Dating the colonization of Sahul (Pleistocene Australia–New Guinea): a review of recent research

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Abstract

The date for the initial colonization of Sahul is a key benchmark in human history and the topic of a long-running debate. Most analysts favor either a 40,000 BP or 60,000 BP arrival time, though some have proposed a much earlier date. Here we review data from more than 30 archaeological sites with basal ages >20,000 years reported since 1993, giving special attention to five sites with purported ages >45,000 years. We conclude that while the continent was probably occupied by 42–45,000 BP, earlier arrival dates are not well-supported. This observation undercuts claims for modern human migrations out of Africa and beyond the Levant before 50,000 BP. It also has critical but not yet conclusive implications for arguments about a human role in the extinction of Sahul megafauna.

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1. Introduction

Sahul is the continent formed when glacio-eustatically lowered sea levels exposed dry land connections between Australia, New Guinea and Tasmania [7]. Despite decades of inquiry, the date for its initial human colonization remains a contentious issue. Some favor a 40–45,000 year (40–45 ka) BP figure [3,60]; others one ≥60 ka [107,112]; still others one ≥100 ka [72,142]. Resolving the matter has important implications for a wide range of questions, among them the pattern and timing of early modern human population movements out of Africa [53,84] and the role of humans in Sahul megafaunal extinctions [94,116]. Here we briefly review the history of the problem, note some recent developments in radiocarbon chronometry that affect current debate, then consider in detail the key data, with emphasis on information from five localities published in the last decade or so. We conclude that while an initial occupation date of 42–45 ka BP now seems well-supported, earlier dates do not, largely for taphonomic reasons. We comment briefly on the implications of these findings for debates about early modern human population movements and their environmental impact.

2. Some history

As recently as the early 1960s, humans were thought to have arrived in Sahul less than ten thousand years ago [96]. By the early 1980s, widespread application of the radiocarbon technique had pushed the minimum date to just under 40 ka [103,121]. While agreeing that this figure was the proper conservative estimate, the late Rhys Jones [77, p. 30] observed that it was “suspiciously close” to the limits of $^{14}$C chronometry, and suggested that an earlier date might well be documented by another technique. In the early 1990s, his prediction was arguably met by the report of luminescence dates of 50–60 ka from the Arnhem Land sites of Malakunanja and Nauwalabila [109,112] (see Fig. 1 for locations of all sites mentioned in text).
In the decade since, debate about the initial occupation date has crystallized along two main lines: one underlining the technical limits of $^{14}$C dating and championing the virtues of luminescence [31,78,108], all in support of a minimum 60 ka date for Sahul colonization; the other contending that whatever the merits of luminescence as a technique, its application requires greater sensitivity to archaeological context than enthusiasts have so far displayed, and that the case for a date much greater than 40 ka is at best poorly warranted [2,97].

Quietly paralleling these developments for a time was the emergence of an argument for a much earlier date. Writing in the mid-1970s, Kershaw [80] suggested that the occupation of Sahul might be marked by certain changes in fossil pollen records indicating the appearance of anthropogenic fire regimes, much like those known ethnographically [76]. Singh et al. [122] applied this line of reasoning to the analysis of a sediment core from Lake George, near Canberra, proposing that a decline in pollen from fire-sensitive taxa, coincident with a sharp rise in charcoal particle counts, indicated the arrival of humans in the surrounding countryside as early as 130 ka BP. Though archaeologists were reluctant to take this suggestion seriously [143, p. 42], palynologists and other Quaternarists continued to develop

Fig. 1. Sahul and adjacent parts of southeast Asia, showing sites and localities mentioned in text and tables. Shaded areas indicate land exposed by a 200 m fall in sea level.
it, ultimately pushing for colonization dates as early as 185 ka [72,81,142]. In the mid-1990s, this argument drew apparent support from reports on Jinnium, an archaeological site in northwestern Australia, dated by luminescence at 116–176 ka [54].

As it happened, the Jinnium dates were overturned almost as soon as they were published: reanalysis showed that the archaeological record there had accumulated within the last 20 ka [114]. Meanwhile, the proposed evidence of early anthropogenic fire was found to be attributable mainly to sharp changes in climate and related increases in fire frequency, not human activity [25,68,82].

This leaves us with the dispute between proponents of what are now called the “long” (≥ 60 ka) and “short” (ca. 40 ka) chronologies [3]. Further discussion requires a brief review of recent developments in radiocarbon dating.

3. On 14C chronometry

Critics of the use of radiocarbon in dating Sahul colonization have focused on two closely related issues: the technical limits of the method and the problem of sample contamination. It is generally agreed that conventional 14C analysis cannot produce reliable dates >40 ka. In principle, accelerator mass spectrometry (AMS) can yield dates >50 ka, but small amounts of post-depositional contamination can generate erroneously young age estimates in any sample, particularly those with real ages >30 ka.

This problem has been alleviated (though not entirely eliminated [18]) by the development of improved pretreatment protocols, notably “acid base wet oxidation with stepped combustion” (ABOX-SC) [17]. Paired with AMS, this particular technique re-establishes the possibility of generating accurate sample age estimates >50 ka. As we will see, it has already had an important impact on Sahul chronology.

A different but equally important problem has been brought into focus by continuing efforts to “calibrate” 14C dates. It has long been recognized that age estimates produced by analysis of radiocarbon may differ significantly from real sample ages, primarily as a function of past changes in rates of atmospheric 14C production and exchange with the marine reservoir. Simply put, 14C years are not the same as solar years, and the relationship between the two varies through time. This relationship is well-controlled for the Holocene but remains highly problematic for earlier time periods [104,138].

Analyses of terrestrial and marine data sets by various combinations of radiocarbon, U-series, luminescence, paleomagnetic and stratigraphic techniques indicate very large fluctuations in atmospheric 14C content in the >30 ka time range, mainly as a function of changes in geomagnetic field strength and North Atlantic thermohaline circulation [14,37,83,86,139,146]. As a result, 14C age estimates on samples deposited prior to this date may fall short of real values by up to 7 ka. Complicating matters further, estimates of the timing and magnitude of these excursions vary significantly across data sets, making it impossible at present to produce a reliable calibration curve.

