Quaternary Science Reviews 191 (2018) 204–228

Contents lists available at ScienceDirect

Quaternary Science Reviews

journal homepage: www.elsevier.com/locate/quascirev

Carpenters Gap 1: A 47,000 year old record of indigenous adaption and innovation

Tim Maloney [a, b, *], Sue O'Connor [a, b], Rachel Wood [c], Ken Aplin [a], Jane Balme [d]

[a] Department of Archaeology and Natural History, College of Asia and the Pacific, Australian National University ACT, 0200, Australia
[b] Centre of Excellence for Australian Biodiversity and Heritage, Australian National University ACT, 0200, Australia
[c] Radiocarbon Facility, Research School of Earth Sciences, ANU College of Physical and Mathematical Science, Australian National University ACT, 0200, Australia
[d] Archaeology, School of Social Sciences, University of Western Australia, Perth, Australia

A R T I C L E I N F O

Article history:
Received 1 November 2017
Received in revised form
1 May 2018
Accepted 14 May 2018
Available online 21 May 2018

Keywords:
Pleistocene
Sahul
Colonization
Kimberley
Bayesian modelling
LGM refugia

A B S T R A C T

Here we present the first detailed analysis of the archaeological finds from Carpenters Gap 1 rockshelter, one of the oldest radiocarbon dated sites in Australia and one of the few sites in the Sahul region to preserve both plant and animal remains down to the lowest Pleistocene aged deposits. Occupation at the site began between 51,000 and 45,000 cal BP and continued into the Last Glacial Maximum, and throughout the Holocene. While CG1 has featured in several studies, the full complement of 100 radiocarbon dates is presented here for the first time in stratigraphic context, and a Bayesian model is used to evaluate the age sequence. We present analyses of the stone artefact and faunal assemblages from Square A2, the oldest and deepest square excavated. These data depict a remarkable record of adaptation in technology, mobility, and diet breadth spanning 47,000 years. We discuss the dating and settlement record from CG1 and other northern Australian sites within the context of the new dates for occupation of Madjedbebe in Arnhem Land at 65,000 years (±5700), and implications for colonisation and dispersal within Sahul.

1. Introduction

The site of Carpenters Gap 1 (CG1) located in the Napier Range within the Devonian reef system of the southern Kimberley, Western Australia (Figs. 1 and 2), has long been known as one of the earliest radiocarbon dated occupation sites on the Sahul continent (O'Connor, 1995). The age of the excavated deposits and exceptional preservation of organic remains makes the site significant; providing one of the richest archaeological records of early settlement of inland environments in Sahul. CG1 has already provided critical data to our understanding of the technology and artistic traditions which accompanied the first Australians, such as early evidence of edge-ground axe production (Hiscock et al., 2016), the earliest known bone personal ornament (Langley et al., 2016), and pigment use earlier than 40,000 cal BP (O'Connor and Fankhauser, 2001:299). Other studies from this site have produced a long anthracological, macrobotanical and phytolith record (Frawley and O'Connor, 2010; McConnell and O'Connor, 1997, 1999; Wallis, 2001). These studies of CG1 have added to our knowledge of Pleistocene life, yet the stone artefacts and fauna have not been previously published in any analytical detail. Here we present the first detailed analyses of the stone artefacts and fauna from Square A2, the oldest and deepest square in CG1, in chronostratigraphic context. We also present all available radiocarbon dates for the first time, plotted within stratigraphic sections. This information is used to construct a Bayesian chronology. Together with a growing number of Australian sites, such as Riwi, Boodie Cave, Madjedbebe (formally known as Malakunanja II), Nawarla Gabarnmang, Nauwalabila, Warratyi, Devils Lair, and Mungo (Fig. 1); CG1 provides critical archaeological evidence for the economic and social lives of the first Australians.

Until recently, the colonisation of Sahul was thought to have occurred at around 50,000 cal BP, with a consistent pattern of dates for the earliest occupation levels of sites such as Riwi (Wood et al., 2016), Devils Lair (David et al., 2011; Turney et al., 2001), Nawarla Gabarnmang (David et al., 2011), Nauwalabila (Bird et al., 2002; Roberts et al., 1994), Vilkuav (Summerhayes et al., 2010), and

* Corresponding author. Department of Archaeology and Natural History, College of Asia and the Pacific, Australian National University ACT, 0200, Australia.
E-mail address: tim.maloney@anu.edu.au (T. Maloney).

https://doi.org/10.1016/j.quascirev.2018.05.016

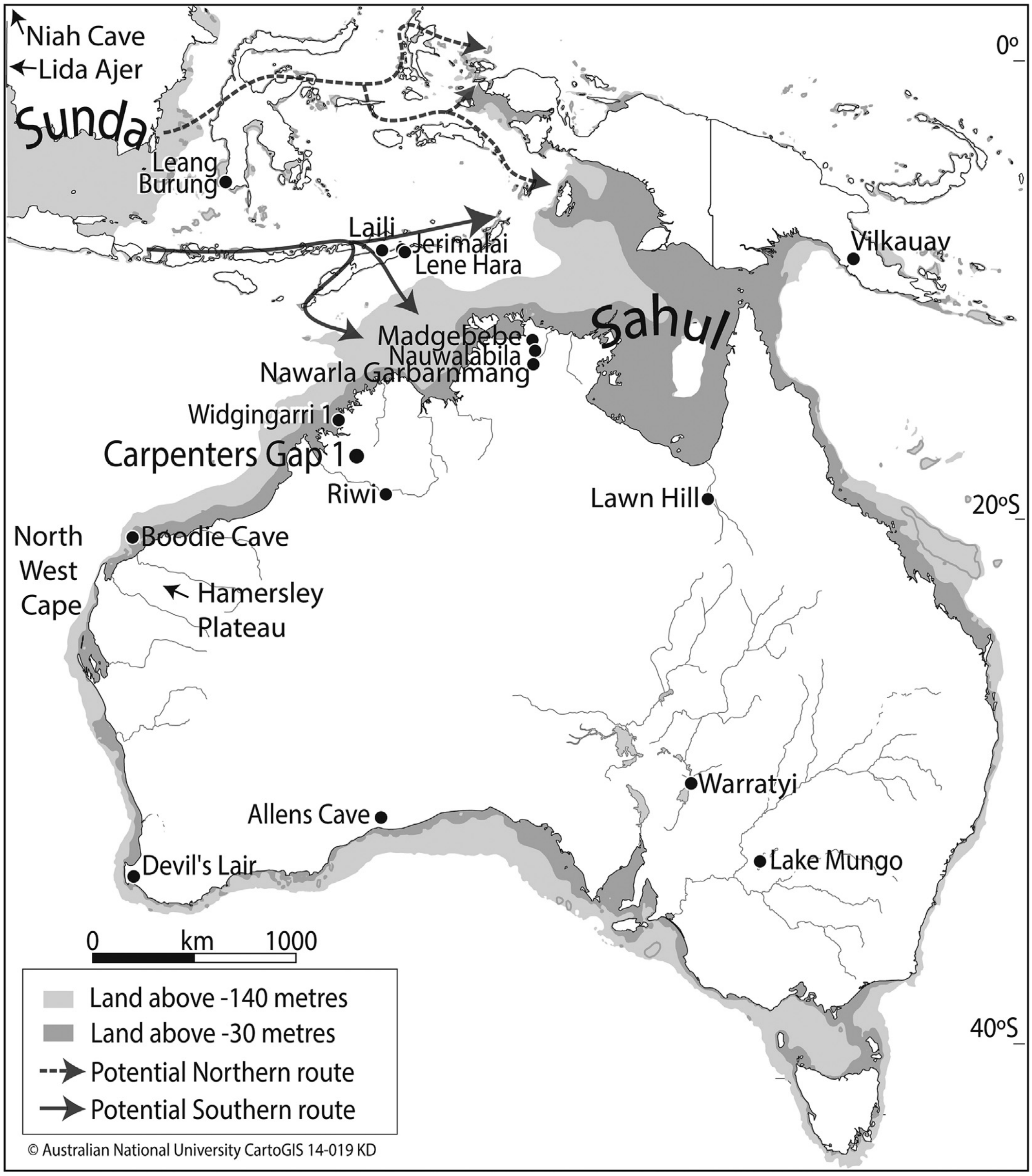

Fig. 1. Sunda and Sahul illustrating Pleistocene sites mentioned in text and possible migration routes.

Boodie Cave (Veth et al., 2017:23) ranging between about 50,000 and 44,000 BP. A detailed review of the dates can be found in Wood et al. (2016). Recent results from Madjedbebe has revealed a dense band of cultural material, coincident with first occupation of this site, occurring between '65.0+/− (3.7, 5.7) and 52.7+/− (2.4, 4.3) kyr' (Clarkson, 2006:309). The absence of dates of comparable antiquity in the islands to the north of Australia, from where colonisation should logically have proceeded, appeared to present a challenge to such an early colonisation of Sahul. However, shortly after the publication of the Madjedbebe dates, Westaway et al. (2017:2) reported ages of '68 ± 5 kyr (mean ± 1σ, age range 73–63 kyr)' for a human fossil at Lida Ajer, Sumatra Island, Indonesia. This new data for the age of Sahul colonisation also reveals that the first Australians co-occupied northern Australia with megafauna species for at least 20,000 years before the latter's extinction (Saltré et al., 2016; Van der Kaars et al., 2017).

At the time of initial colonisation of northern Sahul at ~65,000 years ago, climatic conditions were favourable for human habitation. In the inland savannah regions, rivers witnessed a peak in fluvial activity and the inland lakes of both northern and southern Australia, which are dry today, experienced lake full conditions (Johnson et al., 2016:3–4; Saltré et al., 2016:3). This evidence is taken to indicate a generally more humid climate with temperatures perhaps comparable to those of the Holocene (Van der Kaars et al., 2006:888). This is corroborated by the phytolith record derived from the bulk sediment samples recovered from CG1, which indicates that at the time of first occupation vegetation communities were similar to those seen in the vicinity of the site today with 'a high diversity of grass species and at least medium level rainfall' (Wallis, 2001:111).

Following this early period, drier and cooler conditions prevailed across the continent although with marked regional variability. Cooler conditions throughout Late MIS3 (35,000–32,000 BP) in northern Australia most likely resulted in decreased evaporation (Reeves et al., 2013). This period witnessed a peak in fluvial activity both in the north (Nanson et al., 2008; Veth et al., 2009) and

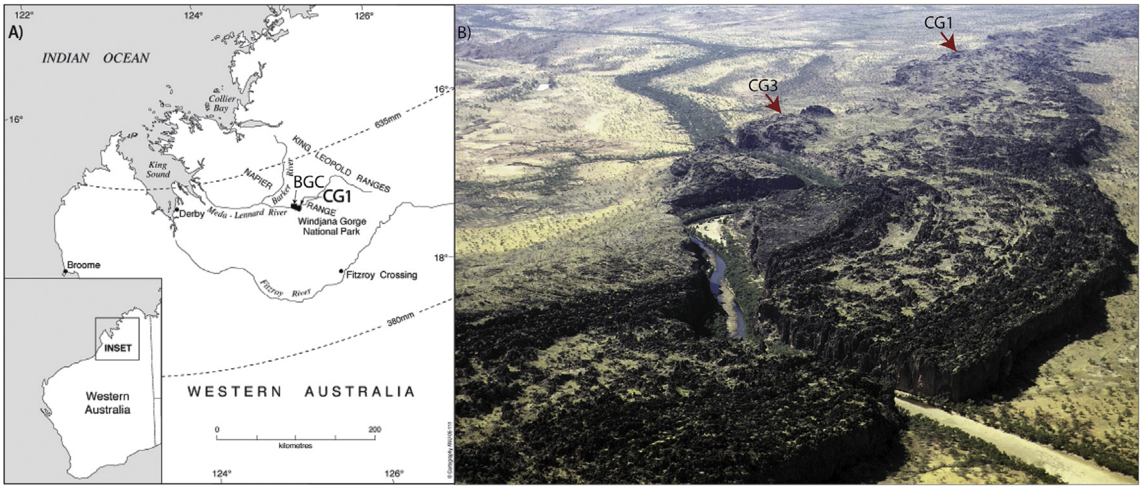

Fig. 2. A) Western Australia showing location of CG1 and present day annual rain isohyets (in mm) B) Proximity of CG1 to Windjana Gorge and CG3, adapted from Playford et al. (2009:233).

in the temperate zone, and inland lakes maintained high water levels throughout this time (Reeves et al., 2013:26–27). The Last Glacial Period [hereafter LGP], corresponding to OIS2, which began around 30,000 BP, marks the onset of increasingly drier conditions. The most arid phase of human occupation, the Last Glacial Maximum [hereafter LGM], occurred between 22,000 and 18,000 cal BP (Petherick et al., 2013:59, 65–72; Shulmeister et al., 2016:1140). However, climatic data on the LGP and LGM in northwest Australia is somewhat contradictory. For example, van der Kaars et al. (2006:888) report that at Northwest Cape in the Pilbara (Fig. 1), the interval spanning the period 32,000 to 20,000 BP 'saw the driest conditions for the last 100,000 years' with virtually no summer (monsoonal) rain. In contrast, the time series data for the stalagmite record from Ball Gown Cave (BGC) in the Napier Range, located near CG1 (Fig. 2A), shows a dynamic Last Glacial Indo-Australian Summer Monsoon (IASM), 'including an active albeit variable monsoon occurring across the western Kimberley during the Last Glacial Maximum (LGM)' (Denniston et al., 2013:164). The BGC time series is thus at odds with the prevailing view of this period which has been that of a system severely weakened by reduced atmospheric and ocean temperatures, as well as land-sea temperature contrasts, and a weakened or collapsed monsoon at the LGM (Denniston et al., 2013:264). Carpenters Gap 1 provides a record of how people responded to these environmental changes, which is outlined here for the first time.

It is still unclear to what degree different environments in north Western Australia were affected by these major climatic changes. Veth (1989, 1995, 2005) has suggested that this period saw the loss of many permanent water sources and food staples on desert lowlands, forcing people to restrict their territorial range, probably concentrating in refugia areas where there was reliable freshwater. While some sites in northern Australia appear to have been abandoned during this time (O'Connor, 1999; O'Connor et al., 1998) others, such as Lawn Hill, supported populations in permanently watered gorge systems (Hiscock, 1988:245–248), or local springs in the Hamersley Plateau (Marwick, 2002:29). Located in close proximity to the permanent gorge systems of the Lennard River and its tributaries (Fig. 2B) and with a well preserved botanical and faunal record, CG1 provides an apt testing ground for examining the environmental changes accompanying the LGP and the refugia model, in the inland Kimberley.

The stratigraphy of CG1 shows marked lateral variation across the site. Previous studies concentrating on individual excavated squares, have suggested that the extent to which the site continued to be occupied during the LGM (e.g. McConnell and O'Connor, 1997, 1999; O'Connor, 1995; Vannieuwenhuyse et al., 2017; Wallis, 2001) is equivocal. By examining the pattern of stone artefact and faunal deposition from CG1 Square A2, the area of the excavated deposit with the most complete chronostratigraphic sequence, the complex occupational history of the site has become clearer, confirming the significance of the gorges of the Devonian reef for human occupation in the Kimberley during the LGM.

During the LGM in particular, the CG1 assemblage analyses reveal adaptions in subsistence and technological organisation. Subsistence patterns are organized around the variation in time and space of desired resources, and technology has a closely embedded relationship with those subsistence practices (Kuhn, 1995; Torrence, 1989:58). From this framework, we expect both the faunal assemblage and technological record, to reflect responses to changes in these resources, brought on by the changing environment. People will adjust their circumstances to ensure access to food and water, by shifting settlement patterns, social alliances, technological adaptions and resource provisioning. This body of theory involves foraging risk – the probability and severity of failure in subsistence (Bamforth and Bleed, 1997:112–113; Torrence, 1989:59; Winterhalder et al., 1999:302). This probability and severity can relate to dietary needs and access to fresh water (Torrence, 1989:58–59), or the capture or encounter of dangerous animals (Ellis, 1997); but most pragmatically is used to refer to overall subsistence viability. To engage with this theoretical framework for CG1, we use the stone artefact assemblage as a means of quantifying changes in raw material procurement, which reflects changes in mobility and provisioning, and use the faunal evidence as a measure of subsistence.

As an underlying cause of stone tool variation, the abundance and quality of raw materials could be the central factor in determining different technological strategies (Andrefsky, 1994; Bamforth, 1986). The distribution of suitable stone does not necessarily correlate with the active need for stone tools in social and ecological tasks and so material is often transported. Transportation of stone away from the source has evoked a distance decay principle, which holds that the further away from the source, the more there is a need to conserve and maintain stone technology. This relationship can be described as a decaying exponential (Goodale et al., 2008), which encourages people to keep existing tools usable for longer, when access to replacement material is

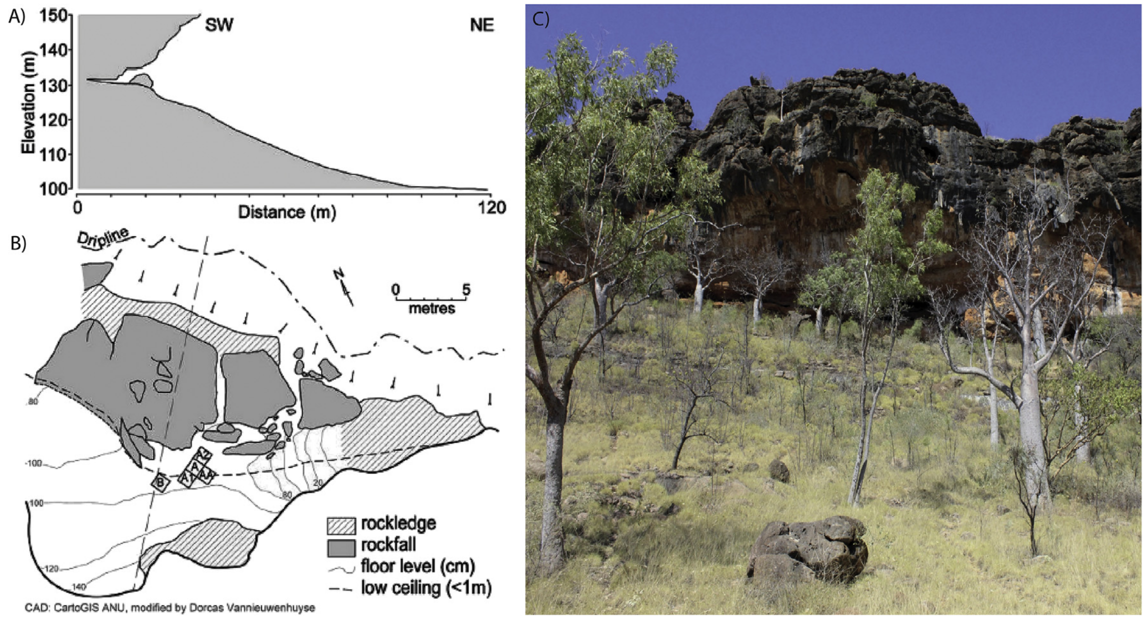

Fig. 3. A) Shelter profile showing approaching slope B) Site map showing location of squares and surface topography (from Vannieuwenhuyse et al., 2017:174) C) photo showing approach to site facing south.

limited, or unknown. Raw material diversity scales on the other hand, are an exponentially decreasing function of raw material quality, where diversity is highest when quality is lowest (Goodale et al., 2008:323). Stone can also be efficiently used in terms of cutting or working edge per gram of stone (Mackay, 2008), and it has be recently demonstrated that creating small, thin flakes, is an extremely efficient use of stone for mobile peoples (Muller and Clarkson, 2016). Similarly, bipolar reduction has been shown to be capable of producing such efficient flakes, regardless of raw material quality and nodule size (Clarkson et al., 2018:180).

