)	OSL/TL (ka)	U-Series (ka)	Reference
Sunda								
Niah Cave	Borneo	OxA-V-2057-31	45.9±0.8	est. 49–50				1
		APNIAH2					35.2±2.6	
Wallacea								
Jerimalai	Timor	Wk 17831	38.26±0.6	42.48±0.85	44.18–40.78			2
Lene Hara		Wk 26405	38.21±0.61	42.41±0.86	44.14–40.69			3
Far North Sahul								
Bobongara	Huon Peninsula, PNG						<60.0–38.0	4
Buang Merabak	New Ireland	ANUA 15808/15809	39.59±0.55	43.46±0.92	45.30–41.63			5
Ivane-Vilakauv	Eastern Highlands, PNG	Wk 27072	41.95±1.57	46.13±3.01	52.15–40.10			6
Ivane-South Kov		Wk 23354	40.3±0.96	44.16±1.59	47.34–40.97			
Ivane-Airport Mound		Wk 23356	39.84±0.91	43.81±1.47	46.75–40.87			
Ivane-AER Trench 2		Wk 17901	35.05±0.67	39.80±1.41	42.61–36.98			
Kupona na Dari	New Britain	OxL 1426				39.8±5.2		7
Matenkupkum	New Ireland	ANU 8179	35.41±0.43	40.01±0.96	41.92–38.10			8
Yombon	New Britain	BETA 62319	35.57±0.48	40.23±0.50	42.44–38.02			9
Mid-North Sahul								
Carpenters Gap	Kimberley, WA	ANUA 7616	40.6±0.8	44.28±1.36	47.00–41.56			10
Ganga Maya	Pilbara, WA	Wk 38073	40.44±0.91	44.22±0.76	45.74–42.71			11
Djadjiling		Wk 23313	35.75±0.55	40.37±1.16	42.69–38.04			12
Ngarrabullgan	Atherton, Qld	ANUA 8806	35.46+0.75/-0.69	40.10±1.40	43.70–37.94			13
GRE 8	Carpenteria, Qld	Wk 11429	37.11±2.95	43.10±6.12	55.33–30.87			14
Jansz	Cape Range, WA	Wk 8919	35.23±0.45	39.83±1.11	42.05–37.60			15
Nawarla Gabarnmang	Arnhem Land, NT	Wk 32126	42.87±1.45	46.95±2.75	52.44–41.46			16
Riwi	Kimberley, WA	ANUA 13005	41.3±1.0	44.98±1.91	48.78–41.16			17
Mid-South Sahul								
Allens Cave	Nullarbor Plain, SA	Ox$_{OD}$AC390				39.8±3.1		18
Devils Lair	Southwest WA	ANUA-11709	41.46+1.4/-1.19	45.44±2.57	50.59–40.30			19
Menindee	Western NSW	NZA 23736	41.53±1.63	45.86±3.10	52.06–39.67			
		LM10				43.1±3.7		20
PACD H1	Port Augusta, SA	GNS NZA 34976	40.5±0.95	44.29±1.60	47.50–41.09			21
Upper Swan	Southwest WA	SUA-1500	39.5+2.3/-1.8	44.77±3.92	52.60–36.94			22
Willandra	Western NSW	AA 4252	38.1±1.1	42.56±1.92	46.40–38.72			23
		MG-1				40.9±4.5		24

Table 3 Earliest secure dates for archaeological sites occupied by anatomically modern humans (*H. sapiens sapiens*) in Sunda, Wallacea and various parts of Sahul. Radiocarbon dates are calibrated by reference to OxCal 4.2 (via IntCal13); the date for Niah is beyond calibration by this method. References: [1] Barker et al. 2007; [2] O'Connor 2007; [3] O'Connor et al. 2010; [4] current text, [5] Leavesley and Chappell 2004; [6] Summerhayes et al. 2010; [7] Torrence et al. 2004; [8] Allen and Gosden 1996; [9] Pavlides and Gosden 1994; [10] Fifield et al. 2001; [11] Morse et al. 2014; [12] Law et al. 2010; [13] David 2002; [14] Slack et al. 2004; [15] Smith 2013; [16] David et al. 2013; [17] Fifield et al. 2001; [18] Murray and Roberts 1997; [19] Turney et al. 2001a; [20] Cupper and Duncan 2006; [21] Walshe 2012; [22] Pearce and Barbetti 1981; [23] Bowler and Price 1998; [24] Bowler et al. 2003; [25] Cosgrove 1995; and [26] Allen 1996. Continued overleaf.

Site Name	Location	Sample Number	^{14}C ka	Calibrated ^{14}C ka OxCal 4.2 (1σ)	Calibrated Range ka (2σ)	OSL/TL (ka)	U-Series (ka)	Reference
Far South Sahul								
Parmerpar Meethaner	Northern Tasmania	Beta 68158/ CAMS 10270	33.85±0.45	38.13±0.63	39.38–36.87			25
Warreen	Southwest Tasmania	Beta 42122A/ ETH 7665B	34.79±0.51	39.46±1.07	41.61–37.32			26

Table 3 continued.

Figure 2 Locations for sites listed in Table 3.

al. 2007; Hudjashov et al. 2007; van Holst Pellekaan 2013), this led to the Pleistocene populations of Sahul being isolated from the rest of the world until the terminal Pleistocene, the implications of such isolation for understanding the prehistories of Sahul and Wallacea are as yet barely realised.