For the moment, there is no easy way around this problem: 14C dating must remain an important source of information on Sahul chronology, yet in the absence of data from other sources the precise significance of any pre-30 ka radiocarbon date must also be considered unclear. Relying primarily on the summary in Van der Plicht [138], we assume for the sake of discussion that 14C dates in the 30–42 ka range may be up to (but not necessarily as much as) 7 ka short of true calendar values. For 14C dates >42 ka, the offset may be somewhat less, possibly in the 3–4 ka range, perhaps even smaller (1–2 ka). All 14C dates reported here are uncalibrated and their “real” ages assessed on a case-by-case basis, often by comparison with associated luminescence dates, which are generally seen to be expressed in the rough equivalent of solar years [105].

4. Data from the last decade

In their comprehensive early 1990s review of the field, Smith and Sharp [124] listed 58 sites east of Wallacea with basal dates >20 ka, 27 with dates >30 ka. Collectively, they indicated human occupation in a variety of site types, dated by several radiometric techniques, located across a wide range of environments throughout Sahul and in island Melanesia nearby to the east. The oldest were Malakunanja at 55–60 ka, Nauwalabila at >53 ka, and Huon Peninsula at ca. 40 ka (all ages estimated on the basis of techniques other than radiocarbon). No other reported archaeological age determination exceeded 40 ka in its central tendency.

Data published since 1993 fall into two categories: (1) those from newly discovered and/or reported sites, and (2) those from previously known sites that have been re-dated, often with different and/or refined radiometric techniques. Tables 1 and 2 show the oldest claimed ages for sites in each category.

Table 1 lists 14 trans-Wallacean sites published since Smith and Sharp’s compilation: twelve from Sahul and two from island Melanesia. Four have produced dates >30 ka, but only one of these, a non-finite date, is older than 40 ka. While previous contamination-related criticisms of radiocarbon dates in the 30–40 ka range might equally well be leveled at Table 1 sites, these results reflect a pattern remarkably similar to that available a decade ago [2].

Table 2 lists 18 trans-Wallacean localities, several of which (including some also shown on Table 1) have been re-dated more than once. Seventeen are in Sahul; one is
in island Melanesia. Only three have newly reported dates older than 50 ka: (1) Mungo, dated by Thorne et al. [131] at 62 ka; (2) Huon Peninsula at 47–61 ka; (3) Malakunanja at 56–61 ka, similar to the original estimate. Of the remaining 15 sites, only Devil’s Lair has a new date in excess of 45 ka. The other 14 are all pegged at <45 ka.

Luminescence dating has been used at nine of these sites; ABOX-SC and AMS dating at eight. Four sites have been reassessed using both techniques.

4.1. Re-dating by luminescence

Of the nine sites in this group, two—Malangangerr and Allen’s Cave—yielded results from levels below those containing datable carbon. Neither new date exceeds 40 ka in its central tendency. In two other sites, Parmerpar Meethaner and Puritjarra, newly reported luminescence dates have been rejected in favor of more coherent \(^{14}C\) chronologies (for details, see [3,126]). At Cuddie Springs and Ngarrabullgan, OSL dates are in essential agreement with newer radiocarbon chronologies. At Mungo, OSL dates were used to support the U-series age of 62±6 ka for the M-III burial [131]. They were later used by another dating team [24] to reduce the age of this interment to 40±2 ka, and the claimed presence of humans in the area to 46–50 ka. At Malakunanja, as indicated above, new dates are consistent with the original estimates. Finally, at Devil’s Lair, OSL dates generally support the newer radiocarbon chronology, suggesting human occupation there before 43 ka, but not before 51 ka.

4.2. Re-dating by AMS with ABOX-SC pretreatment

Six of the eight sites in this group returned ages similar to or slightly younger than those reported earlier. Finite ages were produced for the initial occupations at Riwi and Carpenter’s Gap; dates for the first uses of Puritjarra, Cuddie Springs and Warreen were marginally reduced. The technique also managed to correct previous anomalies in the sequence for Puritjarra, suggesting that discrepancies were the product of contaminants that had escaped pre-treatment in earlier analyses [126]. At Nauwalabila, multiple analyses yielded dates so inconsistent with those produced by luminescence that they were rejected as contaminated [18] (see below for further discussion). At Devil’s Lair, the ABOX-SC technique proved remarkably successful in extending the previous \(^{14}C\) chronology. Five samples, arrayed in proper stratigraphic order, produced finite dates down to 48.13±2.59/−1.96 ka, plus three infinite readings from deeper in the profile (see also below).

4.3. Summary of recent re-dating

Reanalysis of nine sites by luminescence suggests occupation at Devil’s Lair, Mungo and the Huon Peninsula at 45–50 ka, and at Malakunanja >50 ka. Data from the other five sites offer no support for ages greater than 40 ka. Of the eight sites re-dated by AMS with ABOX-SC pre-treatment, only Devil’s Lair produced a significantly earlier date, but again not older than 50 ka. Overall, re-dating has marginally extended the ages of a number of sites, but has mostly failed to support the long (>60 ka) chronology. The five sites where claims for human antiquity >45 ka persist are Huon Peninsula, Devil’s Lair, Lake Mungo, Nauwalabila, and Malakunanja. We now turn to a more detailed review of each.

5. Five key sites

5.1. Huon Peninsula

The site is located at Bobongara (or Fortification) Point on the Huon Peninsula, northeast New Guinea [66]. It consists of a series of seven raised coral terraces, the uppermost of which is now about 400 m above sea level. Each terrace was formed when glacio-eustatic rises in sea level overtook the land, itself undergoing a process of continual tectonic uplift [30]. As reported by Groube et al. [66], the site was identified by the surface presence of flaked stone artifacts, including more than 100 waisted and grooved
axes, most >20 cm long and weighing >1 kg. Artifacts were found in creek beds cutting across terrace IIIa and the higher, older terrace IVb. A series of three tephras (volcanic ash deposits) was trapped in the depression behind terrace IIIa and on the lower front of the rise to terrace IVb. Neither tephras nor artifacts were found on the younger, lower terraces, beginning with IIIb, indicating that these terraces had yet to emerge from the sea when the artifacts and tephras were deposited. The ages for terraces IIIa and IIIb thus provide a general age range for the artifacts, assuming the reconstructed depositional sequence is accurate. Under these conditions, the artifacts are not younger than 44.5 ± 0.7 ka (terrace IIIb), nor older than 61.4 ± 0.6 ka (the oldest of several dates from terrace IIIa), as reported by Chappell and associates [30, Table 2; 32, Table 1]. (Note that these U-series dates have been generated more recently than those reported earlier by Groube et al. [66] and increase the terrace ages cited there by about 10%.)