2. Materials and methods

2.1. Excavation methods

Five 1 m^2 squares were sequentially excavated over two field seasons in 1993 and 1994, (Fig. 3), reaching bedrock between 66 and 155 cm below the surface. The first squares to be excavated in 1993, A and B, followed arbitrary excavations units [EU] which averaged 2 cm in depth. The subsequent squares were excavated in EUs but within stratigraphic units [SU], where well-defined hearths and ashy features were present. Elsewhere, in the more homogenous lower sediments, EUs of 2 cm were followed. This procedure has allowed the ordering of complex SUs in Squares A2, A1, and AA, particularly those covering the terminal Pleistocene and Holocene boundary. All sediments were sieved through nested 6 mm and 3 mm screens, with bulk sediment samples used for phytolith and anthracological studies.

2.2. Radiocarbon calibration and Bayesian model

All radiocarbon dates in this paper (including dates from sites other than CG1) have been calibrated using OxCal v. 4.3 (Bronk Ramsey, 2009), with the Southern Hemisphere Atmospheric curve [SHCal 2013] (Hogg et al., 2013). The 95.4% probability range has been given for all Probability Distribution Functions unless otherwise stated. Samples included charcoal (n = 97), wood (n = 1), a *Terminalia* sp. seed (n = 1), a marine shell bead (n = 1), and resin from a hafted stone tool (n = 1). In the upper feature rich units samples were taken in situ from hearths or other features for dating. However, in the lower Pleistocene units, which are homogeneous and largely lack well-defined features, charcoal pieces were sampled during excavation directly from the stratigraphic section or in plan. Optically Stimulated Luminescence samples were taken from the profiles, however, as noted by O'Connor and Fankhauser (2001:289), the background radiation was high and the OSL signature saturated, particularly in the lower sediments. We have excluded the oxalate crust dates in Watchman et al. (2005:371) from the discussion and model.

Over more than twenty years, multiple laboratories, including Waikato Radiocarbon Dating Laboratory (Waikato), the Australian Nuclear Science and Technology Organisation (ANSTO), and the Australian National University (ANU), ANU AMS laboratory (ANUA) and ANU Single Stage Accelerator laboratory (SANU), have generated dates using a variety of pre-treatment methods, as new methods were developed. As %C was not measured for any of the samples dated from CG1, it is not possible to assess the cleanliness or preservation state of the charcoal dated. Although charcoal fragments were often large from CG1, and single fragments could have been dated with conventional methods, laboratory notes indicate that at least some of the samples submitted for dating were not single entities (Tables 1 and 2). This means that samples which are found to be outliers, could result from movement between context, chemical contamination not removed during pretreatment or because charcoal of different ages were mixed.

The Bayesian model is constructed from Sequences, in which events are assumed to be chronologically ordered, and phases, in which events are not ordered but are assumed to be uniformly distributed between two Boundaries. Where more than one radiocarbon date was obtained on the same piece of charcoal, the weighted average of the conventional age has been calibrated and modelled. All samples have been ascribed a 5% prior probability of being an outlier within the General t-type Outlier Model (Ramsey, 2009) except for samples that are greater than 30,000 cal BP not treated with ABOxSC or the Waikato ABA pre-treatment protocols, which were ascribed a prior probability of 50%.

Table 1
Radiocarbon dates from CG1 Square AA.

Lab Code	ID Code	EU	SU	Context description	Recovery method	Material	Pre-treatment	Measurement method	dC13 (*assumed)	Curve	Radiocarbon Age (BP)	Calibrated Age Range 95.4%	Reason for model exclusion
Wk-38362		–	1	South wall in situ	South Wall A	charcoal				SHCal13	795 ± 20	723–664	–
OZE 771	CG1/AA – SB	–	2	South wall in situ	South Wall B	charcoal			−26.36	SHCal13	2550 ± 40		–
OZE 773	CG1/AA – SC	–	3	Very top of SU3 ash, south wall in situ	South Wall C	charcoal			−27.55	SHCal13	2740 ± 40		–
Wk-38363		–	3	Bottom of SU3 ash, south wall in situ	South Wall F	charcoal				SHCal13	2905 ± 24	3075–2872	–
OZE 772	CG1/AA – SH	–	3c	Above dark brown sediment	South Wall H	charcoal			−23.64	SHCal13	3310 ± 40		–
ANU-11294	CG1/AA/25 cm bsl	12a	7	Collected in situ from base of hearth during excavation	In situ during excavation	charcoal			−26.2 ± 0.3	SHCal13	3380 ± 90	3828–3786 (4.3%) 3780–3383 (91.1%)	–
OZE776	CG1/AA/25 cm bsl	12	7	Collected in situ during excavation, stratigraphically below 12a	In situ during excavation	charcoal			−25.0	SHCal13	23,220 ± 120	27,685–27,229	–
ANU-11290	CG1/AA/I		7	Orange sediment, South wall in situ	South Wall I	charcoal			−26.2 ± 0.3	SHCal13	22,630 ± 880	28,732–25,243	–
Wk-38365		30	7	Orange sediment, isolated charcoal from spit	Sieve	charcoal				SHCal13	30,767 ± 350	35,387–34,031	–
Wk-38366		35	8	Orange sediment, isolated charcoal from spit	Sieve	Charcoal				SHCal13	43,190 ± 1692	49,949–44,413	–
Wk-38364	77bsl	38	8	Orange sediment, isolated charcoal from spit	Sieve	charcoal				SHCal13	43,357 ± 1725	… – 44,580 48,433–45,252 (68.2%)	–

2.3. Stone artefact analysis

Stone artefacts were identified following Hiscock (2007:204), whereby any ambiguous piece is excluded from the count of artefacts. Together with the frequency of flakes, flake fragments, cores and flaked pieces (making the total number of artefacts [TNA]); the A2 assemblage was also quantified using the minimum number of flakes [MNF] (Hiscock, 2002). Using these values, artefact discard rates can be assessed with some independence from the influence of post depositional fragmentation and heat shatter. Additionally, a morphological analysis of all complete flakes (lacking transverse or longitudinal snaps) and cores was conducted to quantify morphological variation and reduction levels. Methods followed Clarkson (2007). Artefacts were inspected with a digital microscope (Dinolite Pro) for adhering resin and staining, as well as signs of use such as pronounced edge rounding, striations, and small scars indicative of use wear. All data used in this analysis is available online at 10.5281/zenodo.1211406.

The modern distribution of knappable stone in the study area was mapped over three field seasons 2013-15 (Maloney, 2015:42–45) and was combined with the geological mapping of the region (Playford et al., 2009), to evaluate the probable raw material availability. Following Andrefsky (1994), we consider raw material availability the relationship between knapping quality and raw material abundance. Variation in the selection of raw material is taken as evidence sensitive to procurement range.

2.4. Faunal analysis

All bone from each EU sieve fraction was weighed separately. The remains were then categorized and weighed by burning condition, using a 3-stage system described by Aplin et al. (2015); 1) unburnt: with no or little heat modification, 2) burnt: charred, carbonized and/or partially calcined, or 3) calcined: most of the fragment is calcined. Aside from indicating the intensity of firing of the remains, which has significant implications in terms of distinguishing bone that is burnt as a result of human activity vs natural agency (e.g. bushfires), this categorization can also provide useful insights into the extent to which post-depositional degradation has affected the faunal assemblage (Aplin et al., 2015). All bone was also examined for cut and percussion marks, manufacturing marks or use, or signs of carnivore activity such as tooth scoring marks and surficial digestion related to gut passage.

The fauna from each EU was then examined for taxonomically assignable remains such as teeth, fragments of cranium and the pelvic and pectoral girdles, bones of the hand and foot, and the articular ends of all limb elements. A preliminary sort of the potentially diagnostic remains was made into major taxonomic categories: mammals, bird, reptile, amphibian, and fish. Each of these classes of remains was weighed by burning class, thereby allowing the extent of burning to be compared between the major taxonomic categories. The 'unidentified' fraction consists of bone fragments that were not readily allocated to one of the major taxonomic groups. More intensive study of these remains will result in a higher proportion of 'coarsely identified' remains but is unlikely to yield additional specimens suitable for more precise taxonomic identification to genus or species.

3. CG1 results

3.1. Stratigraphy and excavation

CG1 was re-opened in April 2014 to undertake a detailed examination of the sedimentation processes and obtain samples for microstratigraphic analyses (Vannieuwenhuyse et al., 2017). This

Table 2
Radiocarbon dates from CG1 Square A.

Lab Code	ID Code	EU	SU	Context description	Recovery method	Material	Pre-treatment	Measurement method	dC13 (*assumed)	Curve	Radiocarbon Age (BP)	Calibrated Age Range 95.4%	Reason for model exclusion
Wk-3075	CG1/A/2	2	1	Collected in situ during excavation from emerging charcoal rich sediment	In situ during excavation	charcoal		Conventional	–25.8	SHCal13	650 ± 90	721–700 (2.2%) 690–499 (93.2%)	–
ANU-11292	CG1/A-A1		1	South wall in situ	South Wall C	charcoal			–28.4 ± 0.3	SHCal13	560 ± 70	656–455	–
ANU-11295	CG1/A/5	5	1	Collected in situ during excavation from base of hearth in west wall	In situ during excavation	charcoal			–24.0 ± 2.0*	SHCal13	830 ± 80	905–854 (6.7%) 844–630 (82.9%) 601–564 (5.8%)	–
ANU-11298	CG1/A/6	6	2	Isolated charcoal from spit from either darker or lighter strata	Sieve	charcoal			–26.2 ± 0.3	SHCal13	3470 ± 130	4074–4040 (1.3%) 3993–3383 (94.1%)	–
ANU-11299	CG1/A/6	6	2	Isolated charcoal from spit from either darker or lighter strata	Sieve	Wood			–24.0 ± 0.3	SHCal13	4440 ± 70	5286–5158 (21.7%) 5143–5099 (5.7%) 5089–4845 (68.0%)	–
ANU-11297	CG1/A/7	7	2	Collected in situ during excavation from lighter ashy sediment	In situ during excavation	charcoal			–27.4 ± 0.3	SHCal13	3930 ± 120	4802–4761 (1.6%) 4693–4676 (0.5%) 4645–3970 (93.1%) 3941–3933 (0.2%)	–
ANU-11293	CG1/A/8	8	4	Excavation proceeded stratigraphically, sample taken from above dark sediment unit	In situ during excavation	charcoal			–25.2 ± 0.3	SHCal13	15,020 ± 210	18,689–17,734	–
ANU-11168	CG1/A/10	10	5	Excavation proceeded stratigraphically, sample taken from below or in dark sediment unit	Sieve	charcoal	A		–24.0 ± 2.0*	SHCal13	17,260 ± 200	21,364–20,259	–
Wk-16839		11	5	Scaphopoda shell bead recovered from sieve	Sieve	Scaphopoda bead	Acid leach. Aragonite (Fiegel solution)		5.1±-0.2	Marine20 13	3845 ± 37		Scaphopoda beads often found to be older than context
OZE-775	CG1/A – WD	–	5	West wall ins situ	West Wall D	charcoal			–25.0	SHCal13	18,300 ± 100	22,380–21,860	–
Wk-3956	CG1/A/12	12	5	Isolated charcoal from spit, removed separately from surrounding sediments	Sieve	charcoal			–24.6 ± 0.2	SHCal13	18,220 ± 130	22,379–21,700	–
ANU-11169	CG1/A/13	13	5	Collected in situ during excavation from darker sediment above orange sediment	In situ during excavation	charcoal	A		–24.0 ± 2.0	SHCal13	17,570 ± 280	21,925–20,486	–
Wk-3957	CG1/A/16	16	5	Isolated charcoal from spit, removed separately from surrounding sediments, stratigraphically above samples Wk-3956 and ANU-11169	Sieve	charcoal	ABA	AMS	–25.5 ± 0.2	SHCal13	8100 ± 160	9409–8559	Outlier
Wk-3076	CG1/A/17	17	6	Collected in situ during excavation from lighter orange coloured sediment, removed separately from preceding darker unit	In situ during excavation	charcoal	A	AMS	–23.98	SHCal13	20,760 ± 170	25,434–24,453	–
Wk-3077	CG1/A/20	20	6	Isolated charcoal from lighter orange coloured sediment, removed separately from preceding darker units	Sieve	charcoal	A	AMS	–25.16	SHCal13	18,940 ± 170	23,218–22,409	–
ANU-11167	CG1/A/23	23	6	Collected in situ during excavation from lighter orange	In situ during excavation	charcoal	A	AMS	–24.0 ± 2.0*	SHCal13	21,390 ± 180	25,982–25,284	–

(*continued on next page*)

Table 2 (*continued*)

Lab Code	ID Code	EU	SU	Context description	Recovery method	Material	Pre-treatment	Measurement method	dC13 (*assumed)	Curve	Radiocarbon Age (BP)	Calibrated Age Range 95.4%	Reason for model exclusion
				coloured sediment, removed separately from preceding darker unit DBS 1.495 (should logically be 0.495									
ANU-11166	CG1/A/27	27	6	Isolated charcoal from lighter orange coloured sediment	Sieve	charcoal	A		–24.0 ± 2.0*	SHCal13	20,210 ± 240	24,999–23,682	–
ANU-11165	CG1/A/32	32	7	Isolated charcoal from lighter orange coloured sediment	Sieve	charcoal	A		–24.0 ± 2.0*	SHCal13	26,830 ± 270	31,285–30,550	–
ANU-11164	CG1/A/37	37	7	Isolated charcoal from lighter orange coloured sediment, lower units removed separately	Sieve	charcoal			–24.0 ± 2.0*	SHCal13	27,760 ± 520	33,046–30,897	Most likely from SU7, sample from unit removed separately from surrounding orange sediments
Wk-3078	CG1/A/40	40	7	Isolated charcoal from lighter orange coloured sediment	In situ during excavation	charcoal		AMS	–26.87	SHCal13	39,700 ± 1000	45,347–42,124	–
ANU-11163	CG1/A/40	40	7	Isolated charcoal from lighter orange coloured sediment	Sieve	charcoal	A		–24.0 2.0	SHCal13	25,390 ± 370	30,480–28,685	–
ANU-11241		40	7		Sieve	charcoal	A		–20.1		23,140 ± 620		–
ANU-11162	CG1/A/43	43	7	Isolated charcoal from lighter orange coloured sediment	Sieve	charcoal	A		–24.0 ± 2.0*	SHCal13	22,940 ± 670	28,440–25,915	–
ANU-11240		43a	~7			charcoal			–21.9		23,380 ± 1000	29,942–25,784	Most likely from SU7, sample from unit removed separately from surrounding orange sediments
ANU-11161	CG1/A/45	45	7	Isolated charcoal from lighter orange coloured sediment	Sieve	charcoal	A		–24.0 ± 2.0*	SHCal13	25,440 ± 880	31,164–27,897	–
OZD 058	CG1/A/45	45	7	Isolated charcoal from lighter orange coloured sediment	Sieve	*Terminalia* sp.			–20.00	SHCal13	30,700 ± 650	36,058–33,655	–
ANUA-8130	CG1/A/45 1st sample	45	7	Isolated charcoal from lighter orange coloured sediment	Sieve	charcoal	ABOx, combusted at 880 °C	AMS	–25*	SHCal13	33,200 ± 600	38,852–35, 993	–
ANUA-8227	CG1/A/45 1st sample	45	7	Isolated charcoal from lighter orange coloured sediment	Sieve	charcoal	ABOx, combusted at 660 °C	AMS	–25*	SHCal13	33,000 ± 700	38,899–35,570	–
ANUA-8226	CG1/A/45 2nd sample	45	7	Isolated charcoal from lighter orange coloured sediment	Sieve	charcoal	ABOx, combusted at 340 °C	AMS	–25*	SHCal13	33,100 ± 800	39,331–35,507	–
ANUA-8222	CG1/A/45 2nd sample	45	7	Isolated charcoal from lighter orange coloured sediment	Sieve	charcoal	ABOx, combusted at 660 °C	AMS	–25*	SHCal13	32,800 ± 500	38,347–35,772	–
ANUA-7626	CG1/A/45 2nd sample	45	7	Isolated charcoal from lighter orange coloured sediment	Sieve	charcoal	ABOx, combusted at 880 °C	AMS	–25*	SHCal13	33,600 ± 500	39,030–36,465	–
OZD-161	CG1/A/48	48	8	Collected in situ during excavation from lighter orange coloured sediment	In situ during excavation	charcoal			–25	SHCal13	42,800 ± 1850	49,919–43,877	–

ANUA-7615	CG1/A/48 1st sample	48	8	Isolated charcoal from lighter orange coloured sediment	Sieve	charcoal	ABOx, combusted at 340 °C	AMS	−25*	SHCal13	39,800 ± 600	44,596–42,598	–
ANUA-7616	CG1/A/48 1st sample	48	8	Isolated charcoal from lighter orange coloured sediment	Sieve	charcoal	ABOx, combusted at 660 °C	AMS	−25*	SHCal13	40,600 ± 800	45,604–42,894	–
ANUA-7617	CG1/A/48 1st sample	48	8	Isolated charcoal from lighter orange coloured sediment	Sieve	charcoal	ABOx, combusted at 880 °C	AMS	−25*	SHCal13	40,300 ± 800	45,365–42,713	–
Wk-3079	CG1/A/49	49	8	Collected in situ during excavation from lighter orange coloured sediment	In situ during excavation	charcoal		AMS	−26.7	SHCal13	39,220 ± 870	44,713–41,946	–

study of the stratigraphy of Squares A and A1 has produced a record of site formation history. Vannieuwenhuyse et al. (2017) identified eight major stratigraphic units within this area of the site, which are mostly paralleled in the adjacent squares. With the addition of several unique layers and features not found in Squares A and A1, we use the same major stratigraphic units as phases to build our Bayesian chronology.

