Comparison of Sedimentation and Occupation Histories Inside and Outside Rock Shelters, Keep-River Region, Northwestern Australia

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This paper compares archaeological evidence of Aboriginal occupation inside rock shelters and outside in adjacent sand sheets, focusing on two locations in the Keep-River region, northwestern Australia. Luminescence and radiocarbon dating reveal that occupation sequences inside rock shelters are generally younger (< 10,000 yr B.P.) than outside (< 18,000 yr B.P.). Differences in occupation chronology and artifact assemblages inside and outside rock shelters result from depositional and postdepositional processes and shifts in site function. An increase in regional sedimentation rate from 10 cm/ka^{-1} in the Pleistocene to 20 cm/ka^{-1} in the Holocene may account for late buildup of sediments within rock shelters, increased artifact accumulation, and reduced postdepositional disturbance in some settings. More intense use of rock shelters in the Late Holocene is indicated from a change in hunting technology and greater production of rock art. The results indicate that some cultural interpretations might be flawed unless archaeological evidence from rock-shelter and open-site excavations is integrated. © 2006 Wiley Periodicals, Inc.

INTRODUCTION

In many parts of the world, rock shelters provide a fundamental source of archaeological evidence because they act to contain occupation debris in a relatively limited area. Dating the human use or occupation of such sites is, however, often problematic because of the complexity of sedimentation (Farrand, 2001), including potential human disturbance of sedimentation (Stockton, 1973; Hughes and Lampert, 1977; Villa and Courtin, 1983; Theunissen et al., 1998; Walthall, 1998).

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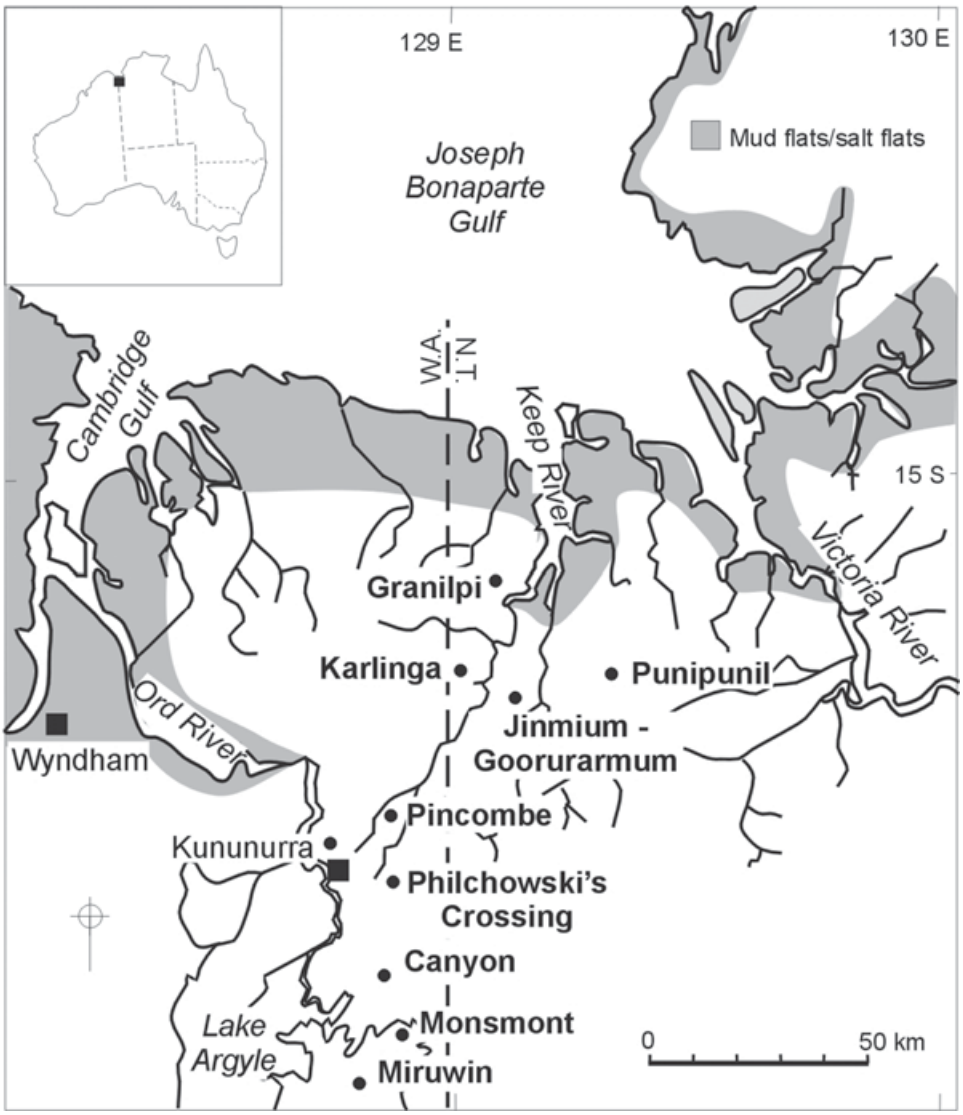


Figure 1. Location map of main archaeological sites in the lower Keep-River region, including Karlinga, Goorurarmum (this study), Jinmium (Fullagar et al., 1996), Granilpi, Punipunil (Atchison et al., 2005), Pincombe, Philchowski's Crossing, Conyon (Veth, 1995), Monsmont and Miruwin (Dortch, 1977) bounded by the larger catchments of the Ord River and Victoria River.

Rock shelters are a common focus of archaeological study in Australia, even though it has been inferred from some ethnographic and archaeological data that they were less frequently occupied than open camp sites (Smith and Sharp, 1993;

Lourandos and David, 1998). However, Attenbrow (2002, p. 105; 2004) questioned the archaeological perspective that expects Aboriginal people to have lived under shelter in open sites, and argued that around the coast in the Sydney sandstone country, they did commonly live in caves and rock shelters. Apart from any differences in site use, the preservation of cultural material inside and outside rock shelters are unlikely to be similar because they each have a distinct suite of sedimentary processes that act to control the nature of preservation (Farrand, 2001; Ward and Larcombe, 2003). There is also a clear bias that has favored the dating of archaeological deposits from rock shelters over those from open deposits, and inadequate sampling of open-site occupation currently constrains interpretations of settlement history in Australian archaeology (Ulm, 2004; Ward, 2004). There have been only a few comparative studies of cultural deposits or of sedimentary processes inside and well outside the dripline of rock shelters (e.g., Morwood, 1981; Jones and Johnson, 1985; Morwood et al., 1995; Boer-Mah, 2002) so that understanding of site formation and settlement history remains incomplete.

A general assumption is that rock shelters and caves provide better conditions for preservation and recovery of intact archaeological deposits than open sites (Walthall, 1998; Ulm, 2004). Excavations outside Devil's Lair, a limestone cave in southwestern Australia, provided an occupation history spanning about 19,000 years (Dortch, 1986), compared with a deep sequence inside the cave now thought to span at least 43,000 years (Turney et al., 2001). However, whether longer depositional sequences are actually better preserved inside or outside rock shelters may depend on cultural, sedimentological, and postdepositional processes (Farrand, 2001; Attenbrow, 2002, 2004; Ward, 2004; Ward et al., in press).

This case study of the lower catchment of the Keep River, northern Australia (Figure 1), questions the assumption that rock shelters necessarily provide better preservation conditions or longer records of human occupation than open sandy environments. Previous research in the Keep-River region has indicated that there are major discrepancies between the apparent age of some rock shelter and adjacent sand-sheet deposits (cf. Fullagar et al., 1996; Roberts et al., 1998, 1999; Galbraith et al., 1999) and between the subsurface archaeological sequences and the painted and engraved rock art (Watchman, 1999; Taçon et al., 2003). These discrepancies highlight the need to identify the spatial and temporal scales of deposition in rock shelters and adjacent sand sheets, and to determine how rock art sequences are linked, if at all, with subsurface archaeological remains. In this article, we focus on two archaeologically rich site complexes, Karlinga and Goorurarmum, and compare the "inside" (rock shelter) and "outside" (sand plain) records of deposition and disturbance. We attempt to distinguish cultural, sedimentological, and postdepositional processes to assess the implications for interpreting long-term changes in site function and settlement history.