Excavations consisted of cleaning back a vertical section of creek bank, ca. 30 m long, and cutting a trench ca. 10 m long at right angles to the creek section [66, Table 2]. The three superimposed tephras thus exposed (T1 the youngest) sit above bedded tuff and reef limestone. Artifacts were recovered from four findspots within the tephras. Findspots 1–3 produced a single waisted axe each; findspot 4 a core and two flakes. Findspots 1 and 2 are located at the intersection of T2 and T3; findspot 4 is within T2; findspot 3 is in the upper part of T1.

TL dates were obtained by Groube et al. [66] for each of the three tephras (Table 3). There are uncertainties in the dose rate, discussed by Groube et al. [66, p. 454] and Roberts [105, pp. 867–868], mainly involving potassium and water content. Review of these considerations led Groube et al. to estimate a minimum age of ca. 40 ka for both the tephras and the artifacts they contain. Roberts [105, p. 868] subsequently recalculated a minimum age of ca. 47 ka based on different assumptions about water content.

Groube et al. were cautious about the possibility of post-depositional disturbance at the site. The cleaned section is steeply sloping, and the excavators identified slope wash and re-deposition post-dating each tephra.
fall as well as subsequent down-slope creep. They also allowed that the absence of tephras on younger terraces could reflect post-depositional erosion. That said, the axe at findspot 2 was found in several pieces, apparently buried “after breakage with little subsequent displacement”[66, p. 454].

Unless these artifacts were discarded on an ancient tephra and then buried by a similarly ancient but re-deposited tephra, the several lines of evidence reviewed here suggest that the Huon artifacts date to more than 44 ka. Establishing a maximum age less than the 52–61 ka limit imposed by the date for terrace IIIa is not possible at this time.

5.2. Devil’s Lair

Devil’s Lair is a large limestone cave in the far southwest of Western Australia, excavated and reported by C. Dortch[45]. The most recent dating program reported by Turney et al. [134] has produced a coherent pattern of radiocarbon determinations, generally supported by related OSL dates. Table 4 lists the stratigraphic layers and dates relevant to this discussion. We include the electron spin resonance (ESR) dates although these are largely discounted in Turney and associates’ analysis.

The lowest in situ feature is a set of four nested hearths, referred to as the “hearth complex in layers 27–30.” The radiocarbon age of the layer 28 hearth is 41.46+1.4/−1.19 ka, consistent (given the general comments on 14C chronometry above) with associated OSL dates of 41.2–45.6 ka and 42.3–46.5 ka. While there are uncertainties surrounding the precise stratigraphic relationships of these remains, and hence their relationships with the dates[3], it seems clear that they reflect a human presence at the site somewhere in the 41–46 ka range.

Claims for artifacts deeper in the sequence are more problematic. Underlying layer 30 Upper is layer 30 Lower, a 25–30 cm thick fan of in-washed soils, devoid of artifacts and distinctly different from the sandy brown sediments above. At one standard deviation, it is dated by 14C at 44.26–46.89 ka. Further below, layers 31–38 reflect episodes of heavy erosion, marked by numerous channels and convoluted scouring features. The matrix contains large amounts of limestone rubble and boulders, weathered to sub-rounded and sub-angular forms, typical of cave entrance debris. Layers 28–30 Upper also display erosional features, but not to the extent shown in layers 31–38.

Numbers of artifacts tallied for these layers have differed through time as analyses have continued. Dortch [45, p. 56] originally claimed fourteen, with another half-dozen “probables.” Turney et al. [134, p. 5] cite six, one each in layers 32–35, 37, and 38. Dortch (pers. comm.) now counts seven, including four calcrete and two quartz flakes plus two halves of a limestone concretion thought to have been used as a hammerstone. The lowest of these items was associated with layer 37. Table 5 shows the distribution in Turney and associates’ published tally, compared with those in overlying layers 19–30 Upper.

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Turney et al. [134, p. 11] and Dortch (pers. comm.) agree that the artifacts in layers 31–38 are probably not in primary depositional context. Dortch contends that they are unlikely to have filtered down from higher in the deposit, given the thickness of sterile layer 30 Lower.
and the fact that upper level assemblages include proportionally more quartz and fewer calcrete items. Instead, he favors the notion that these remains were re-deposited from older sediments elsewhere in the cave or from area(s) outside a now-blocked cave entrance. The presence of charred bone in layers 31–38 is cited in support of this argument.

Clearly, if these artifacts were washed in from elsewhere and are now overlain stratigraphically by layer 30 Lower, they must be older than 44.47 ka. Nevertheless, we remain skeptical about that inference for several reasons:

- Uncertainty about the size and nature of the early assemblage. The stone tools represented are at best few in number, and charred bone is by Dortch’s [45, p. 18] own account “not unequivocally associated with human activities.”
- The absence of evidence for older deposits elsewhere in the cave or outside the former entrance. Excavations in the latter area produced no date greater than 20 ka BP [45, p. 47].
- The observation, discussed more fully below for Nauwalabila, that artifacts can easily be displaced downward over the distances involved here, even through seemingly unbroken strata. Dortch’s suggestion that differences in raw material composition refute this possibility might be right, but the small size of the layer 31–38 assemblage makes it difficult to assess.

While a human presence at Devil’s Lair somewhere in the 41–46 ka range is now indicated, the argument for an earlier occupation remains equivocal.