Sediments at CG1 accumulated primarily as a result of in situ weathering of layers of softer sedimentary rocks embedded in the limestone reef, from which the shelter is formed, with the addition of aeolian components and several hearths (Vannieuwenhuyse et al., 2017). Wallis (2001) also comments on a consistent deposition of animal dung throughout the upper parts of the deposit. Large boulders at the front of the shelter have contained the deposit (Fig. 3) and protected the area from fire, but it is likely that sediment was removed in some areas (Vannieuwenhuyse et al., 2017).

Vannieuwenhuyse et al. (2017:181) describe the Pleistocene layers of Squares A and A1, as an ‘accumulation of orange-brown (10YR4/4) sandy sediment, grading up into dark greyish brown (10YR3/2), as the deposit progressively darkens as the charred components proportion increases’. The lower part of the deposit accumulated primarily from geogenic processes and only a single remaining hearth feature remains intact in this part of the site. While Squares A and A1 do not preserve deposit dated between 15,000 and 3000 BP, much of the upper part of the deposit across the remaining squares, is a complex of finely laminated stratigraphic features covering this period. Fig. 4 illustrates the western wall, including sections of Squares A1, A and A2 with radiocarbon samples plotted. Fig. 5 is the stratigraphic profile of Square A2. All other stratigraphic sections for individual squares are presented in supplementary figures A to D. Profiles from Square A and A1 vary slightly from those presented in Vannieuwenhuyse et al. (2017), as the sections were scraped back in 2014 after removal of the backfill and prior to microstratigraphic sampling.

Much of the upper part of the deposit contains a complex laminated stratigraphy covering the Holocene, with numerous anthropogenic dug features disturbing the top of the deposit. In Square A, Vannieuwenhuyse et al. (2017) suggest that the inclined layering (notable in supplementary B) probably reflects a dome of sediment which resulted from dumping of material from cleaning of combustion features in another area of the cave. There is significant lateral variation in these upper units, with some areas such as the western profile of Squares A and A1 containing more homogenous sediments at the macroscale (although at the microscale fine laminations are visible) (Vannieuwenhuyse et al., 2017).

Except in Squares A and B these upper laminated layers were excavated stratigraphically. Where multiple stratigraphic units were cross-cut by removal in EUs, we have merged several layers into one stratigraphic unit, SU2, following Vannieuwenhuyse et al. (2017). These authors identify ten strata within this unit of Square A1 for example; all of which are above EU 8, dated to between 3441 and 3076 cal BP (ANU-10029), and below surface units dated to 674–496 cal BP (ANU-10028). Despite the stratigraphic removal of units in adjacent squares, often involving lenses less than 1 cm that were rarely horizontally bedded, it is likely that some cross-cutting of units occurred during excavation, and that movement may have occurred within the soft sandy sediments.

3.2. Chronological modelling

Over 100 radiocarbon dates, primarily on charcoal, have been obtained from all of the excavated squares at CG1 (Tables 1–5). The more rigorous cleaning protocol, ABOx-SC, does not appear to cause the age of charcoal at CG1 in comparison with the routine method ABA. Although no charcoal fragments were dated with ABA and

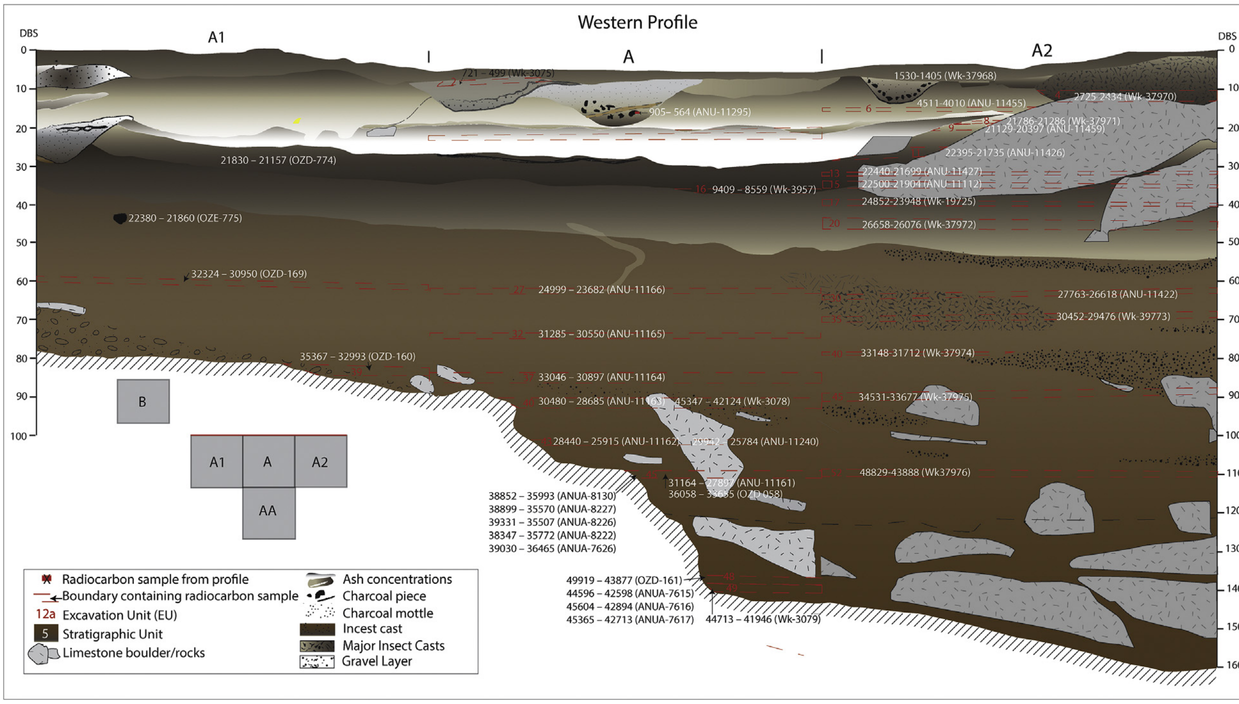

Fig. 4. Stratigraphic profile of the western wall, showing sections of Square A1, A and A2, with radiocarbon samples plotted.

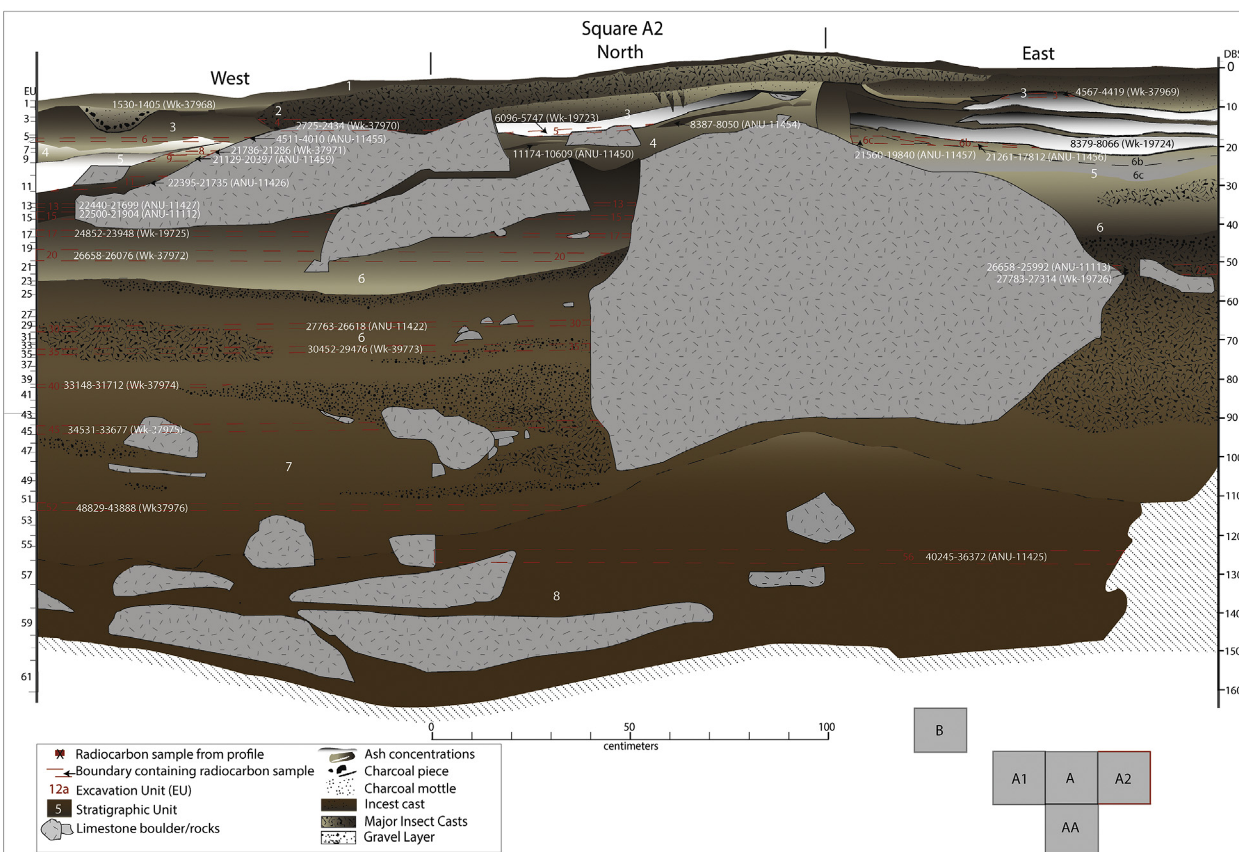

Fig. 5. Stratigraphic profile of Square A2 with radiocarbon samples plotted.

Table 3
Radiocarbon dates from CG1 Square A2.

Lab Code	ID Code	EU	SU	Context description	Recovery method	Material	Pre-treatment	dC13 (*assumed)	Curve	Radiocarbon Age	Calibrated Age Range 95.4%
Wk-37968	CG1-A2-2	2	2	In situ from uppermost layer	In situ during excavation	charcoal	ABA	−26.3 ± 0.2	SHCal13	1611 ± 20	1530−1405
Wk-37970	CG1-A2-4	4	2a	In situ from insect cast layer	In situ during excavation	charcoal	ABA	−27.0 ± 0.2	SHCal13	2527 ± 20	2725−2434
Wk-37969	CG1-A2-3	3	2b	Hearth ash rich unit in east wall	In situ during excavation	charcoal	ABA	−25.1 ± 0.2	SHCal13	4059 ± 20	4567−4557 (2.0%) 4547−4544 (0.5%) 4533−4419 (92.9%)
ANU-11455	CG1/A2/6	6	3	Stratigraphically above 5 and 5a	In situ during excavation	charcoal		−26.6 ± 0.1	SHCal13	3900 ± 70	4511−4484 (1.6%) 4442−4082 (92.8%) 4030−4010 (1.0%)
Wk-19723	CG1-A2-5	5	3	Dark brown deposit in SE Corner		charcoal		−26.0 ± 0.2	SHCal13	5204 ± 45	6096−6085 (0.7%) 6004−5841 (73.5%) 5833−5747 (21.2%)
ANU-11454	CG1/A2/5A	5A	4	Hearth Feature Towards South Wall, marked on north, as same stratigraphic unit	In situ during excavation	charcoal	ABA	−26.6 ± 0.1	SHCal13	7470 ± 70	8387−8152 (88.3%) 8142−8131 (0.9%) 8121−8105 (1.4%) 8095−8050 (4.8%)
Wk-19724	CG1/A2/7	7	4	Excavation proceeded stratigraphically, removed separately from 6b and 6c	In situ during excavation	charcoal	ABA	−26.0 ± 0.2	SHCal13	7468 ± 51	8379−8160 (94.2%) 8085−8066 (1.2%)
ANU-11450	CG1/A2/7	7	4	Excavation proceeded stratigraphically, removed separately from 6b and 6c	In situ during excavation	charcoal		−25.7 ± 0.1	SHCal13	9600 ± 80	11,174−10,659 (95.2%) 10,612−10,609 (0.2%)
ANU-11458		7	4			charcoal	ABA			9650 ± 80	
ANU-11456	CG1/A2/6b	6b	5	Excavation proceeded stratigraphically, removed under ash layers as separate unit	In situ during excavation	charcoal	ABA	−24.9 ± 0.1	SHCal13	16,000 ± 710	21,261−17,812
ANU-11457	CG1/A2/6c	6c	5	Excavation proceeded stratigraphically, removed under ash layers as separate unit	In situ during excavation	charcoal	ABA	−24.0 ± 2.0*	SHCal13	17,130 ± 330	21,560−19,840
Wk-37971	CG1-A2-8	8	5	From solid ash, didn't remove surrounding dark sediment	Sieve	charcoal	ABA	−25.2 ± 0.2	SHCal13	17,814 ± 57	21,786−21,286
ANU-11459	CG1/A2/9	9	5	From solid ash, didn't remove surrounding dark sediment	Sieve	charcoal	ABA	−25.2 ± 0.1	SHCal13	17,240 ± 130	21,129−20,397
ANU-11426	CG1/A2/11	11	5	From solid ash, didn't remove surrounding dark sediment	Sieve	charcoal	ABA	−25.0 ± 0.1	SHCal13	18,240 ± 130	22,395−21,735
ANU-11427	CG1/A2/13	13	6	Below multilayered section	Sieve	charcoal	A	−25.0 ± 0.1	SHCal13	18,270 ± 160	22,440−21,699
ANU-11112	CG1/A2/15	15	6	Below multilayered section	Sieve	charcoal	A	−24.0 ± 2.0*	SHCal13	18,430 ± 130	22,500−21,904
Wk-19725	CG1/A2/17	17	6	Below multilayered section	Sieve	charcoal	ABA	−25.5 ± 2.0	SHCal13	20,292 ± 150	24,852−23,948
Wk-37972	CG1-A2-20	20	6	Below multilayered section	Sieve	charcoal	ABA	−25.5 ± 0.2	SHCal13	22,192 ± 94	26,658−26,076
Wk-19726	CG1/A2/25	25	6	From next layer with insect cast, from SE corner	In situ during excavation	charcoal	ABA	−24.4 0.2	SHCal13	23,366 ± 150	27,783−27,314
ANU-11113	CG1/A2/25	25	6	From next layer with insect cast, from SE corner	In situ during excavation	charcoal	A	−24.0 ± 0.2*	SHCal13	22,130 ± 200	26,658−25,992
ANU-11422	CG1/A2/30	30	6	Within spit from next layer with insect cast	Sieve	charcoal	ABA	−25.5 ± 0.1	SHCal13	23,050 ± 300	27,763−26,618
Wk-37973	CG1-A2-35	35	7	Within spit from next layer with insect cast	Sieve	charcoal	ABA	−25.1 ± 0.2	SHCal13	25,791 ± 147	30,452−29,476
Wk-37974	CG1-A2-40	40	7	In next more orange layer, taken from under/adjacent insect cast layer	Sieve	charcoal	ABA	−25.2 ± 0.2	SHCal13	28,540 ± 203	33,148−31,712
Wk-37975	CG1-A2-45	45	7	Within spit	Sieve	charcoal	ABA	−24.5 ± 0.2	SHCal13	30,022 ± 241	34,531−33,677
Wk-37976	CG1/A2/52	52	7	Within spit	Sieve	charcoal	ABA	−25.4 ± 0.2	SHCal13	42,496 ± 1185	48,829−43,888
ANU-11425	CG1/A2/56	56	8	Under large rock close to SE corner, lowest unit	In situ during excavation	charcoal	ABA	−25.9 ± 0.1	SHCal13	33,980 ± 790	40,245−36,372

Table 4
Radiocarbon dates from CG1 Square A1.