STUDY AREA

The Keep-River region (Figure 1) is situated in the subtropical monsoonal region of northern Australia. In the lower catchment area, dissected plateau rise about

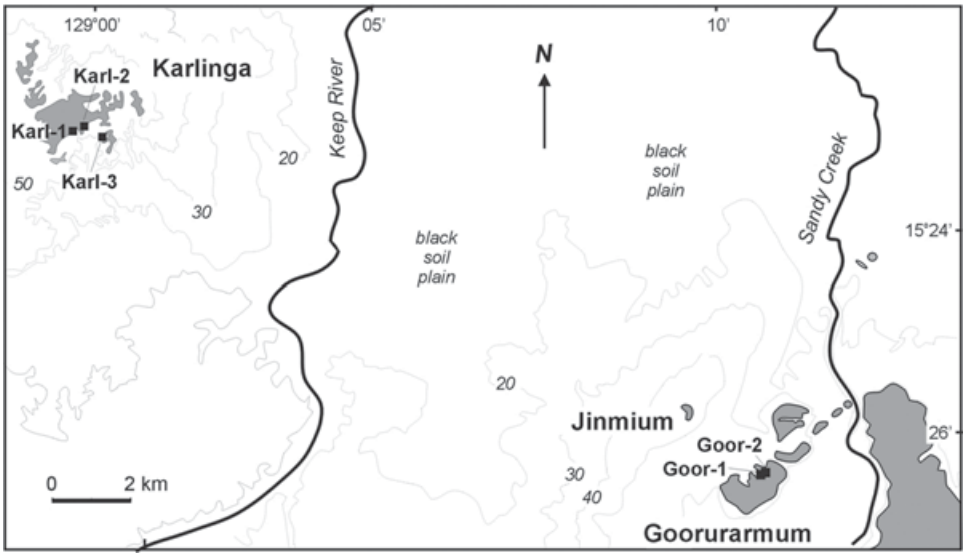


Figure 2. Location of archaeological excavations and auger transects around the three main archaeological sites of Jinmium, Goorurarmum, and Karlinga.

200 m above the alluvial plains, which generally lie less than 20 m ASL. The environment includes estuaries and coastal floodplains, open woodlands (dominated by *Eucalyptus* spp., *Tristania*, *Grevillea*, *Banksia* spp.), tall-grass covered (*Poaceae* spp.) sandy plains, and rugged hills of quartzite, sandstone, and conglomerate. The modern sand sheets represent the latest Quaternary phase of alluvial sedimentation in northern Australia (Roberts, 1991; Nanson et al., 1993; Ward et al., in press). To understand archaeological site formation, a sampling program was undertaken in rock shelters, adjacent sand sheets, and nearby creeks, which has provided a more detailed analysis of the geomorphological and paleoenvironmental context (Ward et al., in press) and regional chronology (Ward, 2004).

More than 600 archaeological and other Aboriginal sites in the East-Kimberley region have been recorded in State databases and published documents, and demonstrate ongoing Aboriginal attachment to this landscape (Fullagar, 1996; Fullagar and Head, 1999). Recorded open sites in the Keep-River area include several stone quarries and stone-artifact scatters that are indicative of ancient tool making and campsites. Rock paintings and engravings account for more than 85% of the recorded sites in the immediate study area (Legune 4767, 1:100,000 map sheet) and are most common in rugged sandstone hills and rocky outcrops.

In this study, primary focus is on two site complexes, Goorurarmum and Karlinga, (Figure 2), but we also refer to three nearby locations: Jinmium, Granilpi, and Punipunil (Fullagar et al., 1996; Leslie, 2000; Atchison et al., 2005). Goorurarmum lies approximately 1 km to the southeast of Jinmium at the same relative elevation of ~50 m ASL (Figure 2). The escarpment there peaks at ~85 m, and dips gently to

the southeast to form a northwest-facing amphitheatre around the sand sheet, on the northeast side of which is a large rock shelter. The Karlinga escarpment is situated about 10 km to the northeast of Goorurarmum (Figure 2). The escarpment range around Karlinga is one of the highest in the landscape, peaking at around 180 m ASL, but the elevation above the main rock shelter (the largest recorded in the lower Keep-River region) is only 75 m.

Rock art is an integral part of the archaeological record in this region and is an important indicator of site function. Taçon et al. (1997, 1999, 2003) describe a five-phase engraving sequence, and a seven-phase sequence for pigment and wax art. Briefly, the oldest art sequences are represented by cupule engravings (< 10,000 yr B.P.) and purple-red pigment art (Watchman et al., 2000; Taçon et al., 2003). The latter includes paintings resembling Bradshaw ("Gwion Gwion") figures of the west Kimberley (Taçon et al., 1999) that are probably Holocene but older than about 4000 yr B.P. (Watchman, 2001; Bednarik, 2002). Direct dating of oxalate-crusts formed over cupules in some rock shelters gives minimum ages ranging from 2280 yr B.P. to 4320 yr B.P. (Watchman et al., 2000; Watchman, 2001). The youngest (< 150 yr B.P.) art sequences are represented by scratched figures and by figures done in beeswax and charcoal (Taçon et al., 2003).

The stone tool record in the Keep-River region is also predominantly Holocene in age. The earliest uniface and bifacial stone points were associated ethnographically with hunting, ceremony, and exchange in northwestern Australia (Akerman et al., 2002) and have been dated to around 4000 yr B.P. (Bowdler and O'Connor, 1991, p. 53), although they may appear earlier in Arnhem Land (Jones and Johnson, 1985; Hiscock, 1993) and later in the East Kimberley (Fullagar et al., 1996; Akerman et al., 2002; Atchison et al., 2005). In northern Australian archaeological sequences, evidence of stone point production provides a rough chronological marker for similar technological changes that, in other places in Australia, have been linked with climate change, resource distribution, and Aboriginal responses to a more risky environment (Hiscock, 2002).

METHODS

To evaluate and integrate archaeological evidence from sand sheets and rock shelters, we examined variability in sedimentation, site use, and postdepositional modification. Site function refers to the nature of human activities around the site (including inside and outside rock shelters), and this was interpreted generally based on stone artifacts, ochre, rock-art sequences, and other archaeological components. Of primary interest here is the focus of habitation and the relative abundance of flaked stone artifacts in rock shelters compared with open sites, which was measured in terms of number and weight of artifacts per unit of sediment. Postdepositional modification here refers mainly to human and faunal bioturbation.

At Goorurarmum, two pits were archaeologically excavated: Goor-2 in the main rock shelter and Goor-1 approximately 25 m away at the base of a 2-m scree slope in the adjacent sand sheet (Figure 2). Archaeological pits were also excavated at three separate locations in the Karlinga complex: Karl-1 and Karl-2 in rock shelters

of the main Karlinga escarpment, and Karl-3 on the open sand sheet about 500 m from a low, sandstone outcrop (Figure 2). The main rock-shelter site (Karl-1) is separated from the surrounding sand sheet by a 10-m-high scree slope. The second rock-shelter site (Karl-2) is located about 200 m from the main rock shelter, in a terrace elevated ~80 m above the sand sheets (Figure 2). The locations of the Goor-1 and Karl-3 sand-sheet excavations were chosen from a preliminary augering investigation, which identified them as the deepest deposits close to the escarpments. Significantly, stone artifacts were absent on the surface at these locations, although they are a common surface feature in eroding parts of the sandy plains and adjacent landforms. In addition to the excavations, auger transects of the sand sheets were undertaken between Jinmium and Goorurarmum, and around Karlinga. Coring was achieved to depths up to 6 m (the length of the auger), or until encountering either a pisolitic horizon, bedrock, or the water table.

Variations in stone artifact size, morphology, and cortex distribution can provide information about stages of manufacture and reduction of particular raw materials at different locations (Andrefsky, 1998). All excavated sediments were dry sieved in the field using 2-mm and 4-mm nested aluminum sieves, and were further sieved and sorted in the laboratory. Stone (and glass) artifacts were sorted by raw material, reduction type, and completeness. For whole flakes, attributes including size, shape, and platform type (a platform is a surface from which a flake was detached) were also recorded. Frequencies were measured by weight and by number per liter of sediment in each excavation unit. Descriptions of the archaeological assemblages are given by Boer-Mah (2002).

Both thermoluminescence (TL) and optically stimulated luminescence (OSL) techniques were used for age determinations of sediments from the sand sheets and the rock-shelter sites; for the latter, OSL was usually preferred due to concerns about incomplete bleaching. Samples were taken from the excavation pits only after all archaeological investigation and sampling had been completed. For consistency with previous luminescence dating in the region (Fullagar et al., 1996; Spooner, 1998, Roberts et al., 1998, 1999; Galbraith et al., 1999; McCoy et al., 2000), TL and OSL analyses used the 90–125-mm quartz fraction and similar laboratory methods. Thermoluminescence methods follow those of Fullagar et al. (1996). Optically stimulated luminescence methods derive from Galbraith et al. (1999) but follow the most recent and robust protocol of single-aliquot-regenerative-dose (SAR) outlined by Murray and Wintle (2000) and modified from Murray and Roberts (1998).