5.3. Lake Mungo

Lake Mungo is one of thirteen inter-connected dry lake basins on the lower reaches of Willandra Billabong Creek, western New South Wales. It has been studied by geomorphologists and archaeologists since the late 1960s (see [24] and the many sources cited therein for review). Sedimentary units pertinent to this discussion fall into two groups: Lower Mungo (hereafter LM) deposits, defined in lake-bordering lunettes by a predominance of quartz sands, indicating relatively high lake levels; and Upper Mungo (UM) deposits, marked by a predominance of pelletal clay sands, indicating fluctuating, generally low lake levels (Fig. 2). At least six, possibly seven calcareous soils are identified in LM components of the Mungo lunette, each reflecting regional drying, absence of sediment supply and/or plant colonization. The upper boundary of the LM phase is defined either by a particularly well-developed soil, sometimes called the Lower Mungo Soil (hereafter LM soil), or by a sharp interface between LM quartz sands and UM pelletal clays, indicating that the LM soil has been removed by erosion. Wüstenquartz (silt-sized quartz grains with red clay skins), an indicator of arid conditions west of the Willandra area, is present in small amounts intermittently through LM times, becoming more common in the UM phase.

Chronometric control is provided primarily by radiocarbon and luminescence dates from several localities, mainly on the Mungo and nearby Arumpo lunettes (see [3] for a detailed summary). Comprehensive review of the radiocarbon record [58,59] indicates frequent uncertainty about the nature of materials being dated, the impact of sample contamination, and the effectiveness of pre-treatment. Some of the luminescence dates are equally open to question because of local differences in dose rates and degree of peri-depositional bleaching [21,62]. In addition, relationships between dates and key sedimentary features are sometimes uncertain [19,21].

Twenty-one luminescence and ^14C dates for the UM phase range from 16–42 ka [3]. The oldest nine radiocarbon dates are >34 ka. At one standard deviation, eight bracket the period 34.5–35.4 ka (Fig. 3a). Two of three luminescence dates from the Joulni locality, at the southern end of the Mungo lunette, bracket the period...
36.9–39.5 ka. Given the adjustments indicated in the section on chronometry above, the $^{14}$C dates are probably consistent with the luminescence determinations. Bowler et al. [24] use these data to peg the beginning of the UM phase at ca. 38–40 ka.

Eighteen radiocarbon and luminescence dates on the LM soil range from 16–45 ka [3]. Seven $^{14}$C dates are >34 ka (Fig. 3b). At one standard deviation, all bracket the period 35–37 ka. Rough calibration might put them as early as 43 ka. Five luminescence dates on the LM soil, all from Joulni, are in the 40–44 ka range. Bowler et al. [24] appeal to both radiocarbon and luminescence dates in placing this component at ca. 40–42 ka.

Thirty-two luminescence dates come from LM deposits below the LM soil at Joulni (Fig. 4a–c) [3]. Fourteen TL dates are in the 34–58 ka range; 18 OSL dates are in the 41–62 ka range. The dates show no clear relationship with depth, inviting skepticism about their precise validity and/or stratigraphic relationships.

Archaeological materials from Willandra have not been published in much detail, but are reportedly present in some quantity ($>$10$^3$ artifacts; $>$10$^2$ features) in the LM soil on the Mungo lunette and in the LM phase sands immediately underlying it [1,19,23,24,74,117,141]. Items most frequently mentioned include lithics, hearths, roasting pits, and small, shallow middens containing fish, shellfish and small mammal remains. Despite recent erosion and displacement, at least some of these materials must be at the point of initial deposition, implying ages equivalent to that of the LM soil or slightly older, roughly 40–43 ka.
Similar remains are associated with the LM soil (but not the underlying sands) on the Arumpo lunette [21, pp. 133, 147].

Arguments for earlier dates on the archaeology appeal to two data sets. One is a collection of eleven silcrete flakes found well down in LM phase quartz sands at Joulni (Fig. 2) [24,120]. Stratigraphic position and roughly bracketing OSL dates of 50.1 ± 2.4 ka and 49.7 ± 2.7 ka (above the artifacts) and 47.9 ± 2.4 ka and 45.7 ± 2.3 ka (below) are read by Bowler et al. [24] and Shawcross [120] to indicate a 46–50 ka age for the assemblage; but we are skeptical, partly because of the small size of the assemblage, but mainly because of its problematic sedimentary context and the inversion of the bracketing dates. Bowler [19, p. 122] notes that LM quartz sands are typically marked by “steep avalanche bedding” and “cross sets,” indicating erosional and depositional processes likely to facilitate the movement of artifacts well below the point of initial deposition. Stratigraphic relationships may also have been disrupted by burrowing animals, which were once common in these deposits [55,141]. The lack of a strong age-depth relationship in any of the three luminescence-dated transects shown in Fig. 4 further underlines the need for caution here. Conjoining exercises involving these eleven flakes have not yet been attempted, but Shawcross [120, pp. 193–195] reports such efforts from higher in the Joulni section where the core and some flakes in one refitted set are separated vertically by up to 60 cm. In light of all this, the case for a pre-45 ka date for the lowest-lying eleven items must be considered unproven.

The second argument for a pre-45 ka date involves the human burial called here M-III [131]. The skeleton was found at Joulni, partly exposed on an eroded surface in LM quartz sands. The stratigraphic origin for the pit in which it was placed could not be observed directly. In their first report, excavators Bowler and Thorne [22, p. 134] argued that the burial was in place before the LM soil was formed, partly because dark humic sands from the soil were absent from the grave fill. Compelling as that reasoning may have been at the time, it is undercut by more recent descriptions of the grave fill as containing Wüstenquartz, pelletal clay and (most notably) “dark, reworked soil” [24, p. 840], collectively implying an interment no earlier than the formation of the LM soil (i.e. 40–42 ka BP), possibly even post-dating it (see also [3,19, p. 150, Fig. 9; 20, Fig. 2]).

Thorne et al. [131] have developed a very different chronology for the burial, based on eight U-series and ESR analyses of the skeleton itself, one U-series analysis of the attached calcite matrix, and two OSL determinations on LM sediments they claim are stratigraphically equivalent to the burial’s position (Table 6). Ages range from 50–103 ka, with the preferred estimate for the burial itself being 62 ± 6 ka. Despite its inconsistency with the regional chronology, this estimate has been widely accepted by non-Australianists [89,128].

Bowler and others [20,60,62] have offered detailed and compelling critiques of Thorne and associates’ dating methods (see [67] for reply). The complexity and experimental nature of the U-series and ESR analyses, the assumptions required in controlling uranium uptake and loss, and (especially) the mismatch with the luminescence-based chronology for the LM sands outlined by Bowler et al. [24] all count against Thorne and associates’ position. Of the ten OSL dates in the array that transects the M-III burial site, only one is >52 ka (Fig. 4c). All ten apparently underlie the interment stratigraphically [21,24]. The luminescence dates reported by Thorne et al. still might be seen to support their argument, but the fact that the samples they analyzed were collected several hundred meters away from the M-III burial location greatly weakens that support.