Lastly, the geographical distribution of these early sites (Figure 2) begins to identify the patterns of continental colonisation. The early occupation of the New Guinea Highlands is a surprise, as is the early settlement of the semi-arid fringes around the desert centre (O'Connell and Allen 2012). While the later occupation of central and southwest Tasmania (Tas.) have environmental explanations that help define the nature of the advance of early settlement, the continued near-absence of early sites along the eastern seaboard and in Victoria (Vic.) imply different explanations. While southeast Vic. may have been, like eastern Tas., a less hospitable environment to occupy on any significant basis, the major east coast river valleys would seem, *a priori*, to have been more enticing. As noted, Pleistocene occupation in the Hunter River valley remains elusive; there the post-LGM stripping of alluvial deposits containing riverine archaeology provides one persuasive explanation that might apply more widely along the eastern seaboard.

Conclusion

A strong argument can be made that the first humans arrived in Sahul shortly after 50 ka—on current evidence not earlier than 47–48 ka. This body of evidence is now sufficiently robust to suggest that dates for sites well in excess of this figure should be treated as outliers in the data. As a matter of course, these sites will require especially close scrutiny before acceptance.

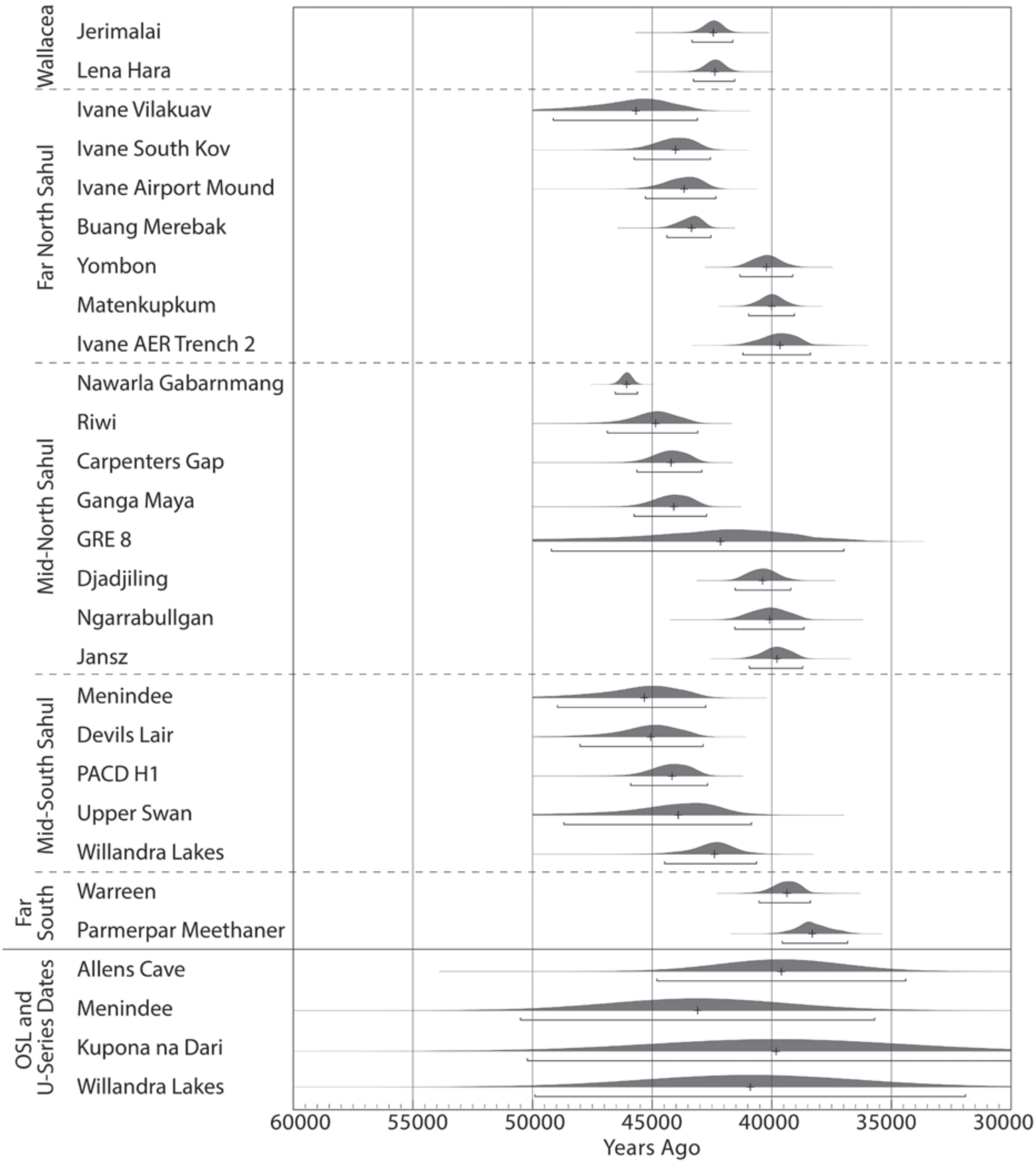

Figure 3 Plot of calibrated radiocarbon dates and other radiometric age estimates for early human colonisation of Sahul and nearby islands. Data from Table 3. Plus signs under each polygon indicate the central tendency; bars under those signs show two sigma limits bracketting that tendency. Tails show the absolute outer limits for each date or age estimate.

Epilogue

> In 2001 JA spent a day with Rhys Jones, shortly before Rhys died. We reminisced about our past and inevitably arrived at the dating question that had divided us a decade earlier. Rhys prefaced this conversation with 'Whichever one of us is proved right …'—the only time I ever heard him concede the possibility that he might be wrong on this subject. Maybe we were both half right.

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