Radiocarbon samples were prepared using acid-extraction methods detailed by Bird et al. (1999) and dated by AMS radiocarbon dating at Waikato and Australian Nuclear Science Technology Organization (ANSTO) laboratories. In general, the radiocarbon chronologies are preferred for the rock shelters because of concerns regarding insufficient bleaching of sediments in the rock shelters (Ward et al., in press). Conversely, the luminescence chronologies are seen as more reliable for the well-bleached sand-sheet sites because fluctuating water tables make radiometric ^{14}C ages unreliable beyond depths of 150 cm (Fifield et al., 2001; Ward, 2004). Where there is a choice, it is suggested that the OSL age provides a more accurate estimate of depositional ages than the TL ages (Ward et al., in press). Sediment descriptions,

age determinations, and artifact densities are summarized for each of the sand-sheet (Figure 3a) and rock-shelter (Figure 3b, 3c) excavations at Karlinga, and for the sand-sheet and rock-shelter (Figure 4b) excavation at Goorurarmum. Readers are referred to Ward et al. (in press) for more detailed site descriptions.

RESULTS

Basic analyses of rock-shelter and sand-sheet sediments indicate that while there are some differences between the Goorurarmum and Karlinga site areas, there is little stratigraphic or sedimentological differentiation within any one site. Typically, sediments from rock-shelter excavation pits and sand-sheet auger cores comprise unconsolidated charcoal-enriched surface sands overlying slightly more compact sands, which themselves overlie rubble and/or a bedrock base. There is no clear demarcation of occupation events, or well-defined features, such as organic residues or hearths. The lack of clearly defined strata is typical of sandy sediments across northern Australia (Davidson, 1935; Dortch, 1977; Ward and Larcombe, 2003). Even where there are identifiable color changes within deposits (e.g., Jones and Johnson, 1985; Allen and Barton, 1990), the relationship between these and individual depositional events is not always clear.

In the absence of well-defined anthropogenic features or strata, chronostratigraphy based on absolute-age estimates provides the main evidence of depositional events, three of which are recognized here: (a) sand-sheet horizons between Goorurarmum and Jinmium with a maximum age of about 100,000 yr B.P., (b) sand sheets closer to the Gooruarmum and Karlinga escarpments with a maximum age of about 20,000 yr B.P., and (c) rock-shelter sites with Holocene deposits (see also Figure 12, Ward et al., in press). These three depositional events permit the identification of different processes of cultural, sedimentological, and postdepositional change in the lower Keep-River catchment.

Sand-Sheet Sedimentation History (100,000–20,000 yr B.P.)

The sand-sheet sediments range from moderately sorted, medium-fine (~220 μm) uniform red sands (2.5YR 4/6) near the Goorurarmum escarpment, to slightly coarser (~280 μm) mottled red (10R 4/6) to orange-yellow sands (5YR 4/6) and occasional pisolitic sands between Jinmium and Goorurarmum, to more coarse (~360 μm) and leached yellow sands (7.5YR 3/2–5YR 4/6) near the Karlinga escarpment. These color differences are indicative of variations in the level of the water table across the Keep-River region. The otherwise similar sandy sediments reflect the consistent source (mostly quartz sandstones), transport (runoff, mass wasting, sheet flow), weathering (which preserves only resistant inorganic minerals), and secondary mixing processes (particularly by termites).

The oldest dated sequence occurs in the thick red sand sheets between Goorurarmum and Jinmium, with an age of 76,000 yr B.P. obtained from the base of the 6-m-long auger (Table I). These results are in broad agreement with previous age determinations of the sand sheets around Jinmium of 103,000 ± 14,000 yr B.P. at 5-m depth (Fullagar et al., 1996) and indicate that the bulk of the present sand

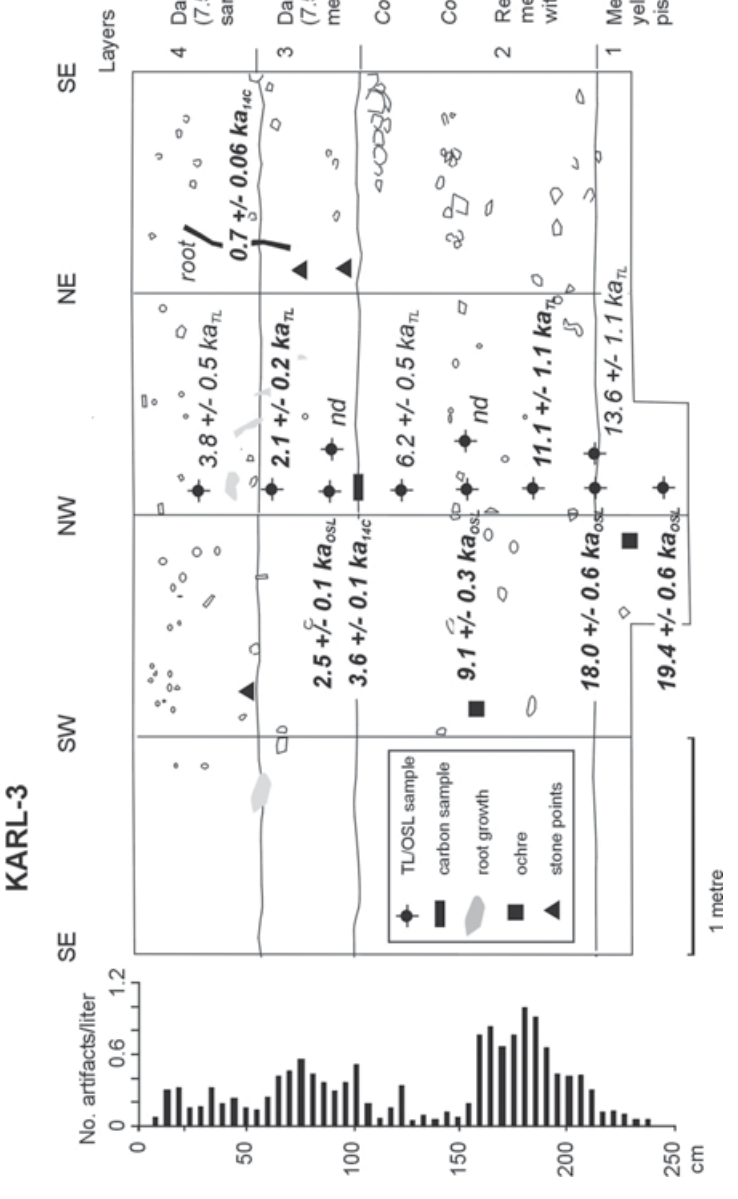


Figure 3a. Summary diagram for Karlinga Karl-3 sand-sheet excavation. The ages in boldface highlight the most reliable chronology as given by Ward et al. (in press).

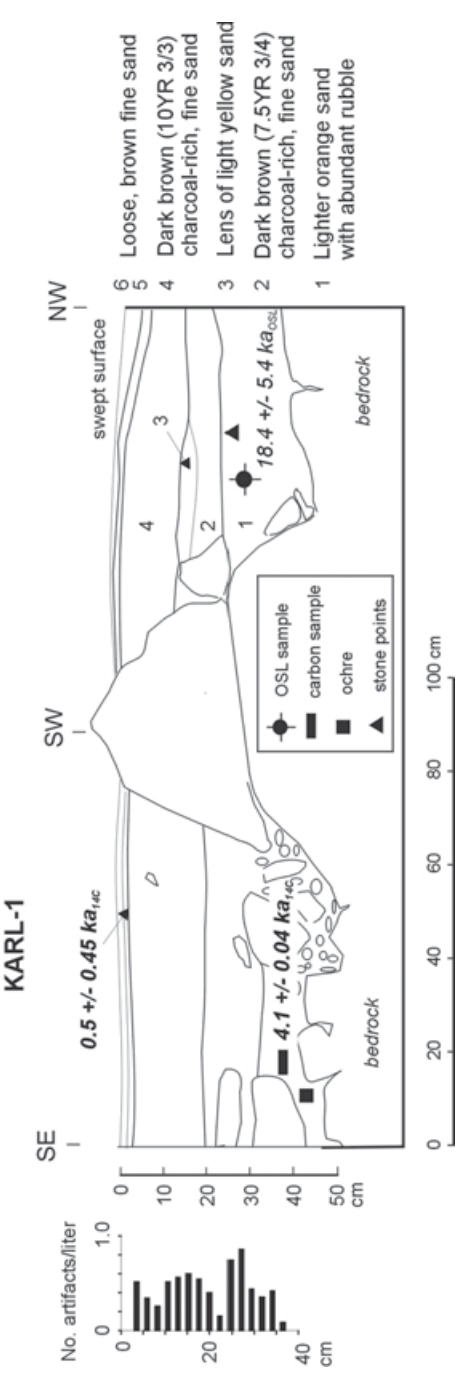


Figure 3b. Summary diagram for Karlinga Karl-1 rock-shelter excavation. The ages in boldface highlight the most reliable chronology as given by Ward et al. (in press).