We conclude from all this that neither the M-III burial nor the local archaeological record provides solid evidence for a human presence at Lake Mungo before ca. 43 ka.

5.4. Nauwalabila

This site is a rockshelter formed by an outlier of the Arnhem Land escarpment, about 200 km east of Darwin [79]. Artifacts are found through 2.5 m of sand deposits and into 30–40 cm of underlying sandstone rubble, the latter underlain by more sand and bedrock (Fig. 5). Fourteen radiocarbon and five luminescence dates cited in early reports indicated fairly steady accumulation from ca. 60 ka, with the lowest artifacts found in the rubble zone, bracketed between OSL dates of 53 ± 5.4 ka and 60.3 ± 6.7 ka [112]. A recent paper by Bird et al. [18] offers new data and arguments in support of this antiquity.

### Table 6

<table>
<thead>
<tr>
<th>Sample</th>
<th>Age (ka)</th>
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<tbody>
<tr>
<td>Mass spectrometry</td>
<td>96.8 ± 2.1</td>
</tr>
<tr>
<td>Bone/M-III</td>
<td>58.3 ± 1.2</td>
</tr>
<tr>
<td>Sediment</td>
<td>50.7 ± 0.9</td>
</tr>
<tr>
<td>Gamma spectrometry</td>
<td>54.5 ± 0.7</td>
</tr>
<tr>
<td>ESR</td>
<td>82 ± 21</td>
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<tr>
<td>OSL</td>
<td>74 ± 7</td>
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<tr>
<td>OSL</td>
<td>60 ± 5</td>
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<tr>
<td>OSL</td>
<td>59 ± 3</td>
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<tr>
<td>OSL</td>
<td>63 ± 3</td>
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In a previous review [97], we suggested that the site dated no older than ca. 40 ka, and that the apparent association of artifacts, sandstone rubble and dated sands at the base of the deposit was secondary, the artifacts and rubble having settled into older sediments as a result of post-depositional termite activity in the overlying deposits. Both the process and its displacement effect on larger clasts are well-documented in similar situations elsewhere [27]. Bird and colleagues [18] attempted to determine whether this had occurred at Nauwalabila by examining clay particle size distribution down the profile, but the results were inconclusive. The significant point not addressed in their analysis is that large clasts were so well-represented at the base of the deposit that they were defined by the excavators as a separate stratigraphic unit—the rubble layer. Stone layers like this are elsewhere routinely taken as indicators of termite disturbance [27,144].

In the course of their analysis, Bird et al. also discovered small charcoal particles extending down to the base of the deposit, ca. 1 m below the lowest previously reported radiocarbon date. These particles were analyzed using ABOX-SC and other pre-treatment techniques and both AMS and conventional $^{14}$C dating. Results from samples recovered from 110 cm below ground surface to the base of the deposit are shown in Table 7, together with OSL dates on some of the same strata previously reported by Roberts et al. [112, p. 579]. Clearly the $^{14}$C dates show no coherent relationship with depth, nor do they match well with the OSL dates. Instead, their distribution is consistent with the random downward displacement of small charcoal particles through bioturbation.

Bird et al. reject this reading and offer a counter hypothesis based in part on the intra-site distribution of small iron oxide nodules called pisolites (sometimes pisoliths). The presence of these items below 110 cm is said to imply a fluctuating but generally high groundwater table, at or near the paleo-surface of the site, at or very near the Pleistocene–Holocene transition. Bird et al. [18, p. 1071] suggest higher rainfall, higher wet season runoff, higher river base levels and higher sea levels as possible explanations for this phenomenon. These processes are said be reflected in a gap in the calibrated radiocarbon dates between ca. 12.5 ka and 9.2 ka (Table 7).

The purpose of this reconstruction is to support the view that a significant proportion of the dated charcoal samples below 110 cm have had their carbon composition altered by the proposed high water table. Above
this level, hard black fragments of charcoal retain their internal structure, whereas below 110–130 cm and especially below 180 cm large charcoal fragments are sparse, often heavily coated with clays and iron oxides, and often soft and brown in appearance. The internal structures of these altered fragments are degraded and their carbon contents are mostly below 25%, compared with 36–47% for unaltered samples. Microbial activity is suggested as the vector of carbon replacement. Radiocarbon ages, especially below ca. 180 cm, are thus seen to reflect the age of this alteration, not the age of the sediments from which they were recovered.

We agree that carbon samples from below 110 cm have been degraded, but for reasons developed at length elsewhere [3], we are much less certain that high ground water levels and microbial activity are in any way implicated. For charcoal aged between 30 ka and 50 ka to yield apparent dates of 6–10 ka would require that the samples be composed almost entirely of carbon which is on average much younger than the proposed 9.2–12.9 ka period of high groundwater. Thus the questions remain: what happened to the original carbon in the charcoal? How has so much young carbon been incorporated in the samples in a form capable of resisting ABOX-SC pre-treatment, which is designed to remove humic acids and other soil organic compounds?

Even more problematic for Bird and associates’ hypothesis, some of the charcoal from deeper levels of the site is neither degraded nor in situ. They report that small quantities of black and vitreous charcoal with

Table 7
Nauwalabila 14C dates below 110 cm from Bird et al. [18, Table 1]. Samples subjected to ABOX-SC pre-treatment grouped separately. Samples pre-treated in other ways but designated by an ANUA code have been dated by AMS. All others are assumed to be conventional dates. Calibrated ages from Bird et al. [18, Table 1], except ANUA-6906 from p. 1066. Where more than one calibrated date is possible, only the one with the highest probability factor is listed. See Bird et al. [18] for additional details. OSL dates drawn from Roberts et al. [112, Table 2] cited ± the total uncertainty listed therein.