Lab No.	ID Code	EU	SU	Context description	Recovery method	Material	Pre-treatment	dC13 (*assumed)	Curve	Radiocarbon Age (BP)	Calibrated Age Range 95.4%	Reason for model exclusion
ANU-10028	CG1/A1/1	1	1	In situ wall sample, immediately above hearth	South Wall A	charcoal with fragments of paperbark	A	−24.0 ± 2.0*	SHCal13	620 ± 80	674–496	–
ANU-10029	CG1/A1/8	8	3	Collected in situ during excavation, removed separately from lighter ashy sediment	In situ during excavation	charcoal	A	−24.0 ± 2.0*	SHCal13	3110 ± 60	3441–3431 (0.7%) 3402–3076 (94.7%)	–
ANU-11421		8b	3	In situ from hearth feature	South Wall C	charcoal			SHCal13	2960 ± 40	3209–3191 (1.7%) 3185–2927 (93.7%)	–
SANU - 39039			3	Resin on stone point, recovered from ashy unit removed separately	Sieve	resin		−18 ± 2.01	SHCal13	2950 ± 25	3160–2954	–
ANU-10030	CG1/A1/8C	8c	3	Removed separately from darker units	Sieve	charcoal	A	−24.0 ± 2.0*	SHCal13	3300 ± 60	3632–3365	–
OZF-211		8D	3	In situ from ashy feature	South Wall E	charcoal in sediment			SHCal13	5730 ± 40	6633–6396 (93.7%) 6368–6350 (1.7%)	–
ANU-11460	CG1/A1/9	9	3	Collected in situ during excavation, removed separately from ashy sediment	In situ during excavation	charcoal	ABA	−25.7 ± 0.1	SHCal13	3180 ± 70	3557–3531 (01.9%) 3510–3165 (93.5%)	–
ANU-11462	CG1/A1/10	10	3	Collected in situ during excavation, removed separately from ashy sediment and proceeding charcoal rich unit	In situ during excavation	charcoal	ABA	−24.0 ± 2.0*	SHCal13	3190 ± 60	3553–3533 (1.5%) 3493–3206 (93.0%) 3197–3182 (1.0%)	–
OZF-210	CG1/A1/9A	9a	5	In situ wall sample below olive brown sediment, within charcoal rich unit	South Wall F	charcoal				11,980 ± 60	13,976–13,575	–
ANU-11423	CG1/A1/10a	10a	5	In situ wall sample collected from ashy unit	South Wall G	charcoal	A	−24.0 ± .2.0*	SHCal13	15,040 ± 360	19,030–17,394	–
ANU-11296	CG1/A1/11a	11a	5	In situ wall sample collected from ashy unit	South Wall H	charcoal		−26.1 ± 0.3	SHCal13	12,090 ± 150	14,441–13,542 (95.0%) 13,515–13,489 (0.4%)	–
ANU-10027	CG1/A1/13a	13a	5	In situ wall sample collected from very thin ashy unit	South Wall J	charcoal - fine dark brown humic looking sand and silt, with fine to coarse carbonate coated soil and charcoal fragments, plus at least two bone fragments		−24.0 ± 2.0*	SHCal13	16,050 ± 150	19,682–18,925	–
ANU-11291	CG1/A1/14a	14a	5	In situ wall sample collected from	South Wall K	charcoal		−25.8 ± 0.3	SHCal13	17,150 ± 420	21,802–19,674	
OZD-774	CG1/A1 – WB	–	5	26 cm below surface	West Wall	charcoal		−24.06	SHCal13	17,800 ± 100	21,830–21,157	Uncertain relationship
OZD-775				In situ wall sample	West Wall	charcoal		−25.36	SHCal13	18,290 ± 100	22,375–21,850	Uncertain relationship
OZD-169	CG1/A1/29A	29a	7	Depicted within EU	North Wall	charcoal		−25.00 ± 3.22*	SHCal13	27,600 ± 330	32,324–30,950	–
OZD-160	CG1/A1/39	39	7	Isolated charcoal piece from spit residue	Sieve	charcoal		−25.00 ± 2.36*	SHCal13	30,100 ± 600	35,367–32,993	–

Table 5
Radiocarbon dates from CG1 Square B.

Lab No.	ID Code	EU	SU	Context description	Recovery method	Material	Pre-treatment	dC13 (*assumed)	Curve	Radiocarbon Age (BP)	Calibrated Age Range 95.4%	Reason for model exclusion
ANU-10603	CG1/B/3	3a	2	From ash rich hearth feature, shown on north wall	In situ during excavation	Charcoal – black charcoal fragments and very fine sand containing rootlets, unclear what was selected for dating	A	−24.0 ± 2.0	SHCal13	3970 ± 60	4526–4220 (89.9%) 4208–4156 (5.5%)	Square B is not continuous with other excavation squares, making stratigraphic correlation uncertain
ANU-11424	CG1/B13	13	3	From bottom of large hearth feature in south wall, stratigraphically above SU 3,4,5, but excavated later, i.e. hearth cuts through all these layers	In situ during excavation	charcoal	ABA	−26.1 ± 0.1	SHCal13	4120 ± 70	4821–4423	Square B is not continuous with other excavation squares, making stratigraphic correlation uncertain
ANU-10005	CG1/B/9	9	4	From spit removed separately from within ashy unit. Adjacent but stratigraphically below large hearth feature in south wall (18)	Sieve	charcoal	A	−24.0 ± 2.0*	SHCal13	5250 ± 60	6183–5886 (90.2%) 5819–5761 (5.2%)	Square B is not continuous with other excavation squares, making stratigraphic correlation uncertain
ANU-10006	CG1/B/16	16	6	In situ sample	In situ during excavation	charcoal	A	−24.0 ± 2.0*	SHCal13	18,070 ± 150	22,284–21,438	Square B is not continuous with other excavation squares, making stratigraphic correlation uncertain
ANU-10605	CG1/B/24	24	8	From hearth feature depicted in East Wall	In situ during excavation	Black charcoal fragments	A	−24.0 ± 2.0*	SHCal13	17,910 ± 200	22,193–21,057	Square B is not continuous with other excavation squares, making stratigraphic correlation uncertain
ANU-11461	CG1/B/30	30	8	Frim spit within lowest orange sediment	Sieve	charcoal	ABA	−24.0 ± 0.0*	SHCal13	17,940 ± 710	23,465–20,021	Square B is not continuous with other excavation squares, making stratigraphic correlation uncertain

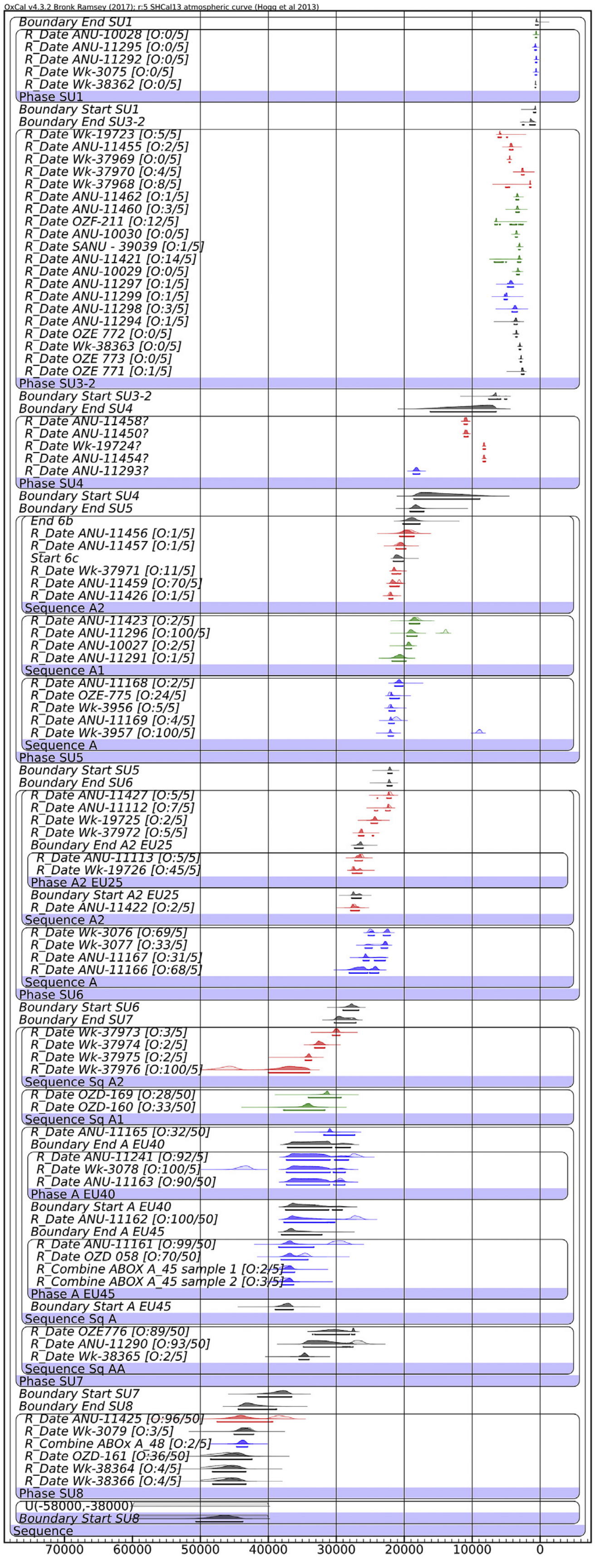

Fig. 6. Bayesian model of radiocarbon dates obtained from CG1. Samples from Square AA are grey, A are blue, A1 are green and A2 are red. Pale probability distributions represent the uncalibrated date, and dark distributions the modelled date. Brackets beneath the probability distributions represent the 95.4% probability range of the modelled age. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

ABOxSC pre-treatment methods, increasing the stepped combustion temperature has no impact on age of three fragments (Fifield et al., 2001). Moreover, the group of samples from CG1 dating beyond 41,000 cal BP includes charcoal treated with both ABA and ABOx-SC methods. This group of samples contains one charcoal dated at ANSTO, and five dated by Waikato (Tables 1 and 2). Therefore, whilst it is impossible to be confident in the accuracy of samples dated beyond 30,000 BP without ABOx-SC pre-treatment backed up by high %C values, it is probable that the majority of dates are accurate, and in particular those from Waikato.

A chronological model has been built to address particular chronological questions, focusing on the earliest age for occupation at CG1 and the continuity of occupation during the LGM. The OxCal code for this model is available at 10.5281/zenodo.1211406.

Each of the Pleistocene units, SU8 to 5 is modelled as a phase within the overall modelled Sequence, with the upper units, SU4 to 1, merged together as a single phase (Fig. 6, supplementary table G). Where multiple dates have been obtained from a given square, a Sequence has been placed within the phase. Dates from SU4 have been excluded from the model as they are few and very widely spaced. When included the model would not converge. Although the start and end modelled ages for SU4 are therefore based on dates in SU5 and 3, the radiocarbon dates in SU4 appear consistent with the model. Of particular interest was the sub-unit rich in fish bone within SU5 (EU6b and 6c). To examine the age of this sub-unit, the dates within Square A2 were organised into a Sequence, and a Boundary placed before the radiocarbon date obtained from 6c and another above the date obtained from 6b.

Given the complexity of the stratigraphy and wealth of information contained in the site, alternative models designed to focus on different parts of the stratigraphy (particularly in the 8 upper Holocene units) are undoubtedly possible. It was possible to assign the majority of samples to a single SU, following those units previously identified by Vannieuwenhuyse et al. (2017). Samples that have come from more than one SU (e.g. where an EU cut across an SU), or where stratigraphic information was missing are not included in the model (Tables 1–5). Dates from Square B are not included in the model as the square is separate (Fig. 3), and so stratigraphic relationships are uncertain. Finally, although similar to surrounding dates, the date on a Scaphopoda shell bead is not included in the model because these shells have elsewhere been found to be older than their context (Balme and O'Connor, 2017).

The analyses of stone technology and faunal remains from the A2 assemblages use these six phases. The phases used to describe the A2 assemblage through time are as follows:

Phase 1 SU8 (EU 61 to 56); 51,000–43,800 to 44,400–38,800 cal BP

Phase 2 SU7 (EU 55 to 35); 41,400 to 36,600 to 30,300–27,100 cal BP

Phase 3 SU6 (EU 34 to 13, including Glacial Period); 29,000–26,700 to 22,500–21,800 cal BP

Phase 4 SU5 (EU 12 to 6b/6c, including the LGM period); 22,400–21,800 to 19,200–17,100 cal BP

Phase 5 SU4 (EU 7 to 5a); 18,600–8900 to 16,200–6500 cal BP

Phase 6 SU3, 2 and 1 (EU 5 to the surface); 7600–4900 to 700–300

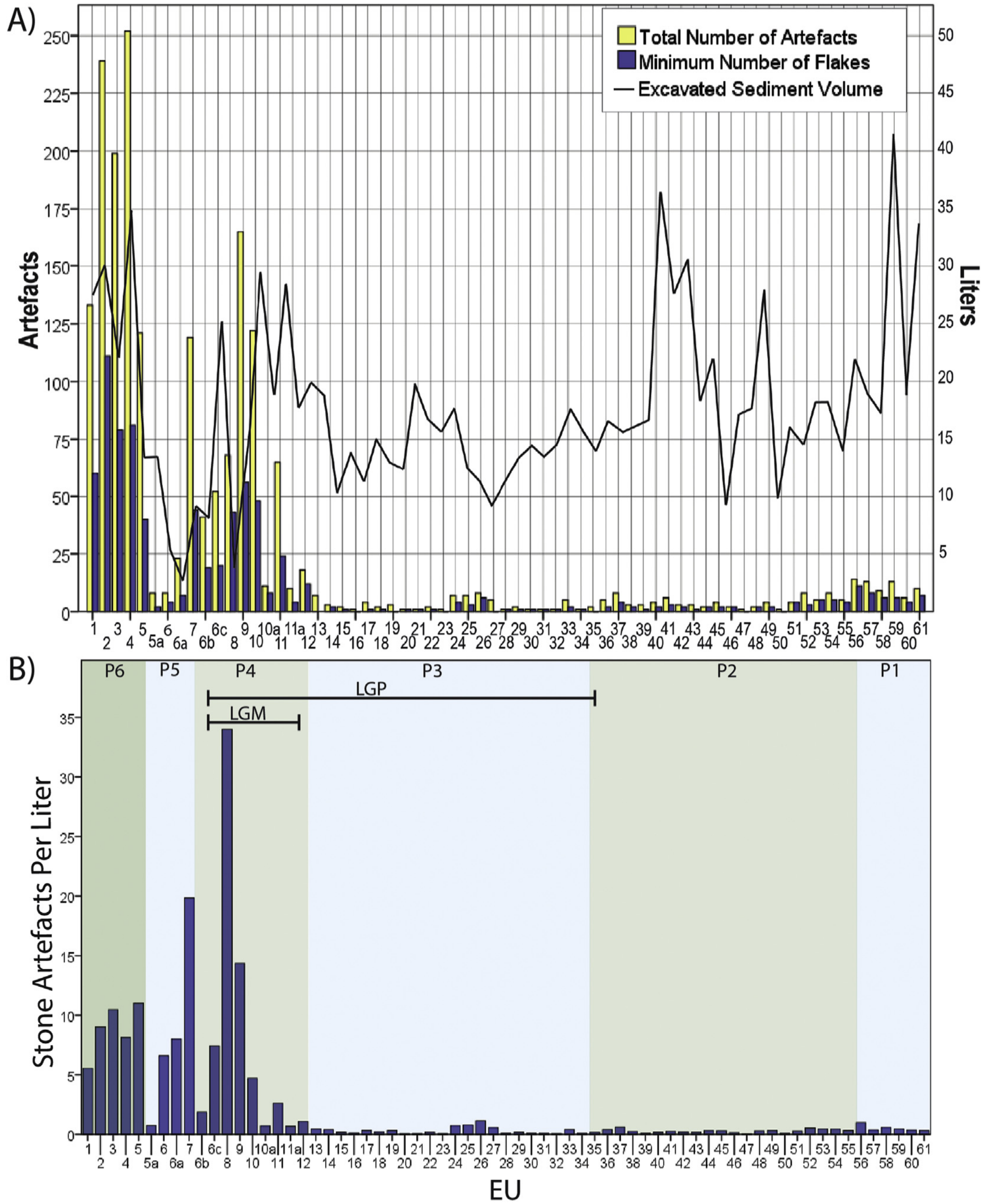

Fig. 7. A) Total number of artefacts and minimum number of flakes, relative to excavated volume and excavation unit B) Number of artefacts adjusted per litre, across excavation units and time phases.

There are a number of radiocarbon outliers throughout the sequence at CG1. These radiocarbon outliers can provide an indication of mobility between stratigraphic units. The clearest suggestion of movement between SU8 and SU7 is provided by two anomalously old dates in SU7 (Wk-37976 and Wk-3078) that are the same age as the oldest dates in SU8. It is difficult to know whether the young age of ANU-11425 is due to poor pre-treatment or inclusion of young charcoal in the dated sample. From this we can conclude that although the majority of material in SU8 predates 40,000 cal BP, there is a small probability younger material may be included.

3.3. Stone artefacts and technological change over time

In Square A2 a total of 1872 flaked stone artefacts were recovered. Fig. 7 depicts the total number of stone artefacts and minimum number of flakes, relative to excavated volume (Table 8). The agreement between these two discard values suggests breakage from agents such as scuffing, treading, or heat damage, have had little effect on the observed trends, using a Cohen's kappa coefficient ($k = 0.113$, $p = 0.01$). Instead, the artefact accumulations represent distinct pulses of occupation. These data also reflect the relatively smaller amount of excavated volume of the finely laminated units removed as discrete contexts (5, 5a, 6, 6a, 7, 6b and 6c, 8, 9). Adjusting the TNA relative to excavated volume (artefacts per litre), shows that there were relatively more artefacts deposited per unit volume during the LGM (Fig. 7B) than during the proceeding Holocene phase. The technology recovered from each of the six phases will be now summarized.

The first artefact discard peak occurs in Phase 1 (c. 51,000 to 38,800 cal BP) between XU 61 to 55 (Fig. 7), representing the earliest technological activities at the site, and showing an early pulse of activity following initial settlement. This stone artefact accumulation is unlikely to be the result of vertical displacement, creating a trickling effect of smaller artefacts moving towards the bedrock (e.g. Marwick et al., 2017) for two reasons. First, Hiscock et al. (2016:6) used metric attributes such as mass, percussion length and maximum lineal dimension with univariate statistical tests, to rule out size sorting within this Pleistocene deposit of A2. Second, in EUs 61 and 60, three flakes of green hornfels – an exotic raw material which is rare in the overall assemblage, were able to be conjoined, demonstrating some level of discrete knapping activity within these units (Fig. 8A). Overall, the stone artefact assemblage from this early phase displays technological differences from the later phases and this further diminishes the likelihood of vertical movement.

The artefacts discarded in Phase 1 (n = 65) include flakes and cores, made predominantly from locally available, high quality crystal quartz (83.1%). This material is of exceptional knapping quality lacking incipient fractures and naturally occurs as small nodules, such as formed crystals and occasionally small secondary pebbles, in low to moderate abundance. In contrast, white vein quartz, albeit of much lower knapping quality, is extremely abundant in the local geomorphology but it appears to have been completely eschewed for artefact production during this phase. Nine fine-grained hornfel flakes from this phase are consistently small (mean percussion length = 10.42 mm, SD = 7.8 mm) with comparatively low external platform angles (70º ±14 vs 85º ±8 for crystal quartz), possibly resulting from the removal of flakes from the low angled platform edge of a retouched flake. Fine-grained basalt was also used including a single edge-ground flake (Fig. 8B), demonstrating that the maintenance of edge-ground axes was undertaken within the shelter during its earliest occupation (Hiscock et al., 2016). Overall, raw material selection from this early phase indicates a preference for the highest quality material in the local area only.