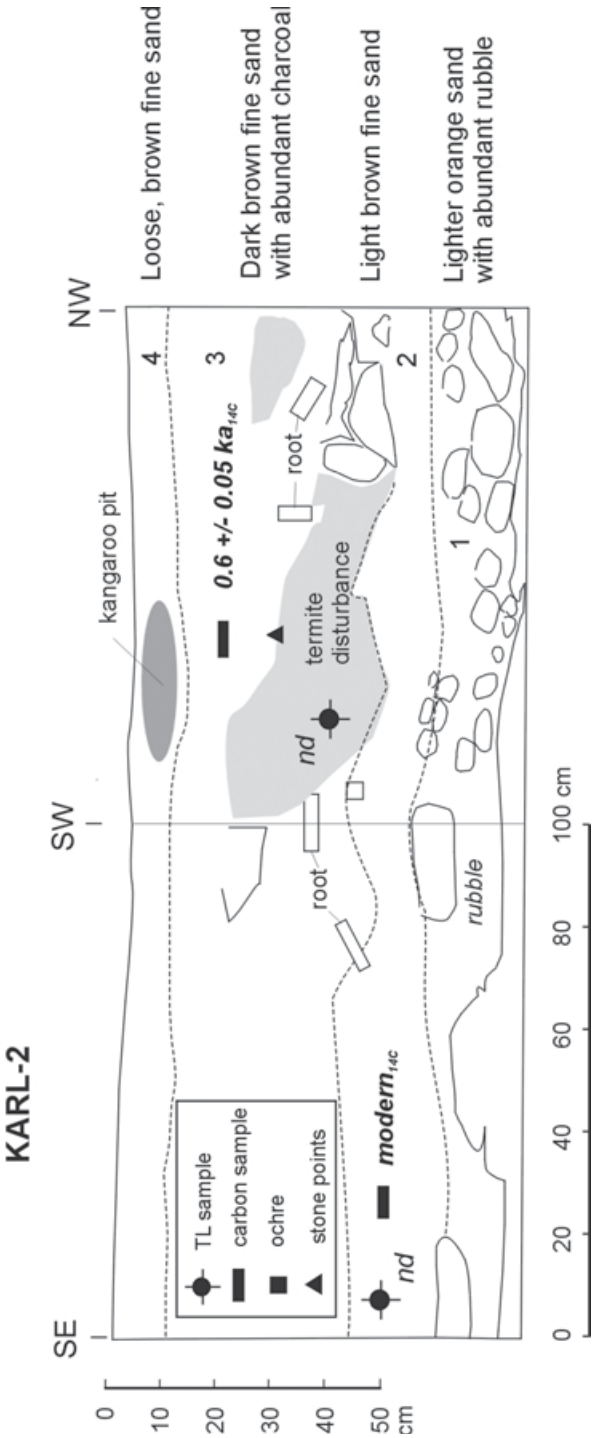


Figure 3c. Summary diagram for Karlinga Karl-2 rock-shelter excavation. The age in boldface highlights the most reliable chronology as given by Ward et al. (in press).

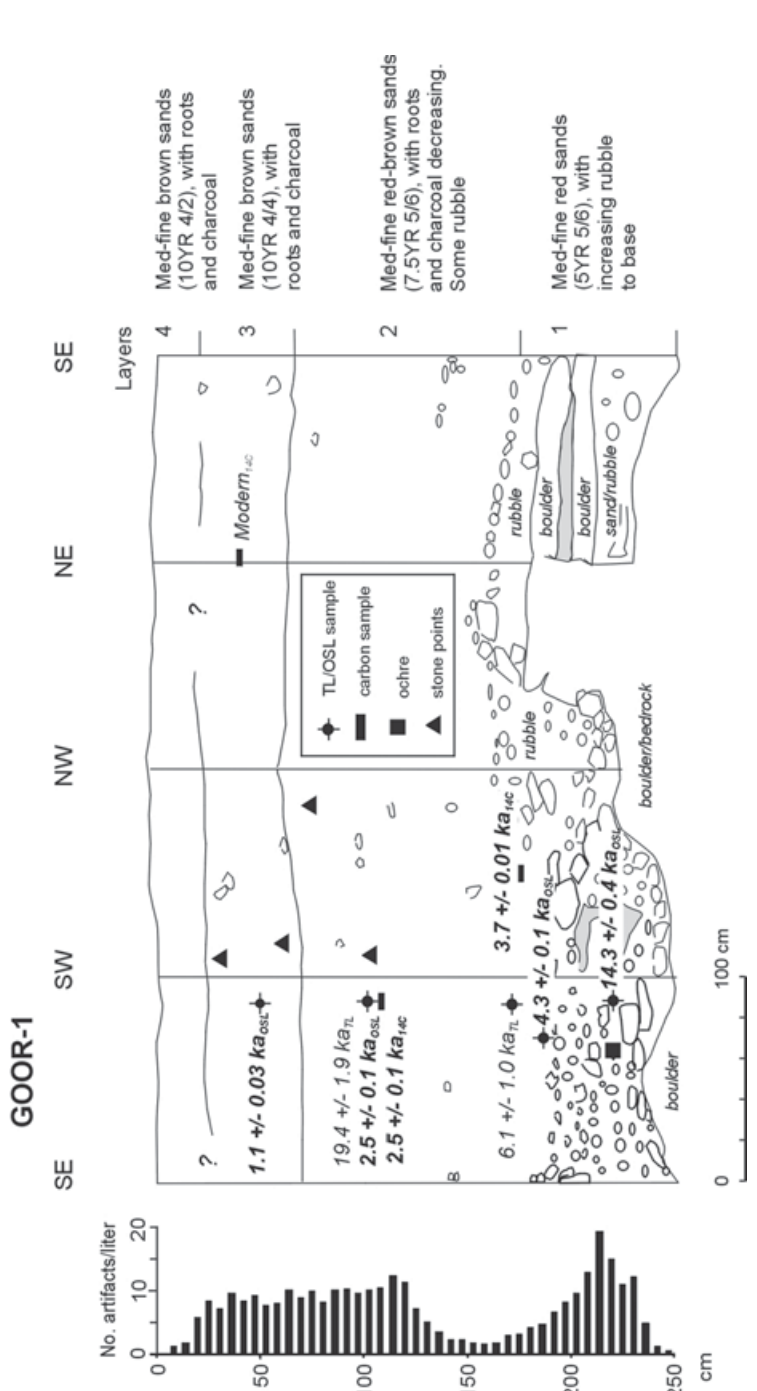


Figure 4a. Summary diagram for Goorurarmum Goor-1 sand-sheet excavation. The ages in boldface highlight the most reliable chronology as given by Ward et al. (in press).

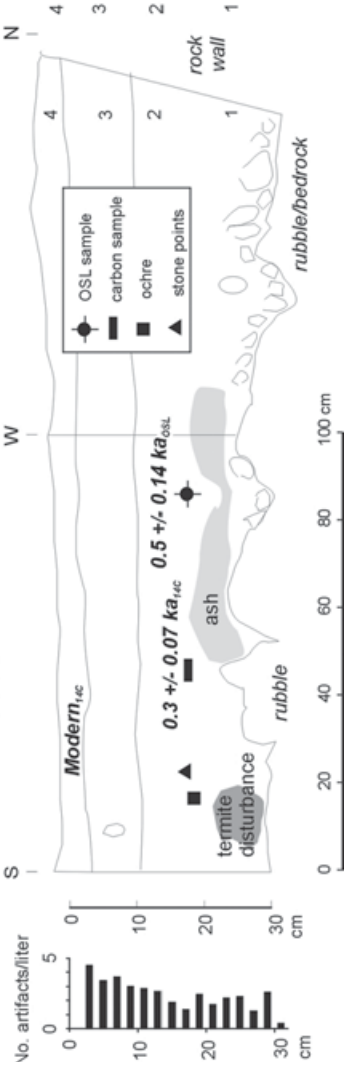


Figure 4b. Summary diagram for Goorurarmum Goor-2 rock-shelter excavation. The ages in boldface highlight the most reliable chronology as given by Ward et al. (in press).

Table I. Thermoluminescence (TL) and optically stimulated luminescence (OSL) age estimates for rock-shelter and sand-sheet sediments, grouped according to location.