<table>
<thead>
<tr>
<th>Depth below surface (cm)</th>
<th>Sample</th>
<th>ABOX-SC AMS (ka)</th>
<th>Other 14C dates (ka)</th>
<th>14C calibrated (BP)</th>
<th>OSL (ka)</th>
</tr>
</thead>
<tbody>
<tr>
<td>104–110</td>
<td>OXODK172</td>
<td>8.18 ± 0.07</td>
<td>13.5 ± 0.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>107</td>
<td>ANU-8653</td>
<td>10.53 ± 0.24</td>
<td>9140–9028</td>
<td></td>
<td></td>
</tr>
<tr>
<td>111</td>
<td>ANU-8654</td>
<td>9.81 ± 0.12</td>
<td>12877–12105</td>
<td></td>
<td></td>
</tr>
<tr>
<td>115</td>
<td>ANU-8677</td>
<td>11.09 ± 0.24</td>
<td>11345–11081</td>
<td></td>
<td></td>
</tr>
<tr>
<td>123</td>
<td>ANU-8678</td>
<td>10.92 ± 0.11</td>
<td>13213–12872</td>
<td></td>
<td></td>
</tr>
<tr>
<td>127</td>
<td>SUA-236</td>
<td>13.19 ± 0.18</td>
<td>13044–12871</td>
<td></td>
<td></td>
</tr>
<tr>
<td>139</td>
<td>ANU-10929</td>
<td>12.33 ± 0.12</td>
<td>16222–15500</td>
<td></td>
<td></td>
</tr>
<tr>
<td>151</td>
<td>ANU-9513</td>
<td>18.33 ± 0.28</td>
<td>14423–14102</td>
<td></td>
<td></td>
</tr>
<tr>
<td>151</td>
<td>ANU-9905</td>
<td>13.29 ± 0.18</td>
<td>22230–21314</td>
<td></td>
<td></td>
</tr>
<tr>
<td>151</td>
<td>ANU-9906</td>
<td>13.89 ± 0.34</td>
<td>16315–15624</td>
<td></td>
<td></td>
</tr>
<tr>
<td>152</td>
<td>ANU-10928</td>
<td>19.99 ± 0.36</td>
<td>17121–16204</td>
<td></td>
<td></td>
</tr>
<tr>
<td>164</td>
<td>ANU-10927</td>
<td>12.00 ± 0.25</td>
<td>24196–23138</td>
<td></td>
<td></td>
</tr>
<tr>
<td>164</td>
<td>ANUA-9514</td>
<td>17.12 ± 0.30</td>
<td>14336–13500</td>
<td></td>
<td></td>
</tr>
<tr>
<td>164</td>
<td>ANUA-9907</td>
<td>16.45 ± 0.32</td>
<td>20840–19919</td>
<td></td>
<td></td>
</tr>
<tr>
<td>170–175</td>
<td>OXODK166</td>
<td>22.84 ± 0.52</td>
<td>20078–19139</td>
<td></td>
<td></td>
</tr>
<tr>
<td>176</td>
<td>ANU-3177</td>
<td>12.00 ± 0.60</td>
<td>26660–25420</td>
<td></td>
<td></td>
</tr>
<tr>
<td>176</td>
<td>ANU-3182B</td>
<td>14457–13405</td>
<td></td>
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<tr>
<td>176</td>
<td>ANU-9512</td>
<td>8.75 ± 0.1</td>
<td>9895–9599</td>
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<td></td>
</tr>
<tr>
<td>176</td>
<td>ANU-9908</td>
<td>14.6 ± 0.34</td>
<td>17938–17022</td>
<td></td>
<td></td>
</tr>
<tr>
<td>180</td>
<td>SUA-237</td>
<td>19.97 ± 0.365</td>
<td>24179–23122</td>
<td></td>
<td></td>
</tr>
<tr>
<td>180</td>
<td>ANUA-8131</td>
<td>5.88 ± 0.15</td>
<td>6805–6498</td>
<td></td>
<td></td>
</tr>
<tr>
<td>180</td>
<td>ANUA-8223</td>
<td>7.05 ± 0.14</td>
<td>7973–7724</td>
<td></td>
<td></td>
</tr>
<tr>
<td>236</td>
<td>ANUA-6906</td>
<td>27.35 ± 0.44</td>
<td>31500–29700</td>
<td></td>
<td></td>
</tr>
<tr>
<td>236</td>
<td>ANUA-9902</td>
<td>12.73 ± 0.14</td>
<td>15634–15148</td>
<td></td>
<td></td>
</tr>
<tr>
<td>236</td>
<td>ANUA-9909</td>
<td>6.96 ± 0.14</td>
<td>7871–7673</td>
<td></td>
<td></td>
</tr>
<tr>
<td>228–240</td>
<td>OXODK168</td>
<td>8.21 ± 0.12</td>
<td>9298–9025</td>
<td></td>
<td></td>
</tr>
<tr>
<td>241</td>
<td>ANUA-10317</td>
<td>9.106 ± 0.12</td>
<td>10426–10174</td>
<td></td>
<td></td>
</tr>
<tr>
<td>241</td>
<td>ANUA-10318</td>
<td>10688–10236</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>256</td>
<td>ANUA-9903</td>
<td>9.28 ± 0.18</td>
<td>8483–8107</td>
<td></td>
<td></td>
</tr>
<tr>
<td>293</td>
<td>ANUA-7618</td>
<td>7.51 ± 0.23</td>
<td>7862–7657</td>
<td></td>
<td></td>
</tr>
<tr>
<td>293</td>
<td>ANUA-7619</td>
<td>6.92 ± 0.14</td>
<td>8454–8182</td>
<td></td>
<td></td>
</tr>
<tr>
<td>293</td>
<td>ANUA-9904</td>
<td>7.56 ± 0.14</td>
<td>10878–10493</td>
<td></td>
<td></td>
</tr>
<tr>
<td>285–301</td>
<td>OXODK169</td>
<td>9.45 ± 0.18</td>
<td>60.3 ± 6.7</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
well-preserved woody structures are found throughout the deposit below 110 cm [18, pp. 1070–1071]. Regardless of pre-treatment, these samples also yield dates that are too young to represent the ages of the sediments in which they were found. Bird et al. [18, p. 1071] suggest that these un-degraded fragments “have most likely fallen down termite galleries from high in the sequence.” Though they do not say which of the deeper samples are degraded or intact, their own analysis thus indicates that bioturbation has affected all of the lower deposit to some unknown degree. It is not impossible that all or most of the samples, intact and degraded, have moved down the profile. The general similarity in ages of eleven of twelve charcoal samples below 180 cm supports this notion.