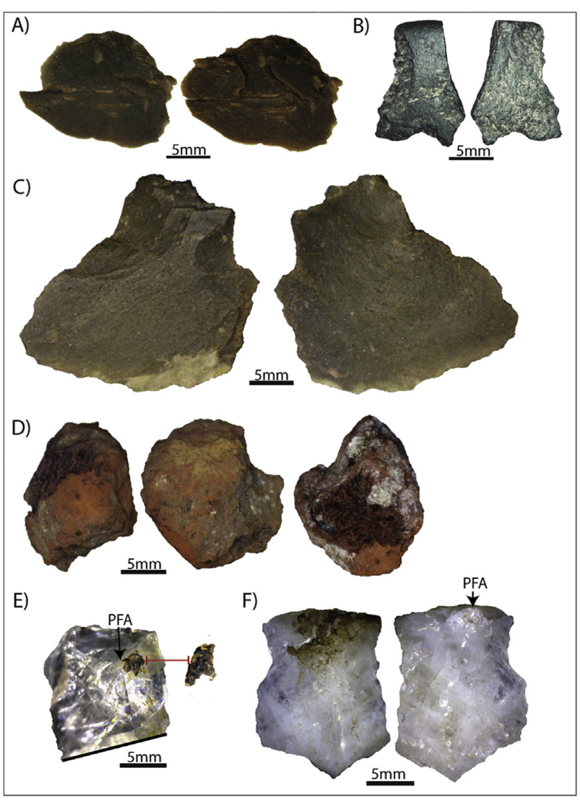

Fig. 8. Stone artefacts. A) Green hornfels flake with two smaller conjoining flakes from EU 61 and 60 B) Edge-ground volcanic flake from EU 52 reported in Hiscock et al. (2016:6) C) Thin green hornfels flake from EU 59, with fine edge damage and rounding. D) Haematite piece from EU 46 with signs of abrasion E) Crystal quartz flake fragment, showing proximal portion of a transverse snap, with resin adhering to the longitudinally snapped surface F) Quartz flake with resin adhering only to the proximal dorsal surface and platform. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

The cores (n = 3) are all crystal quartz and exhibit signs of heavy reduction with three to four rotations with maximum lineal dimensions smaller than 31 mm. These cores were reduced until freehold reduction was no longer possible, seeing one reduced on an anvil using the bipolar technique, demonstrating the efforts made to maximise core utility from such small nodules.

The size of flake scars (7.9–30.5 mm) is within the range of discarded flakes, suggesting that the production of small, sharp, morphologically irregular flakes was a priority for reduction within the shelter.

The complete flakes from this phase are predominantly tertiary (n = 55, 84.6%), with typically more than one dorsal scar direction (n = 26, 40%), further suggesting high reduction levels for crystal quartz. The low proportion of dorsal surfaces retaining formed crystal cortex (n = 5, 7.7%) suggests that initial reduction usually took place outside the shelter. Flake platform types, also sensitive to core reduction, are predominantly focalised (n = 16, 24.6%) with frequent use of faceting and overhang removal (n = 17). Focalised platforms indicate a high flake mass relative to small platform area, which may suggest efforts to maximise working edge relative to flake mass (Braun, 2005; Clarkson and Hiscock, 2011:1061). Two complete bipolar flakes were identified. Few of the Phase 1 flakes have any evidence of use, such as concentrated marginal edge damage scars (n = 2), and pronounced rounding (n = 2). Two artefacts, a relatively thick crystal quartz flake and a thin hornfels flake, exhibit both edge damage and rounding (Fig. 8C) and were probably used for cutting or light abrasion.

Three flakes within this early phase have bending initiations, each with moderately low external platforms angles (<60°), although none with moderate ventral curvature, and only a single flake with faceting scars; which we suggest does not provide a strong case for bifacial thinning in the early record, contra the early Madjedbebe flaked technology (Clarkson et al., 2015:54).

There are no traces of resin on flakes in the earliest phase, despite evidence for resin production from the macrobotanical records in the early units (McConnell and O'Connor, 1997:24–27). However there is evidence for stone tools potentially being used for modifying bone, as Langley et al. (2016:204) report on a bone artefact from EU59.

The stone artefacts (n = 84) discarded during Phase 2 (41,400 to 27,100 cal BP) represent a comparatively higher diversity of exploited raw materials (Table 6). Crystal quartz remains dominant (67.9%) but tool makers began to exploit the locally abundant white vein quartz for the first time, as well as more exotic siliceous stone (quartzites and chert). Siliceous stone found close to the site in either conglomerate bands or river gravels (Maloney, 2015:42–45; Playford et al., 2009:145) are seldom brittle enough for knapping, suggesting these materials were more likely sourced from elsewhere.

Table 6
Raw material summary per time phase.

Phase	Crystal Quartz		Vein Quartz		Fine Grained Quartzite		Medium Grained Quartzite		Hornfels		Chert		Chalcedony		Silicified Limestone		Volcanic	
	n	%	n	%	n	%	n	%	n	%	n	%	n	%	n	%	n	%
1	54	83.1	0	0	1	1.5	0	0	9	13.8	0	0	0	0	0	0	1	1.5
2	57	67.9	5	6	1	1.2	2	2.4	9	10.7	2	2.4	0	0	0	0	8	9.5
3	59	85.5	2	2.9	0	0	4	5.8	0	0	0	0	2	2.9	0	0	1	1.4
4	349	62.3	121	21.6	0	0	37	6.6	23	4.1	12	2.1	2	0.4	1	0.2	14	2.5
5	445	85.1	57	10.9	0	0	7	1.3	8	1.5	1	0.2	0	0	1	0.2	4	0.8
6	525	91.9	28	4.9	1	0.2	5	0.9	4	0.7	5	0.9	2	0.4	0	0	1	0.2

Overall, discard is much lower during Phase 2, with fewer than four artefacts per EU and on average 0.8 artefacts per litre (Fig. 7B), which most likely suggests reduced site visitation. Three flakes were observed with edge damage and pronounced rounding concentrated on parts of the margin. Both of these are on the upper range of flake size and have relatively steep margins. Five haematite pieces were recovered from units in this phase (EU 55, 54, 46, 45, 43), with one exhibiting some possible signs of abrasion (Fig. 8E), which together with the pigment coated slab recovered from contemporaneous units in Square A (O'Connor and Fankhauser, 2001), indicates use of pigments during this phase.

There is no discernible technological change during Phase 3 (29,000 to 21,900 cal BP), although a slight increase in discard between EU 27 and 23 (Fig. 7) suggests pulses of visitation throughout this phase. Three complete retouched flakes were discarded, each with steep marginal retouch initiated from the ventral surface, with three to four flakes removed before discard.

The largest discard peak relative to volume occurs during Phase 4 (22,400 to 17,100 cal BP) (Fig. 7B), which spans the LGM. The proportion of artefacts relative to excavated volume is more than double that found in the late Holocene, and much greater than the preceding Pleistocene phases. There is neither discernible evidence for a change in reduction strategies nor a disproportionate increase in artefact fragments relative to the MNF (Fig. 7A), which would otherwise account for the increased accumulation (Attenbrow, 2004:29). We suggest that this discard peak is therefore strong evidence for dramatically increased site visitation during the LGM. Moreover, this discard peak coincides with the greatest diversity of raw materials exploited. Locally available crystal quartz remains dominant (Table 6), but the proportion of vein quartz dramatically increases, as does the portion of chalcedony, chert, silicified limestone, fine and coarse grained quartzite, and basalt (Table 6). This diversity indicates reduced reliance on higher quality local material. Like the previous phase, only a relatively small proportion of flakes (n = 12, 2.1%) have any evidence of use and only two retouched flakes were discarded. Regardless of the increase in artefact numbers during this phase, retouched flakes were still not a frequent technological component discarded at the site.

The presence of one or more parallel dorsal ridges on complete flakes during this phase (n = 60, 10.7%), suggests greater control in flake production was occurring during this time, as dorsal ridges can be used to propagate flake fracture in more predictable ways (Flenniken and White, 1985:135–136). There is also a slight increase in overhang removal and faceting during this phase (OHR: n = 74, 13.2%; Faceting: n = 16, 2.9%) compared to the previous (OHR: n = 11, Faceting: n = 4) but these trends are not statistically significant.

Phase 4 also marks the first observation of thermoplastic resin adhesive on stone artefacts. The resin is exclusively found on small flakes and flake fragments (<15 mm), and even some flaked pieces. The observation of resin on both ventral and dorsal surfaces, as well as on longitudinally and transverse split fracture surfaces (e.g. Fig. 8E), indicates that resin is unlikely to have been deliberately applied to all of these artefacts. If flakes were removed from a hafted tool, the resin would be confined to the dorsal surface and platform only (e.g. Fig. 8F), which was exposed to resin before a flake was removed. Following this logic, Table 7 lists the frequency of all resin observations on flake dorsal surfaces only, and those on fractured surfaces more likely to have accumulated coincidentally. These data suggest that from phase 4 onwards, hafted tools were occasionally maintained while in the haft, and resin manufacture probably occurred simultaneously within the site, resulting in stone tool manufacturing debris accumulating resin. It is also conceivable that resin accumulated naturally on stone from the burning of spinifex grass on the approach to the site, however, we argue that this is less likely, as the site is largely sheltered from the talus approach which supported resinous spinifex grass throughout most of the occupation (McConnell and O'Connor, 1997; Wallis, 2001).

Following the LGM, Phase 5 (18,600 to 6500 cal BP) occupation is represented by several complex SUs and features, removed in context plan. Raw material diversity remains similar to the previous phase, but with increasing preference for crystal quartz, and artefact discard decreases relative to volume (Fig. 7B).

Phase 5 stone artefacts, particularly flakes, are the only sample to display significant morphological differences to preceding phases. For example, comparing several morphological measures of complete flakes between Phase 4 and 5 with a Mann Whitney test reveals a significant change in percussion length ($Z = -2.232$, $p = 0.026$), platform width ($Z = -2.291$, $p = 0.022$), mass ($Z = -3.179$, $p = 0.001$), and elongation ($Z = -2.197$, $p = 0.028$). These morphological measures suggest increased efforts to produce longer and more elongate flakes, while the decreased mean values for mass (Phase 4 = 0.44g, Phase 5 = 0.16g) suggest efforts to remove less

Table 7
Number of observations of resin on individual stone artefacts, distinguishing those with resin on dorsal surfaces only, from those with resin on ventral and fractured surfaces.

Phase	Resin on dorsal and platform surfaces only	Resin on ventral or longitudinally/transverse fracture surfaces
1	0	0
2	0	0
3	0	0
4	4	1
5	5	3
6	17	26

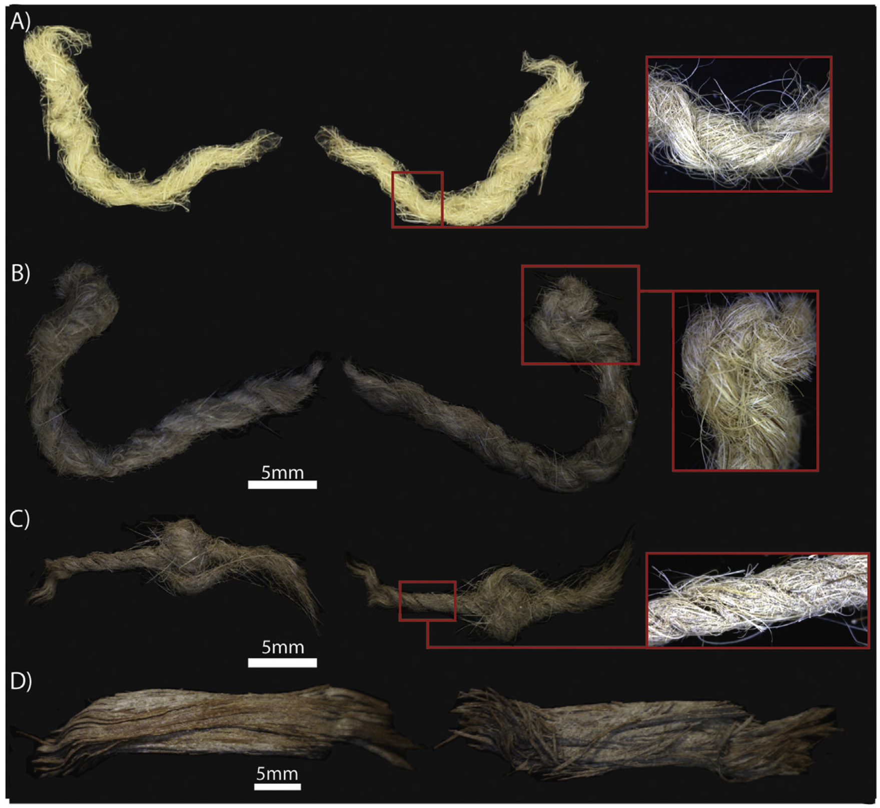

Fig. 9. Fibre and wood shavings recovered from Square A2 A) Twisted fibre from EU 4 B) Twisted fibre from EU 2 C) Twisted and knotted fibre from EU 2 D) Wood shaving from EU 7.

mass per flake, relative to working flake margins. These morphological changes resemble trends in early Holocene technological change, where flakes were increasingly produced with higher elongation values approaching the morphology of blanks used for bifacial point production in the mid Holocene, as detected at the nearby site of CG3 (O'Connor et al., 2014:17) and in other northern Australian sites (Clarkson and David, 1995). Notably, unlike CG3 the flakes from Phase 4 and 5 do not indicate a significant difference in marginal angle, using a Mann Whitney test ($Z = -0.6111$, $p = 0.541$) as would be expected if flakes were being increasingly produced with converging distal margins.

Occupation Phase 6, includes EU 5 to the surface (7600–300 cal BP). This mid to late Holocene phase is marked by a notable shift in raw material selection, to refocus on the locally available crystal quartz in higher proportions than any other phase (Table 6). Retouched flakes increase and include a bifacial point fragment from EU 5, four other retouched flakes, and two retouched flake fragments. Fourteen utilized flakes (3.1%) were observed with marginal edge damage and pronounced rounding. The presence of resin on flakes also increases (Table 7). Preservation of organics improves significantly in Phase 6 and wood shavings and fragments of fur and fibre string occur (Fig. 9). Two bone tools recovered in contemporaneous units in Square A1, were identified by Langley et al. (2016:113–114) as a piercing tool, associated with a date of 3441–3076 cal BP (ANU-10029), and a pressure flaking tool associated with a date of 674–496 cal BP (ANU-10028).

3.4. Faunal records

The A2 assemblage comprises 1876.4 g of bone. The bones and teeth are exceptionally well preserved throughout, with adherent dried tissues present within the Holocene layers, and little or no surface degradation or carbonate encrustation even in the lowest levels.

Fig. 10 shows the distribution by mass of four categories of fauna represented in the deposit for each of the six phases of occupation. Table 8 summarises the species present in each of the six phases and supplementary E provides a list of species identified in each EU. Although there is some correspondence between the volume of sediment excavated and the amount of bone (Fig. 10A), there are some changes that are not correlated to sediment volume. The question then arises – to what extent is the assemblage the result of human agency?

3.4.1. Establishing anthropogenic agency

Apart from humans, animal remains in CG1 could derive from other predators and natural deaths within the cave. Two major kinds of evidence suggest that the faunal remains primarily represent the prey of people: the lack of diagnostic criteria for other predators (carnivores and raptors) and the burning profile of the bone.

There is surprisingly little evidence of carnivore activity anywhere through the sequence. This evidence is particularly compelling given the excellent state of preservation of the assemblage that can be examined in fine detail for the usual signs of tooth scoring and corrosional rounding of fracture edges. One bone fragment from EU 59 of Square A2 shows extensive surface digestion typical of bone that has survived passage through a carnivore's gut; the size of the fragment suggests a Tasmanian devil or possibly a thylacine. A few other fragments through the sequence have numerous small surface scoring marks suggesting chewing by a smaller carnivore; the most likely candidate being the western quoll (*Dasyurus geoffroyi*), which is represented by skeletal remains in several EUs.

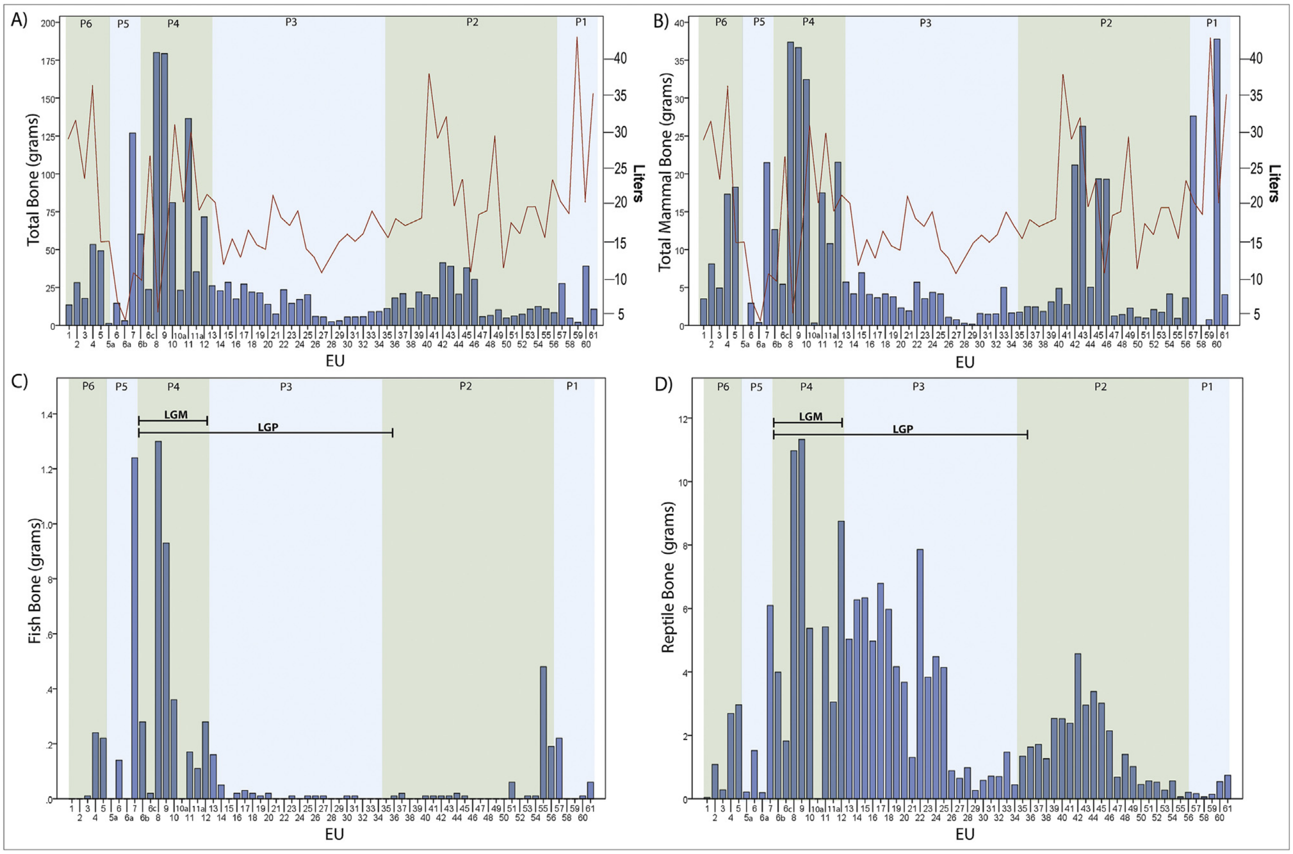

Fig. 10. Distribution of fauna according to occupation phase and EU A) Total bone B) Mammal bone C) Fish bone D) Reptile bone.