Sample code	Sample source	Depth (cm)	TL/OSL	Palaeodose (Grays)	Dose rate (Gray/yr)	Age (ky B.P.)
Goorurarmum						
Goor-2	Excavation	20	OSL	0.40 ± 0.01	0.76 ± 0.04*	0.53 ± 0.14
Goor-1	Excavation	50	OSL	1.30 ± 0.03	1.22 ± 0.03	1.10 ± 0.30
Goor-1	Excavation	95	TL	23.70 ± 2.20	1.22 ± 0.03	19.40 ± 1.90
Goor-1	Excavation	100	OSL	3.10 ± 0.05	1.22 ± 0.03	2.50 ± 0.07
Goor-1	Excavation	155	TL	5.90 ± 1.00	0.96 ± 0.03	6.10 ± 1.00
Goor-1	Excavation	175	OSL	5.20 ± 0.08	1.21 ± 0.03	4.30 ± 0.13
Goor-1	Excavation	185	TL	5.90 ± 1.00	0.96 ± 0.03	6.10 ± 1.00
Goor-1	Excavation	220	OSL	17.20 ± 0.23	1.20 ± 0.03	14.30 ± 0.41
Gu-2	Auger	180	TL	11.10 ± 0.90	1.20 ± 0.03	9.20 ± 0.80
Jinmium						
JG1	Auger	210	TL	22.40 ± 1.90	1.43 ± 0.03	15.70 ± 1.40
JG2	Auger	390	TL	49.30 ± 4.30	1.22 ± 0.03	40.50 ± 3.70
JG2	Auger	560	TL	84.70 ± 6.10	1.11 ± 0.03	76.10 ± 5.80
JG4	Auger	420	TL	40.70 ± 2.90	1.05 ± 0.03	38.70 ± 2.90
JG4	Auger	590	TL	93.20 ± 8.00	1.28 ± 0.03	73.10 ± 6.50
Karlinga						
Karl-1	Excavation	27	OSL	19.70 ± 0.27	1.06 ± 0.08*	18.50 ± 1.38
Karl-3	Excavation	30	TL	6.00 ± 0.50	1.06 ± 0.03	3.80 ± 0.50
Karl-3	Excavation	60	TL	3.10 ± 0.30	1.46 ± 0.03	2.10 ± 0.20
Karl-3	Excavation	90	OSL	3.40 ± 0.05	1.38 ± 0.04	2.50 ± 0.08
Karl-3	Excavation	120	TL	8.10 ± 0.70	1.29 ± 0.03	6.20 ± 0.50
Karl-3	Excavation	150	OSL	11.40 ± 0.18	1.25 ± 0.03	9.10 ± 0.29
Karl-3	Excavation	180	TL	13.40 ± 1.30	1.21 ± 0.03	11.10 ± 1.10
Karl-3	Excavation	210	OSL	24.20 ± 0.28	1.25 ± 0.04	19.40 ± 0.64
Karl-3	Excavation	240	TL	17.60 ± 0.50	1.30 ± 0.03	13.60 ± 1.10
Karl-3	Excavation	240	OSL	23.40 ± 0.55	1.307 ± 0.03	18.00 ± 0.56
Ka-2	Auger	235	TL	9.10 ± 0.90	0.97 ± 0.03	9.40 ± 1.00
Ka-4	Auger	200	TL	6.30 ± 0.50	1.08 ± 0.03	5.80 ± 0.50
Ka-4	Auger	360	TL	27.50 ± 2.80	1.86 ± 0.03	14.80 ± 1.50
KN2	Auger	100	TL	4.20 ± 0.40	0.96 ± 0.03	4.40 ± 0.40
KN3	Auger	145	TL	7.40 ± 0.60	1.03 ± 0.03	7.10 ± 0.60
KN3	Auger	230	TL	15.00 ± 2.00	1.17 ± 0.03	12.80 ± 1.70
KN4	Auger	115	TL	6.00 ± 0.50	1.08 ± 0.03	5.60 ± 0.50

Note. All TL palaeodose estimates are calculated from the 375°C peak and all OSL estimates were calculated using the central-age palaeodose. Dose rate was determined from thick-source alpha-counting (TSAC) and high-resolution gamma spectrometry for the two rock-shelter samples (see Ward, 2003; Ward et al., in press for full details).

sheets have accumulated in the past 75,000–100,000 years. This age range is consistent with the estimates of 230,000–100,000 yr B.P. for the sand sheets dated in Arnhem Land by Roberts (1991). No microdebitage or other artifacts have been found in any auger samples of this age, notwithstanding that these thick sand sheets have never been excavated archaeologically.

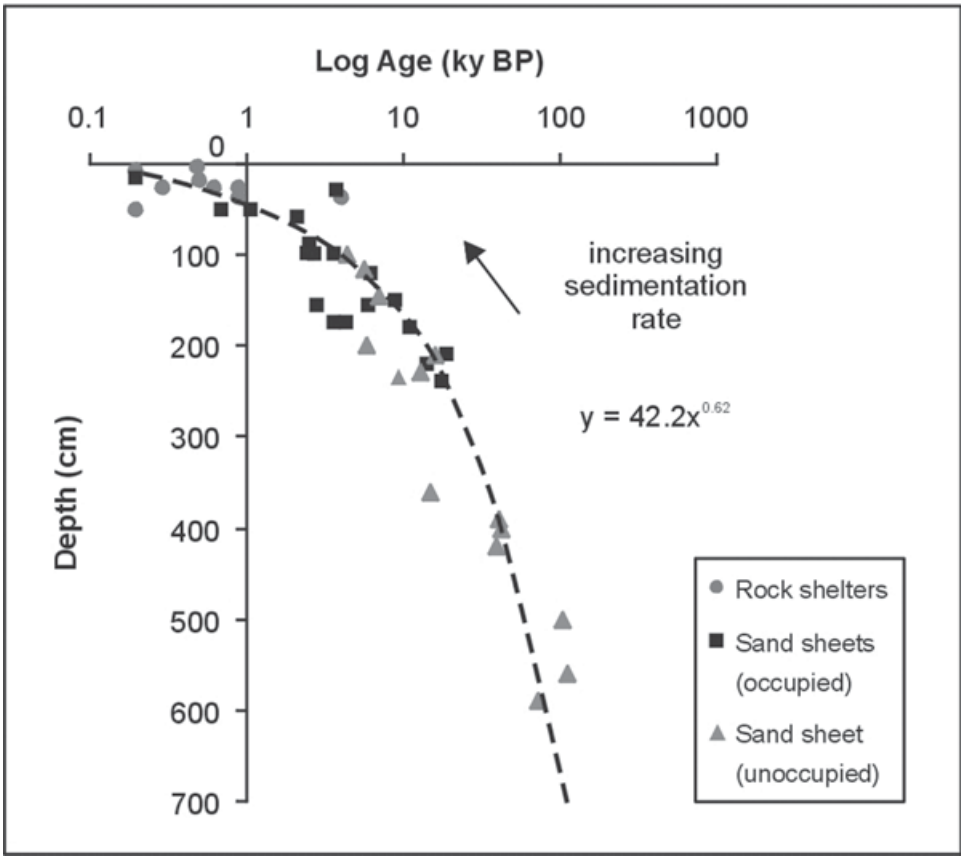


Figure 5. Linear-log plot of depth (cm) against age (ky B.P.) for sand-sheet and rock-shelter samples from the sites of Jinmium, Goorurarmum, and Karlinga. Note the overall increasing trend in sedimentation rate.

The luminescence results collated from all excavations and auger samples indicate an increase in mean net sedimentation rate from < 10 cm/ky^{-1} in the late Pleistocene to > 20 cm/ky^{-1} during the Holocene (Figure 5). Similar patterns are observed in sand-sheet deposits with and without evidence of occupation, and the higher Holocene sedimentation rate probably results from enhanced monsoonal activity (Nanson et al., 1992; Schulmeister, 1999) rather than human activity (see Ward et al., in press).

Sand-Sheet Occupation Deposits (20,000 yr B.P. to Present)

Karlinga

In the Karlinga (Karl-3) sand sheet excavation, sediments consist of coarse (~300 µm), dark-brown (7.5YR 3/2) quartz sands at the surface, underlain by coarse (~330

μm) mottled yellow (5YR 4/6) and orange sands, with coarse (~300 μm), dark red (2.5YR 3/6) pisolitic material at the base of the 250-cm excavation pit (Figure 3a). Discrete rubble layers, comprising (imbricated?) cobbles 5–10-cm thick, were encountered at depths of 100 cm and 155 cm (Figure 3a). These cobble layers were not found in any adjacent profiles and may be significant boundary markers (Robbins et al., 2000), reflecting a change in deposition, an isolated lag deposit, or possibly an anthropogenic feature.

The excavation contained 973 flaked-stone artifacts (22% are whole flakes) of which less than half accumulated since 3600 yr B.P. (Table III). Quartzite makes up 84% raw material for the whole flakes at Karl-3, with chert (6.5%) and quartz (6%) dominating the remainder. The site also contains eight (33.8 g) stone points, and 15 pieces of red and yellow ochre (Table III). Ochre appears from the earliest levels in both open sites but is more abundant in the modern ($<$ 1000 yr) period. The first appearance of a unifacial stone point is dated between 2100 yr B.P. and 2500 yr B.P. (OSL), and the first bifacial point is dated between 2500 yr B.P. (OSL) and 3680 yr B.P. (6). The deepest artifacts were found at a depth of 240 cm, just below sediments dated by OSL at 18,000 yr B.P. and 19,400 yr B.P. (Table III). Due to observed fluctuating water tables below 150 cm, the radiocarbon age of 2810 $\pm$ 40 yr B.P. (OZG340) at 155 cm in the same profile is considered unreliable (Ward, 2004; Fifield et al., 2001). There is a general positive correlation between sediment accumulation rate and artifact concentration (number of artifacts per liter) at this site (Figure 6a). However, between 11,100 yr B.P. and 9100 yr B.P. there is a relative increase in artifact accumulation and, conversely, between 2500 yr B.P. and 2100 yr B.P., a relative decrease in artifact accumulation (Figure 6a).