The rubble layer at the base of the site and the distribution of relatively young but unaltered charcoal fragments below 110 cm collectively provide strong evidence for the vertical displacement of objects, including artifacts, through the lower two-thirds of the deposit. This process makes it difficult to assess the actual ages of those artifacts, particularly the ones found in the rubble layer, the area in which displacement indicators are most prominent. We therefore continue to be skeptical of the idea that Nauwalabila provides evidence of a human presence in Sahul >40 ka BP.

5.5. Malakunanja

Malakunanja is a small rockshelter located about 45 km north of Nauwalabila [109]. It contains a sandy deposit >4 m deep, at the base of which is a sandstone rubble layer, similar to the one at Nauwalabila. Artifacts are found to a depth of 260 cm, bracketed by luminescence dates of 52±8 ka (above) and 55.5±8.2 ka, 60.7±7.5 ka and 61±10 ka (below) [105,109,115]. Bird et al. [18, Table 1] have recently published several new ABOX-SC/AMS dates, one of which comes from the 254 cm level, in close proximity to the lowest artifacts. All available 14C and luminescence dates below 145 cm are shown in Table 8.

Since—apart from the original brief announcement and several subsequent reports of dates—this site remains unpublished, little can be made of its claimed antiquity. Early comments by the excavators touted the site’s stratigraphic integrity [109–111]. More recently, Roberts [105, p. 856] has allowed the possibility of downward displacement of the lowest artifacts, but maintains the in situ status of those associated with “a small pit feature” at 232 cm, overlain by a TL date of 45±7 ka and OSL dates of 45.7±4.1 ka and 44.2±4.7 ka. While there is no published evidence allowing independent assessment of this feature, it is important to note that the underlying 14C date (10.81±0.20) is clearly too young. This sample may reflect vertical displacement of the kind and magnitude indicated at Nauwalabila, raising questions about the stratigraphic integrity of this part of the deposit, including the association of artifacts, dated sediments and the pit feature.

If the artifacts and luminescence-dated sediments associated with the pit feature are in primary context, then humans were present at this site as early as 45 ka BP. Arguments for an earlier date, certainly one >50 ka, remain undocumented.

6. Discussion

In our 1998 review, we found the evidence for a >40 ka Sahul arrival date unconvincing. Half a decade later, the situation is not much different. Improvements in 14C dating and the wider application of luminescence techniques have demonstrated a 40–45 ka human presence at eight sites—Allen’s Cave, Buang Merabak, Carpenter’s Gap, Devil’s Lair, GRE 8, Huon Peninsula, Mungo and Riwi. Malakunanja and Nauwalabila might ultimately make the cut as well, but not on currently available data: the stratigraphic connections between artifacts and dated materials are simply too tenuous. The case for a >45 ka figure is much less certain. The best candidate—Huon Peninsula—remains loosely dated; arguments for the other four (Devil’s Lair, Malakunanja, Mungo and Nauwalabila) are undercut by small numbers of artifacts and/or (again) uncertainties about the depositional relationships between dates and artifacts. There is still no firm evidence for a date >50 ka. This finding has implications for a wide range of questions in Upper Pleistocene paleoanthropology and ecology. Here we comment briefly on just two: the
timing of modern human migrations out of Africa and the role of humans in the extinction of Sahul megafauna.

6.1. Out of Africa

Archaeological data have been used to support several scenarios for modern human movement beyond a probable African homeland, one pegged at about 45–50 ka BP [84], others at various dates >50 ka [53,85]. The earliest of the latter, set at about 90–120 ka, is grounded on archaeological and fossil data from the Levant [57,90,93,118,136,137] and appears to have been related to the spread of a suite of African biota into this region during a period of relatively warm inter-glacial conditions [129]. Modern humans were clearly part of this phenomenon, but there is no indication that they moved into other parts of southwest Asia or beyond at this time. In fact, the available evidence shows that they disappeared from the Levant with the return to cooler climatic conditions after 70 ka BP [6,13,57,90,119,129,135].

Another scenario commonly rehearsed posits an ex-African migration in the 60–70 ka range, possibly along the southern coast of Eurasia leading ultimately to southeast Asia and Sahul [56,85,140]. Elements of this model guide speculation about the genetic and morphological characteristics of migrant groups and their respective technological capabilities and economic orientations [38,47,128].

Support for the 60–70 ka date is drawn from two sources: certain features of Pleistocene Sahul lithic assemblages and the dates on the five problematic sites reviewed above, particularly Mungo, Malakunanja and Nauwalabila. As we have seen, the latter basis carries no weight: none of these sites indicates a definite human presence >45 ka BP. Data from adjacent areas of southeast Asia show a similar pattern: no evidence of occupation by modern humans >45 ka BP (Table 9).

<table>
<thead>
<tr>
<th>Site</th>
<th>Region</th>
<th>Reference</th>
<th>Technique</th>
<th>Earliest date (ka)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Golo Cave</td>
<td>Moluccas</td>
<td>[15]</td>
<td>C14</td>
<td>35.57 ± 0.48</td>
</tr>
<tr>
<td>Kota Peninsula</td>
<td>Malaysia</td>
<td>[147]</td>
<td>C14</td>
<td>~31</td>
</tr>
<tr>
<td>Tampan</td>
<td>SW Thailand</td>
<td>[4,5]</td>
<td>C14</td>
<td>&gt;43</td>
</tr>
<tr>
<td>Lang</td>
<td>S Sulawesi</td>
<td>[63]</td>
<td>C14</td>
<td>~31</td>
</tr>
<tr>
<td>Leang</td>
<td>East Timor</td>
<td>[100]</td>
<td>C14</td>
<td>34.65 ± 0.63</td>
</tr>
<tr>
<td>Buring</td>
<td>Borneo</td>
<td>[10]</td>
<td>ABOX/AMS</td>
<td>42 ± 0.67</td>
</tr>
</tbody>
</table>

This model is difficult to defend. As many have observed (and as its proponents [53] themselves concede), Modes 3 and 4 work best as descriptive devices in western Europe; elsewhere they display much less integrity [9,12,89]. Moreover, the order in which these and other modes appear is not unidirectional. The classic example is Howiesons Poort, a Mode 5 industry that surfaces briefly in southern Africa around 70 ka BP, succeeding a Mode 3 industry and later replaced by one [89]. An obvious inference is that these industries represent facultative responses to regional ecological (including social and demographic) circumstances, not phylegetic markers, as advocates of the “mode” argument would have it. If so, they cannot be taken as a basis for speculation about the timing of Sahul colonization.