Although some of the long-bone elements from the Holocene levels of Square A2 have tooth crushing damage at the ends, no fragments have adherent faecal material and embedded animal hairs and none show rounding of fracture edges of the kind seen in bone derived from carnivore scats.

Two groups of raptors are known to accumulate prey remains in caves across arid and northern Australia – day hunting kestrels and night-hunting owls. Because most Australian small mammals are strictly nocturnal, kestrels typically capture large numbers of reptiles, especially smaller species of surface-active skinks (Scincidae) and dragons (Agamidae). In contrast, owl usually take far more small mammals than reptiles, and the few reptiles captured are more likely to be snakes and geckos that display more nocturnal activity. The reptile remains in both the 3 mm and 6 mm fractions are primarily derived from larger reptiles such as goannas, larger species of dragons and skinks, and moderate to large pythons and venomous snakes (colubroids). This profile does not suggest either kestrel or owl hunting activity. Having said this, the mammal remains do include significant numbers of small to medium-sized taxa (Table 8, Supplementary E) that might be derived either from regurgitated owl pellets or from human hunting. Identifying the likely source of these remains will be aided by careful study of digestion patterns on the remains (these are diagnostic for owl pellet remains).

The distribution of the three classes of burnt bone in the assemblage highlights two aspects of the assemblage that illustrate its anthropogenic character (raw data given in supplementary F). The first is the presence throughout the lower part of the sequence of calcined bone fragments.

Calcination of bone (i.e. fully combusted organic components) only commences when the combustion temperature rises above 600 °C and is not complete until it attains 900 °C (Etok et al., 2007; Stiner et al., 1995). It cannot occur through prolonged exposure to lower temperatures and is also unlikely to occur in the context of natural grass or scrub fires that typically involve lower combustion temperatures. Second, there is a consistently higher proportion of burnt bone in the 6 mm fraction compared with the 3 mm fraction (Supplementary F). This non-random distribution by size also points to human agency rather than the chance firing of bone exposed on a cave floor.

There is also a marked contrast in the burning profile from Phase 4 (the LGM) and above with >20% burnt and phases 1–3 (usually <10% burnt; sole exception in EU60). Two possible explanations for this pattern are: 1) that a much larger proportion of the bone from the upper levels derives from human agency and was burned during cooking or disposal of consumed remains; and 2) there was a sustained behavioural shift that resulted in more bone being burned during the more recent phase of occupation of the site.

Most of the larger wallaby and kangaroo remains are unambiguously derived from human activity, although it is possible that a few derive from natural deaths in the cave. Burning and other signs of human activity such as cut marks and tooth marks are present on a selection of these remains but the majority is unmarked.

3.4.2. Change in prey selection

The faunal assemblage presents a well-preserved record of foraging behaviour and range. The faunal assemblage of the earliest occupation (Phase 1) is predominantly comprised of reptile bones, such as medium to large-sized snakes (including colubroids) and lizards, some freshwater turtle and fish bone. Frog and bird bone feature sporadically. Mammal bone is not as well represented in the

Table 8
Fauna represented in each of the six occupation phases at CG1.

Phase 1	Phase 2	Phase 3	Phase 4	Phase 5	Phase 6
Macrotis lagotis Small *Isoodon* sp.	*Bettongia* sp.	*Macrotis lagotis Macrotis*/large	*Macrotis lagotis*	Bettongia Macrotis/large isoodon	*Macrotis*/large *Isoodon* sp.
Rattus sp.	*Macrotis*/large *Isoodon* sp.	*Isoodon* sp.	Macrotis/large *isoodon*	Small Isoodon *Rattus* sp.	Small *Isoodon* sp. Small murid
Leggadina sp. *Pseudomy* sp.	Small *Isoodon* sp.	Small *Isoodon* sp.	Large *Isoodon* Small Isoodon	Small murids	*Conilurus* sp.
Small murids	Large *Isoodon* sp.	*Rattus* sp.	Rattus sp.	*Dasyurus geoffroii*	*Dasyurus hallucatus*
Small dasyurid	*Rattus* sp.	*Pseudomys* sp.	Small murids	Small, medium & large macropod	*Trichosurus vulpecula*
Tachyglossus	*Notomys* cf. *amplus Pseudomys* sp. *Leggadina* sp.	Small murids	*Wyulda squamicaudata*		Small, medium & large macropod
Phalangeridae	Small murids	*Tachyglossus*	Phalangeridae		
Small macropods	Small dasyurid	Small & medium macropod	*Petaurus breviceps Pteropus* sp.		
	Small & medium macropod		Small, medium & large macropod		

earliest faunal assemblage. The apparent peak in the basal units (Fig. 10B) represents two large macropod post-cranial elements.

During Phase 2, when artefact discard suggests infrequent visitation, the faunal composition indicates a major change. A diffuse secondary peak between EU 36 and 46 occurs in the total bone weight, with a notable increase in both mammal and reptile bone but very scant fish remains (Fig. 10C D). Reptiles were increasingly consumed at the site during Phase 2, with species dominated by large monitors and snakes. The mammal species represented also show a change in emphasis and include smaller arid adapted species, such as the greater bilby (*Macrotis lagotis*), golden bandicoot (*Isoodon auratus*), and western quoll (*Dasyurus geoffroii*), all of which were most likely hunted from burrows and trees on the open plains away from the limestone range. A proportionally smaller component of the mammal assemblage came from the rugged habitat of the Napier Range, most notably the rock wallabies (*Petrogale* sp.) and scaly-tailed possum (*Wyulda squamicaudata*) – although these species show a notable increase in Phases 3 and 4.

During the LGP (Phase 3) mammal and reptile remains increase, with a notable peak around the LGM (Phase 4) (Fig. 10B D). The increase in mammal bone during the LGM, cannot be attributed to increased excavated volume and is comprised of both range dwelling species as well as arid adapted plain species, suggesting increased diet breath. This change was most notably captured by the removal of specific lenses or features, such as EU 6b, 6c, 8, 9 and 10 – which are ashy, charcoal rich and particularly rich in bone from small freshwater fish and mussel shell (Fig. 10C, Table 8). These ash layers, evident in the west wall of Fig. 5, contain the majority of the fish bone. When stone artefact discard is at its highest (relative to excavated volume) during the peak of LGM aridity, people were most likely collecting fish from the nearby Windjana Gorge. The fishing technology employed is unclear, however, the consistently small size of the species recovered may suggest the use of nets or traps (Balme, 1990:179–185).

The faunal record for Phases 3 and 4 corresponds well with the results of the earlier macrobotanical study that found both Chenopodiaceae (saltbush and bluebush – including saltbush *Atriplex* spp.) and Cyperaceae (sedges) were abundant during the LGM (McConnell and O'Connor, 1997). The presence of chenopods, grasses and spinifex indicates poor, saline or calcareous soils and dry conditions and would not be unexpected at this time. However, the abundance of the aquatic-associated sedges was unexpected. Sedges are found only in moist locations and their closest occurrence to the site today is the edges of the permanent pools in Windjana Gorge, about 4 km to the northwest (Fig. 2B).

During the Holocene phase, there is an additional change, with an increase in both mediumsized and large macropods (probably *Notamacropus agilis* and *Osphranter robustus*), while reptile remains proportionally decrease. The arid adapted mammal species (*Macrotis lagotis*, *Isoodon auratus*, *Dasyurus geoffroii*) are still present, although make a smaller contribution to the assemblage overall (Fig. 10B). The increased presence of large macropods, particularly in Phase 6, may suggest that new stone technologies such as hafted stone points, which first appear at this time in the southern Kimberley region (Maloney et al. 2014, 2017), were occasionally used as hafted projectiles to targeting these larger species. It is also apparent however, that bifacial points are predominately multifunctional, with both experimental and archaeological data suggesting infrequent projectile use (Brindley and Clarkson, 2015; Maloney et al., 2017).

3.5. Other excavated materials

The assemblage of organic materials from Square A2 includes

Table 9
Data summary Square A2.

XU	Volume (l)	TNA	MNF	Artefacts per litre	Bone (g)	Charcoal (g)	Mussel Shell (g)	Crustacean (g)	Avian Shell (g)	Seeds (g)	Ochre (g)	Wood Shavings (n)	Fibres (n)
1	24	133	60	5.5	13.52	212.49	7.73	0.39	0.11	10.72		1	1
2	26.5	239	111	9.0	28.18	578.96	2.59	1.7	0.59	7.85			2
3	19	199	79	10.5	17.87	460.13	0.86	1.13	0.91	14.87	0.77		
4	31	252	81	8.1	53.43	514.88	0.58	0.21	2	14.91			1
5	11	121	40	11.0	49.24	75.97	1.81	0.07	1.13	12.31		2	
5a	11	8	2	0.7	1.38	4.27	0.01			0.21			
6a	1	8	4	8.0	14.71	2.97			0.15	0.19			
6	3.5	23	7	6.6	3.05	27.03	0.02		0.59	19			1
7	6	119	44	19.8	23.75	32.26	3.96		4.17	2.87		1	
6b	22	41	19	1.9	126.93	89.26	0.71		1.56	2.29			
6c	7	52	20	7.4	60.22	7.28	0.29		0.91	0.5			
8	2	68	43	34.0	180.09	57.2	2.33	0.35	3.23	8.26			
9	11.5	165	56	14.3	179.31	26.26	5.535		2.61	0.63			
10	26	122	48	4.7	81.01	47.83	2.6		0.69	0.31			
10a	16	11	8	0.7	23.09	60.56	0.8		0.5	2.29	0.05		
11	25	65	24	2.6	136.53	51.48	2.78		0.99	1.2			
11a	15	10	4	0.7	35.41	46.7	0.25		0.3	1.21			
12	17	18	12	1.1	71.56	192.74		0.16	0.77	4.08			
13	16	7	2	0.4	26.19	32.11			0.16	2.29			
14	8	3	2	0.4	22.89	17.74				2.02			
15	11.5	2	1	0.2	28.43	20.71			0.1	1.02			
16	9	1	0	0.1	17.42	8.13		0.03	0.6	2.41			
17	12.5	4	1	0.3	27.28	14.35			0.26	5.54			
18	10.5	2	1	0.2	21.9	12.31			0.17	2.86			
19	10	3	0	0.3	21.49	8.73	0.02		0.3	3.71			
20	17	1	1	0.1	13.91	9.17			0.13	1.14			
21	14	1	1	0.1	7.53	4.62			0.22	1.1			
22	13	2	1	0.2	23.62	20.09	0.04		0.29	16.43			
23	15	1	0	0.1	14.56	29.15			0.16	2.03			
24	10	7	4	0.7	17.08	30.7			0.17	2.78			
25	9	7	3	0.8	20.35	148.9	0.65		0.2	2.88			
26	7	8	6	1.1	5.96	20.09			0.05				
27	9	5	0	0.6	5.53	20.15			0.05	0.9			
28	11	1	1	0.1	2.34	5.87				0.06			
29	12	2	1	0.2	2.95	10.14				0.28			
30	11	1	1	0.1	5.49	15.44			0.01	0.49			
31	12	1	1	0.1	5.59	15.82				0.41			
32	15	1	1	0.1	5.72	12			0.04	0.3			
33	13	5	2	0.4	9.06	17.33			0.05	0.04	3.55		
34	11.5	1	1	0.1	9.18	19.15			0.07	0.2	5.72		
35	14	2	0	0.1	11.1	17.75			0.02	0.06			
36	13	5	2	0.4	18.12	28.99			0.05	0.23			
37	13.5	8	4	0.6	21.02	32.4			0.1	0.15			
38	14	3	2	0.2	11.37	28.52			0.07	0.21			
39	32.5	3	1	0.1	21.91	41.64	0.01		0.13	0.25			
40	24	4	2	0.2	20.27	36.67			0.15	0.09			
41	27	6	3	0.2	18.18	51.95	0.08		0.14	0.58			
42	15.5	3	2	0.2	41.33	58.06	0.03		0.03	1.05			
43	19	3	1	0.2	39.01	40.92			0.05	1.07	3.15		
44	7	2	2	0.3	20.59	43.55				0.98			
45	14.5	4	2	0.3	37.97	44.94				1.13	0.48		
46	15	2	2	0.1	30.42	22.26				0.83	0.49		
47	24.5	1	0	0.0	5.78	10.56				0.51			
48	7.5	2	2	0.3	6.64	9.72				0.76			
49	13.5	4	2	0.3	10.29	8.25				0.35			
50	12	1	0	0.1	4.92	3.83				0.19			
51	15.5	4	4	0.3	6.25	8.32				0.72			
52	15.5	8	3	0.5	7.43	6.24				0.68			
53	11.5	5	5	0.4	10.72	13.77				1.63			
54	19	8	5	0.4	12.48	13.83				0.49	8.71		
55	16	5	4	0.3	10.95	10.91				0.27	0.754		
56	14.5	14	11	1.0	8.46	11.36				0.26			
57	37.25	13	8	0.3	6.88	30.81				0.26			
58	16	9	6	0.6	4.8	7.36				0.13			
59	30	13	6	0.4	2.05	3.74				0.14	2.72		
60	18	6	4	0.3	39.09	1.45	0.03			0.22			
61	34	10	7	0.3	10.67	2.58	7.73	0.39	0.01	0.07			

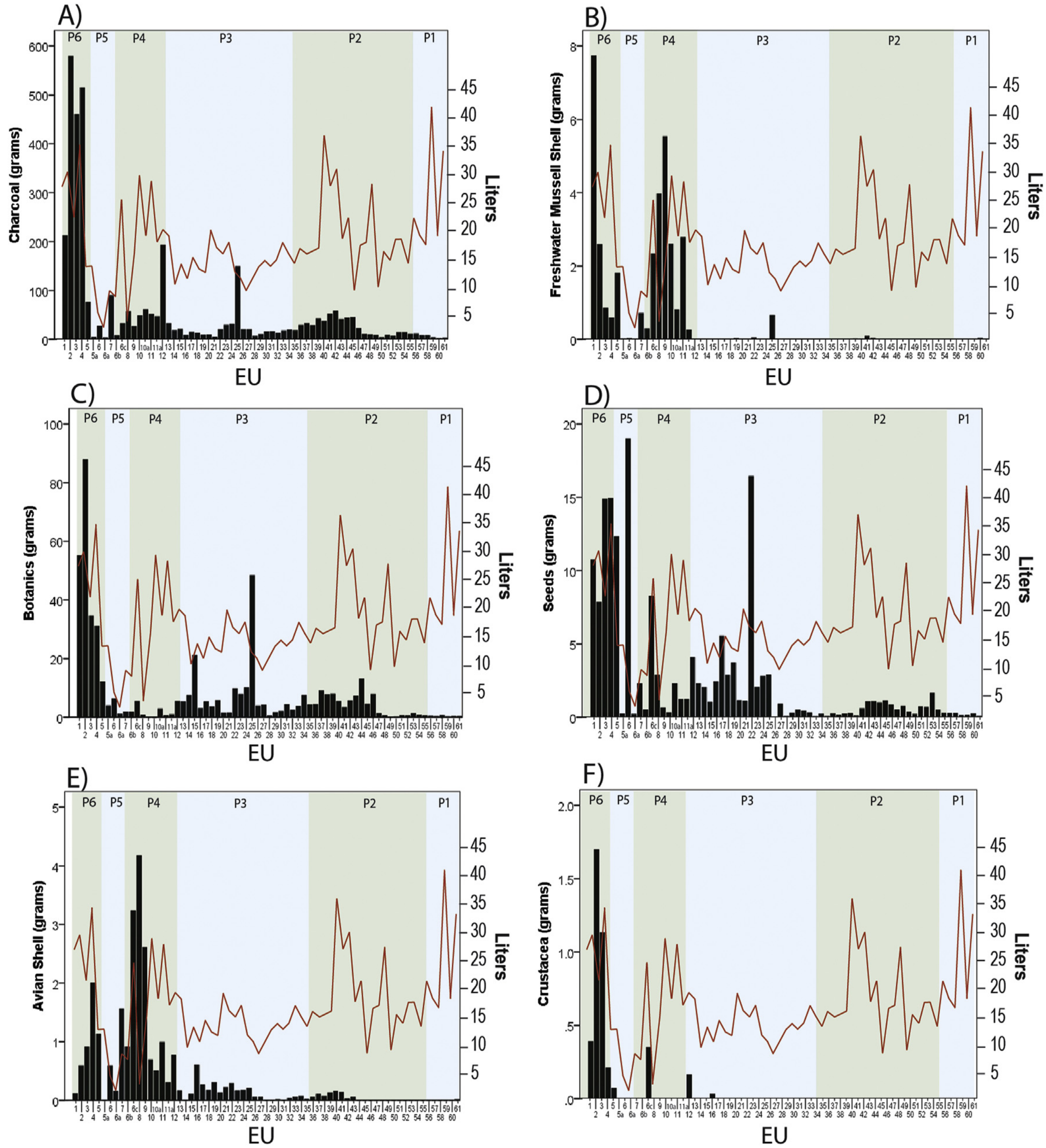

Fig. 11. Summary of organic materials per EU and relative to excavated volume. A) Charcoal B) Fresh water mussel shell C) Botanics D) Seeds E) Avian shell F) Crustacea.

charcoal, mussel shell (*Lortiella froggatti*), freshwater crayfish (cherubin) exoskeleton, avian egg shell, seeds, ochre, wood shavings and segments of string made from fibre and fur (Table 9). Fig. 11 presents summaries of the major organic components relative to excavated volume. While each of these groups show a consistent Phase 6 (late Holocene) peak, the Pleistocene distributions are more varied. For example, while minor traces of freshwater mussel shell are present in the earliest two phases, it only peaks in the LGM features and the Holocene (Phase 4 and 6). Similarly, bird eggshell peaks only within the LGM units, although became increasingly present from EU 43. The crustacean remains are present in Phase 4 and 3, although peak in Phase 6. Additionally, ten pieces of haematite were recovered, although only one displays evidence of modification (Fig. 8D).