Goorurarmum

Sediments within the Goorurarmum amphitheatre are moderately sorted, medium-fine (~220 μm) quartz sands that overlie an indurated horizon or bedrock. The sandsheet excavation (Goor-1) reveals a profile with little stratigraphic differentiation. Sediments comprise medium-fine (~200 μm) quartz sands, with colors ranging from red-brown (10YR 4/2 to 7.5YR 5/4) near the surface to increasingly red (5YR 5/6) towards the bedrock/rubble base at about 240-cm depth (Figure 4a). The darker hue and color near the surface probably results from recent burning. The lowermost sediments in the Goor-1 excavation provide an OSL age of ~14,000 yr B.P. at 250 cm (Table I).

The Goor-1 excavation contained 3562 flaked stone artifacts (16% are whole flakes), the majority of which accumulated since 3600 yr B.P. (Table III). Quartzite (78%) is again the predominant raw material for the whole flakes alongside chert (9%) and quartz (3%). The site also contained 9 stone points and 16 pieces (66.1 g) of red and white ochre (Table III). The first appearance of unifacial and bifacial stone points in this sequence is also around 2500 yr B.P. Although peaks in artifact accumulation rates are not synchronous, the stone technologies at both open sites are generally similar. The correlation between sediment accumulation rate and artifact accumulation rate is less clear at this site (Figure 6b). The highest rate of artifact

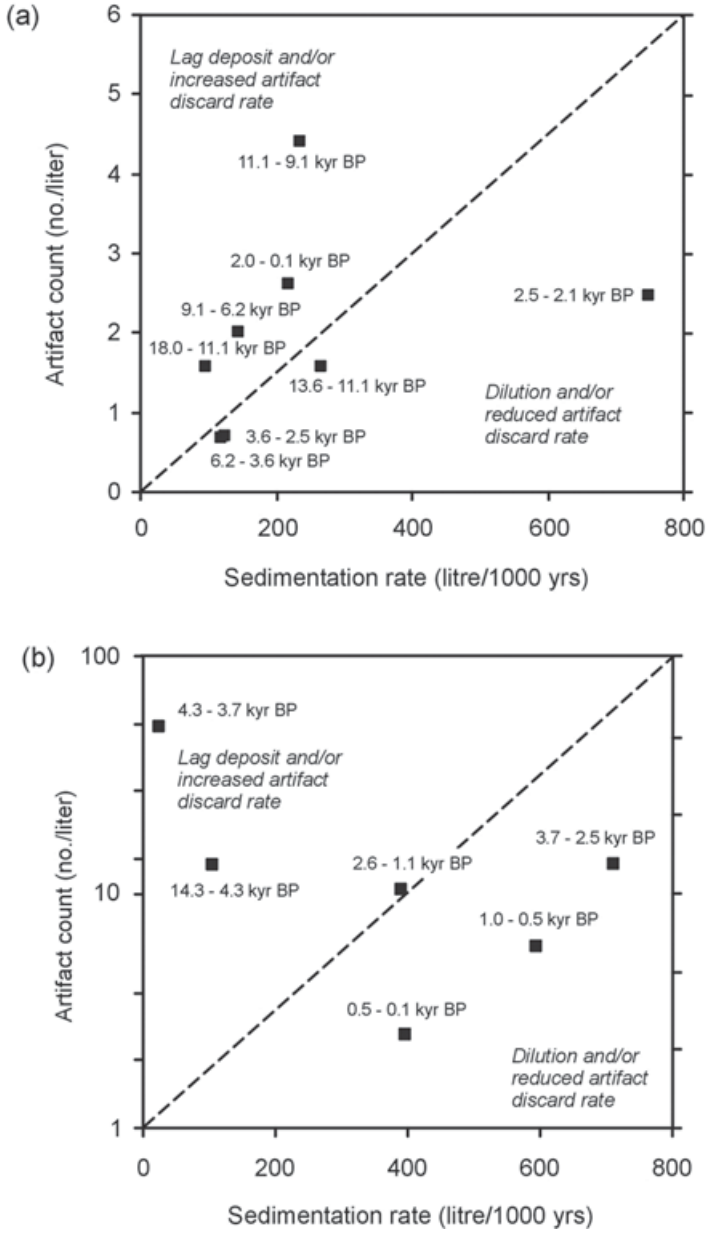


Figure 6. Plot of artifact accumulation rate against sedimentation rate (liters/1000 years) for the sand-sheet excavation at (a) Karl-3, and (b) Goor-1 (log-linear). The sedimentation rate is calculated as the net volume per time interval defined from the most reliable luminescence and radiocarbon ages. Artifact accumulation is measured as the number of artifacts ($>$ 4 mm) per liter for the same time interval. Points lying in the top left of the plot may be indicative of a lag deposit or increased artifact discard rate, while points lying in the bottom right may be indicative of a dilution or decreased artifact discard rate.

accumulation occurs after 2600 yr B.P. (Figure 6b), with a relative increase in artifact accumulation between 14,300 yr B.P. and 3700 yr B.P. (Figure 6b).

Rock-Shelter Occupation Deposits (10,000 yr B.P. to Present)

Karlinga

In the Karlinga (Karl-1) rock shelter, six depositional units are recognized (Figure 3b), which from top to bottom are: loose, dark brown (10 YR 3/3) moderately sorted quartz silty-sand (~270 µm) with abundant charcoal (~5%); a lens (< 10 cm) of ashy, yellow medium-fine (~260 µm) quartz sand; brown (7.5 YR 4/3) medium-fine (~250 µm) quartz sand, with abundant charcoal (~5%) and stone artifacts; bedrock/rubble base, which contains no artifacts.

In the Karl-1 rock shelter (Figure 3b), flaked-stone frequency decreases markedly with depth, from about 500 yr B.P., to frequencies similar to that present in the sandsheet sediments dated beyond 3000 yr B.P. (Figure 3a). The total number of lithic artifacts in this excavation was 145 (21% are whole flakes), and 6 pieces (1.5 g) of red ochre (Table III). The first appearance of a unifacial stone point occurs at a depth of 15 cm, although the exact date is uncertain. Quartzite is again the predominant (64%) raw material for the whole flakes in all the rock shelters but with greater relative proportions of chert (16.5%), fine quartzite (14%), and only minor quartz (2%).

For sediments near the base of the Karl-1 rock shelter, an OSL age of 18,500 ± 1400 yr B.P. (Table I) is considered problematic because the sediments are poorly bleached and may derive from the slow disintegration of the overlying and surrounding bedrock (Ward, 2004; Ward et al., in press). We regard a younger radiocarbon age of 4080 ± 40 yr B.P. (OZG 338) from similar levels as a more reliable estimate of basal age (Table II). A radiocarbon age of 917 ± 76 yr B.P. (Wk 10784) at 6 cm indicates very low rates of sedimentation in this rock shelter. The walls of the Karl-1 rock shelter have many superposed layers of pigment art which span the full temporal range of the regional art sequence (Taçon et al., 2003) and include several "Bradshaw"-like figures. The 4000 yr B.P. basal age is comparable with the chronology provided for similar Bradshaw-style paintings elsewhere in the Kimberley (Watchman et al., 1997).

In the elevated rock shelter at Karlinga (Karl-2, Figure 3c), four units are recognized, which from top to bottom are loose, brown, medium-fine quartz sand; dark brown, medium-fine quartz sand with abundant charcoal and artifacts; light brown, medium-fine quartz sand with few artifacts; and a bedrock/rubble base that contains no artifacts. The uppermost sediments have been disturbed by resting kangaroos (sleeping hollows). Karl-2 contained 275 lithic artifacts (27% are whole flakes), 12 pieces of red, white, and orange ochre, and two pieces of metal in the uppermost sediments (Table III). Rock art was plentiful in this shelter, including numerous paintings, stencils, and drawings that probably span the last 3000 years but mostly relates to the last 500 years (Table III). Radiocarbon dates indicate considerable disturbance of these rock-shelter sediments. At their base is a modern date (Wk 10787), above which is an older radiocarbon age of 628 ± 46 yr B.P. (Wk 10785).

Table II. Radiocarbon ages for samples taken from the Goorurarmum rock shelter (Goor-2) and sand sheet (Goor-1), and from the Karlinga rock shelter (Karl-1) and sand sheet (Karl-3).