While this does not necessarily imply that modern humans were restricted to Africa and (on occasion) immediately adjacent parts of southwest Asia before 50 ka BP, it does mean that archaeological data from Sahul do not support a significantly earlier excursion.

6.2. Megafaunal extinctions

Pleistocene Sahul witnessed the disappearance of more than 20 genera of large-bodied fauna sometime in the middle-to-late Upper Pleistocene [51]. The possible role of humans in this process has been a focus of attention for some time [50,65,75,145]. Recent results from four projects offer potentially important purchase on the problem:

- Miller et al. [94] report amino acid racemization, U-series, and AMS ¹⁴C dates on Genyornis eggshell and luminescence dates on associated sediments indicating that this large, now-extinct flightless bird disappeared from parts of the Eyre Basin (a large area of interior Australia) at 50±5 ka BP.
- Roberts et al. [116] report ¹⁴C, luminescence and U-series dates on a taxonomically diverse sample of megafaunal remains and associated sediments continent-wide suggesting that many species disappeared within a very narrow time frame,
possibly around 46 ka BP, probably between 40–50 ka BP.

- Cosgrove and Allen [40] report that the earliest sites in Tasmania, a series of rockshelters in the southwest dated by radiocarbon and luminescence to 34 ka BP, contained no extinct megafauna among >600,000 bones analyzed from eight locations.
- Field and others [48,116] report 14C and luminescence dates of 29–36 ka BP on sediments containing the remains of six now-extinct taxa, including Genyornis, from Cuddie Springs (northern New South Wales).

The Miller and Roberts data sets are seen by some to support the idea that all Sahul megafauna were driven to extinction by humans shortly after they arrived on the continent [44]. Flannery has in fact recently modified the 60 ka date he once favored for colonization [50] downward to 46 ka to better conform with the results of the Roberts et al. analysis [52, p. 21]. Given some flexibility in reading the data, our own assessment of the likely colonization date, 42–45 ka BP, fits comfortably with this scenario. The Tasmanian collection might be seen to do so as well, assuming it contains a comprehensive sample of the large-bodied taxa locally present at the time the sites from which it was drawn were formed.

Neat as this formulation seems to be, we see several problems with accepting it [65,145]. Detailed review is beyond the scope of this paper, but three points are critical:

- Most obvious are the Cuddie Springs data, which count against a rapid, continent-wide extinction model closely tied to the initial human colonization date. Though some have dismissed the association between megafauna and relatively late dates at this site on taphonomic grounds [61,106,116], there are good reasons to see it as reliable [36,48].
- Equally important is the question of the process [26]. The mechanisms most commonly nominated by proponents of human causation are direct predation (“overkill”) and habitat modification via anthropogenic change in the fire regime [50,73,94]. The overkill option is countered by the complete absence of any direct evidence of human predation on megafauna, and by the fact that Pleistocene human populations were almost certainly too low to have effected rapid extermination on a continental scale. The fire-related argument is challenged by the observation that the sharpest changes in Sahul vegetation evident over the last few hundred thousand years are climate- rather than human-driven, and that clear-cut prehistoric human impacts unconnected with agriculture are difficult to identify in the Sahul pollen record [25,34,69,70,82].
- Since Tasmania was cut off from the mainland by relatively high sea levels until after 37 ka [71], extinctions must have taken place there after this date if humans were involved. Their absence from the very large faunal collection noted above counts against this possibility. If they disappeared before 37 ka, then some factor other than human interference must be implicated.

We conclude that, despite the apparent coalescence of certain provocative chronometric data, the case for rapid continent-wide extinction of megafauna as a result of human colonization has yet to be made. More complex models, involving detailed ecological analyses on a regional scale, will be required to resolve this issue satisfactorily.

7. Conclusion

In the wake of reports of 50–60 ka luminescence dates for archaeological remains at Malakunanja, many welcomed the fall of the “radiocarbon barrier” and predicted an ensuing flood of similarly early dates continent-wide. Now, more than a decade later, aggressive application of improved dating techniques, including various forms of luminescence, ABOC-SC/AMS 14C and U-series, has yet to produce the anticipated deluge. The outside date for human colonization has shifted from ca. 40 ka BP to ca. 45 ka BP, an adjustment that might have been expected given only what we now know about calibrating 14C dates >30 ka BP. No earlier dates have survived careful scrutiny unchallenged.

The American case provides an obvious and instructive parallel [91]. There, an 11–12 ka BP colonization date was demonstrated almost as soon as the first relevant 14C analyses were reported. In the half century since, older dates have often been proposed, but in the end few have won broad acceptance. Those that have been affirmed have not changed the baseline date all that much [92]. The time required to refute the others, Martin’s [88] “shelf-life” for pre-Clovis sites, has averaged about ten years [91]. Uncertainties about dates and/or their association with evidence of a human presence have plagued each questionable case, and it has taken time to resolve them.

The Sahul argument has so far developed along similar lines, prompting us to make an important point. Continuing improvements in dating technology have clearly been central to establishing the age of continental colonization. But contrary to recent statements by participants on one side of the debate [29,78,108], they are not the only consideration. As we hope our discussions of individual sites here and elsewhere [3,97] have shown, this problem is and always will be in large part about depositional context. In other words, this is an archaeological issue as much as it is a chronometric one. Characterizing a continuing concern with this aspect of
the problem as a reluctance to “[break] the moulds into which prehistory has been poured” [29, p. 80], or more pointedly as “carping” commentary [78, p. 53], is in the end simply dodging a fundamental element of the discussion. On current evidence, 45,000 calendar years is the best outside date for the colonization of Pleistocene Sahul. It requires more than the mere announcement of yet another old date, without adequate consideration of context, to change this conclusion.

Acknowledgements

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