4. Discussion

4.1. Early colonisation

The oldest records from Madjedbebe indicate early innovation of edge-ground axe technology and artistic traditions beyond 50,000 BP and possible as early as 65,000 BP, although lack of bone preservation at depth has precluded an understanding of early dietary breadth (Clarkson et al., 2015, 2017). CG1 provides evidence for initial occupation of the inland southern Kimberley between 51,000 and 44,000 cal BP, as much as 15,000 years after the earliest known occupation of Sahul. Distinct technological changes and adaptation to novel faunal regimes are associated with this record providing a platform for comparison and review with other early sites in Sahul.

When CG1 was first occupied the phytolith and macrobotanical record indicate an environment with a diverse grassland ecology but including rainforest thicket fruiting trees such as *Terminalia* (McConnell and O'Connor, 1997:26; Wallis, 2001:114). The first settlers at CG1 were probably equipped with edge-ground axes, which utilize fine grain volcanic material for the blanks, and sandstone for grinding; both of which occur as very isolated outcrops in the study area. The other flaked stone tools from the early phase of occupation indicate a preference for only the highest quality local raw materials. The stone used and the fauna exploited, indicate high mobility and a good understanding of the distribution of knappable stone. Stone was reduced efficiently, in terms of cutting or working edge per gram of stone (Mackay, 2008), and utilized bipolar reduction as one means of producing an abundance of small sharp flakes. The Pleistocene technology was focused on producing many small, thin flakes, which Muller and Clarkson (2016) have shown to be the most efficient use of raw material nodules for high mobility. In addition, this technology can be seen as an abundance strategy (Hiscock, 2006), where people maximised the number of small sharp flakes, rather than keeping individual tools useable for longer. Overall, the majority of the faunal remains from the earliest Pleistocene occupation (Phase 1) were derived from hunting and foraging in relatively arid habitats, with initial reliance on reptiles, including large snakes and lizards, and freshwater fish. At least some of the fauna also came from the rugged limestone habitats of the Napier Range and the refugia habitats of Windjana Gorge, for example scaly-tailed possum (*Wyulda squamicaudata*). These species proportionally increase during the LGM (Phase 4), concurrently with fish remains.

Although Windjana Gorge presumably provided resources critical to survival during this time, the sand plain habitats beyond the gorge also formed a focus for hunting and foraging activities. Elsewhere, in the coastal desert regions of Western Australia, people had developed a foraging strategy that incorporated a range of arid zone terrestrial fauna as well as coastal resources such marine shellfish, beginning between 51,100 and 46,200 BP (Morse, 1993; Veth et al., 2017:26). Veth et al. (2017) argue that these early colonizers were engaged in highly mobile configurations, which linked these coastal resources with the terrestrial game from further inland. This early strategy of broad spectrum exploitation of resources from a range of environments, including the coast, can also be seen in the islands to the north of Australia in Timor Leste, at Laili Cave, where by 43,283 - 44,631 cal BP the inhabitants were using a range of marine resources from the coast, ca. 4 km distant from the site, as well as riverine, open grassland and forest catchments closer to the site (Hawkins et al., 2017:70). This type of broad spectrum foraging strategy was clearly one which allowed greatest flexibility for colonisers moving into unfamiliar environments and reduced foraging risk.

4.2. The onset of aridity and LGM adaptations

CG1 is uniquely placed to test the LGM refugia model proposed by Veth (1989). The site is close to the modern arid boundary (Fig. 2A) and was within the arid zone during peak aridity – occurring between 22,000 and 18,000 cal BP (Petherick et al., 2013:59, 65–72; Shulmeister et al., 2016:1140). During this time at CG1, we have shown an unprecedented increase in the proportion of fish bone recovered from LGM dated features. Concurrently, there is an increased abundance of freshwater mussel shell as well as the largest relative portions of mammal and reptile bone. Windjana Gorge holds large pools of water with abundant fish during the dry season. If conditions were similar during the LGM, and the gorge regularly held water during the dry season, this would have been the closest water source to collect fish and mussel shell.

The presence of abundant fish bone and the increase in mussel shell during the LGM, provides a strong indication that people congregated around Windjana Gorge during these extremely arid times. The CG1 macrobotanical and phytolith records provide further support for the Gorge providing an LGM refuge, as sedges, sponge spicules and diatoms increase in abundance during this time (McConnell and O'Connor, 1997:23; Wallis, 2001), whereas grasses and vine thicket taxa reduce in diversity (Wallis, 2001). The anthracological record indicates that a predominance of dry woodland species was used as firewood during the LGM (Frawley and O'Connor, 2010:318).

Together with the botanical records, the change in stone raw material procurement and high quantities of fish bone; CG1 provides support for the LGM refuge model. Other sites have similarly provided supporting evidence of this model, such as Lawn Hill (Hiscock, 1988), Warratyi (Hamm et al., 2016), and Milly's Cave (Marwick, 2002).

4.3. Technology and mobility in the Pleistocene

Analysis of the new data emerging from the oldest Pleistocene records in Sahul has produced a repeated pattern of innovation. The Madjedbebe records demonstrate development of bifacial and edge-ground axe technology, and use of ochre and micaceous stone for decorative or symbolic purposes simultaneous with earliest settlement (Clarkson et al., 2015:58–59, Fig. 11). CG1 shows that bone technology (Langley et al., 2016), edge-ground axe technology (Hiscock et al., 2016), and pigment art (O'Connor and Fankhauser, 2001) were also part of the technological package of the first settlers of the inland Kimberley ranges. The faunal record from CG1 shows that hunting occurred in a wide range of environments, including the limestone foothills, sand plains, and the resources of the Gorge itself. Ironically, evidence for exploitation of the freshwater resources is most pronounced during the periods of maximum aridity.

Changes in raw material use throughout the CG1 stone artefact sequence provide a record of changing procurement strategies, whereby different sources are exploited through time. Unlike trends observed at Madjedbebe (Clarkson et al., 2015:54), where raw material changes are associated with technological change, we have shown that at CG1 raw material selection is more likely a reflection of procurement range. The first occupants predominantly reduced the high quality local material, crystal quartz, while also maintaining edge-ground axes made on volcanic stone. The technology from the early phase of CG1 indicates an exclusively local focus for flaked stone tools, with some measure of uniformity in stone reduction, while faunal records indicate an initial focus on large reptiles and fish. Bipolar core reduction also suggests efforts at utility extension of preferred materials.

Following the initial small discard peak in Phase 1, visitation to CG1 became less frequent leading into the more arid phase of the Last Glacial Period, where stone raw material reflects a wider procurement range. This included the first consistent use of locally abundant and poor quality white vein quartz, as well as flake production from a variety of exotic sources. The fauna from this phase also indicates increased diet breadth. Extreme flexibility in mobility strategies is a plausible explanation for the Pleistocene technological repertoire recovered from CG1. It has been proposed that, with an unpredictable and scarce resource distribution, we should expect very high residential mobility, small group sizes, low population density, assemblage uniformity and very high diet breadth (Ambrose and Lorenz, 1990; O'Connor et al., 1993). According to other principles of raw material availability (Andrefsky, 1994), the initial focus on local high quality stone for producing both formal tools, such as edge-ground axes, and informal tools, such as flakes and cores; suggests technological flexibility. Flakes, being consistently small and sharp, with the additional technique of bipolar reduction, indicates an efficient strategy in terms of mass per cutting edge (Mackay, 2008), plus an abundance strategy, where many flakes are produced per unit of stone (Hiscock, 2006). In subsequent periods of the Pleistocene, this technological flexibility was applied to a wider range of stone sources, including lower quality stone, which equipped people with tools over presumable longer forays from the CG1 site and Gorge area. In doing so, adapting these reduction strategies to a range of stone sources allowed a constant supply of material, without a great need to resharpen tools.

When aridity peaks during the LGM, the raw material diversity reaches maximum diversity, while overall discard was at its absolute highest. However, during this time there is also a significant increase in the proportion artefacts made from local white vein quartz that outcrops between CG1 and the Gorge. The LGM evidence suggests a greater emphasis on aquatic foods from the Gorge coupled with an increase in mammals. This may reflect both an increased foraging range coupled with intensive use of the predictable resources of the Gorge. The qualitative data shows that greater control in flake production was emphasised during this time, perhaps aimed at conserving the higher quality raw material that was not locally available. This phase was also the first to preserve resin adhering to stone artefacts, which became more prolific in the Holocene.

Some morphological change in flakes was detected between Phase 4 and 5, which probably mirrors technological changes noted elsewhere in the Kimberley (O'Connor et al., 2014:17) and the Wardaman region of the Northern Territory (Clarkson and David, 1995).

4.4. The Holocene

Accompanying the morphological change in flakes in the Holocene phase is a shift back towards an exclusive use of higher quality local materials. By the mid to late Holocene, tools were more frequently hafted, as indicated by the presence of remnant resin, and bifacial point technology is first recorded at CG1 and other nearby sites (Maloney et al., 2014, 2015; 2017). Bifacial points were gradually reduced through resharpening (Maloney et al., 2017), therefore their presence in the CG1 record represents a shift towards a maintenance strategy, where tools are kept usable for longer, rather than the preceding abundance strategy (Hiscock and Maloney, 2017). The development of pressure flaked bifaces is represented in the CG1 sample by a single large hornfels biface, recovered in Square A EU2, which is associated with a date of 721–499 cal BP (Wk-3075). A bone pressure flaking tool identified by Langley et al. (2016) from Square A EU1 is associated with a date of 674–496 cal BP (ANU-10028). Both of these artefacts indicate pressure flaking was conducted within the shelter during the last millennium.

String and fibre are only present within the last 3000 years of the CG1 record, although it is often thought to have accompanied the first colonizers (e.g. Balme, 2013). However, it is possible that nets or traps, which may have incorporated string and fibre, were used by the CG1 inhabitants in the capture of small fish from the Gorge during the LGM.

5. Conclusions

The first Australians' adaptation to inland environments began by 50,000 BP and possibly as early as 65,000 years ago, with evidence for settlement at Madjedbebe in Arnhem Land (Clarkson et al., 2017:309). This date is considerably earlier than any other Australian site, which typically have initial occupation age estimates no older than 47,000 to 48,000 cal BP (Wood et al., 2016:21), and suggests a 'bottleneck' or prolonged period when populations remained within Arnhem Land, minimally for 10,000 years, prior to dispersal into other parts of the continent. During this time populations would have learnt new landscapes (cf. Meltzer, 2003), gained familiarity with the diversity of edible plants and animals available in the north, and very likely encountered megafauna species. The initial phase of settlement at Madjedbebe records many innovations, such as the earliest evidence in the world for edge-ground axe production. Stone axes are not found in the Pleistocene archaeological record of any site in the Wallacean islands so, regardless of whether the first colonists traversed a northern or southern route through these islands, it appears that they managed this without hafted stone axes. Edge-ground axe technology was presumably developed within Sahul where it was probably needed for exploiting the hardwoods found in the inland savannah regions of the continent. Use of a range of pigments, including micaceous materials, is also seen in the Madjedbebe record. Although fauna is not preserved at Madjedbebe, the stone artefact assemblage in the earliest occupation deposits are sizeable in comparison with the oldest sites outside Arnhem Land which may also support the idea that populations built up during the 'initial adaptation phase' of settlement in Arnhem Land.

Evidence for edge-ground axe and pigment use are also found in CG1 in the earliest levels, suggesting that this technology spread south with the earliest wave of settlers some 15,000 years later. Compared with Madjedbebe, stone artefact numbers associated with earliest occupation levels at CG1 are low, suggesting initial populations were smaller, or more mobile, than in Arnhem Land. The presence of flakes detached from edge-ground axes made on volcanic rocks and a clear preference for selecting high quality materials, indicates that people quickly mapped onto the geological resources within the new environments they entered. The CG1 fauna and botanic record tells the same story and reflects ready adaptability to changing ecological regimes. They also provide a window into palaeoclimate during the Pleistocene and support Denniston et al.'s (2013) interpretation of the Ball Gown Cave speleothem data, which demonstrates that the north west monsoon extended into the inland Kimberley during the Last Glacial Maximum. While it may have been less frequent or intense, the cooler temperatures during this period may have reduced evaporation resulting in rivers with seasonal flow or at least permanent pools. This would also account for the increased presence of aquatic fauna as well as Cyperaceae, sponge spicules and diatoms during the LGM, in tandem with a lowered diversity of grasses and decrease in fruiting vine thicket taxa; taxa which have relatively high water requirements (Wallis, 2001).

Data used in this paper is available at 10.5281/zenodo.1211406.

Acknowledgements

We thank the Bunuba Aboriginal Corporation for their assistance in this work. Radiocarbon dates obtained in 2013 and 2014 and micromorphological research by Vannieuwenhuyse were funded by the Australian Research Council grant LP100200415 'Lifeways of the first Australians' with contributions from the Kimberley Foundation Australia and the Department of Sustainability, Water, Populations and Communities, awarded to O'Connor and Balme, as well as support from the Centre of Excellence for Australian Biodiversity and Heritage as well as support from the Australian Research Council Centre of Excellence for Australian Biodiversity and Heritage (CE170100015).

Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.quascirev.2018.05.016.