Sample name	Depth (cm)	Laboratory code	$\Delta^{13}C$	Age (Cal yr B.P.)
Goor 1 – Spit 4	16	Wk 10779	–25.5 ± 0.2	Modern
Goor 1 – Spit 21	100	Wk 10780	–25.8 ± 0.2	2536 ± 105
Goor 1 – Spit 21	100	OZG337	na	2780 ± 40
Goor 1 - Spit 35	175	OZG339	na	3680 ± 50
Goor 2 – Spit 3	7	Wk 10781	–25.6 ± 0.2	Modern
Goor 2 – Spit 11	27	Wk 10782	–23.4 ± 0.2	286 ± 71
Karl 1 – Spit 3	6	Wk 10783	–26.3 ± 0.2	484 ± 45
Karl 1 – Spit 12	39	Wk 10784	–25.8 ± 0.2	917 ± 76
Karl 1 – Spit 12	39	OZG338	na	4080 ± 40
Karl 2 – Spit 5	26	Wk 10785	na	628 ± 46
Karl 2 – Spit 5T	26	Wk 10786	na	1119 ± 61
Karl 2 – Spit 10	51	Wk 10787	na	modern
Karl 3 – Spit 10	52	Wk 10788	–24.4 ± 0.2	708 ± 57
Karl 3 – Spit 20	100	Wk 10789	–24.7 ± 0.2	3619 ± 122
Karl 3 – Spit 31	155	OZG340	na	2810 ± 40

Note. Samples with OZG lab numbers derive from NaOH soluble extracts of charcoal (na = not available).

Table III. Summary of archaeological data for each of the rock-shelter and excavation sites, including number and type of artifacts (stone, ochre), age of first appearance of ochre and stone points in each profile, estimated age of rock art for each site (based on sequence of Taçon et al., 2003), and earliest occupation age.

Site	No. artifacts	No. whole flakes	No. ochre pieces	Lowest ochre (ky B.P.)	No. stone points	Lowest points (ky B.P.)	Oldest rock art (ky B.P.)	Main rock art (ky B.P.)
Goor-1	2319	562	16	14,300	9	2500		
Goor-2	653	161	16	200	10	< 200	> 1200	< 500
Karl-1	145	30	6	900	2	500–900	< 3000	< 500
Karl-2	275	75	12	< 628	3	< 628	< 3000	< 500
Karl-3	973	216	15	19,400	8	2500		

Goorurarmum

In the Goorurarmum (Goor-2) rock shelter (Figure 4b), four depositional units are recognized, which from the top to bottom comprise loose, well-sorted medium-fine (~216 mm) brown silty-sand to firm medium-fine (~200 mm) dark reddish-brown (5 YR 3/3) quartz sand; dark reddish-brown (5 YR 2.5/2) medium-fine (~197 mm) sand; and a bedrock/rubble base. Charcoal and stone artifacts are present throughout the profile. The total number of lithic artifacts was 660 (24% are whole flakes), and 16 pieces of red, white, and yellow ochre (Table III). Bifacial and unifacial points are dated to < 500 yr B.P. In the top 10 cm of the sequence were a number of small glass flakes and fragments (total 39 pieces weighing 1.8 g).

Close to the base, a single OSL age of 500 ± 140 yr B.P. from well-bleached sediments (Table I) is broadly consistent with the radiocarbon age of 286 ± 71 yr B.P.

Table IV. Oldest reliable ages for rock shelters and sand-sheet sites in the lower Keep-River region.

Rock shelter	Site code	Lab no.	Method	Oldest reliable age (yr B.P.)
Granilpi[a]	G1	W2459	TL	8400 ± 100
Punipunil[a]	PP	Wk 7698	^{14}C	3540 ± 70
Karlinga[b]	Karl-1	OZG 338	^{14}C	4080 ± 40
Karlinga[b]	Karl-2	Wk 10785	^{14}C	628 ± 46
Goorurarmum[b]	Goor-2	Goor-2-21	^{14}C	600 ± 200
Miriwun[c]		ANU-1008	^{14}C	17,980 +1370 –1170
Monsmont[c]		SUA-57	^{14}C	1730 ± 80
Kununurra[d]		SUA-56	^{14}C	3110 ± 85
Pincombe[d]		GaK-1767	^{14}C	3560 ± 100
Philchowski's Crossing[d]		na	^{14}C	3640 ± 110
Canyon[d]		SUA-58	^{14}C	680 ± 75
Sand sheet	**Site code**	**Lab no.**	**Method**	**Oldest reliable age (yr B.P.)**
Karlinga[b]	Karl-3	Karl-3-210	OSL	19,400 ± 210
Goorurarmum[b]	Goor-1	Goor-1-220	OSL	14,300 ± 400

Note. All radiocarbon ages are determined from charcoal, with the exception of Punipunil (Wk 7698), which was determined from fruit seed.

[a]Sourced from Atchison et al., 2005. [b]Sourced from Ward, 2003. [c]Sourced from Dortch, 1977. [d]Sourced from Veth, 1995, p. 737).

(Table II). Within the Goor-2 rock shelter there are many cupule engravings dating to at least 1200 years (Taçon et al., 2003, p. 3) as well as more recent paintings and stencils. Although the Goorurarmum area lacks the Bradshaw figures found at Karlinga, both localities reflect previously identified sequences spanning > 3000 yr B.P. to present (Taçon et al., 1997, 1999, 2003).

DISCUSSION

Chronological Comparison of Rock-Shelter and Sand-Sheet Sequences

Nearly all occupied rock shelters in the lower catchment of the Keep River have basal or near-basal dates well within the Holocene, although the ages of individual sites vary considerably (Table IV). At Granilpi, the lowest occupation levels have a TL age of around 8400 ± 100 yr B.P. (Atchison et al., 2005). At Karlinga (Karl-1), the lowest occupation levels are radiocarbon dated to 4080 ± 40 yr B.P., at Punipunil to 3540 ± 70 yr B.P., and at Goorurarmum to 600 ± 200 yr B.P. (Table IV). Indeed, the available records for the whole of the East Kimberley indicate that the majority of rock-shelter sites in northwestern Australia have occupation records dated to < 4000 yr B.P. (see summary in Ward, 2004, p. 4).

Associated with these basal dates, the available archeobotanical (Atchison et al., 2005) and archeological records (Fullagar et al., 1996; Roberts et al., 1998) indicate

that stone artifacts are more abundant within the past 4000 years when sediment accumulation rates are relatively high (Figure 5). The earliest unifacial and bifacial points in the Keep-River region are from Jinmium and are dated to 3000 yr B.P. (Akerman et al., 2000) and ~1700 yr B.P., respectively (Fullagar et al., 1996: 764; Akerman et al., 2002; Atchison et al., 2005). In this study, the first appearance of unifacial and bifacial points in the sand sheets range between $<$ 3680 yr B.P. and $>$ 2100 yr B.P. and before 900 yr B.P. in the rock shelters. Taçon et al. (2003) also argue for a possible expansion of Late-Holocene rock art associated with rock shelters.

Evidence for late-Pleistocene occupation of the area is provided by the continuous presence of stone artifacts in the sand sheets near the Goorurarmum and Karlinga rock shelters. In the Goorurarmum sand sheet, the lowermost stone artifacts and ochre occur just below sediments dated to 14,300 $\pm$ 400 yr B.P. (OSL age). This evidence is particularly striking compared to the much younger archaeological sequence (600 $\pm$ 200 yr B.P.) of the adjacent rock shelter. In the Karlinga sand-sheet excavation, stone artifacts are present from about 19,000 yr B.P., contrasting with the younger basal ages ($<$ 4100 yr B.P.) of the two rock-shelter sites, Karl-1 and Karl-2. These differences between rock shelter and open-site chronologies may partly result from the elevated location of the rock shelter sites above the sand sheets. The rock shelters will have more limited and localized sediment inputs and outputs compared to the more exposed sand sheets (Ward et al., in press). In some circumstances, it may be necessary for the sand-sheet sediments to accumulate to a similar level as the rock shelters for sediments to accumulate within them (e.g., Morwood et al., 1995).

The inferred age of occupation for the site of Jinmium is also complex. Recent publications (Atchison et al., 2005; Ward et al., in press) argue that the earliest occupation of the rock shelter is probably less than 10,000 yr B.P. The OSL age estimates of sediments within the rock shelter ranges from 22,700 yr B.P. using single aliquots to 1200 yr B.P. (central-age) using single grains, giving an average of about 10,000 yr B.P. (for the complete range, see Roberts et al., 1998). An excavation in the sand sheet 10 m away from rock shelter provided a TL age of 8500 yr B.P. near the base (Fullagar et al., 1996), which, unlike the chronology for the rock-shelter sediments, has not been revised. Thus, the average maximum age of the sediments within the rock shelter is at least comparable with that of the adjacent sand-sheet sediments. This may reflect the geomorphology of the Jinmium rock shelter site, which, unlike the Karlinga and Goorurarmum rock shelters, is incorporated within the sand plain rather than elevated in the escarpment above it, and is more likely to have a sediment input and output similar to the surrounding sand plain (Ward et al., in press).

Certain environments, such as the floodplains of the lower Keep River, are unlikely to show continuous sediment accumulation because of the episodic nature of flooding and deposition in this region (e.g., Woodroffe, 1993). The former riverine site of Miriwun, located ~80 km to the south (Figure 1), is dated to about 18,000 yr B.P. with a chronological hiatus and subsequent reoccupation in the mid-Holocene (Dortch, 1977). It is difficult to identify the true nature of human occupation from a record that is discontinuous, both spatially and temporally (see also Holdaway et al., 1998, 2002). However, alluvial deposition, including periodic flooding at Miriwun, has resulted in better accumulation of Pleistocene cultural remains compared to the

lower catchment of the Keep River, where sediment is predominantly distributed by sheet flow (Ward et al., in press). The different chronologies between the sandsheets and rock-shelter sites highlights the importance of sampling a range of sedimentary environments in a study area to ensure reliable interpretations of natural and cultural site formation (Allen and Barton, 1990; Attenbrow, 2002, 2004; Ulm, 2004; Ward, 2004; Ward et al., in press).

Postdepositional Disturbance

A comprehensive review of the influence of physical and biogenic processes on archaeological site formation and landscape evolution is given by Johnson et al. (2002) and more specifically for Australia by Ward and Larcombe (2003) and Attenbrow (2004). These reviews argue the importance of recognizing natural disturbance processes and the scales over which they overlap with other depositional processes at archaeological sites. Disturbance processes may be quite localized, and may account for the inverted dates within the Karl-2 rock shelter and the surface sediments of the Karl-3 excavation. In the Keep-River region, the major biogenic agents of disturbance are burrowing organisms (especially termites) and humans.

In the Keep-River region, the presence of faunal disturbance, particularly in rock-shelter sites, is evident from goanna burrows, kangaroo hollows (e.g., Figure 3c), termite mounds, and tunnel castings (e.g., Figure 4b) within the buried sediments. Readers are referred to McBeaty (1990) for a study of termite disturbance on archaeological site formation. Published rates of sediment disturbance caused by termite reworking are about 2.5 cm/ka^{-1} (Holt et al., 1980; Colin et al., 2001), which, if applied to the Keep-River region, would give an error of $\pm$ 25% and $\pm$ 12%, respectively, on Pleistocene and Holocene sedimentation rates. Hence, chronological resolution should be better in Holocene sequences than in Pleistocene sediments.

The presence of human disturbance is indicated by campfires (e.g., Figure 4b), tree clearing for paper-bark bedding, caching of equipment, and rock alignments to divert runoff. Rock shelters with evidence of repeated human visitation, evident from the multiple layers of rock art, are also likely to be prone to human disturbance of their deposits. Such disturbance may be deliberate (e.g., burying or caching human remains, building fire pits, and clearing occupation debris) or unintentional (e.g., treadage). In the Keep-River region, the uppermost 20 cm or so that is likely to have been affected by recent human (and/or faunal) disturbance in the rock shelters covers around 500 years (cf. Hughes and Lampert, 1977, p. 136). Thus, studies aimed at determining small-scale processes are severely limited in their resolution in many of these younger rock-shelter sequences.

Changes in Site Use

The general correlation between increased artifact number and increased sedimentation rate in the sand sheets (Figure 6a, b) highlights the important consideration of sedimentation rate when evaluating the intensity of site use (see also Farrand,

2001; Ward and Larcombe, 2003). These plots help distinguish changes in the rate of artifact accumulation that may reflect natural or cultural processes; for example:

1. Unusually high artifact concentrations and low rates of sediment accumulation may be indicative of a lag deposit and/or increased artifact discard rates—in the Karlinga sand-sheet excavation, only the lower cobble layer reflects this trend.
2. Unusually low artifact concentrations and high rates of sediment accumulation may be indicative of dilution and/or a reduced rate of artifact discard.

Factors which influence preservation, such as water-table fluctuations, are also important. For example, in the Jinmium excavation, Atchison et al. (2005) argued that decreased abundance of fruit seeds with depth, together with their increased degree of weathering, reflected preservation factors rather than the actual onset of human activity. In rock shelters, a primary control upon the surface occurrence of artifacts is generally low sedimentation rates (Figure 5) and relatively sheltered environmental conditions. Secondary influences include cultural processes, such as discard and cleaning (Morwood, 1981), and natural processes, such as removal through runoff (Schick, 1987).

While differences in artifact accumulation may be due, in part, to sedimentary or postdepositional processes, more subtle differences in the nature of the stone technology may provide further important information about site use. At both Karlinga and Goorurarmum, the stone technology and other archaeological components described for the rock-shelter and sand-sheet excavations indicate similar technologies, at least during the Late Holocene. The stone-tool data indicate that point production occurred at both the rock-shelter and open sites. In both the sand-sheet and rock-shelter sequences, the stone platforms are predominantly plain, indicating that only a late stage of reduction was taking place. Early stages of reduction may have occurred in different parts of the landscape, such as the chert and quartzite quarry located at Bungyala approximately 15 km northeast of Goorurarmum (Fullagar and Head, 1999, p. 329). Locations of silcrete and quartzite close to Keep River and Sandy Creek have cores and flaking debris associated with early stages of point production, as do more distant locations in the Kimberley (Akerman et al., 2002). This pattern of technological organization is evident in other parts of northern Australia (Jones and Johnson, 1985, p. 199). This study demonstrates that activities are not limited to rock shelters and that archaeological material may be found in adjacent open areas as well as in distant locations, even where there is no surface indication of buried artifacts.

Overall, the number of whole flakes is greater in the sand sheets than in the rock shelter (Table III), possibly reflecting frequency of site use and/or preservation. Interestingly, in the Karlinga sand-sheet excavation, the total number of artifacts, including whole flakes, is greater before ~3600 yr B.P., whereas in the Goorurarmum sand-sheet excavation, the total number of artifacts is greater after this date. One interpretation is that this reflects location of different sites (but not different site types) within the lower catchment of the Keep River at different periods.

However, within the last millennium, artifacts and whole flakes were present in greater quantities in the Goorurarmum rock shelter than in the open site, and the number of stone points, glass, and ochre (also present in more colors) were present in

Table V. Comparison of archaeological data for the rock shelters and sand sheets in the last millennium, including total number of artifacts, whole flakes, stone points, and ochre.

Site	No. artifacts	No. whole flakes	No. ochre pieces	No. stone points
Goor-1	424	76	4	3
Goor-2	653	161	16	10
Karl-1	52	12	5	2
Karl-2	275	75	12	3
Karl-3	74	22	1	1

Note. The data indicates a shift in the concentration of artifact from outside to inside rock shelters during the most recent period of occupation.

greater quantities in the rock shelters at Goorurarmum and Karlinga (Table V). This may indicate a greater use of rock-shelter sites compared to open sites during the more recent period, particularly for the purpose of production of rock art and for shelter in adverse weather (Mulvaney, 1996; Head and Fullagar, 1997; Mulvaney and Kamminga, 1999, p. 23; Leslie, 2000). The abundant evidence of recent occupation in the Karl-2 rock shelter, including oral history, rock art, and metal, indicates that this shelter was occupied only over probably the last 100 years. The high elevation of the Karl-2 rock shelter in the escarpment may have provided refuge during hostile times (see Head and Fullagar, 1997), complementing findings from Granilpi (Figure 1) that rock shelters were occupied more intensively during the contact period (Leslie, 2000, p. 95). Overall, initial occupation dates indicate continued expansion of rock-shelter use through the period of European contact.

CONCLUSIONS

Although some discrepancies remain between TL, OSL, and radiocarbon age determinations for the Keep-River region, dating of rock-shelter and sand-sheet sediments has provided a new framework within which the archaeological record can be interpreted. The thick sand-sheet deposits preserve a late-Pleistocene record and relatively abundant artifact assemblage, whereas the shallow rock-shelter deposits preserve a Holocene record, in which the artifact assemblage is more abundant and varied in the last millennium only.

The presence of older occupation deposits (back to ~20,000 yr B.P.) in the sand sheets immediately outside the rock shelters indicates that rock shelters may have been used for much longer than is revealed by luminescence or radiocarbon dating of the shelter deposits themselves. In this region of the Keep River, there is an absence of Late-Pleistocene deposits in rock-shelter sites, which may reflect sparse cultural deposition but may also reflect a geomorphological limitation for sediment accumulation.

The overarching implication from this study is that settlement patterns and cultural interpretations may be fundamentally flawed if they are constructed predominantly based on rock-shelter deposits in similar sandy environments. Furthermore, the climatic and environmental limitations imposed on archaeological reconstructions in northern Australia mean that multidisciplinary studies of rock shelters, sand sheets, and other types of open sites are fundamental to understanding cultural change.

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