References

Ambrose, S.H., Lorenz, K.G., 1990. Social and ecological models for the middle stone age in southern africa. In: Mellars, P.A. (Ed.), The Emergence of Modern Humans. Edinburgh University Press, Edinburgh, pp. 3–33.
Andrefsky Jr., W., 1994. Raw material availability and the organisation of technology. Am. Antiq. 59, 21–35.
Aplin, K., Manne, T., Attenbrow, V., 2015. Using a 3-stage burning categorization to assess post-depositional degradation of archaeofaunal assemblages: some observations based on multiple prehistoric sites in Australasia. J. Archaeol. Sci.: Report 7, 700–714.
Attenbrow, V., 2004. What's Changing? Population Size or Land-use Patterns? the Archaeology of Upper Mangrove Creek, Sydney Basin. Terra Australis No. 21. Pandanus Books. Australian National University, Canberra.
Balme, J., 1990. A Pleistocene Tradition: Aboriginal Fishery on the Lower Darling River, Western N.S.W. PhD Thesis. Australian National University, Canberra.
Balme, J., 2013. Of boats and string: the maritime colonisation of Australia. Quat. Int. 285, 68–75.
Balme, J., O'Connor, S., 2017. Traditions and change in Scaphopoda shell beads in northern Australia from the Pleistocene to the recent past. In: Bar-Yosef Mayer, D.E., Choyke, A.M. (Eds.), Not Just for Show: the Archaeology of Beads, Beadwork and Personal Ornaments. Oxbow Books, Oxford and Philadelphia, pp. 7–18.
Bamforth, D.B., 1986. Technological efficiency and tool curation. Am. Antiq. 51, 38–50.
Bamforth, D.B., Bleed, P., 1997. Technology, flaked stone technology, and risk. In: Barton, C.M., Clark, G.A. (Eds.), Rediscovering Darwin: Evolutionary Theory in Archaeology. Archaeological Papers of the American Anthropological Association. American Anthropological Association, Washington, pp. 109–140.
Braun, D.R., 2005. Examining flake production strategies: examples from the middle paleolithic of southwest asia. Lithic Technol. 30, 107–125.
Bird, M.I., Turney, C.S.M., Fifield, L.K., Jones, R., Ayliffe, L.K., Palmer, A., Cresswel, R., Robertson, S., 2002. Radiocarbon analysis of the early archaeological site of Nauwalabila I, Arnhem Land, Australia: implications for sample suitability and stratigraphic integrity. Quat. Sci. Rev. 21, 1061–1075.
Brindley, J., Clarkson, C., 2015. Beyond a suggestive morphology: were Wardaman stone points exclusively spear armatures? Aust. Archaeol. 80, 81–92.
Bronk Ramsey, C., 2009. Bayesian analysis of radiocarbon dates. Radiocarbon 51 (1), 337–360.
Clarkson, C., 2006. Explaining point variability in the eastern victoria river region, northern territory. Archaeol. Ocean. 41, 97–106.
Clarkson, C., 2007. Lithics in the Land of the Lightening Brothers: the Archaeology of Wardaman Country, Northern Territory. Terra Australis 25. ANU E Press, Canberra.
Clarkson, C., David, B., 1995. The antiquity of blades and points revisited: investigating the emergence of systematic blade production south-west of Arnhem Land, northern Australia. Artefactum 18, 22–44.
Clarkson, C., Hiscock, P., 2011. Estimation of original flake mass from 3D scans of platform area. J. Archaeol. Sci. 38, 1062–1068.
Clarkson, C., Smith, M., Marwick, B., Fullagar, R., Wallis, L.A., Faulkner, P., Manne, T., Hayes, E., Roberts, R.G., Jacobs, Z., Carah, X., Lowe, K.M., Mathews, J., Florin, S.A., 2015. The archaeology, chronology and stratigraphy of Madjedbebe (Malakunanja II): a site in northern Australia with early occupation. J. Hum. Evol. 83, 46–64.
Clarkson, C., Zenobia, J., Marwick, B., Fullagar, R., Wallis, L., Smith, M., Roberts, R.G., Hayes, E., Lowe, K., Carah, X., Florin, S.A., McNeil1, J., Cox, D., Arnold, L.J., Hua, Q., Huntley, J., Brand, E.A., Manne, T., Fairbairn, A., Shulmeister, J., Lindsey, L., Salinas, M., Page, M., Connell, K., Park, G., Norman, K., Murphy, T., Pardoe, C., 2017. Human occupation of northern Australia by 65,000 years ago. Nature 547, 306–309.
Clarkson, C., Hiscock, P., Mackay, P., Shipton, C., 2018. Small, sharp and standardised: convergence in backed microlith technology globally. In: O'Brien, M.J., Buchannan, B., Erin, M. (Eds.), Convergent Evolution in Stone-tool Technology. The MIT Press, Cambridge, MA, pp. 175–200.
David, B., Geneste, J.M., Whear, R.L., Delannoy, J.J., Katherine, M., Gunn, R.G., 2011. Nawarlagabarnmang, a 45,180±910 cal BP site in Jawoyn country, southwest Arnhem land plateau. Aust. Archaeol. 73, 73–77.
Denniston, R., Wyrwol, K.H., Asmerom, Y., Polyak, V., Humphreys, W., Cugley, J., Woods, D., LaPointe, Z., Peota, J., Greaves, E., 2013. North atlantic forcing of millennial-scale IndoAustralian monsoon dynamics during the last Glacial Period. Quat. Sci. Rev. 72, 159–168.
Etok, S.E., Valsami-Jones, E., Wess, T.J., Hiller, J.C., Maxwell, C., Rogers, K.D., Manning, D.C., White, M.L., Lopez-Capel, E., Collins, M.J., Buckley, M., Penkman, K.E.H., Woodgate, S.L., 2007. Structural and chemical changes of thermally treated bone apatite. J. Mater. Sci. 42, 9807–9816.
Ellis, C.J., 1997. Factors influencing the use of stone projectile tips. In: Knecht, H. (Ed.), Projectile Technology. Plenum, New York, pp. 37–74.
Flenniken, J.J., White, J.P., 1985. Australian flaked stone tools: a technological perspective. Record Aust. Mus. 36, 131–151.
Fifield, L.K., Bird, M.I., Turney, C.S.M., Hausladen, P.A., Santos, G.M., Di Tada, M.L., 2001. Radiocarbon dating of the human occupation of Australia prior to 40 ka BP—successes and pitfalls. Radiocarbon 43 (2 PARTII), 1139–1145.
Frawley, S., O'Connor, S., 2010. A 40,000 year wood charcoal record from Carpenter's Gap 1: new insights into palaeovegetation change and indigenous foraging strategies in the Kimberley, Western Australia. In: Haberle, S.G., Stevenson, J., Prebble, M. (Eds.), Altered Ecologies: Fire, Climate and Human Influence on Terrestrial Landscapes. ANU ePress, Canberra, Australia, pp. 257–279.
Goodale, N.B., Kuijt, I., MacFarlan, S., Osterhoudt, C., Findlayson, B., 2008. Lithic core reduction techniques: a model for predicting expected diversity. In: Andrefsky Jr., W. (Ed.), Lithic Technology Measures of Production, Use and Curation. Cambridge University Press, Cambridge, pp. 317–336.
Hamm, G., Mitchell, P., Arnold, L.J., Prideaux, G.J., Guestiaux, D., Spooner, N.A., Levchenko, V., Foley, E.C., Worthy, T.H., Stephenson, B., Coulthard, V., Coulthard, C., Wilton, S., Johnston, D., 2016. Cultural innovation and megafauna interaction in the early settlement of arid Australia. Nature 539 (7628), 280–283.
Hawkins, S., O'Connor, S., Maloney, T., Litster, M., Kealy, S., Fenner, J., Aplin, K., Boulanger, C., Brockwell, S., Willan, R., Louys, J., 2017. Oldest human occupation of Wallacea at Laili rockshelter, Timor-Leste, shows broad-spectrum foraging throughout the late Pleistocene. Quat. Sci. Rev. 171, 58–72.
Hiscock, P., 1988. Prehistoric Settlement Patterns and Artefact Patterns at Lawn Hill, Northwest Queensland. PhD Thesis. University of Queensland, Brisbane.
Hiscock, P., 2002. Quantifying the size of artefact assemblages. J. Archaeol. Sci. 29, 251–258.
Hiscock, P., 2006. Blunt and to the point: changing technological strategies in Holocene Australia. In: Lilley, I. (Ed.), Archaeology in Oceania. Australia and the Pacific Islands Blackwell Publishing, Oxford, pp. 69–95.
Hiscock, P., 2007. Looking the other way: a materialist/technological approach to classifying tools an implements, cores and retouched flakes. In: McPherron, S.P. (Ed.), Tools versus Cores: Alternative Approaches to Stone Tool Analysis. Cambridge Scholars Publishing, Newcastle, pp. 198–222.
Hiscock, P., O'Connor, S., Balme, J., Maloney, T., 2016. World's earliest ground-edge axe production coincides with human colonisation of Australia. Aust. Archaeol. 82 (1), 2–11.
Hiscock, P., Maloney, T., 2017. Australian lithic technology: evolution, dispersion and connectivity. In: Hodos, T. (Ed.), Routledge Handbook of Archaeology and Globalisation. Routledge, Abingdon, Oxon, pp. 301–318.
Hogg, A.G., Hua, Q., Blackwell, P.G., Niu, M., Buck, C.E., Guilderson, T.P., Heaton, T.J., Palmer, J.G., Reimer, P.J., Reimer, R.W., Turney, C.S.M., Zimmerman, S.R.H., 2013. SHCal13 southern Hemisphere calibration, 0–50,000 years cal. BP. Radiocarbon 55 (4), 1–15.
Johnson, C.N., Alroy, J., Beeton, N.J., Bird, M.I., Brook, B.W., Cooper, A., Gillespie, R., Herrando-Perez, S., Jacobs, Z., Miller, G.H., Prideaux, G.J., Roberts, R.G., Rodrıguez-Rey, M., Saltre, F., Turney, C.S.M., Bradshaw, C.J.A., 2016. What caused extinction of the Pleistocene megafauna of Sahul? Proc. R. Soc. B 283, 20152399.
Kuhn, S., 1995. Mousterian Lithic Technology. Princeton University Press, Princeton.
Langley, M., O'Connor, S., Aplin, K., 2016. A >46,000-year-old kangaroo bone implement from Carpenter's Gap 1 (Kimberley, northwest Australia). Quat. Sci. Rev. 154, 199–213.
Mackay, A., 2008. A method for estimating edge length from flake dimensions: use and implications for technological change in the southern African MSA. J. Archaeol. Sci. 35 (3), 614–622.
Maloney, T., O'Connor, S., Balme, J., 2014. New dates for point technology in the Kimberley. Archaeol. Ocean. 49, 137–147.
Maloney, T., Wood, R., O'Connor, S., Whitau, R., 2015. Directly dated resin hafted stone technology in Australia: points as composite tools in the mid Holocene. Aust. Archaeol. 81, 35–43.
Maloney, T., O'Connor, S., Balme, J., 2017. The effect of retouch intensity on mid to late Holocene unifacial and bifacial points from the Kimberley. Aust. Archaeol. 83, 42–55.
Maloney, T., 2015. Technological Organisation and Points in the Southern Kimberley. PhD Thesis. Australian National University, Canberra.
Marwick, B., 2002. Milly's Cave: evidence for human occupation of the Inland Pilbara during the last glacial maximum. In: Ulm, S., Westcott, C., Reid, J., Ross, A., Lilley, I., Prangnell, J., Kirkwood, L. (Eds.), Barriers, Borders, Boundaries: Proceedings of the 2001 Australian Archaeological Association Annual Conference. Tempus 7. Anthropology Museum, University of Queensland, Brisbane, pp. 21–33.
Marwick, B., Hayes, E., Clarkson, C., Fullagar, R., 2017. Movement of lithics by trampling: an experiment in the Madjedbebe sediments, northern Australia. J. Archaeol. Sci. 79, 73–85.
McConnell, K., O'Connor, S., 1997. 40,000 year record of food plants in the southern Kimberley ranges, Western Australia. Aust. Archaeol. 44, 20–31.
McConnell, K., O'Connor, S., 1999. Carpenters Gap Shelter 1: a case for total recovery. In: Mountain, M.J., Bowdery, D. (Eds.), Taphonomy: the Analysis of Processes from Phytoliths to Megafauna. Research Papers in Archaeology and Natural History, No. 30. ANH Publications, Canberra, pp. 23–34.
Meltzer, D.J., 2003. Lessons in landscape learning. In: Rockman, M., Steele, J. (Eds.), Colonization of Unfamiliar Landscape. Routledge, London, pp. 169–189.
Morse, K., 1993. Shell beads from mandu creek rock-shelter, Cape range peninsula, western Australia, dated before 30,000 b.p. Antiquity 67 (257), 877.
Muller, A., Clarkson, C., 2016. Identifying major transitions in the evolution of lithic cutting edge production rates. PLoS One 11 (12) e0167244. https://doi.org/10.

1371/journal.pone.0167244.
Nanson, G.C., Price, D.M., Jones, B.G., Maroulis, J.C., Coleman, M., Bowman, H., Cohen, T.J., Pietsch, T.J., Larsen, J.R., 2008. Alluvial evidence for major climate and flow regime changes during the middle and late Quaternary in eastern central Australia. Geomorphology 101, 109–129.
O'Connor, S., 1995. Carpenters Gap rockshelter 1: 40,000 years of aboriginal occupation in the napier range, Kimberley, WA. Aust. Archaeol. 40, 58–59.
O'Connor, S., 1999. 30,000 Years of Aboriginal Occupation: Kimberley, North West Australia. Terra Australis 14. ANU E Press, Canberra.
O'Connor, S., Veth, P., Hubbard, N., 1993. Changing interpretations of postglacial human subsistence and demography in Sahul. In: Smith, M.A., Spriggs, M., Frankhauser, B. (Eds.), Sahul in Review: the Archaeology of Australia, New Guineas and Island Melanesia. Prehistory, Research School of Pacific Studies. The Australian National University Press, Canberra, pp. 95–105.
O'Connor, S., Veth, P., Campbell, C., 1998. Serpent's glen rockshelter: report of the first Pleistocene aged occupation sequence from the western desert. Aust. Archaeol. 46, 12–22.
O'Connor, S., Fankhauser, B., 2001. Art at 40,000 BP? One step closer: an ochre covered rock from Carpenter's Gap shelter 1, Kimberley region, Western Australia. In: Anderson, A., Lilley, I., O'Connor, S. (Eds.), Histories of Old Ages, Essays in Honour of Rhys Jones. Pandanus Books, Canberra, pp. 287–300.
O'Connor, S., Maloney, T., Vannieuwenhuyse, D., Balme, J., Wood, R., 2014. Occupation at Carpenters Gap 3, Windjana gorge, Kimberley, western Australia. Aust. Archaeol. 78, 10–23.
Playford, P.E., Hocking, R.M., Cockbain, A.E., 2009. Devonian reef complexes of the canning basin, western Australia. Geol. Surv. West. Aust. Bull. 145.
Petherick, L., Bostock, H.C., Cohen, T.J., Fitzsimmons, K.E., Tibby, J., Moss, P., Mooney, S., Barrows, T.T., Reeves, J.M., Kemp, J., Jansen, J.D., Nanson, G., De Deckker, P., Fletcher, M., Dosseto, A., Members, O.Z.-I.N.T.I.M.A.T.E., 2013. Temperate records from Australia on INTIMATE timescales: a summary. Quat. Sci. Rev. 74, 58–77.
Ramsey, C.B., 2009. Dealing with outliers and offsets in radiocarbon dating. Radiocarbon 51 (3), 1023–1045.
Reeves, J.M., Barrows, T.T., Cohen, T.J., Kiem, A.S., Bostock, H.C., Fitzsimmons, K.E., Jansen, J.D., Kemph, J., Krause, C., Petherick, L., Phipps, S.J., Members, O.Z.-I.N.T.I.M.A.T.E., 2013. Climate variability over the last 35,000 years recorded in marine and terrestrial archives in the Australian region: an OZ-INTIMATE compilation. Quat. Sci. Rev. 74, 21–34.
Roberts, R.G., Jones, R., Spooner, N.A., Head, M.J., Murray, A.S., Smith, M.A., 1994. The human colonisation of Australia: optical dates of 53,000 and 60,000 years bracket human arrival at Deaf Adder Gorge, Northern Territory. Quat. Sci. Rev. 13, 575–583.
Saltré, F., Rodrıguez-Rey, M., Brook, B.W., Johnson, C.N., Turney, C.S.M., Alroy, J., Cooper, A., Beeton, N., Bird, M.I., Fordham, D.A., Gillespie, R., Herrando-Perez, S., Jacobs, Z., Miller, G.H., Nogues-Bravo, D., Prideaux, G.J., Roberts, R.G., Bradshaw, C.J.A., 2016. Climate change not to blame for late Quaternary megafauna extinctions in Australia. Nat. Commun. 7, 1051.
Shulmeister, J., Kemp, J., Fitzsimmons, K.E., Gontz, A., 2016. Wind regimes during the last glacial maximum and early Holocene: evidence from little Llangothlin Lagoon, New England tableland, eastern Australia. Climate 12, 1435–1444.
Stiner, M., Kuhn, S., Weiner, S., Bar-Yosef, O., 1995. Differential burning, recrystallization, and fragmentation of archaeological bone. J. Archaeol. Sci. 22, 223–237.
Summerhayes, G.R., Leavesley, M., Fairbairn, A., Mandui, H., Field, J., Ford, A., Fullagar, R., 2010. Human Adaptation and plant use in highland New Guinea 49,000 to 44,000 years ago. Science 330, 78–81.
Turney, C., Bird, M., Fifield, L., Roberts, R.G., Smith, M., Dortch, C.E., Grun, R., Lawson, E., Ayliffe, L.K., Miller, G.H., Dortch, J., Creswell, R.G., 2001. Early human occupation at Devil's Lair, south-western Australia. Quaternary Research 55, 3–13.
Torrence, R., 1989. Re-tooling: towards a behavioral theory of stone tools. In: Torrence, R. (Ed.), Time, Energy and Stone Tools. University of Cambridge, Cambridge, pp. 57–66.
Van der Kaars, S., Miller, G.H., Turney, C.S.M., Cook, E.J., Nürnberg, D., Scöfield, J., Kershaw, A.P., Lehman, S.J., 2017. Humans rather than climate the primary cause of Pleistocene megafaunal extinction in Australia. Nat. Commun. 8, 14142.
Van der Kaars, S., de Deckker, P., Gingele, F., 2006. A 100 000-year record of annual and seasonal rainfall and temperature for northwestern Australia based on a pollen record obtained offshore. J. Quat. Sci. 21 (8), 879–889.
Vannieuwenhuyse, D., O'Connor, S., Balme, J., 2017. Settling in Sahul: investigating environmental and human history interactions through micromorphological analyses in tropical semi-arid north-west Australia. J. Archaeol. Sci. 77, 172–193.
Veth, P., 1989. Islands in the interior: a model for the colonization of Australia's arid zone. Archaeol. Ocean. 24 (3), 81–92.
Veth, P., 1995. Aridity and settlement in north West Australia. Antiquity 69, 733–746.
Veth, P., 2005. Cycles of aridity and human mobility: risk-minimization amongst late Pleistocene foragers of the western desert, Australia. In: Veth, P., Smith, M.A., Hiscock, P. (Eds.), Desert Peoples: Archaeological Perspectives. Blackwell Publishing, Oxford, p. 100115.
Veth, P., Smith, M., Bowler, J., Fitzsimmons, K., Williams, A., Hiscock, P., 2009. Excavations at parnkupirti, lake gregory, great sandy desert: OSL ages for occupation before the last glacial maximum. Aust. Archaeol. 69, 1–10.
Veth, P., Ward, I., Manne, T., Ulm, S., Ditchfield, K., Dortch, J., Hook, F., Petchey, F., Hogg, A., Questiaux, D., Demuro, M., Arnold, L., Spooner, N., Levchenko, V., Skippington, J., Byrne, C., Basgall, M., Zeanah, D., Belton, D., Helmholz, P., Bajkan, S., Bailey, R., Placzek, C., Kendrick, P., 2017. Early human occupation of a maritime desert, Barrow Island, NorthWest Australia. Quat. Sci. Rev. 168, 19–29.
Wallis, L., 2001. Environmental history of northwest Australia based on phytolith analysis at Carpenters Gap 1. Quat. Int. 83/85, 103–117.
Watchmen, A., O'Connor, S., Jones, R., 2005. Dating oxalate minerals 20–45 ka. J. Archaeol. Sci. 32, 369–374.
Westaway, K.E., Louys, J., Awe, R., Morwood, M.J., Price, G., Zhao, J., Aubert, M., JoannesBoyau, R., Smith, M.T., Skinner, M.M., Compton, T., Bailey, R.M., van den Bergh, G.D., de Vos, J., Pike, A.W.G., Stringer, C., Saptomo, E.W., Rizal, Y., Zaim, J., Santoso, W.D., Trihascaryo, A., Kinsley, L., Sulistyanto, B., 2017. An early modern human presence in Sumatra 73,000–63,000 years ago. Nature 23452.
Winterhalder, B., Lu, F., Tucker, B., 1999. Risk sensitive adaptive tactics: models and evidence from subsistence studies in biology and anthropology. J. Archaeol. Res. 7, 30–348.
Wood, R., Jacobs, Z., Vannieuwenhuyse, D., Balme, J., O'Connor, S., Whitau, R., 2016. Towards an accurate and precise chronology for the colonization of Australia: the example of Riwi, Kimberley, Western Australia. PLoS One 11 (9) e0160123. https://doi.org/10.1371/journal.pone.0160123.